[redacted]

HYDRAULIC MANUAL

[redacted]

HYDRAULIC MANUAL

CONSISTING OF

WORKING TABLES AND EXPLANATORY TEXT

INTENDED AS

A GUIDE IN HYDRAULIC CALCULATIONS AND FIELD OPERATIONS

BY

LOWIS D'A. JACKSON

AUTHOR OF 'CANAL AND CULVERT TABLES' 'AID TO SURVEY PRACTICE'
'ACCENTED FIVE-FIGURE LOGARITHMS' 'MODERN METROLOGY'
AND OTHER WORKS

FOURTH EDITION.

REWRITTEN AND ENLARGED

LONDON

CROSBY LOCKWOOD AND CO.

7 STATIONERS'-HALL COURT, LUDGATE HILL

1883

LONDON: PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
AND PARLIAMENT STREET

PREFACE

TO

THE FOURTH EDITION.

IN this edition, some alterations and extensive additions have been made. Chapter I. remains generally as before, the alterations being comparatively small; in the portion devoted to Sections of Flow, the quotation from Neville's work has been expunged, and that subject has been newly treated; in the portion devoted to Distribution of Velocity in Section, full advantage has been taken of the deductions made by Major Allan Cunningham, and these have been inserted with his consent, but also with some modification for which he is not responsible; the references to Box's work and to Stoddard and Dwyer's works have been entirely expunged; and the whole chapter has been revised.

In Chapter II., a summary of the methods of gauging and of the operations of Major Allan Cunningham in his recent experiments on the Ganges Canal, has been added. This has been reprinted from 'Engineering' with the consent of the editor, and with that of Major Cunningham. This chapter has also undergone revision.

[redacted]

SUMMARY.

TEXT.

WORKING TABLES.

MISCELLANEOUS TABLES AND DATA.

[redacted]

CONTENTS.

TEXT.

CHAPTER I.

EXPLANATION OF THE PRINCIPLES AND FORMULÆ ADOPTED IN CALCULATION AND APPLIED IN THE WORKING TABLES.

CHAPTER II.

ON FIELD OPERATIONS AND GAUGING.

CHAPTER III.

PARAGRAPHS ON VARIOUS HYDRAULIC SUBJECTS.

WORKING TABLES.

MISCELLANEOUS TABLES AND DATA.

HYDRAULIC MANUAL.

CHAPTER I.

EXPLANATION OF THE PRINCIPLES AND FORMULÆ ADOPTED IN CALCULATION AND APPLIED IN THE WORKING TABLES.

1. Hydrodynamic Theories. 2. Notation and Symbols. 3. Rainfall, Supply, and Flood Discharge. 4. Storage. 5. Discharges of Open Channels and Pipes. 6. The Hydraulic Section of Channels and Pipes. 7. The Hydraulic Slope. 8. Distribution of Velocity in Section. 9. Discharges of Rivers. 10. Bends and Obstructions. 11. Discharges of Orifices, Sluices, and Weirs. 12. Discharge from Basins, Locks, and Reservoirs.

1. Hydrodynamic Theories.

The science of hydraulics, yet in its infancy, may be said to depend, as far as its practical application by the hydraulic engineer is concerned, on a combination of certain known laws with the empirical results of observation and experiment; the former few in number, and eliminated principally by the philosophers and mathematicians of the past; the latter also few, and, if we except the old observations which were carried out on a very petty and limited scale, exceedingly modern. Previous to the experiments of d'Arcy in 1856, little was known about the velocities and discharges through pipes; until the operations of Captains Humphreys and Abbot on the Mississippi in 1858, the discharge of large rivers was a comparatively unexplored subject; in 1865 the experiments of Bazin led the way to a more accurate knowledge of the discharges and velocities of water in small channels and culverts, and the effects of roughness of surface and variety of material on these velocities. In 1870 Kutter and Ganguillet, from observations on Swiss hill-streams, deduced a more exact law for effect of declivity on discharge, and besides added greatly to the knowledge of effect of roughness. In 1880 the extensive experiments of Captain Allan Cunningham on the Ganges Canal had substantiated the truth of Kutter's laws when applied to very large canals, and dealt the final blow to the velocity-formulæ of all the older hydraulicians.

Before 1856 the less important subjects alone had been investigated to any practical purpose, such as the vena contracta, the discharges through small orifices, over certain forms of overfall, and through short and small pipes, the discharges from reservoirs, and the velocities in troughs 18 inches wide. There was, however, plenty of theory, and a large number of formulæ, some of them exceedingly complicated in form, mostly resulting from a number of superimposed theories, the more ancient of which were based on very limited experiments: in fact, the mode often adopted seems to have been to assume a new form of formula, and to prove it by a few partial experiments, a principle worthy of ancient soothsayers, and which, had it been further supported by traditionary and name-reverencing hydraulic schools of believers, could only have resulted in prolonged and permanent error. Even now a reference to some works comparatively recently published in England will show formulæ to be supported by a most heterogeneous collection of experimental data; discharges of pipes irrespective of their material or internal surface, of large and small rivers irrespective of the quality of their beds and the bends in their courses, of canals in any material, down to wooden troughs, all seem to prove the correctness of a fixed formula having an unvarying constant coefficient. Other works again, having greater accuracy of result in view, go to the opposite extreme in method and recommend the adoption of two distinct formulæ for cases in which the principles involved do not vary in the least, as for instance, in discharges through pipes with low velocities, a formula distinct from that for those with high velocities is often adopted; this, amounting to a method of successive approximation imperfectly worked out, is almost as unfortunate as the other. From a continuance of this, however, the modern experiments have already saved us to a great extent, and further and more extended experiment will probably relieve us from it altogether.

Taken generally, the mass of hydraulic science and of hydraulic data bearing on the flow of water under various conditions, prior to about 1856, may be considered superannuated, defective, and often excessively misleading. Old hydraulic data, such as discharges of rivers, canals, and pipes, seldom can afford the means of arriving near the truth, unless accompanied both by the formulæ used by the observer, and by a large number of conditions of the case, then mostly neglected.

At present the hydraulic engineer is still quite as dependent for correctness of calculated result on the so-called empirical data, obtained by experiment and put into convenient form, as on purely abstract theories or laws. The correct application of all known mechanical laws cannot, however, fail to be valuable in cases admitting of them; those relating purely to hydrodynamics are comparatively few, and the most important and best known of them are the four following:—

First, uniform motion.—If fluid run through any tube of variable section kept constantly full, the velocities at the different sections will be inversely as the areas, or

$$A\,V = A'\,V'.$$

This theory of uniformity of motion is also supposed to hold generally with reference to mean velocities of discharge in open channels under constant supply. This is actually little more than assuming a theoretical velocity that will fulfil the conditions of the law, in order to render calculation convenient, for there is no reason to believe that actual velocities in a tube of variable section would all vary inversely with the area of cross section.

Second, velocity of issue.—The velocity of a fluid issuing from an orifice in the bottom of a vessel kept constantly full, is equal to that which a heavy body would acquire in falling through a space equal to the depth of the orifice below the surface of the fluid, which is called the head on the orifice; or by way of formula

$$V = (2\,g\,H)^{\frac{1}{2}}$$

where H = the head and g = force of gravity. The quantity g represents the accelerating force of gravity, which varies at different places on the earth's surface and elevations above the mean sea level, and is also affected by the spherical eccentricity of the earth at the place, a quantity that again varies with the latitude; above the earth's surface g varies inversely with the square of the distance from the earth's centre, below the earth's surface direct with the distance from the earth's centre; to obtain the exact value of g, d'Aubuisson's formulæ applied to English feet are—

$$r = 20\,887\,540\,(1 + 0{\cdot}001\,64 \cos 2\,l)$$
$$g = 32{\cdot}1695\,(1 + 0{\cdot}002\,84 \cos 2\,l)\left(1 - \frac{2e}{r}\right).$$

The values of this formula for different latitudes and elevations are given in Working Table No. I., and the values of g, obtained from observation at different latitudes, are given in Table No I. of the Hydraulic Statistics. For purposes of ordinary calculation in England, and hence throughout these tables, g is generally taken as 32·2 feet per second; in India, however, it would be more correct to use 32·1; but the convenience of using English data will probably outweigh the need of this exactness until the science of hydraulics can arrive at higher accuracy.

The above theory supposes that the orifice is indefinitely small, and neglects the conditions and size of its sectional area, friction, the pressure of the atmosphere, and the resistance of the air to motion (which increases with the square of the velocity of the issuing fluid); the practical application of it that shows its discrepancies most strongly is the fact that the height of a jet is never equal to the head of pressure on it.

Third, general theory of flow.—This is a combination of the two previous theories in a modified form, assuming both uniform motion and the principle of gravitation, and is best expressed in the form of a formula—

$$V=(f\,g\,R\,S)^{\frac{1}{2}}$$

where V = the mean velocity generated,
R = the mean hydraulic radius of the water-section,
S = the hydraulic slope or sine of the slope of the water-surface.

This formula is a simple equation of the accelerating force of gravity down an incline with the retarding force of friction at any section at right angles to the course of flow, namely :—

$$g\,S=\left(\frac{V^2}{Rf}\right)$$

since, for uniform motion, the total accelerating force is equal to the total resistance.

This theory is the basis of calculation of flow in full tubes, and in open channels and unfilled pipes, where the principle still holds, but f then becomes a symbolic representation of retardation due to a combination of various causes, including direct friction on the general incline at the given section.

Fourth, the principle of retardation.—This is represented by a collection of various small formulæ and methods of making allowance for loss of velocity under different conditions by a calculated head. These retardations may be introduced into any general formulæ, or may be treated separately. The ordinary sources of retardation are :—

1. Roughness of surface, varying from that of polished glass to rock-strewn or deeply-incised rocky torrent-beds ; also surface-adhesion of liquids.

2. Irregularity of form, varying from that of a recently made and trimmed rectilinear canal of one single uniform inclination and direction down to that of a river bed consisting of an infinity of heterogeneous planes and curved surfaces. Any departure from uniformity, lateral and vertical deviations and bends.

3. Varying head, inconstant pressure, diminution of supply, loss of effective head from excess of withdrawal.

4. Contraction at exit, want of perfect freedom of fall, backwater, contraction of passage, obstacles.

5. Air resistances and effect of wind; atmospheric pressure; differential liquid pressure internally.

6. Low specific gravity of the liquid in motion, turbidity, viscosity, and variation in weight.

7. The effect of variation of heat inducing motion in the liquid, and thus producing perturbation, and the minute effects of local change of temperature generally.

8. Absorption of velocity by yielding material, which may imperfectly deflect velocity, and partly absorb direct action.

However rigid these theories may appear in neglecting important points, they are yet generally true in the abstract, and no substitutes for them have yet been discovered; the consequence is that all hydraulic calculations are made to depend on them, their defects being compensated by using experimental coefficients. It becomes, therefore, one of the important duties of a hydraulic engineer to apply these principles with care and circumspection, especially guarding against taking for granted the formulæ and tabular results of different calculators, which vary in form and in result to a very great extent; some authors even giving a half more discharge than others as due to the same data. During practical work, time forbids a lengthy examination of principles; for this reason, therefore, this short chapter is given as an easy guide to the proper management and application to every-day wants of the Working Tables that follow.

2. Notation, Symbols, and Units of Measure.

To ensure clearness and rapidity of application of these theories, it is absolutely necessary that the nomenclature should be neither doubtful nor inconvenient, that the symbols be free from confusion, and the units of time, weight, and measurement, once adopted, generally adhered to as much as possible; this alone can cause the form of a formula to give at a glance any definite idea of the values of its terms and expressions. Decimalised measures are also necessary for the same purpose.

The English foot has been generally, though not quite exclusively, adopted in this work as the unit of length, surface, and capacity, being the measure ordinarily used for heights and depths, as well as distances in survey work, and being now more capable of extended application than either the yard, link, or inch. The footweight, or weight of a cubic foot of water at its utmost density (the English talent), has been taken as the unit of weight, being now a recognised legal standard unit. The whole system of decimal measures founded on these are on the scientific scale at 32° Fahrenheit, so as to afford exact correspondence between cubicity and weight, and to admit of facile conversion to metric values. The second has been generally taken as the unit of time, so that the numbers expressing discharges and velocities, which often are high numbers, may be as small as possible. This has been found to be perfectly manageable in practice. In the canal departments of Northern India the engineers have succeeded in abolishing poles, yards, and inches from their plans, estimates, and calculations, and in adhering generally to the second as a unit of time; they have also, on the Bari Doab Canal, adopted the old London mile of 5 000 feet to the exclusion of the statute mile of 5 280. The league of two such miles, or 10 000 feet, being a decimal unit, is now far preferable. The acre, pole, and old Gunterian chain of 4 poles being highly inconvenient, the substitutes for these are the rod of 10 feet; the chain of 100 feet (Ramsden's); the square chain of 10 000 feet, nearly a rood; the century, or square cable, of 100 square chains; and the square league of 100 centuries. This decimal system of measures, though retaining the use of a familiar unit, and saving much needless labour in calculation, at the same time has some difficulties to contend with, the principal of which are the old habits of measuring water-supply for towns in gallons instead of cubic feet, and of using dimensions of pipes in inches, instead of tithes or tenths of a foot, estimating pressure on the square inch instead of on the square foot and square tithe; these obstacles will probably gradually disappear.

As regards the French metric system, although it is now adopted for external commerce in most civilised countries in Europe, there seems little chance of its entirely replacing our own measures. English scientific measures are naturally more convenient for an Englishman to think and calculate in, and are in closer accordance with English commercial units adopted in trade, manufactures, and contractors' plant and appliances; besides, natural units are preferable to artificial ones.

The hydraulic engineer more especially can adopt the decimal system of measures based on the English foot with extreme convenience; nor apparently are there any very good reasons why the railway engineer should not do so also, except perhaps the tradition-loving habits of the multitude, and the meddlesome legislation in social matters under which we suffer, which enforces on him the adoption in Parliamentary plans of the whole of the old measures, with the alternative of using foreign measures. This difficulty will perhaps be eventually removed by permissive legislation, allowing the use of the complete English decimal series for all technical, engineering, and scientific purposes, apart from ordinary trade, and fixing the standards finally on the principles proposed and long advocated by the author,—namely, at a single normal temperature in vacuo, the single temperature both for material and for water being that of the maximum density of distilled water,—a method far superior to the dual temperature of the French system. In the meantime it may be remembered that decimalisation on any English units is permissive under the Act of 1878, thus actually including the whole of the English decimal scientific system; while there exists no legal prohibition of the *ad interim* temperatures 32° and 39° in vacuo used in French measure.

The advantage of adhering to one set of symbols in hydraulic formulæ, which sometimes appear very complicated, is sufficiently evident; with this view, therefore, the following general notation is drawn up. The velocity notation of the Mississippi survey is also attached for purposes of reference.

General Notation.

F = the rainfall expressed in depth.
K = catchment area drained.
Q = quantity of water discharged in cubic feet per second.
V = mean velocity of discharge in feet per second.
V_x = corresponding maximum velocity in the same section.
U = verticalic velocity, or velocity past a vertical line or axis.
Y = transversalic velocity, or velocity past a transversal, or transverse axis.
A = sectional area; a, a_1, a_2, subsidiary areas.
P = wetted sectional perimeter, exclusive of the surface-width, W.
R = the mean hydraulic radius $= \frac{A}{P}$.
R_1 = diminished hydraulic radius $= \frac{A}{P+W}$.
R_2 = augmented hydraulic radius $= \frac{A}{P-W}$.
S = hydraulic slope or gradient in terms of its sine $= \frac{H}{L}$;

$$\text{thus } S = \frac{1}{500} = 0{\cdot}002 \text{ for a slope of 1 in 500.}$$

L = a longitudinal length taken in the direction of flow.
H = the fall on any such length; or a vertical head of pressure.
h = difference of level of the water surface at the two ends of l.
$h_{,}$ = the part of h consumed in overcoming longitudinal channel resistances, for a straight, regular course.
$h_{,,}$ = the part of h consumed in overcoming transverse channel resistances or irregularities.
W = a transverse width at water surface across the direction of flow.
D = a vertical depth from surface level.
B = a bed-width or bottom-width of a section.
T = total time of discharge; t, t_1, t_2, subsidiary times.

---

n = coefficient of roughness and irregularity combined.
$m = n\,(41{\cdot}6 + 0{\cdot}00281 \times \frac{1}{S})$, a combined variable.
k = coefficient for supply from catchments.
c = coefficient for mean velocity in channel discharges.
μ = coefficient for orifice and overfall discharges and velocities.
g = velocity acquired by gravity in one second = 32·2 feet approximately.

When x, y, z, are rectangular co-ordinates taken with reference to flowing water, the following conventional arrangement is usual.

x is taken in the direction of flow, or longitudinally;
y is taken across the flow, or transversely;
z is taken vertically, or perpendicular to x.

All dimensions are generally in feet and decimals, and velocities and discharges are in feet and cubic feet per second. The foot-weight or talent = 1 000 ounces, is the unit of weight; its multiple is the rod-weight = 1 000 fwt. For decimal multiples and submultiples see page 14.

Velocity Notation of the Mississippi Survey.

v = mean velocity of the river.

V = velocity at any point in any vertical plane parallel to the current.

${}_{100\ 30}V$ = velocity at a point 30 feet below the surface at a distance of 100 feet from the base line, measured along the bank.

U = velocity at any point in the mean of all vertical planes parallel to the current.

U_m = grand mean of the mean velocities in all vertical planes parallel to the current.

U_r = the mean of the bottom velocities in all such planes.

${}_{w_l}V$ = velocity at any depth below the surface at a perpendicular distance w_l from the base line.

V_0 = velocity at the surface in any vertical plane parallel to the current.

$V_{\frac{1}{2}D}$ and V_D = velocities at mid-depth and at the bottom in any such plane.

V_{d_l} and V_m = the maximum and the mean velocities in any such plane.

W = river width at any given place.

w = perpendicular distance from the base line to any point of the water surface.

w_l = perpendicular distance from the base line to the surface fillet moving with the maximum velocity.

D = total depth of river at any given point of surface.

d = depth of any given point below the surface.

d_l = depth from the surface of the fillet moving with the maximum velocity in the assumed vertical plane parallel to the current.

m = depth from the surface of the fillet moving with a velocity equal to the mean of the velocities of all fillets in the assumed vertical plane parallel to the current.

Δ = maximum or mid-channel depth.

As it may be convenient to the reader to have conversion tables at hand for reducing the quantities of water, &c., given in foreign works on hydraulics into English measure, and the converse, the following two pages are given to answer this purpose, as far as regards the English decimal system.

For other corresponding purposes, see 'Modern Metrology,' London, 1882, Lockwood, and 'Pocket Logarithms and other Tables,' London, 1880, Allen.

COMPARISON OF FRENCH AND ENGLISH DEC

English Scientific Units	In English Commercial Units at 62° Fahrenheit	French Scientific Equi
Length		
FOOT = 10 tithes (or tenths) . =	1·00029 foot	= 0·304 79 mètre
Rod = 10 feet		= 3·047 95 mètre
Chain = 10 rods		= 3·047 95 décam
Cable = 10 chains		= 3·047 95 hecto
League = 10 cables		= 3·047 95 kilom
Surface		
SQUARE FOOT = 100 sq. tithes =	1·00057 sq. ft.	= 9·289 97 déc.
Square rod = 100 sq. feet . .		= 9·289 97 mèt.
Square chain = 100 sq. rods .		= 9·289 97 ares
Sq. cable or century = 100 sq. chains .		= 9·289 97 hect
Square league = 100 centrs. . .		= 9·289 97 kil.
Capacity		
Fluid mil = 1000 fl. doits . . .		= 28·315 31 mill.
Fluid ounce = 1000 fl. mils = 1 cub. tithe		= 28·315 31 cent.
CUBIC FOOT = 1000 fl. ozs. = 1000 cub. tithes =	1·00086 cub. ft.	= 28·315 31 déc.
Cubic rod = 1000 cubic feet . .		= 28·315 31 mèt.
Weight		
Mil = 1000 doits .		= 28·315 31 milgr
Ounce (millesimal) = 1000 mils .		= 28·315 31 gram
FOOT WEIGHT or talent = 1000 ozs.	= 62·42454 lbs.	= 28·315 31 kilog.
Rod weight = 1000 fwt. .		= 28·315 31 millie

COMPOUND UNITS.

PRESSURE.

1 talent (or foot-weight) per sq. foot .	= 304·794 5 kilog. per mèt. ca
,, ,, ,, . . .	= 0·030 479 45 kilog. per cen
1 talent (or foot weight) per square tithe	= 30·479 45 milliers per mèt.
1 rod-weight per square foot . .	= 304·794 5 milliers per mèt.

IRRIGATION.

1 cubic foot per square chain . .	= 0·304 794 5 mèt. cub. per
1 cubic foot per century . . .	= 0·003 047 9 mèt. cub. per
1 cubic rod per century . . .	= 3·047 945 mèt. cub. per

POWER AND WORK.

1 foot-talent	= 8·630 354 2 kilogrammètr
1 h.-p. = 528 foot-talents per minute .	= 1·012 63 c.-v. force de ch

HEAT AND ELECTRO-MAGNETISM.

1 foot-mil	= 0·008 630 35 mètre-gramr

SIMPLE AND COMPOUND UNITS OF REDUCTION.

English into French

Simple . . .	0·304 794 494	Cubic . . .	0·028 3
Square . . .	0·092 899 683	Fourth power . .	0·008 6

TIFIC SYSTEMS AT 32° AND 39° FAHR. IN VACUO.

h Scientific Units	In English Commercial Units at 62° Fahrenheit	English Scientific Equivalent
Length		
= 10 décimètres . .	= 3·281 83 feet	= 3·280 90 feet
tre = 10 mètres . .	.	= 3·280 90 rods
itre = 10 décamètres . .	.	= 3·280 90 chains
tre = 10 hectomètres. .	.	= 0·328 09 leagues
Surface		
CARRÉ = 100 décim. car. .	= 10·770 43 sq. ft.	= 10·764 30 square feet
= 100 mètres carrés	.	= 10·764 30 square rods
e = 100 ares . .	.	= 10·764 30 sq. chains
ètre carré = 100 hectares .	.	= 0·107 64 sq. leagues
Capacity		
= 1 décim. cube .	.	= 35·316 58 fluid. ozs.
tre = 10 litres . .	.	= 0·353 17 cubic feet
itre = 10 décalitres .	.	= 3·531 66 cubic feet
CUBE = 10 hectolitres .	= 35·346 83 cub. ft.	= 35·316 58 cubic feet
Weight		
amme	.	= 35·316 58 doits
ME = 1000 milligrammes	.	= 3·331 658 mils
amme = 1000 grammes .	= 2·204 62 lbs.	= 35·316 58 ounces
l = 100 kilogrammes	.	= 3·531 66 footweight
= 1000 kilogrammes	.	= 35·316 58 footweight

COMPOUND UNITS.

PRESSURE.

ramme per mètre carré . .	= 0·003 280 9 talents per sq. foot
ramme per centimètre carré .	= 0·328 089 9 talents per sq. tithe
r per mètre carré . . .	= 3·280 899 talents per sq. foot
r per centimètre carré . .	= 32·808 990 rod-weight per sq. foot

IRRIGATION.

cube per hectare	= 3·280 899 cubic feet per sq. chain
" "	= 328·089 9 cubic feet per century
" "	= 0·328 090 cubic rods per century

POWER AND WORK.

rammètre	= 0·115 870 foot-talents
force de cheval (4500) . .	= 0·987 528 h.-p. (scientific)

HEAT AND ELECTRO-MAGNETISM.

-gramme	= 115·870 154 foot-mils

SIMPLE AND COMPOUND UNITS OF REDUCTION.

French into English

. . . .	3·280 899	Cubic	35·316 580 7
. . . .	10·764 299 3	Fourth power . .	115·870 145 02

3. Rainfall, Supply, and Flood-Discharge.

All hydraulic works of irrigation, drainage, storage, water supply, river improvement, and land reclamation, are more or less affected by the amount and periodicity of the rainfall; for many of them careful and trustworthy rainfall statistics and data are absolutely requisite; but the nature and amount of detail required vary with the nature of the work; works of storage being those that, perhaps, require the greatest amount of accurate information. In order that these local records should be sufficient to form a correct basis for the engineering data of these latter works, they should comprise observations extending over a period of ten years, or of the local period comprehending a cycle of rainfall from one season of maximum rainfall to another, including years of extreme drought; from these the following results can be deduced :—

1. The mean, maximum, and minimum monthly rainfall, from which the mean and extreme falls for each natural local season, wet, cold, and hot, can be obtained.

2. The mean and maximum daily falls in twenty-four hours, for each month in the rainy season.

3. Mean and maximum hourly falls, longest continuous falls and droughts, and special occurrences.

These, arranged in a convenient tabular form, are all the rainfall data that the engineer will generally require.

In most cases, also, and especially in hot climates, evaporation records are also necessary; and sometimes, too, it is advisable to possess other meteorological data, such as those of humidity, temperature, atmospheric pressure, and wind; and, what is often difficult to procure, some data of absorption and percolation that would be applicable to the soils of the district under consideration.

On many of the works before mentioned, the first duty of the engineer is to account for the whole of the downfall, or to discover what becomes of it all, under both ordinary and unusual circumstances, so that he may be able to deal with more certainty of knowledge with that portion of it that more intimately affects his works; as, for instance, the bridge-builder with the floods, the engineer of storage works with the drought, and those of canals and river-improvement with both. A geographical and geological knowledge of the catchment area, whose rainfall affects the works, is hence also needful; the boundaries of this area, its lines of watershed and drainage, its disposition as regards prevailing winds, the nature and porosity of its soil, and the amount of vegetation or cultivation on it, as well as any available records from which the quantities of water actually run off by its streams and rivers in various seasons may be arrived at, are all data necessary for establishing satisfactorily a perfect knowledge of the disposal of the whole of the rainfall under any circumstances.

In many instances it is, from want of sufficient information, utterly impossible to obtain this perfect knowledge: in others, the deficient data may be supplied by approximative deduction from the data of other places, so that a tolerably correct approximate balance may be struck between the downfall and the amount evaporated, absorbed, and run off; in any case, however, the engineer may, with time and means at his disposal, gauge the streams and rivers affecting his works, and make correct records of the amount of water run off in them at different seasons of the year, and in exceptional floods. Failing, however, both time and opportunity, such data have to be observed in a rapid manner that will enable him to determine this approximately; such as the section and fall of the rivers, the depths at various stages, floodmarks, and a few velocity observations.

The results principally required are the flood or maximum discharge, in cubic feet per second, of the river or stream draining the catchment area; its mean discharge throughout the year; and its minimum discharge in seasons of extreme drought, as well as in its ordinary low stage; dividing each of these by the catchment area, similar results per unit of catchment are obtained, to obtain the depth in feet of rainfall run off under each of those conditions. The relation between these quantities and the probable or approximate downpour over the catchment area can then be compared with those known to exist in other corresponding cases, and a valuable check on these important results thus obtained.

Flood discharge.—The determination of the quantity of water discharged from a catchment area in a river or stream at a time of extreme flood is a matter that is very often of the highest importance. Costly bridges have continually been sacrificed, and long lengths of canal damaged for want of sufficient attention having been paid to this subject.

When the data mentioned in the foregoing paragraphs can be obtained, and are properly handled, there is little difficulty in arriving at a generally correct result;

but, as in many cases only some of these are forthcoming, the bases of calculation are considerably narrowed, and the various and partial modes that have to be adopted necessarily vary with the available data.

First.—If the catchment area is not very large—that is, not exceeding 400 square miles, or 100 square leagues—it may sometimes be assumed that the whole of it is simultaneously subject to the same amount of maximum downpour, and that the loss by absorption and evaporation is also tolerably uniform over the whole; if then some trustworthy data for this loss should be available, the flood discharge can be computed direct; thus:

Let F, the actual downpour in 24 hours, be 0·8 feet, and the loss by absorption and evaporation one fourth; then the effective rainfall $f=0{\cdot}8-0{\cdot}2=0{\cdot}6$; and the corresponding flood discharge per second, Q, from a catchment (K) of 4 square leagues, will be

$$Q=\frac{0{\cdot}6\times4\,(10\,000)^2}{24\times60\times60}=2778 \text{ cubic feet per second.}$$

If the rainfall or the loss vary over portions of the catchment, the parts may be treated in the same way, to obtain a total value of Q through summation. For this purpose Table II., Part 3, can be used.

Second.—If the catchment area under consideration happen to form part of some large region, whose rainfall has been thoroughly investigated, and in which numerous flood discharges have been arrived at through velocity observations and computation, some general coefficient of drainage (k) may have been determined for that region. In that case the computation for flood discharge from any portion of it can be computed by formulæ.

The three best-known formulæ for this purpose are

$$(1)\quad Q=k_1\,27\,(K)^{\frac{1}{2}}.$$
$$(2)\quad Q=k_2\,100\,(K)^{\frac{3}{4}}.$$
$$(3)\quad Q=k_3\,1300\,K\,(L)^{-\frac{1}{3}}.$$

In all these K is the catchment in square statute miles, Q the flood discharge in cubic feet per second; in the third L is the length of the main river or stream under consideration, in statute miles; while the coefficients k_1, k_2, k_3 are the local drainage coefficients suitable to each formula respectively.

Formula (1) requires a very wide range of values of k_1, and is hence inconvenient, though simple in form.

Formula (2) is preferable; it is a modification of Colonel Dickens's formula, $Q=825\,(K)^{\frac{3}{4}}$, suited to Bengal proper and Bahar; though it afterwards appeared that Formula (2) with coefficients near to $k=8{\cdot}25$ was suited to large tracts of Indian plains having an annual rainfall of from 24 to 50 inches.

It seems, however, more rational to use a coefficient more closely dependent on a similarity of general conditions, of which the maximum day's downpour is perhaps the most important. In Northern India where this latter is about 1·5 feet in or near hills, and 1·0 foot in the plains, the flood waterway allowed for bridges has generally been based on the assumption that the rainfall run off would amount to 1·0 foot in depth over the whole; and allowance has been made with these data for the flood waterway of the streams and rivers crossing both the Ganges Canal and the Sarhind Canal; in other cases, also, in Northern India, two-thirds of the depth of downpour is assumed to pass off in flood. It is hence better to use a coefficient suitable to similar conditions of catchment area, within narrower range.

The values of k_2 for India generally lie between 1 and 24: see coefficients in the Working Tables at Table XII., Part 1;—some further values of it, applicable to various river basins in India, are also given in the table of flood discharges at page [8] of the Hydraulic Statistics in the second part of this Manual. The values of the general expression, for a value of $k_2 = 1$, are given for catchment areas of various sizes in the Working Tables, at Table IV., Part 1, and the local coefficient can be readily applied to these quantities.

Formula (3) was deduced by Mr. Burge, of the Madras Railway, from observations in the tract through which that line passes; and is suited to it, with a value of $k_3 = 1$; the conditions being that the maximum downpour in 12 hours was 6 inches, and the area elevated from 500 to 1300 feet above mean sea level, consisting principally of unstratified rocks. It was deduced from observations on 27 bridges, of above 80 feet span, on the Madras Railway, and its results correspond closely with those of recorded flood sections; the errors lying between 4·64 feet too high and 3·40 too low in height of section. Mr. Burge argued justly that the length of the river necessarily extends the time of the discharge, and hence diminishes the quantity passing off within a certain time; and that also the functions of discharge, the hydraulic slope, the cross section, and the head affected by the sinuosities in greater length, are reduced by it. Admitting this, the same principle would apply not only to the main river, but also to its tributaries; the number and conditions of the tributaries would probably be a more important consideration. Again, there is much difficulty in saying where a main river begins; so much so, that in the first place the introduction of an index of $\frac{2}{3}$ against a coefficient of 1300 would appear to be a needless attempt at exactitude; and in the second place the introduction of the length of the river at all in an equation of this sort is a matter incapable of very extended application; although in the instances from which this formula was laid down it has been very successfully introduced.

A better mode of introducing a function somewhat similar to this would be to apply the ratio of extreme breadth to extreme length of catchment area; and introduce it in formula (2), the range of whose coefficients (k_2) for India seem to be between 1 and 24—an important step already gained. It then takes the form,

$$(4) \qquad Q = k_4 \frac{B}{L} 100 (K)^{\frac{3}{4}},$$

where B = extreme breadth of catchment area.
and L = extreme length of catchment area,
and k_4 = a new coefficient,
obtaining a more tangible improvement, capable of extended application. It is unfortunate, however, that for this formula a sufficient number of values of the new coefficient are not yet forthcoming; although in the instances in which it has been applied the improvement seems clearly manifested in reducing the range, so that for the present it is generally better to use formula (2), while in special cases the ratio can be easily introduced to obtain values of k_4.

Third.—When coefficients of the class k_1, k_2, k_3, k_4, are not available, and the conditions of rainfall and of absorption and evaporation are so defective as to be insufficient, direct observation of each single river or stream within the catchment becomes the sole guide. It then becomes necessary to fall back entirely on recorded flood-marks, as a means of approximating to the flood discharge; and, after gauging the discharges of the channels in their ordinary stages, to assume the flood discharges to be proportional to them according to the ordinary formula,

$$Q=\frac{A\,q\,.\,R^{\frac{1}{2}}}{a\,r^{\frac{1}{2}}},$$

where A is the sectional area up to flood-mark, R its hydraulic mean radius, and a and r are similar quantities corresponding to the discharge (q) determined under the conditions of observation in each separate channel.

4. STORAGE.

Reservoirs generally have for their object either the detention of flood water that might otherwise cause damage, as in works of river improvement, or the utilisation of it in canals, of navigation, irrigation, or driving machinery, or for town supply. For the first purpose they must, to effect their purpose, be very extensive, and strongly aided by the natural formation of the country; for the last purpose they are, in one respect, excepting under very favourable conditions, particularly ill-fitted.

The collection of drinking-water from the surface of land needs, in the first place, a clean, uncultivated and uninhabited tract of land as a catchment area; and in the second place, the water stored in the reservoir, which is liable to become putrescent, or seriously affected by the organisms, plants, and animalculæ that inhabit stagnant water, requires a very perfect and careful filtration, of a sort beyond the ordinary economic powers of municipalities or public companies. Indeed, it is now asserted to be an incontrovertible fact, that it is to the tainted water of rivers and reservoirs that one-half of most preventible diseases are due, the other half being caused by want of ventilation, faulty drainage, and mistaken modes of managing sewage, or, in other words, that impure air and tainted water are the chief enemies of human life; and there is, therefore, every reason to believe that in the future, when the general public become awake to this, and acquire enough energy to throw off the incubus of vested interests in the form of water-companies, both tainted rivers and open reservoirs will be universally condemned as sources of drinking-water supply, and that the water filtered, stored, and preserved against impurity by nature in the permeable and unvitiated strata of the earth, will be considered, as it justly is, a necessary of life and health, and be drawn on in a more scientific and enlightened way than is at present usual. Another quarter of a century may show us scientific men objecting, on sanitary grounds, to the watering of our streets with such water as is now habitually and unconcernedly used in preparing our food.

It will therefore be only under conditions very favourable for clean collection and storage, or under circumstances that admit of no better alternative, that the water of storage reservoirs will be used for drinking purposes. Such water will, however, still remain valuable under ordinary circumstances, for extinguishing fires, watering streets, and many other purposes, in which it is not habitually brought into contact with the human body, and where its impurities are of little avail.

The determination of the size and dimensions of a storage reservoir is a matter entirely governed by local circumstances and requirements. The assumptions that the area covered by it should bear a certain proportion to that of the catchment area, or that the amount of water stored should be as nearly as possible one-third of the available supply, are not by any means rules to be applied without a very large discretionary power, although there are rules laid down in various forms by different hydraulic engineers that very much resemble these. The object being the collection and retention of a certain amount of water for a definite purpose, and the circumstances being the local formation of the ground and the amount of available downpour on the catchment area, all the economic considerations depend on these points.

The intention may either be to store as much water as possible within a certain amount of expenditure of cost, or only a definite amount sufficient for a certain purpose, or to store all that can possibly be obtained with a knowledge that the extreme amount would not be enough. Again, in some cases the quality of the water and the convenience of proximity, or of cleanliness of site, may be considerations outweighing all others. If, therefore, the latter is the case, there are generally not many local conditions answering the purpose within which any choice can be made; the same may be generally said to be true with reference to the second case in which a definite amount is required. It is only therefore under special circumstances, when the object is to store and utilise as much water as possible, that much choice is left to the engineer.

Large artificial reservoirs being generally made on the natural surface of the ground, and bounded in one direction only by an embankment of earth or a dam of masonry or brickwork, the first object is to choose a site or sites where the greatest amount of water can be stored with the shortest and least amount and length of embankment; for this purpose a river gorge, narrow and precipitous, terminating a great length of country, having a gradual fall towards it, offers the best ordinarily natural conditions; if, in addition, the lateral or transverse slope of the country is also very gradual, it becomes a large natural basin, with one narrow outlet; and if this admits of being easily dammed, an extraordinary advantage not often available presents itself.

The economy of constructing one large reservoir in preference to two or more small ones to hold the same amount would, perhaps, be evident at first sight to most people. The author has, however, met so large a number of persons that believe the contrary, that he is constrained to give the following mathematical proof of it by Graeff.

Let a single reservoir, or rather its contents when full, be supposed to consist of a number of laminæ, or layers of water, the sum of which will equal the total content, and let

H = the height of any one layer;

P and S = the perimeter and surface of its lower side;

P' and S' = the perimeter and surface of its upper side; then the volume of this layer will be

$$= aH + \frac{bH^2}{2} + \frac{cH^3}{3};$$

$$\text{where } a = S;\ b = \frac{2P(S' - S}{H(P' + P)};\ c = \frac{(S' - S)(P' - P)}{H^2(P' + P)};$$

Hence the above expression becomes

$$=\frac{H}{3(P'+P)}\left\{3S.\overline{P'+P}+P'.\overline{S'-S}+2P.\overline{S'-S}\right\}$$

$$=\frac{H}{3(P'+P)}\left(P.\overline{2S'+S}+P'.\overline{2S+S'}\right).$$

In the case where the lateral and longitudinal slopes of the ground are uniform, we can imagine the reservoir to consist of one only of these layers; and its contents will then represent that of the whole reservoir. In this case the height of the layer will be the extreme depth of water stored, and the quantities S and P will become indefinitely small in comparison with S' and P', and may hence be neglected: hence the total volume of water stored $=\frac{1}{3}HS'$, and this is the volume of a reversed cone having S' for its base; a demonstration that proves how rapidly the amount of storage increases with the depth of water, or with the height of the embankment.

To the height of dams, again, there is a practical limit; earthen dams of great height require an enormous section, being consequently very costly as well as dangerous, and are in themselves difficult to manage as regards escape; masonry dams have a limit to their height, due to the pressure per unit of surface on the foundation; the highest yet built that is still standing does not exceed 164 feet, and it is very improbable that that height will be greatly exceeded for some time to come, unless iron is made to enter largely into their construction.

After choosing a site for a proposed reservoir, one of the first points requiring attention is the determination of its storage capacity up to different proposed levels of escape. For this purpose, marks are fixed at differences of level of about 5 or 10 feet, on any convenient short line of section; and the contours of these levels are marked out and surveyed all around the basin, in order to obtain the perimeters and areas at each contour; from these, as before shown, the contents of each lamina can be calculated, and the content up to any other contour. If, however, it be preferred to obtain this by means of a series of longitudinal and transverse sections taken up to the heights of the various contour levels, it is perhaps best to direct the former in conformity with the axis or axes of figure of the basin, and the transverse sections at right angles to them, and, as far as possible, at equal distances along them; although in some instances, unequal distances and inclined directions, more suited to the form and disposition of the ground, would give more correct results; the true values of the corresponding rectangular transverse sections can then be obtained from the oblique sectional areas by multiplying them by the cosines of their angles of obliquity. Should a winding river channel or depression form part of the basin, it is often more convenient and correct to estimate its content independently, and add it in afterwards.

The following are the three formulæ most used in obtaining the contents from the sectional areas:—

1. If there be only two sectional areas, A_1, A_2, taken at a time, at a common distance, d,

the contents $=\frac{1}{2}d\,(A_1+A_2)$, or $=\frac{1}{3}d\,(A_1+A_2+\sqrt{A_1\,A_2})$.

2. If there be three equidistant sections, A_1, A_2, A_3, taken at a time, and their common distance is d, the contents $=\frac{1}{3}d\,(A_1+4\,A_2+A_3)$.

3. If there be any even number (n) of equidistant sections, A_1, A_2, &c., up to A_n, at a common distance, d,

$$\text{the contents} = d(\tfrac{1}{2}A_1 + A_2 + \&c. + A_{n-1} + \tfrac{1}{2}A_n).$$

The accuracy of result will of course depend on the closeness of the sections, and the suitability of their positions to the general form of the reservoir.

The capacity of the reservoir being obtained, the amount of supply that can be expected annually from the catchment area may be obtained, either in total quantities or in continuous quantities as cubic feet per second, by the aid of Parts 1 and 2 of Table II. of the Working Tables; in these calculations much labour is saved by deducting, in the first place, the allowance due to evaporation and absorption on the catchment area from the rainfall given, and making use of the available or effective rainfall or rainfall run off as the basis of calculation for supply.

If a small supply alone be involved, the use of Part 1, Table III. of the Working Tables will enable the contents of the reservoir, and extent of catchment area necessary to afford the supply, to be rapidly determined. Part 2, Table III., may also be occasionally useful, where the supply is limited by the needs of an extent of land to be irrigated, or the population of a town requiring water for public purposes.

The section of waterway of escape has next to be determined; this depending on the flood discharge and the maximum downpour in twenty-four hours. In these calculations, Part 3, Table II. of the Working Tables is useful; so also are Parts 1 and 2, of Table IV., in connection with the formula already given for flood discharge.

All these are of course simply modes of calculating, or of shortening, the calculation of the quantities of water; the determination of them has to be left to the discretion of the engineer and the requirements of the case. Should the supply be required to maintain a certain depth of water for navigation in a canal, the seasons, the supply deficient, the loss in the canals from evaporation and filtration, and all such data, will determine the amount;—if for irrigation, the amount of land, its quality of soil, and probable water duty; on this latter subject information is given in Chapter III. and in the Hydraulic Statistics, where data of the waterings and water duty usual in France, Spain, Italy, and Northern and Southern India, are given. Or if the supply is required either for motive power or the public purposes of town supply, the amount and height of delivery require determining with reference to local conditions; in such matters, therefore, no guide would be of use. Lastly, if the object is the control of floods, the whole of the physical conditions of the river and its banks, from its highest watershed down to its mouth or embouchure in the sea, will be matters affecting the amount, and the management and regulation of the storage: on this subject see the paragraph in Chapter III.

5. Discharges of straight, uniform Reaches of Open Channels, and of Pipes.

The various modes of gauging velocities and discharges are described in Chapter II. on field operations and gauging. The calculation of velocity or of discharges, under different conditions and for different data, may be considered independently of gauging. It is important to the engineer that he should at any time be able to calculate, in a few moments, the discharge of any pipe, channel, or canal, from such sufficient data as he may possess, or obtain readily.

The number of calculated velocity formulæ, their variety, and the wonderful amount of complication in them, as well as the want of exactitude of result they give, is truly astonishing; and when, on the other hand, one observes some engineers adhering slavishly to the tables and data of one hydraulician, others to those of another, and others again going through the conscientious, but very lengthy, course of examining everything that every hydraulician has said or done in the matter of calculation of mean velocity of discharge, one cannot but feel pained as well as surprised.

It would be quite out of place in this portion of a Manual of this description, which has for its object the supplying the engineer with information and tables for calculating his quantities and data in as rapid a way as practical correctness will allow, to enter into a detailed investigation of all these formulæ, and the reasons for setting them all aside and adhering to that adopted in preference and to the exclusion of all others; it will, therefore, suffice for the author here to mention the reason for adopting any one formula or conclusion as it is brought forward. A comparison of the results of various hydrodynamic formulæ will be given in Chapter III., among the miscellaneous detached paragraphs.

The general formula for discharge, based on the theories mentioned in the section 1 of this chapter, is

$$Q = A\,V = A\,(f\,g\,R\,S)^{\frac{1}{2}},$$

the terms of which are given in the general notation, page 11; the mean velocity of discharge being the smaller and more convenient quantity to deal with, for open channels and canals, and the discharge itself being the quantity more often required for pipes, sewers, and closed tubes, syphons, or tunnels of all sorts.

Taking, however, the expression for mean velocity of discharge, obtained by equating the accelerating effect of gravity down an inclined plane with the retarding effect of friction, it can be put into the form more convenient for English measures—

$$V = c \times 100 (R\,S)^{\frac{1}{2}},$$

where c is a variable experimental coefficient, depending on the surface, the conditions, the dimensions, and the hydraulic slope of the channel or pipe, and hence also on a further experimental coefficient n of roughness and irregularity combined, which again involves both the functions R and S: its value under extreme conditions varies from 0·25 to about 2·00.

A correct formulated determination of the value of the coefficient, c, for all conditions, is a matter that can only be said to have been even approximately arrived at in the last few years, from an examination of the experimental results of d'Arcy and Bazin on the discharges of pipes, open channels and ordinary rivers, and those of Humphreys and Abbot on the discharges of very large rivers, and on his own observations on Swiss hill-streams and channels, by Herr W. R. Kutter, of Bern.

The determination of coefficients of this type for which we are indebted to him, and tables rendering it easily found for open channels and rivers of any sort or dimensions in metric measures, are given in his valuable articles in the 'Cultur-Ingenieur' for the year 1870. A comparison of these coefficients of Herr Kutter with recorded results, principally Indian, made, collected, and compiled by the author between 1860 and 1873, conduced to the belief that the formula of Kutter was the best extant; but that the classification of coefficients was defective as applied to canals and straight, uniform river-reaches.

The values of the coefficients varying so greatly in the various classes, it became necessary to reinvestigate the subject. This was done, and eventually an extension and an alteration of the classes was made by the author; the formula was freshly worked out for English units, and the whole was set forth in detail in the author's work, 'Canal and Culvert Tables' (London, 1878, Allen).

Under this new arrangement, the values of *c*, the coefficient of mean velocity, are also given in this edition of this book in Part 4, Table XII.

With the aid, therefore, of these tables of coefficients (*c*) and the values of the expression $100\,(R\,S)^{\frac{1}{2}}$, given in Table VII., the values of *V*, the mean velocity of discharge of straight and uniform reaches of canals and open channels can be rapidly determined in a few moments, according to the most improved and correct method yet known.

With the aid of the same tables of coefficients (*c*) and the values of the expression,

$$Q = c \times 39{\cdot}27\,(S\,d^5)^{\frac{1}{2}} \text{ when } c = 1,$$

given in Table VIII., the discharge of any full cylindrical pipe, sewer, or tunnel, may also be determined by applying suitable values of *c*.

These tables, to which explanatory examples are attached, can also be used for the converse purpose of obtaining the head, diameter, hydraulic slope or hydraulic radius, due to given discharges of channels and pipes; it will, however, be necessary for the calculator to remember that all dimensions, even diameters of pipes, are best invariably kept in feet, and that all slopes are kept in the form known as the sine of the slope, mentioned in the general notation, given in section 2 of this chapter. Should it be necessary to reduce these from gradients given in other forms, such as in feet per English mile, or as a fall of unity to a certain length, Table VI. may be used to save calculation.

The Derivation of the Coefficients.—So far for the velocity formula actually adopted, and the mode of working it in calculating results. As regards the formula itself, independently of the determination of the variable coefficient, it is none other but the Eytelwein formula, or Chezy formula, in a very much improved form, having the results of modern experiment incorporated with it. An examination of the old hydraulic formulæ for mean velocity shows that most, in fact almost all of them, were modifications of the Chezy formula, some of them adding an additional term or function, and altering the value of the experimental coefficient, but still asserting its fixity.

In the earlier editions of this Manual, written before Herr Kutter had published his valuable improvement, all the formulæ having fixed coefficients were rejected by the author, who at the same time asserted the principle that no fixed coefficient was suitable to all circumstances, and that the engineer should choose for himself a coefficient most suitable to the special circumstances, dimensions, and condition of the pipe, channel, or river, with whose discharge he was dealing; and that the recorded results of experiment should be always consulted for the purpose of approximating as closely as possible to the special circumstances of the case under consideration. In addition to that recommendation, a mode of arriving at values of *c*, in cases of canals in earth, in good order, under very limited conditions, was also then mentioned. It consisted in a method of successive approximation; first, to assuming $c=1$; and then from the mean velocity *v*, resulting, assuming a second value of *c*, according to the following table, was calculated, or a second true velocity of discharge, *V*.

v	*c*	*v*	*c*	*v*	*c*	*v*	*c*
1·0	·910	1.5	·960	2·0	1·000	2·5	1·023
1·1	·920	1·6	·968	2·1	1·005	2·6	1·026
1·2	·930	1·7	·976	2·2	1·009	2·7	1·030
1·3	·940	1·8	·984	2·3	1·014	2·8	1·033
1·4	·950	1·9	·992	2·4	1·018	2·9	1·037
						3·0	1·040

A few values of *c*, suitable to pipes under various velocities, were also given; but they were detached, and, from want of experiment, very insufficient. Yet the true state of the case, and the mode most advisable for adoption until investigations on a larger scale threw more light on the matter, was then clearly set forth.

Now that the experiments of d'Arcy and Bazin, of Humphreys and Abbot, and of Ganguillet and Kutter, have been reduced to one formulated expression, the labour of choosing a coefficient from general experimental records is rendered needless as far as regards ordinary canals and culverts; although it would be advantageous to experimentalise on the actual case.

As regards natural channels of rivers otherwise than those whose conditions approximate to those of canals,

D 2

the necessity of referring to records of experiment still remains, although the Kutter coefficients may be of great assistance even in this branch of the subject

The determination and tabulation of the coefficients (c) has gone through three stages of development. 1. *The first* was that made by Bazin, based on the experiments conducted by d'Arcy, by Bazin himself, and by various engineers of the French Ponts et Chaussées. The principles asserted were that the coefficient depended on two quantities or qualities only, namely, the condition of surface of the bed and banks touched by the water, and the hydraulic mean radius of the section of discharge. Four categories of coefficients were adopted.

1st. For very smooth surfaces, well-plastered surfaces in cement, and well-planed plank.

2nd. For even surfaces, ashlar, brickwork, and ordinary planking.

3rd. For rough surfaces, as rubble.

4th. For earthen channels generally

The values of an intermediate coefficient c for French measures in these four categories were—

$$(1)\ c_{,}=0{\cdot}00015\left(1+\frac{0{\cdot}03}{R}\right)$$

$$(2)\ c_{,}=0{\cdot}00019\left(1+\frac{0{\cdot}07}{R}\right)$$

$$(3)\ c_{,}=0{\cdot}00024\left(1+\frac{0{\cdot}25}{R}\right)$$

$$(4)\ c_{,}=0{\cdot}00028\left(1+\frac{1{\cdot}25}{R}\right)$$

The corresponding values of the final coefficient c for the English formula in feet may be obtained from the above values of $c_{,}$ by the formula

$$c = \frac{1{\cdot}81}{100\,(c_{,})^{\frac{1}{3}}} = \frac{V}{100\,(R\,S)^{\frac{1}{2}}}$$

under an arrangement that keeps the values of c within a limited range approximating to unity, and throws 100 into the old general expression for the Chezy formula.

The values of these coefficients (c), adapted to the corresponding formula in English feet, are generally as follow, in their respective categories :—

R	c_1	c_2	R	c_3	c_4
1·	1·41	1·18	1	0·87	0·48
1·5	1·43	1·22	2	0·98	0·62
2·	1·44	1·24	3	1·04	0·70
2·5	1·45	1·26	4	1·06	0·76
3·	1·45	1·26	5	1·08	0·80
3·5	1·46	1·27	6	1·10	0·84
4·	1·46	1·28	7	1·10	0·86
4·5	1·46	1·28	8	1·11	0·88
5·	1·46	1·29	9	1·12	0·90
5·5	1·46	1·29	10	1·12	0·91
6·	1·47	1·29	11	1·13	0·92
7·5	1·47	1·29	14	1·13	0·95
8·	1·47	1·30	15	1·14	0·13
19·	1·57	1·30	18	1·14	0·98
20·	1·48	1·31	20	1·14	0·98

These coefficients are not correct for canals in earth generally, and are notoriously incorrect for large canals; they are useless to English engineers, excepting in so far as they afford them a knowledge of the velocities and discharges that French engineers would assume to hold with certain known conditions. In the matter of dogmatic prejudice, and mutual international recrimination, the balance between the French and the English is tolerably even; if the English are insular and coldly impassible, the French are bureaucratic and heated with vanity; yet science will progress in spite of all petty wishes, both individual and national.

The most modern, and probably also the most generally correct mode, of expressing the relation between maximum and mean velocity in a canal section is passing through a transitional stage; it originated with Bazin, and was first connected with his above-mentioned coefficients.

To obtain the values of coefficients of mean velocity from the observed maximum velocity V_s, and from values of R and S in English feet, we obtain from Bazin's formula, $V_m = V_s - 14\sqrt{RS}$ for mètres, which for English feet is $V_m = V - 25{\cdot}34\sqrt{RS}$, the result

$$c = 0{\cdot}01\left[\frac{V_s}{\sqrt{RS}} - 25{\cdot}34\right];$$

applying this coefficient in the formula $V_m = c \times 100\sqrt{RS}$, the mean velocity of discharge V_m is obtained.

It is probable that this mode of determination through observed maximum velocities constitutes the basis of the best way of rapidly arriving at coefficients of mean velocity and of discharge; although this, as very many other hydraulic matters, admits of further improvement through experimental investigation.

The observations of Captain Cunningham on large canals tend to the condemnation of this relation between mean and maximum velocity as a general law; it becomes therefore necessary to confine its direct application to cases corresponding to those of the small *biefs* or branch distributaries on which Bazin made his experiments. (See Chapter II., Bazin's gauging.) In any extended application of the principle some allowance must certainly be introduced for the locus, or sectional position, of the fillet of maximum velocity; and limits must be imposed both to the form of section and conditions of roughness and irregularity. At present the principle is useful to hydraulicians in relative application. It will be further referred to in Section 8 of this Chapter on Velocities.

2. *The second* stage of development was effected by Kutter and Ganguillet. Their own experiments on torrents and streams in Switzerland, combined with the results of Humphreys and Abbot on very large rivers, led them to believe that the coefficient should not be confined within so small a number of categories, and that the coefficient was a function of the hydraulic slope, besides being a function of the roughness of surface acted on by the water, and of the hydraulic mean radius of the section. They therefore extended the categories of coefficients for artificial open channels in earthen beds from one to four distinct classes, and increased the other categories adopted by Bazin from three to six; these new ten classes being arranged in accordance with the following coefficients (n) of roughness and irregularity adopted as suitable to the surface under consideration.

General values.

·009—Well-planed plank.
·010—Very smooth surfaces, plasters in cement.
·011—Plaster in cement, with one-third sand.
·012—Unplaned plank.
·013—Brickwork and cut stone.
·017—Rubble masonry.
·020—Canals with bed and banks of very firm gravel, well punned.
·025—Rivers and Canals in Earth, in perfect order and regimen, and perfectly free from stones and weeds.
·030—Rivers and Canals in Earth, in moderately good order and regimen, having stones and weeds occasionally.
·035—Rivers and Canals in Earth, in bad order and regimen, having stones and weeds in great quantity.

The values of the coefficients of discharge ($c_{\prime}$) depend on the value of (n), as well as on the hydraulic slope and hydraulic radius of the open channel under consideration, in accordance with the following formula for French measures.

$$c_{\prime}=\frac{23+\frac{1}{n}+\frac{0\cdot00155}{S}}{1+\left(23+\frac{0\cdot00155}{S}\right)\frac{n}{\sqrt{R}}}$$

which is also given in the following form:—

$$c_{\prime}=\frac{z}{1+\frac{x}{\sqrt{R}}};$$

$$\text{where } z=23+\frac{1}{n}+\frac{0\cdot00155}{S}\text{; and } x=n\left(23+\frac{0\cdot00155}{S}\right).$$

The values of $c_{\prime}$ for French measures are tabulated in Herr Kutter's book 'Die neuen Formeln für die Bestimmung der mittlern Geschwindigkeit des Wassers etc.' pages 336, 386, and 436, for the three classes in which $n=0\cdot025$, $0\cdot030$ and $0\cdot035$ respectively, and a diagram there given enables $c_{\prime}$ to be roughly read off for any conditions. The same data with complete tables of velocities and discharges suited to French measures are reprinted with the consent of Herr Kutter and attached to a translation entitled 'The New Formula for Mean Velocity of Discharge' (London, 1876, Spon).

The values of c, a corresponding coefficient suited to English feet, may at any time be easily derived from any value of $c_{\prime}$ calculated or given for French mètres by the formula

$$c=0\cdot0181\ c_{\prime}$$

It is, however, preferable to obtain English data in a more direct manner from special English tables, as will be hereafter explained.

3. *The third* stage of development of these variable coefficients was carried out by the author of this book at the request of the Indian Government in 1877 and 1878. The general truth of the formula of Herr Kutter had previously been accepted by him, after a lengthy investigation of the principles and the recorded basic experiments; the formula itself had also already been employed by him in the calculations for some engineering designs for Mr. John Fowler. The elasticity of the formula, however, acted both as an advantage in general applicability and as a disadvantage in choice of category or class; almost everything centred itself in the choice of the value of n, the coefficient of roughness and irregularity; for the effect of various values of R had been justly met in the formula, and that of various values of S had been perhaps too cautiously allowed, yet was approximately and substantially correct. A fresh independent determination of a set of values of n was therefore necessary.

The author having been for many years and in many places a persistent observer and collector of data of hydraulic experiment, having had unusually numerous opportunities since 1859 on works of irrigation, on river improvement works, on canals, and on waterworks both in South America and in Northern, and Southern India, of obtaining such information, and also having been permitted both at Calcutta, Madras, Bombay, and in London to search among official records of such works, it was hoped that enough would be forthcoming to give some limits to the application of the formula for canals by fixed values of n of independent determination.

The result of these labours and collections was successful so far as it affected canals in earth, within the range of the records, of cases that had fallen under his personal observation, and that thus admitted of little doubt as to condition.

Briefly, the results were, that none of the cases in canals in earth were below $n=0{\cdot}017$, that the cases in which $n=0{\cdot}025$ was approximately applicable were not canals in by any means *perfect* order, that any channels of a condition suited to $n=0{\cdot}035$ were from irregularity beyond the scope of anything but excessively coarse and almost useless determination; and that a large number of cases of canals in good order happen to give a value of n not far from 0·0225.

Five fixed classes were therefore assigned to canals in earth of various soils, and in various conditions.

1st $n=0{\cdot}020$ for very firm, regular, well-trimmed soil.
2nd $n=0{\cdot}0225$ for firm earth, in condition above the average.
3rd $n=0{\cdot}0250$ for ordinary earth in average condition.
4th $n=0{\cdot}0275$ for rather soft friable soil in condition below the average.
5th $n=0{\cdot}030$ for rather damaged canals in a defective condition.

The attempts of the author to determine independently values of n suited to canals in artificial materials, plank, rubble, ashlar, and cement, were ineffectual from want of sufficient mention of age, quality, and condition of surface of these materials in recorded cases of experiment then forthcoming. For the special material rubble these latter did not afford quite sufficient reason for objecting to Herr Kutter's value of $n=0.017$ for that material in a normal condition, but they did indicate a wide range of values; as to other materials, nothing resulted on account of the reason before given; the general conclusion was that each material should have a wider range of values of n suited to various conditions. Accepting, therefore, the normal values given by Herr Kutter as correct, the extension of their range was effected by the following arrangement.

$n=0.010$ Smooth cement, worked plaster, planed wood, and glazed surfaces in perfect order.

$n=0.013$ The materials mentioned under 0·010 when in imperfect or inferior condition. Also brickwork, ashlar, and unglazed stoneware in a good condition.

$n=0.017$ Brickwork, ashlar, and stoneware in an inferior condition. Rubble in cement or plaster in good order.

$n=0.020$ Rubble in cement in an inferior condition. Coarse rubble rough-set in a normal condition.

$n=0.0225$ Coarse dry-set rubble in bad condition.

It may be noticed that it might be considered preferable to give more simple values to n, as 1, 1·3, 1·7, 2, $2\frac{1}{4}$, etc., and to modify the general formula to suit them; but as there is yet some doubt on this point, and as established custom must be considered also, the values have for the present been allowed to retain their original form.

Application of the coefficients.—Coefficients, velocities, and discharges suited to canals of practical dimensions and data, were worked out and tabulated in accordance with these results; they will be found in 'Canal and Culvert Tables' (London, 1878, Allen). Tables of the coefficients are also given in the Working Tables of this book (see Table XII.); these can be applied to the tabulated values of $100\sqrt{RS}$, given in Table VII.; thus obtaining for any case the value of a mean velocity, from the formula

$$V=c \,.\, 100\sqrt{RS}.$$

Also to obtain Q, the corresponding quantity of discharge, the values of A, the section of flow, or hydraulic sectional area, may be taken from Table IV., thus completing the data for the formula

$$Q=AV=A \,.\, c \,.\, 100\sqrt{RS}.$$

A value of c may, however, be occasionally, though rarely, required for some intermediate value of n; in that case it may be interpolated without important error, or, if accuracy be required, it should be calculated from the formula. This, after reduction of terms for direct application to English feet, has been altered into the following more convenient form:—

$$c=\frac{\sqrt{R}}{100n}\left(\frac{m+1{\cdot}811}{m+\sqrt{R}}\right)$$

$$\text{where } m=n\left(41{\cdot}6+\frac{0{\cdot}00281}{S}\right).$$

For the converse process of determining a value of n from given data, which is more complicated, see an example at pages 376–377 of 'Canal and Culvert Tables,' before mentioned.

As it is of interest to notice the effect of the values of n on the coefficient c, under ordinary hydraulic slopes of from 1 in 1 000 to 1 in 10 000, the two following pages of tabulated values are here given; they show that c varies there from 0·329 to 2·170, the extremes practicable being about 0·25 and 2·50. From this it is evident that if, from unwillingness to turn over the pages of tabular quantities in this book or in the 'Canal and Culvert Tables,' it be preferred to use a fixed coefficient of unity, $c=1$, for every case of velocity in canals, the extreme error may be thrice in excess, or more than a half in diminution, while the calculated probability of ever being right approximates to zero.

The above-mentioned mode of calculating mean velocities and discharges is intended to apply generally to straight, uniform reaches of open channels. For ordinary natural channels, as of streams and rivers, it affords merely a coarse approximation, as such discharges cannot be accurately ascertained without some velocity-observation.

It will, however, be perfectly evident that the general method does not by any means preclude the application of an allowance or deduction for special circumstances. In actual fact, few channels are either perfectly straight, perfectly regular, or free from easily estimated lateral and longitudinal irregularities; variety in this particular alone may affect the amount of discharge by as much as twenty per cent., even after making allowance for loss of head by bends and obstructions. The local conditions of a channel, the wind, the amount of silt in suspension, the motion of its shoals, the change of the set of its currents, all seriously affect a discharge calculated from data that make no allowance for these circumstances. These causes of retardation are enumerated in section 1 of this chapter.

For canals and regular rectangular and trapezoidal channels in earth in good order, the calculated discharges will be more correct than those for deteriorated and

Coefficients of mean velocity suited to various materials, calculated for a fixed value of S=0·001.

R in feet	Values of *n*							
	·010	·013	·017	·020	·0225	·0250	·0275	·0300
	(1)	(2)	(3)	(I.)	(II.)	(III.)	(IV.)	(V.)
0·5	1·385	1·011	0·730	0·598	0·518	0·455	0·404	0·363
1·	1·562	1·615	0·860	0·715	0·625	0·554	0·496	0·449
1·25	1·614	1·212	0·901	0·752	0·660	0·586	0·527	0·478
1·5	1·655	1·249	0·933	0·782	0·688	0·613	0·552	0·502
1·75	1·688	1·279	0·961	0·808	0·712	0·635	0·573	0·522
2·	1·716	1·305	0·984	0·829	0·732	0·655	0·592	0·450
2·25	1·740	1·327	1·004	0·848	0·750	0·672	0·608	0·555
2·5	1·761	1·346	1·021	0·864	0·765	0·687	0·622	0·569
2·75	1·779	1·363	1·037	0·879	0·779	0·700	0·635	0·581
3·	1·795	1·378	1·051	0·892	0·792	0·712	0·647	0·592
3·25	1·809	1·392	1·063	0·904	0·804	0·723	0·657	0·603
3·5	1·823	1·404	1·075	0·915	0·814	0·733	0·667	0·612
4·	1·845	1·426	1·095	0·935	0·833	0·751	0·685	0·629
4·5	1·865	1·444	1·113	0·951	0·849	0·767	0·700	0·644
5·	1·881	1·460	1·128	0·966	0·863	0·781	0·713	0·657
5·5	1·896	1·474	1·141	0·979	0·876	0·793	0·725	0·668
6·	1·909	1·487	1·153	0·991	0·887	0·804	0·736	0·679
6·5	1·921	1·498	1·164	1·001	0·897	0·814	0·746	0·688
7·	1·931	1·508	1·174	1·010	0·907	0·823	0·754	0·697
7·5	1·940	1·517	1·183	1·019	0·915	0·831	0·763	0·705
8·	1·949	1·526	1·191	1·027	0·923	0·839	0·770	0·712
8·5	1·957	1·534	1·198	1·034	0·930	0·846	0·777	0·719
9	1·964	1·541	1·205	1·041	0·937	0·853	0·784	0·726
10	1·977	1·554	1·218	1·054	0·949	0·865	0·795	0·737
15	2·023	1·599	1·263	1·098	0·993	0·908	0·838	0·780
20	2·051	1·627	1·291	1·126	1·021	0·936	0·866	0·807

Coefficients of mean velocity suited to various materials, calculated for a fixed value of S=0·0001.

R in feet	Values of *n* ·010	·013	·017	·020	·0225	·0250	·0275	·0300
	(1)	(2)	(3)	(I.)	(II.)	(III.)	(IV.)	(V.)
0·5	1·263	0·916	0·658	0·539	0·467	0·410	0·365	0·329
1·	1·478	1·097	0·806	0·669	0·585	0·518	0·465	0·421
1·25	1·545	1·155	0·855	0·713?	0·625	0·556	0·499	0·453
1·5	1·598	1·201	0·895	0·750?	0·659	0·587	0·529	0·480
1·75	1·643	1·240	0·929	0·780	0·687	0·613	0·554	0·504
2·	1·680	1·274	0·959	0·807	0·712	0·637	0·576	0·525
2·25	1·712	1·303	0·984	0·831	0·734	0·658	0·595	0·543
2·5	1·741	1·329	1·007	0·852	0·754	0·676	0·613	0·560
2·75	1·766	1·352	1·028	0·871	0·772	0·693	0·629	0·575
3·	1·788	1·372	1·046	0·888	0·788	0·709	0·643	0·589
3·25	1·809	1·391	1·063	0·904	0·803	0·723	0·657	0·602
3·5	1·827	1·408	1·079	0·918	0·817	0·736	0·670	0·614
4·	1·860	1·438	1·106	0·944	0·842	0·760	0·692	0·636
4·5	1·888	1·465	1·130	0·967	0·864	0·780	0·712	0·655
5·	1·912	1·487	1·152	0·987	0·883	0·799	0·730	0·672
5·5	1·933	1·508	1·170	1·005	0·900	0·816	0·746	0·688
6	1·952	1·526	1·187	1·021	0·916	0·831	0·760	0·702
7	1·985	1·557	1·217	0·050	0·943	0·857	0·786	0·727
8	2·012	1·583	1·242	1·073	0·966	0·880	0·808	0·748
9	2·035	1·605	1·263	1·094	0·986	0·899	0·827	0·767
10	2·055	1·625	1·282	1·112	1·004	0·916	0·844	0·783
11	2·073	1·642	1·298	1·128	1·020	0·932	0·859	0·798
12	2·088	1·657	1·313	1·143	1·034	0·946	0·873	0·811
13	2·102	1·670	1·326	1·156	1·047	0·958	0·885	0·823
14	2·114	1·683	1·338	1·168	1·058	0·970	0·896	0·834
15	2·126	1·694	1·349	1·178	1·069	0·980	0·907	0·845
20	2·170	1·738	1·393	1·222	1·112	1·023	0·949	0·886

irregular channels; the errors due to various irregularities in the former case forming a smaller percentage. Formulæ for velocity and for discharge are, however, almost as frequently used in determining a section of canal intended to convey a certain discharge, as to obtain a discharge from data of an actual canal.

In these cases, a consideration of the various forms of section, suitable to different purposes, is also necessary. This matter has been treated and repeated in nearly the same terms in all works on hydraulics published in the last half-century; the ideas were perhaps due to laborious hydraulicians now forgotten, as they cannot be clearly traced; and little can be now added to them; but as the entire omission of the subject in this Manual might cause disappointment, section 6 will be devoted to that special subject, though its treatment will be slightly modified to suit modern notions of discharge.

The discharge of pipes.

The calculation of the discharge of pipes may be conducted either on the same principle as that of artificial channels or on that of orifices. It is extremely unfortunate that the investigations of Ganguillet and Kutter were limited to open channels, and hence the application of their principles to pipes, though rationally superior to any other mode previously adopted, cannot be conducted with the same amount of experimental record in support.

Assuming then the general formula for mean velocity of discharge—

$$V = c \times 100\, (RS)^{\frac{1}{2}},$$

and adapting it to terms of the diameter of a pipe in feet; it becomes for full cylindrical pipes and tubes of all sorts, where $R=\frac{1}{4}d$ and d is the internal diameter,

$$V=c\times 50\ (dS)^{\frac{1}{2}},$$

and as the actual discharge is the quantity more usually required direct in the case of pipes, this is—

$$Q=AV=c\times 0{\cdot}7854d^2\times 50(dS)^{\frac{1}{2}},$$
$$=c\times 39{\cdot}27(Sd^5)^{\frac{1}{2}},$$

for discharges in cubic feet per second.

The converse forms of this expression being—

$$d=0{\cdot}23\left(\frac{Q^2}{c^2S}\right)^{\frac{1}{5}},$$
$$H=\frac{1}{c^2}\times 0{\cdot}0648\,\frac{Q^2}{d^5},$$

where H is the head in feet for a length of 100 feet, or is equal to 100 S.

The values of these quantities are given in Parts 1, 2, 3, and 4, of Table VIII., for a value of $c=1$, and the values of c given in the table of coefficients of discharge, Table XII., can be applied; the powers and roots of c can be taken from the Miscellaneous Tables.

With regard to these coefficients, it will be noticed that for want of sufficient experimental data, a coefficient of roughness $n=0{\cdot}010$ has been assumed as applicable to glazed or enamelled metal pipes, and one of 0·013 for ordinary metal and 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 this assumption.

In applying, however, to pipes the coefficients of discharge resulting from the foregoing formula, one would naturally be unwilling to push to extremes a principle derived from observation on open channels, and would prefer stopping at a point where the experimental data now forthcoming leave us. It would, therefore, seem imprudent at present to assume that the asserted law of coefficients holds good for an hydraulic radius R less than 0·1 foot. This limiting hydraulic radius of 0·1 foot or of 1 tithe or tenth is that of a 5-inch pipe, or a pipe having a diameter of 0·4 foot; and in cases of falls steeper than 0·001 the corresponding coefficient for glazed pipes is 0·84, and for ordinary pipes 0·61. Hence for the present, and until further experiments have thrown more light on the subject, it may also 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 for those of that diameter.

Reverting to the original formulæ for mean velocity and for discharge in pipes of all sorts,

$$V = c \, . \, 100 \sqrt{RS}$$
$$Q = AV = A \, . \, c \, . \, 100 \sqrt{RS}$$

it must be borne in mind that, though with open channels and unfilled culverts S represents the sine of the slope of the water surface, with filled pipes under low heads due to their inclinations S represents the sine of a mean hydraulic slope that is not necessarily identical with the inclination of any part of the pipes; while if there should, in addition, be any permanent statical head of pressure on the upper entrance of the pipe, the conditions are again changed by this further complication, and the above principle is then only partially applicable.

With siphons also that have been exhausted of air, a statical pressure of one atmosphere is added to the effective differential head.

These matters will be further explained in Section 7, devoted to the hydraulic slope.

It must also be noticed that it is merely with filled cylindrical pipes that the mean hydraulic radius is equal to one-fourth their diameter. In all other cases the value of R must be determined from the section of flow, whatever it may be, by dividing that sectional area by the wet perimeter of the bottom and sides up to water surface level. This subject will be treated in Section 6.

Bearing in mind the liabilities under these two special peculiarities, it yet remains that both S and R have certain values in connexion with pipe discharge that may be applied in the general formulæ originally given.

6. THE HYDRAULIC SECTION OR SECTION OF FLOW.

On examining the equations representing the principle of flow and of discharge (Section 1, Chapter I.), it will be noticed that the sectional area of flow, and its function the hydraulic mean radius, are both involved.

There may still remain considerable doubt whether in all cases the mean hydraulic radius, $R=\frac{A}{P}$, is the exact term for correct introduction into any general formula of the type,

$$Q=AV=A\,.\,c\,.\,100\sqrt{RS}.$$

In excessively wide and comparatively shallow sections of flow the resistance of the air on the water surface becomes an important function, and in that case, the prime hydraulic radius $R_1 = \frac{A}{P+W}$ might, as adopted by Captain Humphreys and Abbot on the Mississippi, be more suitably introduced, with a corresponding new set of coefficients c_1 in place of c. In the converse case of very narrow and very deep sections of flow, an augmented hydraulic radius $R_2 = \frac{A}{P-W}$ might be a convenient means of modification for obtaining the augmented discharges actually resulting in such sections, that are physically due to diminished total friction on the perimeter that mostly consists of the two sides.

There is, however, much doubt as to the mode and limits within which these functions could be correctly introduced; while the two extremes of excessive width and of very great depth of section are of comparatively rare practical occurrence. A general adherence to the use of R, the mean hydraulic radius in all ordinary cases, is hence advisable, and will for purposes of convenience be assumed in this book, except where otherwise mentioned.

The relative dimensions of the hydraulic section or section of flow become important principally from two points of view; first, when the maximum discharge possible through the section has to be considered, as in drainage-cuts, flood-escapes, and such channels where erosion from high velocity might not be a serious defect; secondly, when in design there is sufficient scope for various forms of section that would have equal discharging powers, and among which a choice has to be made.

The conditions of the canal section of maximum discharge.

From the functions involved in the general formula of discharge

$$Q = A\,c\,.\,100\sqrt{R\,S},$$

it is evident that though the conditions of a complete maximum cannot be determined, those of a partial and nearly complete maximum admit of reduction in known terms. Assuming that the side slopes of the section are fixed by practical considerations of soil, &c., that the hydraulic slope is constant, and the coefficient of roughness also; and using the following symbols:

Let t to 1 be the given ratio of the side slope.

b and d the bed width and depth of the water section.

R the mean hydraulic radius.

P the wet perimeter.

S the hydraulic slope.

Now with a trapezoidal section of any proportions,

$$R = \frac{A}{P} = \frac{d\,(b + td)}{b + 2d\,(1 + t^2)^{\frac{1}{2}}}.$$

Under the condition of maximum discharge, A will be a maximum, so also will R; and when these are temporarily constant, P will be a minimum.

hence $\partial A = d\,.\,\partial b + b\,.\,\partial d + 2td\,.\,\partial d = 0$ (1)

$\partial P = \partial b + 2\partial d\,(1 + t^2)^{\frac{1}{2}} = 0$ (2)

Subtracting (1) from (2),

$$2\partial d\left\{(1 + t^2)^{\frac{1}{2}} - td\right\} + \partial b\,(1 - d) - b\partial d = 0\,;$$

substituting for δb its value, $-2\delta d\ (1+t^2)^{\frac{1}{2}}$,

$$2\delta d\left\{d\ (1+t^2)^{\frac{1}{2}}-td\right\}-b\delta d=0\ ;$$

dividing by δd and reducing,

$$b=2d\left\{(1+t^2)^{\frac{1}{2}}-t\right\}$$

substituting this value of b, in $A=d\ (b+td)$,

$$A=d^2\left\{2\ (1+t^2)^{\frac{1}{2}}-t\right\}$$

$$d=\sqrt{A}\ \left\{2\ (1+t^2)^{\frac{1}{2}}-t\right\}^{-\frac{1}{2}}$$

$$b=2\sqrt{A}\left\{2\ (1+t^2)^{\frac{1}{2}}-t\right\}^{-\frac{1}{2}}\times\left\{(1+t^2)^{\frac{1}{2}}-t\right\}$$

$$\text{and } R=\frac{A}{b+2d\ (1+t^2)^{\frac{1}{2}}}$$

Then for any given value of t, the quantities d and b may be expressed in terms of $\sqrt{A}$ with numerical coefficients; according to the following table.

The above results may also be reduced to another form of expression.

If a the angle of inclination with the horizon of the side slope be given, it is evident from the above that $t=\text{cotg}\ a$, and A may be also expressed in the old form, $d^2\,(\text{cosec}\ a+\tan\frac{1}{2}\,a)$; whence also corresponding values of d and b may be reduced from given values of a; this form is, however, not practically as convenient as the former.

The geometrical figure obtained by this process is a trapezoid touching a semicircle; it has the least perimeter for a given area, and has greatest values of R, V, Q, and approximately of c. It cannot be drawn or determined geometrically under ordinary practical conditions, but after algebraic determination it may be verified by diagram.

Table of relative Trapezoidal Sections of maximum discharge having a given area A, *and given side slopes* t *to* 1.

Ratio of side slope t to 1	Numerical factors to be multiplied by $\sqrt{A}$			Corresponding value of A in terms of d^2
	for d depth	for b bed width	for R hydraulic radius	
0 to 1	0·7071	1·4142	0·3536	$2\,d^2$
¼ to 1	0·7430	1·1601	0·3715	$1·8116\,d^2$
½ to 1	0·7590	0·9382	0·3795	$1·7361\,d^2$
⅔ to 1	0·7587	0·8121	0·3794	$1·7370\,d^2$
¾ to 1	0·7559	0·7559	0·3780	$1·75\,d^2$
1 to 1	0·7395	0·6126	0·3745	$1·8284\,d^2$
1¼ to 1	0·7158	0·5021	0·3579	$1·9516\,d^2$
1⅓ to 1	0·7071	0·4714	0·3536	$2\,d^2$
1½ to 1	0·6891	0·4174	0·3445	$2·1056\,d^2$
1¾ to 1	0·6621	0·3517	0·3310	$2·2812\,d^2$
2 to 1	0·6434	0·3003	0·3180	$2·4722\,d^2$
2½ to 1	0·5887	0·2268	0·2944	$2·8852\,d^2$
3 to 1	0·5484	0·1780	0·2742	$3·3246\,d^2$
4 to 1	0·4853	0·1195	0·2426	$4·2462\,d^2$

This general trapezoid comprises also the rectangular and the square sections; these including most ordinary forms of canal and channel section. Sections with curved side-walls may be dealt with by an approximative corresponding process. The theory applied in the foregoing reduction is not complete nor rigidly correct, though nearly so; its application to deep sections in which the depth exceeds the width in moderation will be less accurate, and it probably would not hold at all for those in which the depth exceeds double the width.

The condition of equal-discharging canal sections.

In navigable canals, and canals of supply and of irrigation, high velocities and great fluctuation of draught under variation of supply are generally inadmissible, thus precluding the use of sections of absolute maximum discharge. An economic section will then not allow of any waste of sectional area, or of depth which is more expensive than width, but will have the highest maximum discharge that the limiting predetermined velocity and other fixed local circumstances admit. These circumstances are, the nature of the soil in the bed and banks, their liability to damage from erosion, and the side slope that can be practically maintained in it; the hydraulic slope and the inclination of bed that are locally practicable; and in some cases the navigable depth to be maintained during conditions of lowest supply. The mean width of section therefore generally remains the only important function of discharge that can be much varied in designing the section; hence, if a predetermined depth has to be approximately maintained, the usual practice is, to assume originally some fixed convenient ratio of mean width to depth, such as 10 to 1, 14 to 1, or 16 to 1, and after calculating the velocity due to this as well as the other predetermined conditions, to reduce or increase the assumed mean width by two or three feet at a time by repeated trial until a safe bottom velocity is attained in the form of section.

Such a final section being, then, safe as regards limiting velocity and sufficient for the required discharge, is then perhaps only one out of a number of equal-discharging sections that might be devised; and some other one of these might be preferable for any special reason. It may therefore be necessary to know the relations between mean width and depth in such a series of sections, when the side slopes have been finally determined.

In order to discover the relation between mean width and depth, giving various sections that will discharge the same quantity of fluid, when the hydraulic slope is a constant quantity, we must use the condition that the areas of all such sections are inversely as the square roots of their hydraulic radii; that is,

$A\sqrt{R}=a$, a constant; and as $A=WD$; $R=\dfrac{WD}{W+2D}$;

this becomes $\dfrac{W^3D^3}{W+2D}=a^2$,

which may be reduced to either of the following forms in terms of the modified section according as either d or w is the new quantity sought,

$$d^3-\frac{2a^2}{w^3}d-\frac{a^2}{w^2}=0\ ;\ \text{or}\ w^3-\frac{a^2}{d^3}w-\frac{2a^2}{d^2}=0.$$

In the first case, let $W=100$, $D=1, 2, 3, 4, 5, 6$, successively, then the values of a are thus in each of the six cases,

D . .	1	2	3	4	5	6
a . .	99·01	277·3	504·7	769·9	1066	1389

and for a fixed value $w=90$, the corresponding values of d are

d . .	1·074	2·151	3·232	4·312	5·391	6·483

and for a fixed value of $d=2·5$, the corresponding values of w are

w . .	27·25	72·53	130·1	197·2	272·1	353·8

[redacted]

[illegible] design[illegible] hydrauli[illegible] are t[illegible]

[illegible] arranged in [illegible] practical pur-[illegible]; but in [illegible] compute [illegible] equation [illegible] trigonometrical [illegible] Four Figure [illegible] of those [illegible] with the [illegible]

[illegible]

[illegible] water-pipe admits [illegible] water-pipes and [illegible] and kept con-[illegible] that a circular [illegible] a maximum-discharging section, as it has the least wetted perimeter for a given sectional area. An open semicircle has the same geometrical property, and also has its hydraulic mean radius equal to half its middle depth, but this is not the case with a closed semicircle. The relative dimensions of such sections in terms of the square root of the area are thus :—

[1] Tables of sines to seconds for the first thirty minutes have been added to that book for this special purpose.

Section	Numerical factors to be multiplied by $\sqrt{A}$			Corresponding values of A in terms of d^2
	for d depth	for w surface width	for R hydraulic radius	
Circle . . .	1·1284	0	0·2821	0·7854 d^2
Open semicircle	0·7979	1·5958	0·3990	1·5708 d^2
Open segment of 90°	0·3729	1·8002	0·5642	0·9155 d^2

In old water-pipes the section may be much diminished by incrustation and deposit; when this is the case, the reduced section should be employed in calculating its discharge; but in most cases of old pipes the cause of decreased velocity and discharge is not merely the diminution of section, but the higher friction due to foulness and roughness of the interior surface, so that the former mode of making allowance is grossly insufficient. The correct method is to use a modified coefficient of roughness (n), and the corresponding velocity coefficient (c) due to the conditions of the case in the general formula

$$Q = A \, . \, c \, . \, 100 \, \sqrt{RS}$$

See coefficients suited to old metal, and damaged materials in bad condition, in Working Table, No. XII.

A still better method is to keep the water-pipes free and clean, and apply some enamelling process as that of Dr. Angus Smith, so that the full discharge due to new material in good order may be always maintained.

Sections of Flow in Culverts and Drain-pipes.

The ordinary conditions and purposes of a culvert, sewer, or drain-pipe are, that it shall carry away the [illegible] pressure [illegible] that it shall be [illegible] a low [illegible] over-supplied, that [illegible] lodgment, [illegible] so formed as [illegible] under low discharge, and that the upper part of the section shall possess sufficient strength to withstand the weight of superincumbent earth, when buried in the soil.

The ordinary circular section does not completely meet these requirements, and hence is generally adopted for small culverts and for drain-pipes of half a foot in diameter and less, regard being had to convenience of manufacture and laying.

Larger culverts have been made of an endless variety of sectional form, from squares and deep rectangles with or without curved crowns and inverts, to geometrically constructed and arbitrarily made-up ovals and ellipses. The nature of the material used and economy of construction may outweigh the need of suitability of sectional form in other respects; but when this is not the case the ovals and approximate ovals constitute the best type of culvert section from thoroughly answering the purposes first mentioned. Their crowns are nearly semicircular, thus possessing strength; their inverts are sharply curved, thus giving higher flush when very partially filled; their sides are of flat curvature or nearly straight, thus preventing lodgment. It may perhaps be urged that they have the defect of weakness at the sides under lateral pressure of earth; this would doubtless be a substantial objection in loose soil or under some special circumstances, but in firm soil and in ordinary cases it is a comparatively trivial one, as the blows and shocks received in laying are far more destructive than ordinary lateral pressure; besides this, it must be noticed that the excavation for placing an ovoid culvert is rectangular, slightly exceeding the external width of the culvert, and necessitates packing or backing; thus a slight increase of strength is afforded by the additional concrete filling. The bulging-in of sides of culverts has thus to be provided against under many circumstances, and delicate refinement on this point is impracticable in ordinary cases, while the necessity for avoiding internal lodgment is peremptory. For the same reason straight sides sloping from the springing of the crown to the springing of the invert are generally both unobjectionable and advantageous.

The conditions of culverts and drain-pipes, as well as usual custom and practice, impose limits on their sizes and dimensions in section. Cylindrical culverts and drain-pipes are now seldom made with diameters exceeding 1·5 foot; when used in larger sizes it is in cases where they can be kept steadily well supplied, and not allowed to run very low, a condition that occurs infrequently with diameters exceeding 5 feet. Ovoidal sewers of various patterns are generally adopted in a series of regular sizes from 1 by 1·5 feet up to 6 by 9 feet. The two types of oval most commonly used are Hawksley's and the Metropolitan pattern, originally, it is believed, designed by Phillips; both of these, as well as the following type, are circular-headed. The tendency of engineers up till now having continually been to adopt culvert sections that allow of higher flushing with the same amount of supply, this principle is carried out to the full in the Pegtop form of culvert section designed by the author, where the invert is made small to produce greater scour, and the sides, being straight, possess the great advantage of preventing the lodgment of sediment. These three types of ovoid, together with the cylinder, include all that is commonly necessary: their sectional data given in Table V. are arranged for cases where they are either quite full, two-thirds full—that is, filled to two-thirds of their vertical depths, or one-third full. For any other special depths of flow, which are not frequently wanted, the sectional data must be calculated with the help of a table of circular arcs and sectors (see Miscellaneous Tables); examples of such calculations will be hereafter given.

Culverts and drain-pipes are generally treated as falling in some one of three classes as regards size, the small, the intermediate, and the large; there are also usual practical limits to their inclinations. As regards material, they are made in plain earthenware and glazed stoneware up to dimensions of 2 by 3 feet, rarely above that, and brickwork and concrete, either plain or coated with cement, is used in larger dimensions. Iron of all sorts, either plain, painted, or enamelled, may of course be used in any dimensions, the adoption of wrought iron beginning where cast iron becomes inapplicable from the size of the casting being inconvenient in transport, or from other reasons.

Proceeding to the calculation of hydraulic data for culvert sections.

The calculation of hydraulic radii and sectional areas of partly-filled culverts.

The determination of values of R, the hydraulic radius, and A, the sectional area for culverts when partly filled, being sometimes rather troublesome, a few examples of such cases may be of use as a guide; the cases selected being those of various sections, filled to one-third and two-thirds their depth adopted in Table V. In such cases fractions of areas and of perimeters of circles are frequently used; and for such purposes the table of arcs and sectors in the Miscellaneous Tables has been specially constructed.

Taking the Pegtop section, the geometrical construc tion of which is as follows:—

Taking the transverse diameter$=2$; the long diameter, or total vertical depth$=3$; the radius of the upper circle is 1·0, the radius of the invert is one-eighth the total depth$=0{\cdot}375$; and the straight sides, which are tangential to both upper and lower circles, are each equal to one-half the total depth$=1{\cdot}5$. For the complete section of the culvert, the sector of the upper circle extends beyond the semicircle to nearly 20° on each side; while the sector of the lower circle extends correspondingly to 20° less than the semicircle on each side; *i.e.* these two sectors are 220° and 140° respectively.

The full sectional area—

A_1=Sector of 220° to radius 1·+Sector of 140° to radius 0·375 +twice half depth × mean radius;

(Using the table of arcs and sectors),

$$=1{\cdot}91987\times 1^2+1{\cdot}22173\times(0{\cdot}375)^2+3\times 0{\cdot}6875=4{\cdot}15418.$$

And the complete perimeter—

P_1=Arc of 220° to diameter 2+arc of 140° to diameter 0·75+ twice half depth.

$$=1{\cdot}91987\times 2+1{\cdot}22173\times 0{\cdot}75+3{\cdot}0=7{\cdot}75604.$$

And R_1 the hydraulic radius of the full section$=0{\cdot}536$.

The values of R_1 for any other diameter are proportional.

For the same culvert-section when filled to two-thi[rds]
its depth.

A_2=4·15418—area of semicircle to radius 1

$=4·15418-1·57080 \times 1^2$ $=2·58338$

P_2=7·75604—arc of semicircle to diameter 2

$=7·75604-1·57080 \times 2$ $=4·61444$

And R_2, the required hydraulic radius $=0·560$

The values of R_2 for any other diameter are proportional.

For the same culvert-section when filled to one-th[ird]
the depth.

A_3=sector of 140° to radius $0·375+\frac{3}{4}$ depth $\times \dfrac{R+3r}{4}$

$=1·22173 \times (0·375)^2+0·75 \times \dfrac{1+1·125}{2}$ $=0·96868$

P_3=arc of 140° to diameter $0·75+\frac{1}{2}\frac{3}{4}$ of the total depth

$=1·22173 \times 0·75+\frac{1}{2}\frac{3}{4} \times 3$ $=2·54130$

And R_3, the required hydraulic radius $=0·381$

The values of R_3 for any other diameter are proportional.

Checking the above by calculating for the mid[dle]
portion of the section.

Area=2 sectors of 20° to radius $1+\frac{3}{4}$ depth $\times \dfrac{3R+r}{4}=$

$0·34907+0·75 \times \dfrac{3·375}{2}$ $=1·61470$

and above, $2·58338-0·96868=1·61470$

Perimeter=2 arcs of 20° to diameter $2+\frac{1}{2}\frac{1}{4}$ total depth.

$=0·34907 \times 2+\frac{1}{2}\frac{1}{4}-3$ $=2·07314$

and above, $4·61444-2·54130=2·07314$

Dealing in the same manner with Hawksley's Ovoid Section, the geometrical construction of which is thus,—

Taking the transverse diameter=2, and the radius of the top semicircle=1; the radius of each curved side of 45° is=2, the radius of the invert of 90° is=0·5858, and the total vertical depth is 2·5858. The sectors cut off by the trisection of the depth are 164° 12′ and 21°.

The respective areas are—

$A_1=1{\cdot}5708\times1^2+0{\cdot}7854\times2^2-\frac{1}{2}2+0{\cdot}7854\times(0{\cdot}5858)^2=3{\cdot}9820$
$A_2=0{\cdot}138\times1{\cdot}99+0{\cdot}7854\times2^2-\frac{1}{2}2+0{\cdot}7854\times{\cdot}3432=2{\cdot}6858.$

The middle area being more convenient to calculate, this is

$0{\cdot}138\times1{\cdot}99+{\cdot}36652\times2^2-{\cdot}38386\times\frac{3}{2}+{\cdot}34\times{\cdot}88578=1{\cdot}6580$
and A_3 the area of bottom portion$=2{\cdot}6858-1{\cdot}6580=1{\cdot}0278$

The corresponding perimeters are—

$P_1=1{\cdot}57080\times2+0{\cdot}7854\times4+0{\cdot}7854\times1{\cdot}1716 \quad =7{\cdot}20337$
$P_2={\cdot}13788\times2+0{\cdot}7824\times4+0{\cdot}7854\times1{\cdot}1716 \quad =4{\cdot}33753$

and the perimeter of the middle third is

$={\cdot}13788\times2+{\cdot}36652\times4 \quad -1{\cdot}74184$
$P_3=4{\cdot}33753-1{\cdot}74184 \quad =2{\cdot}59569$

Hence the three corresponding hydraulic radii are

$$R_1=0{\cdot}553,\ R_2=0{\cdot}620,\ R_3=0{\cdot}396.$$

Checking the above by the top area and perimeter to two-thirds the depth,

area$=1{\cdot}5708\times1^2+{\cdot}36652\times2^2-{\cdot}38386+{\cdot}34\times{\cdot}88578=2{\cdot}9542$
and $3{\cdot}9820-1{\cdot}0278 \quad =2{\cdot}9542$
perimeter$=1{\cdot}57080\times2+{\cdot}36652\times4 \quad =4{\cdot}60768$
and $7{\cdot}20337-2{\cdot}59569 \quad =4{\cdot}60768$

In the same way with Phillips' Metropolitan Ov
of which the geometrical construction is thus :—

Taking the transverse diameter=2, and the radiu
the top semicircle=1, the extreme vertical depth is=
the radius of the curved side=3; the radius of the in
is (one-sixth the depth, or) 0·5; and the depth fr
springing to bottom=2; the curved side has an arc
36° 52′ 14″, and the invert an arc of 106° 16′. A tri
tion of the depth cuts off 19° 28′ of the side arc in
middle portion.

The respective areas, when full, two-thirds full, and
third full, are

$A_1=1·5708\times 1^2+·64352\times 3^2+·92735\times(0·5)^2-2\times 1·5=4$

$A_2=4·5942-1·5708 \qquad =3·023$

and the area of the middle portion is

$·33975\times 3^2-2\times\frac{1}{2}\times 2\times ·70693+·29307\times ·82914=1·887$

$A_3=3·0234-1·8868=1·136 \qquad =1·136$

The respective perimeters are

$P_1=1·57080\times 2+·64352\times 6+·92735\times 1 \qquad =7·930$

$P_2= \qquad ·64352\times 6+·92735 \qquad =4·788$

Mid-portion perimeter $=·33975\times 6=2·038$

P_3, of lower third $\qquad =2·75$

Hence the hydraulic radii corresponding are

$$R_1=0·579,\ R_2=0·631,\text{ and } R_3=0·413.$$

For similar culverts of other dimensions the a
can be reduced in the ratios of the squares of these
meters and the hydraulic radii in direct proportion
the diameters themselves.

The above cases show the utility of the Table of and Sectors given in the additional Tables, which can be applied to all similar purposes.

These three types of culvert-section, as well as the cylinder, are illustrated in the Frontispiece of Canal and Culvert Tables by figures of equal sectional area; whose relative diameters are thus,

Cylindrical Section . . .	1·1286
Hawksley's Ovoid . . .	1·0002 and 1·293
Metropolitan Ovoid . . .	0·9331 and 1·3996
Pegtop Section	0·9813 and 1·4720.

They are divided to thirds of their actual longer diameters, and the dotted line on the Pegtop Section shows the gain in height of flushing that this has in comparison with the Metropolitan pattern, of equal full sectional area. Its form is effective in preventing lodgment, and very convenient in calculations for intermediate depths.

For the converse process of finding the height to which a certain quantity of liquid, or a fixed sectional area will fill a cylindrical culvert, there are two practical modes:—

First. Let a be the area of the wet segment,
l its perimeter, or arc of the wet segment,
r the radius of the circle,
n the angle of the sector,
h the required height or depth,

$$\text{Then } h=r-k=r\left(1-\cos\frac{n}{2}\right); \ldots\ldots \text{(I.)}$$

For example.—Let $a=0{\cdot}229$; $r=\frac{1}{2}$; $l=1{\cdot}231$;

Then by Table of Arcs and Sectors, $n=141^\circ\ 0'\ 22''$ and $h=\frac{1}{2}(1-0{\cdot}3337)=0{\cdot}333$.

Second method. Without using cosines

$$k \,.\, \sqrt{r^2 - k^2} = l \times \frac{r}{2} - a\,;$$

or, $$k^2 = \frac{r^2}{2} + \sqrt{\frac{r^4}{4} - \left(\frac{l\,.\,r}{2} - a\right)^2} \quad \ldots\ldots \text{(II.)}$$

Applying this to the same example,

$k^2 = 0{\cdot}125 + \sqrt{{\cdot}015625 - (1{\cdot}231 \times \frac{1}{4} - 0{\cdot}229)^2} = 0{\cdot}02793$, $k = 0{\cdot}1671$; and the required depth $h = r - k = 0{\cdot}333$.

It will be noticed that in either case the length of the arc is assumed; should this not have been previously determined, the height can only be obtained from values of a and r through the tedious process of solving an equation of a high degree. Thus, the formula for the approximate area of a segment is

$$a = \frac{4h^{\frac{3}{2}}}{15}(2\sqrt{4d - 3h} + \sqrt{d})\,; \text{ where } d \text{ is the diameter}$$

Putting $x = \frac{h}{d}$; this becomes $x^{\frac{3}{2}}(2\sqrt{4 - 3x} + 1) = \frac{15a}{4d^2}$.

And putting $y = x^{\frac{1}{2}} = \left(\frac{h}{d}\right)^{\frac{1}{2}}$; $y^8 - \frac{5}{4}y^6 - \frac{5a}{8d^2}y^3 + \frac{75a^2}{64d^4} = 0$

Numerical examples can be solved with this formula by Horner's method, or more readily by the aid of the dual-logarithms of Mr. Oliver Byrne; modes not very well suited to the daily wants of professional men; nor is there any necessity for adopting this method, as the length of the arc must be obtained to calculate the hydraulic radius; and in that case either of the two more practical methods above exemplified affords a more rapid solution.

7. THE HYDRAULIC SLOPE.

The hydraulic slope, inclination, or declivity, sometimes termed the gradient, is an important function in velocities and discharges in open channels and unfilled culverts, even including those just filled. When applied to liquid flowing under gravity free from pressure, the hydraulic slope in any unit of length is the ratio of the difference of level of the water surface in that length to that length, or is the sine of the slope of the water surface. Thus, if the difference of level in 1 000 feet along the central fillet of the water surface be 2 feet, then, $S=\frac{H}{L}=\frac{2}{1000}=0{\cdot}002$; and it is in this form that the inclination is most conveniently introduced in equations and calculations of flow in open channels.

It should be noted that the fall of the bed of a river or canal is not necessarily any function of the velocity, expressed by the value S. The bed may perchance be uniform in regular fall, and also exactly parallel to the water surface for some distance, or it may be otherwise, or highly irregular. When parallel, the fall of the bed happens to be represented by S; when otherwise, the longitudinal irregularity is comprised in the term n, the combined coefficient for roughness and irregularity.

The slightest variation in S having so important an effect on the mean velocity, its value in cases of channels and rivers of slight inclination should be determined by exact levelling operations on both banks between accurate gauge-levels and carefully verified.

In canals and culverts.

In designs of canals for irrigation, water supply, or drainage, the hydraulic slope is generally also the inclination of the bed, and this is determined to suit the limiting velocities allowed in the canal, the maximum being that nearly producing erosion, the minimum one that just deposits sediment. When such canals exist not only in design, but in operation, the actual hydraulic slope must be obtained by observation.

In navigable canals the conditions are sometimes similar, though more often, as the canal may consist of several still-water reaches, a hydraulic slope does not exist or is exceedingly slight.

In culverts and drain-pipes in their ordinary state not under pressure, the hydraulic slope exists as in open canals; the inclination of the bed or invert, arranged in accordance with local conditions and available outfall, being generally nearly parallel to it.

When a culvert is blocked, a low head of pressure may accumulate; the case then becomes one of discharge under pressure, corresponding to that of water-pipes.

In water-pipes.

In pipes under considerable pressure, such as water-pipes under a statical head of 50 feet or more, the term hydraulic slope is not strictly applicable to any actual or theoretical inclination, but is used for the theoretic inclination from the point where the pressure is zero to any point of discharge under consideration.

The discharge and also the velocity at any point in a continuous series of pipes under pressure are those due to the statical head, or difference of level between water surface in the reservoir, or top of the stand-pipe as the case may be, and the point under consideration ; the section at the point of actual severance and discharge may be treated as an orifice under direct head, and the velocity calculated as that due to the head and section less all allowances for friction, bends, and contractions along the whole course of the water from its highest point. All such causes of loss of velocity are represented by the effects that would be produced by corresponding loss of head of pressure. The length of the line of pipes and the sources of friction and retardation are here the important factors in the calculation. Table IX. is given to assist in obtaining such losses.

Water-pipes are irregular in their courses and inclinations ; they are usually placed two or three feet below ground, sometimes following its sinuosities, to protect them from frost and damage, and are rarely allowed to rise above their mean inclination : should they do so, a great loss of head results, unless air vessels are applied at those points, from which the air is allowed to escape through cocks every two or three days. Under such irregular conditions, it becomes difficult to estimate the loss of head due to friction with much accuracy.

The other mode of calculating velocities and discharges of water in pipes under pressure is to treat them in accordance with imaginary hydraulic slopes or inclinations from the highest water surface to the point under consideration ; and to apply the ordinary formula for flow given at page 32. This method presupposes that the pipes have a single inclination throughout from the highest point of supply, and, even after making allowance, can only yield an approximate value of the

discharge, even if it arrives at that. It is, howeve
commonly adopted.

As it is comparatively rare that a single pipe
to any very great distance with a uniform fall, bein
generally cut up into lengths having different falls
comes necessary to proportion the diameter of the
these different lengths, so that the discharge may
[illegible] due to the smallest diameter. Wh
such a series of pipes of different diameters the tota
is given, and the discharge is required, the case do
admit of direct solution, as each pipe must have i
proper head; in this case it is best to assume a disc
and obtain separate heads due to it for each pipe
series; the true heads, both total and separate, n
then obtained by proportion, and the inclinations c
pipe, as well as the mean inclination for the whole
(which is the inclination that would be adopted
single uniform pipe throughout) marked on the s
of the design. The final discharge can then be calc
from any one of the pipes. An example of this
tached to Working Table, No. VIII.

8. THE DISTRIBUTION OF VELOCITY IN SECT OF PIPES AND CHANNELS.

The laws of distribution of velocity in the sect
an open channel, canal, or river, are still incon
The most valuable information on this subject, quo
the remainder of this section, is that deduced by d
and Bazin, by Captain Allan Cunningham and by
phreys and Abbot, from the results of their ext
experiments and investigations.

A certain amount of knowledge has been deduced from observation of the variation of velocity in open channels in the vertical planes, but as regards that in the horizontal planes at a section, nothing has absolutely—and very little relatively—yet been determined. In full cylindrical pipes, on the contrary, the conditions of velocity are comparatively simple.

In full pipes.

The experiments of d'Arcy, in 1851, established the law of velocity in full pipes expressed in the following equation suited to metric measures—

$$\frac{V-v}{\sqrt{RS}}=11{\cdot}3\left(\frac{r}{R}\right)^{\frac{3}{2}}$$

$$\text{or } R\,(V-v)=11{\cdot}3\,.\,r\,.\,\sqrt{rS},$$

where V=central velocity.

v=the velocity anywhere at a distance r from the centre.

R=the radius of the pipe.

S=the loss of head per linear mètre or hydraulic slope.

This formula was deduced by d'Arcy from observations taken at from one-third to two-thirds of the radii of various pipes from the centre; beyond $\frac{2}{3}$ of the radius, it is probable that the law does not hold good, and that the decrement of velocity should be more rapid than that indicated by the formula. Under any circumstances, however, it is clearly established that the velocities in a full cylindrical pipe are equal at all points equidistant from the centre, and that the above law of decrement holds good for the central $\frac{2}{3}$ of the diameter taken in any direction. In a pipe of rectangular section, the velocities are equal at any four points, taken symmetrically with reference to the centre of figure in a corresponding manner.

In small artificial channels.

In open channels, however, this almost mathematical symmetry is entirely absent, and the perturbation produced near the surface of the water does not allow any hope that a formula can be arrived at, which would give the actual velocity at any point in terms of the mean velocity and the co-ordinates determining the position of that point. These perturbations appear to be more considerable in proportion to the diminution of velocity and the increase of depth of channel, and are coincident with a depression of the locus of maximum velocity; in extreme cases, the curves of equal velocity in the section cut the surface of the water very obliquely.

The following are the conclusions drawn by Bazin on this subject:—

1st. For a very wide rectangular channel—

$$\frac{V_s - v}{\sqrt{HS}} = K\left(\frac{h}{H}\right)^2,$$

where V_s = central velocity at the surface.

v = velocity at a point at a depth h below it.

H = total depth of water.

S = hydraulic slope of the water surface.

This law of velocity is proved to hold good for very wide channels; the cases under experiment give a practically constant value of $K = 20\cdot0$, the extremes varying between $15\cdot2$ and $24\cdot9$;—it would also appear that for a rectangular canal of infinite width, in which the influence of the sides is made to disappear entirely, K would $= 24\cdot0$;—the units are metric as before.

When, however, the depth of a rectangular channel is great enough in proportion to the breadth to make the influence of the lateral walls show itself in the middle of the current, this law does not hold, nor does any law of decrement of velocity seem possible, and incomplete generalisations, in terms of the mean velocity, can alone be arrived at.

If, then, V_m = the mean velocity in a canal, the section of which is very great in proportion to its depth—and V_s = central velocity at the surface, the other symbols being used as before,

$$V_m = \frac{1}{H} \int_0^H \left[V_s - K\left(\frac{h}{H}\right)^2 \sqrt{RS} \right] \partial h$$

$$= V_s - \frac{K}{3} \sqrt{RS}$$

and the depth h below the surface is determined by the expression $\left(\frac{h}{H}\right)^2 = \frac{1}{3}$; whence $h = 0{\cdot}577\ H$, which is, in fact, saying that the mean velocity is found at about $\frac{3}{5}$ of the total depth. This, however, assumes the before-mentioned parabolic law of the decrease of velocity in each vertical plane, an hypothesis only admissible in a very large and perfectly regular canal.

In fact, however, and from experiments quoted, it appears that the locus of mean velocity is often below $\frac{3}{5}$ of the depth, and more often below $\frac{3}{4}$ of it; and that when the depth of the canal is great, and the velocity feeble, the curve of mean velocity approaches still nearer the bottom, and goes as low as $\frac{4}{5}$ of the depth.

Taking the above relation $V_m = V_s - \frac{1}{3} K \sqrt{RS}$, where $\sqrt{RS} = V_m \sqrt{A}$, and $K = 24{\cdot}0$, for a channel of infinite width; in this case also we get $V_s = V_m(1 + 8\sqrt{A})$ as a result applicable to this special case, which supposes the parabolic law applicable throughout the whole breadth of the channel; and this differs greatly from the results of the experiments on such channels, which give $V_s = V_m (1 + 14 \sqrt{A})$.

The locus of maximum velocity is, however, not always at the centre of the surface, but is at a greater depth in proportion as the depth of the canal is greater and the mean velocity is less, being sometimes as low as $\frac{2}{3}$ the total depth.

The determination of bottom (V) velocity can, in rectangular canals, be alone made in the special case of one supposed to be of infinite breadth; for this case, putting $h = H$ in the original formula, we obtain the velocity $V_b = V_s - K \sqrt{RS}$; but in all other cases no law can be given. The greatest of bottom velocities is in the middle and the least at the sides.

The velocity along the vertical sides of a rectangular canal is generally greater in the middle than at the top or at the bottom; but beyond this fact, the determination of the exact velocity at any point of the side remains a very difficult problem yet unsolved.

The laws of velocity in canals of semicircular section are far less complicated than those of rectangular section :—the law of decrement of velocity is expressed in the following formula :—

$$\frac{V_s - v}{\sqrt{RS}} = 21 \left(\frac{r}{R}\right)^3,$$

the extreme values of the coefficient deduced from experiment being 18·2 and 23·2; and the terms of the expression being similar to those in the equation for decrement of velocity in sections of pipes before mentioned:—If in this we make $r=R$, we obtain, as for rectangular channels, the bottom velocity,

$$V_b=V-21\sqrt{RS}.$$

And the mean velocity will be deduced thus:—

$$V_m=\frac{1}{\pi R^2}\int_0^R\left[V-K\sqrt{RS}\left(\frac{r}{R}\right)^3\right]2\pi r.\,\partial r$$

$$=V_s-\tfrac{2}{5}K\sqrt{RS}\text{; where }\sqrt{RS}=V_m\sqrt{2A}\text{;}$$

hence $\frac{V_m}{V_s}=1+\frac{2}{5}K\sqrt{2A}$; where $K=21$

$$=1+11{\cdot}9\sqrt{A}:$$

an equation differing but little from that deduced from the experiments on such semicircular canals.

The radius r_p of the circle of mean velocity of the section $=R.\sqrt[3]{\tfrac{2}{5}}=0{\cdot}737R$;—which is saying that this is at about three-quarters of the radius from the centre, whereas in fact it is farther.

Taking finally the two expressions for decrement of velocity in canals of rectangular and semicircular section,

$$\frac{V_s-v}{\sqrt{HS}}=K\left(\frac{h}{H}\right)^2\text{; and }\frac{V_s-v}{\sqrt{RS}}=K\left(\frac{r}{R}\right)^3;$$

a general expression may be deduced from them,

$$V_s-v=\phi\sqrt{RS};$$

and as under these circumstances absolute velocities cannot be dealt with, it is better to make use of relative velocities, and by dividing each side of the general equation by V_m to transform it into the form

$\frac{V_s-v}{V_m}=\phi\sqrt{A}$; which is therefore true for all canals where ϕ is a function of the relative (not of the absolute) co-ordinates determining the position of the point whose velocity is under consideration, their values being taken in proportion to the dimensions of the section.

With regard to velocities in artificial channels generally, by far the most important result arrived at by D'Arcy and Bazin is the relation between the maximum velocity and the mean velocity of discharge, represented by this equation, suitable to mètres:

$\frac{V_x}{V_m}=1+14\sqrt{A}$; and since $A=\frac{RS}{V^2}$; $V_x-V_m=14\sqrt{RS}$

these equations reduced to English measures become

$$\frac{V_x}{V_m}=1+\frac{25\cdot34}{c\times100}; \text{ and } V_x-V_m=25\cdot34\sqrt{RS}.$$

The advantage in gauging derived from the application of this principle is very great; but the coefficients of reduction are doubtful in exactitude, as shown by Captain Cunningham's recent experiments on a large scale, and are certainly not suited to general application.

In large natural channels.

The laws of variation of velocity in horizontal planes with reference to different forms of section have not yet been satisfactorily deduced, such velocities have therefore to be determined locally when required; the horizontal curves of velocity again vary much in different stages of the river or stream under consideration; the records therefore of such velocities involve much labour, and have not yet shown themselves of sufficient practical importance to repay the labour and trouble of their observation.

As to the variation of velocity in vertical planes, the following is the deduction of Bazin ('Annales des Ponts et Chaussées,' Sept. 1875, pages 309 to 351):—

The velocities of a current at different points on the same vertical line vary as the ordinates of a parabola; thus, if D be the total depth,
u the velocity at any depth d below the surface,
U the maximum velocity at any depth d',

$$u=U-M\left(\frac{d-d'}{D}\right)^2,$$

where M is a quantity dependent on d'.
And if u_m = the mean velocity on the vertical line

$$u_m=\int_0^1\left\{V-M\left(\frac{d}{D}-\frac{d'}{D}\right)^2\right\}\partial x\text{; where } x=\frac{d}{D}$$

$$=U-M\left[\frac{1}{3}-\frac{d'}{D}+\left(\frac{d'}{D}\right)^2\right]\text{; where } M=20\sqrt{DI}$$

$$=U-20\sqrt{DI}\left(\frac{d}{D}\right)^2\text{; when } d'=0\text{, or the maximum velocity is at the surface.}$$

Or in this case, the parabola has the equation $y=20x^2$

where y the ordinate $\frac{U-u}{\sqrt{DI}}$, and $x=\frac{d}{D}$.

But when the maximum velocity is below the surface a different value is given to M, and the equation then becomes

$$u=U-20\sqrt{DI}\left(\frac{x-a}{1-a}\right)^2$$

$$\text{where } x=\frac{d}{D}\text{, and } a=\frac{d'}{D}$$

$$\text{and } \frac{u}{u_m}=\frac{U}{u_m}-20\sqrt{A}\left(\frac{x-a}{1-a}\right)^2$$

where U is the mean velocity (V_m) of the whole section.

If then this new value of M is introduced into the general equation above given,

$$u_m = U - M\left(\frac{1}{3} - a + a^2\right)$$

it becomes $$\frac{V_m}{u_m} = 1 + 20\sqrt{A}\left(\frac{\frac{1}{3} - a + a^2}{(1-a)^2}\right)$$

In experiments on regular conduits 6·5 feet wide the value of $\frac{V_m}{u_m}$ varied between 1·09 and 1·19; and in others on the Saône, Seine, Garonne, and Rhine, the value varied between 1·1 and 1·3: the experiments of Humphreys and Abbot on the Mississippi correspondingly give a value of 1·02.

These results are hence both theoretically and practically correct and useful, and generally applicable even on a large scale.

In very large natural channels.

The laws of variation of velocity in vertical planes of very large natural channels have been also fully investigated by Captains Humphreys and Abbot on the great Mississippi Survey.

From their experimental data it has been deduced that the velocities at different depths below the surface in a vertical plane, vary as the abscissæ of a parabola, whose axis is parallel to the water-surface, and may be considerably below it, thus proving the maximum velocity to be generally below the surface; the equation of this curve with reference to its axis, taking the depths, relatively to the total depth, as ordinates, was obtained in the form—

$$y^2 = 1{\cdot}2621\,D^2x$$

where D = total depth of bed below the surface, and x and y are the co-ordinates to the axis.

They also deduced that if d_1 is the depth of the axis of the parabola, or locus of maximum velocity from the surface, then

$$d_1 = (0{\cdot}317 + 0{\cdot}06\,f)\,R$$

where R=hydraulic mean radius, and f=force of wind either positive or negative, and taken $=1$ when the velocity of the wind and current are equal, and $=0$ for a cross wind or calm.

The following are other important equations, with regard to velocity in vertical planes, deduced by Captains Humphreys and Abbot.

(For symbols refer to page 12, Chapter I.)

Formulæ for velocity in any vertical plane:

(1) $b = \dfrac{1{\cdot}69}{(D+1{\cdot}5)^{\frac{1}{2}}} = 0{\cdot}1856$; only when $D \mathrel{7} 30$ feet,

(2) $d_1 = (0{\cdot}317 \times 0{\cdot}06\,f)\,D$; very nearly,

(3) $V = Vd_1 - (bv)^{\frac{1}{2}}\left(\dfrac{d-d_1}{D}\right)^2$,

(4) $V_o = Vd_1 - (bv)^{\frac{1}{2}}\left(\dfrac{d_1}{D}\right)^2$,

(5) $V_D = Vd_1 - (bv)^{\frac{1}{2}}\left(1-\dfrac{d_1}{D}\right)$,

(6) $V_m = \frac{2}{3}Vd_1 + \frac{1}{3}V_D + \dfrac{d_1}{D}(\frac{1}{3}V_o - \frac{1}{3}V_D)$,

(7) $V_{\frac{1}{2}D} = V^m + \frac{1}{12}(bv)^{\frac{1}{2}}$,

(8) $V_{d_1} = V_m + (bv)^{\frac{1}{2}}\left(\frac{1}{3} + \dfrac{d_1(d_1-D)}{D^2}\right)$,

(9) $V = V_m + (bv)\left(\dfrac{D(\frac{1}{3}D-d_1) + (2d_1-d)}{D^2}\right)$,

in which equation (9) is a mere combination of equations (3) and (8).

For velocity in the mean of all vertical planes the following have been deduced :

(1) $b = \frac{1{\cdot}69}{(r+1{\cdot}5)^{\frac{1}{2}}}$.

(2) $d_1 = (0{\cdot}317 + 0{\cdot}06f)r$.

(3) $U_m = 0{\cdot}93v$.

(4) $U = 0{\cdot}93v + \left(\frac{dr(0{\cdot}634 + 0{\cdot}12f) - d^2}{r^2} - 0{\cdot}06f + 0{\cdot}016\right)(bv)^{\frac{1}{2}}$

(5) $U_o = 0{\cdot}93v + (0{\cdot}016 - 0{\cdot}06f)(bv)^{\frac{1}{2}}$.

(6) $U_r = 0{\cdot}93v(0{\cdot}06f - 0{\cdot}35)(bv)^{\frac{1}{2}}$.

(7) $U_{d_1} = 0{\cdot}93v + \{[0{\cdot}317 + 0{\cdot}06f]^2 - 0{\cdot}06f + 0{\cdot}016\}(bv)^{\frac{1}{2}}$.

(8) $v = ([1{\cdot}08\,U_{\frac{1}{2}r} + 0{\cdot}002b]^{\frac{1}{2}} - 0{\cdot}045b^{\frac{1}{2}})^2$.

The most important result of all these data and deductions is the following, a fact of great practical use in gauging rivers, that the ratio of the mid-depth to the mean velocity in any vertical plane is independent of the width and depth of the stream (except for an almost inappreciably small effect) absolutely independent of the depth of the axis of the curve before referred to, and nearly independent of the mean velocity. The formula expressing this is

$$(7)\quad V_{\frac{1}{2}D} = V_m + \frac{(bv)^{\frac{1}{2}}}{12};$$

where V_m is the mean velocity on any curve in the vertical plane.

$V_{\frac{1}{2}D}$ is the mid-depth velocity.

v is the mean velocity of the river.

D is the depth of the river at the spot.

$b = \frac{1{\cdot}69}{(D+1{\cdot}5)^{\frac{1}{2}}}$ generally ; and $= 0{\cdot}1856$, when D 7 30 feet

The application of this result to gauging is shown in Chapter II. on Field Operations.

Verticalic Velocity generally.

The following are Captain Cunningham's deductions resulting from a thorough investigation of the subject in connection with his observations on large canals.

Parabolic Formulæ.—It seems natural to inquire, first whether the mean velocity past a vertical cannot be found from velocity-measurements at only two or three points on that vertical. And here considerable aid may be derived from study of the velocity-parabola. Whether the vertical velocity-curve be really a common parabola or not matters little: it must be admitted that it does certainly approximate to a parabola. This approximation is quite sufficient to admit of its use in determining an approximate value of mean velocity.

And first, it is clear that, as three data suffice to determine the velocity-parabola completely, velocity-measurements at three distinct points on the same vertical will of course suffice to determine the mean velocity.

[The three points must of course be suitably situate to give a tolerably accurate determination.]

The first step is to find an expression for the mean velocity. Adopting the well-known property—

Area of parabola between tangent and diameter $= \frac{1}{3} \times$ circumscribing rectangle, (1), it follows that, the lamina of discharge D, passing by a vertical axis or depth H, is equal to the inclusive rectangle less the sum of the parabolic areas above and below the axis,

or $D = VH - \frac{1}{3}(V - v_0).Z - \frac{1}{3}(V - v_H).(H - Z)$. . . . (2)

where V is the maximum verticalic velocity, $v_\circ$ is the surface velocity, v_H the bed-velocity, Z is the depth at which V exists, z that of v.

Writing the equation of the curve in the form

$$V-v=m(z-Z)^2, \text{ where } m=\frac{1}{p}, \text{ and } p=\text{parameter}. \quad (3)$$

and writing $z=0$, $z=H$ in succession therein (so that v becomes $v_\circ$ and v_H)

$$V-v_\circ=mZ^2, \text{ and } V-v_H=m(H-Z)^2, \quad . \quad (4)$$

Substituting these into the expression (2)

$$\begin{aligned} D &= VH-\tfrac{1}{3}\{mZ^3+m(H-Z)^3\} \\ &= VH-\tfrac{1}{3}mH^3+mH^2Z-mHZ^2, \quad . \quad (5) \end{aligned}$$

$$\begin{aligned} \therefore \text{mean velocity } U=\frac{D}{H} &= (V-mZ^2)+mHZ-\tfrac{1}{3}mH^2, \\ &= v_\circ+mHZ-\tfrac{1}{3}mH^2, \quad . \quad . \quad (6) \end{aligned}$$

by substituting from (4). This is the working expression for U, with which other values obtained in terms of observed velocities are to be compared.

Three-velocity Formulæ.—Now let three velocity-measurements $v_{\lambda H}$, $v_{\mu H}$, $v_{\nu H}$ be taken at *any* depths λH, μH, νH, (where λ, μ, ν are proper fractions,) and let it be proposed to find an expression for the mean velocity in terms of these; let this be—

$$U=a\,.\,v_{\lambda H}+\beta\,.\,v_{\mu H}+\gamma\,.\,v_{\nu H}, \quad (7)$$

where a, β, γ are numerical coefficients to be determined.

Subtracting (3) from (4), there results the following general expression for v:—

$$v = v_\circ + 2mZz - mz^2, \quad . \quad . \quad . \quad (8)$$

Writing $z = \lambda H, \mu H, \nu H$ in succession, this gives—

$$v_{\lambda H} = v_\circ + 2mZ \,.\, \lambda H - m\lambda^2 H^2, v_{\mu H} = v_\circ + 2mZ \,.\, \mu H - m\mu^2 H^2,$$

and $$v_{\nu H} = v_\circ + 2mZ \,.\, \nu H - m\nu^2 H^2, \quad . \quad . \quad (9).$$

Multiplying by α, β, γ in succession, and adding it follows from (7) that—

$$U = (\alpha + \beta + \gamma) \,.\, v_\circ + 2mHZ \ (\alpha\lambda + \beta\mu + \gamma\nu) - mH^2 \ (\alpha\lambda^2 + \beta\mu^2 + \gamma\nu^2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10).$$

This expression becomes identical with (6) by making—

$$\alpha + \beta + \gamma = 1 \,;\, \alpha\lambda + \beta\mu + \gamma\nu = \tfrac{1}{2} \,;\, \alpha\lambda^2 + \beta\mu^2 + \gamma\nu^2 = \tfrac{1}{3} \,;\, (11).$$

These being simple equations in α, β, γ suffice to determine α, β, γ in terms of λ, μ, ν whatever values these may have. The general solution is not of much practical use: the most useful particular solutions appear to be when the three velocity-measurements are made at mid-depth ($\mu H = \frac{1}{2} H$) and at two points equidistant from mid-depth (in which case $\lambda H + \nu H = H$), so that—

$$\mu = \tfrac{1}{2} \,;\, \lambda + \nu = 1, \quad . \quad . \quad . \quad (12).$$

which reduce (11) to—

$$\alpha + \beta + \gamma = 1 \,;\, \alpha\lambda + \tfrac{1}{2}\beta + \gamma\nu = \tfrac{1}{2} \,;\, \alpha\lambda^2 + \tfrac{1}{4}\beta + \gamma\nu^2 = \tfrac{1}{3} \,;\, (13).$$

Multiplying the last two by 2 and by 4 respectively, and subtracting in turn from the first,—

$$a(1-2\lambda)+\gamma(1-2\nu)=0\ ;\ a(1-4\lambda^2)+\gamma(1-4\nu^2)=-\tfrac{1}{3}\ ; \qquad (14).$$

Substituting $\lambda+\nu$ for 1 into the former,—

$(a-\gamma)(\nu-\lambda)=0$; whence $a=\gamma$ (as ν, λ are supposed unequal), ... (15).

And from the latter, $2a.\{1-2(\lambda^2+\nu^2)\}$, or $2a\ \{(\lambda+\nu)^2 -2(\lambda^2+\nu^2)\}=-\frac{1}{3}$

$$\text{whence,}\quad a=\gamma=\frac{1}{6(\lambda-\nu)^2}, \qquad \text{or}=\frac{1}{6(2\lambda-1)^2}. \quad (16a).$$

$$\beta=1-2a=1-\frac{1}{3(\lambda-\nu)^2}, \ \text{or}=1-\frac{1}{3(2\lambda-1)^2}, \quad (16b).$$

Hence by assigning simple values 0, $\frac{1}{6}, \frac{1}{4}, \frac{1}{3}$ to λ, the following simple cases result,

$$U=\tfrac{1}{6}(v_0+4v_{\frac{1}{2}H}+v_H), \quad \text{or}=\tfrac{1}{8}(3v_{\frac{1}{6}H}+2v_{\frac{1}{2}H}+3v_{\frac{5}{6}H}), \ (17a).$$
$$=\tfrac{1}{3}(2v_{\frac{1}{4}H}-v_{\frac{1}{2}H}+2v_{\frac{3}{4}H}), \ \text{or}=\tfrac{1}{2}(3v_{\frac{1}{3}H}-4v_{\frac{1}{2}H}+3v_{\frac{2}{3}H}), \ (17b).$$

The first will be recognised as Simson's well-known formula, that is of no use for practical determination of U, as it involves the bed-velocity which does not admit of direct measurement. The other three give simple values, easily applicable to practical velocity-measurement.

Two-velocity Formulæ.—There being only three equations (11) connecting the six quantities $a, \beta, \gamma, \lambda, \mu, \nu$, it seems worth while to inquire whether an expression could be found for the mean velocity involving velocity-measurements at only two (instead of three) distinct points, as this would materially reduce the field-work necessary to find the mean velocity.

It is sought then to determine a, β, λ, μ, so as to determine U by the simpler formula—

$$U=\alpha v_{\lambda H}+\beta v_{\mu H}, \quad . \quad . \quad . \quad (18).$$

Either by a similar investigation to the preceding, or by simply writing $\gamma=0$ in the previous Result (11), the equations connecting α, β, γ are seen to be

$$\alpha+\beta=1,\ \alpha\lambda+\beta\mu=\tfrac{1}{2},\ \alpha\lambda^2+\beta\mu^2=\tfrac{1}{3}, \quad . \quad (19).$$

from which it is clear that λ, μ are no longer independent; for, solving for α, β in the two first,

$$\alpha=\frac{\mu-\frac{1}{2}}{\mu-\lambda}, \quad \beta=\frac{\frac{1}{2}-\lambda}{\mu-\lambda}, \quad . \quad . \quad (20),$$

And from the third, $\frac{1}{2}\lambda^2-\mu\lambda^2+\mu^2\lambda-\frac{1}{2}\mu^2=\frac{1}{3}(\lambda-\mu)$, the following equation is obtained by substitution, and dividing by $(\lambda-\mu)$, (which is always possible, since λ, μ must be unequal)—

$$\lambda\mu-\tfrac{1}{2}(\lambda+\mu)+\tfrac{1}{3}=0, \quad . \quad . \quad . \quad (21),$$

which is the equation connecting λ, μ, from which in fact

$$\lambda=\frac{\frac{1}{2}\mu-\frac{1}{3}}{\mu-\frac{1}{2}}, \quad \text{or } \mu=\frac{\frac{1}{3}-\frac{1}{2}\lambda}{\frac{1}{2}-\lambda}, \quad . \quad . \quad (22),$$

so that either is determined in terms of the other.

Thus the mean velocity (U) may be found from velocity-measurements at *only two* distinct depths λH, μH—whereof one is arbitrary, and the other is determined by (22)—by the simple formula (18), wherein α, β are given by (20).

Hence by making $\lambda=0, \frac{1}{6}, \frac{1}{4}, \frac{1}{3}$, the following simple cases result,

$$U=\tfrac{1}{4}(v_0+3v_{\frac{2}{3}H}), \quad \text{or}=\tfrac{1}{7}(3v_{\frac{1}{6}H}+4v_{\frac{3}{4}H}), \quad . \quad (23a).$$

$$U=\tfrac{1}{7}(4v_{\frac{1}{4}H}+3v_{\frac{5}{6}H}), \text{or}=\tfrac{1}{4}(3v_{\frac{1}{3}H}+v_H), \quad . \quad (23b).$$

These are the simplest formulæ by which the mean velocity past a vertical can be determined from velocity-measurements at only two distinct points.

The first of the formulæ (23*a*), above[1] is by far the best for general purposes, because it involves only one sub-surface velocity ($v_{\frac{2}{3}H}$), and that at the highest possible level ($\frac{2}{3}H$), and therefore admitting of more accuracy in its determination than those at lower levels involved in the other formulæ. The last is of no practical use, as it involves v_H, a quantity which cannot be practically measured.

[It is not difficult to show that the two velocity measurements must always lie one in the upper third and one in the lower third of the depth, *i.e.*, λ lies between 0, $\frac{1}{3}$, and μ between $\frac{2}{3}$ and 1.]

Test of Formula.—Denoting for distinctness' sake the value of mean velocity derived from the above simple formula (first of 23*a*), by u_m, it is written thus,

$$u_m = \tfrac{1}{4}\left(v_0 + 3v_{\frac{2}{3}H}\right), \quad . \quad . \quad (23a, \textit{bis})$$

The value of this quantity has been calculated for all the 46 average vertical curves of the Roorkee Experiments, and is shown there in the sub-column headed u_m in Abstr. Tab. 3, 4 for comparison with the fundamental value $U = D \div H$. To facilitate this, the discrepancy $(u_m - U)$ is also shown. These discrepancies will be seen to be always small (nowhere exceeding 0·07) as might be expected, and usually negative, showing that $u_m < U$ usually.

The closeness of the values of v_m, U is involved, of course, in the general approximation of the observation curves to parabolæ.

[1] Published for the first time, it is believed, by Capt. Cunningham.

Depth of Mean Velocity-Line.—By the term 'Line of mean velocity' is here meant the stream-line in which the average forward velocity is equal to the average mean velocity past the vertical. To find the depth (h_o) of that line, the equation of the curve (18) gives (writing $z=h_o$, and $v=U$)—

$$U=v_o+2mZh_o-mh_o^2, \quad . \quad . \quad . \quad (24a).$$

$$=v_o+mZH-\tfrac{1}{3}mH^2, \text{ by Result (16)}, \quad (24b).$$

Hence $h_o^2-2Zh_o=\frac{1}{3}H^2-ZH$,

whence $h_o=Z\pm\sqrt{\frac{1}{3}H^2-ZH+Z^2}$, . . . (25),

and $\dfrac{h_o}{H}=\dfrac{Z}{H}\pm\sqrt{\dfrac{1}{3}-\dfrac{Z}{H}+\left(\dfrac{Z}{H}\right)^2}$, . . . (25a),

The quadratic in h_o has of course two roots: but it is easily seen by writing (25) in form—

$$h_o=Z\pm\sqrt{H(\tfrac{1}{3}H-Z)+Z^2}, \quad . \quad . \quad (25b),$$

that one root is always negative when $Z<\frac{1}{3}H$, and is therefore of no[1] interest; when $Z>\frac{1}{3}H$, both roots are +, which shows that there are in this case two lines of mean velocity equidistant from the axis (as is evident from the symmetry of the parabola). It may be shown also that the larger root is always greater than $\frac{1}{2}H$, for writing the larger root of (25) in form—

$$h_o=Z+\sqrt{(\tfrac{1}{2}H-Z)^2+\tfrac{1}{12}H^2}, \quad . \quad (25c),$$

so that

$$h_o=Z+\text{a quantity}>\tfrac{1}{2}(H-Z), \text{ whence } h_o>\tfrac{1}{2}H, \quad (25a),$$

which shows that—

[1] As this would correspond to a line *above the surface.*

'The mean velocity Line is always below the mid-depth,' . . . . (26).

In the illustration of this by diagrams of observed velocities, it is seen that the vertical line drawn through the tip of the mean velocity ordinate (U) cuts the observation-curves below the mid-depth in almost all cases.

It is evident that the depth of the mean velocity-line (defined by h_0) depends on the position of the maximum velocity line (defined by Z), and varies therefore with the variation of the latter; also from (25*a*) it follows that :—

'The relative depth of the mean velocity line ($h_0 \div H$) depends solely on the relative depth of the maximum velocity line ($Z \div H$),' . . . (27*a*).

The range of the maximum velocity line appears in the same diagrams to be from a little above the surface down to about mid-depth. The values of h_0 corresponding to various values of Z within this range are shown below.

Value of $Z \div H$,	$-\frac{1}{4}$,	$-\frac{1}{6}$,	0,	$\frac{1}{8}$,	$\frac{1}{6}$,	$\frac{1}{4}$,	$\frac{1}{3}$,	$\frac{1}{2}$,
Value of $h_0 \div H$,	·554,	·560,	·577,	·598,	·607,	·632,	0 & ·667,	·211 & ·789.

whence it follows that—

'The mean velocity past a vertical cannot be directly measured in practice by any single velocity-measurement,' . . . . (27*b*),

as the single measurement would be required in the mean velocity line, a line whose position is not known *a priori*.

Again, taking the larger root of (25) (which is the one of most interest), viz.,

$$h_o = Z + \sqrt{(\tfrac{1}{3}H - Z)H + Z^2}, \quad . \quad . \quad (25 \ bis),$$

it is clear that the surd is $> = < Z$ when $\frac{1}{3}H > = < Z$,

$$\therefore h_o > = < 2Z \text{ when } Z < = > \tfrac{1}{3}H, \quad . \quad (28).$$

Now from the symmetry of the curve it is clear that the velocity (v_{2Z}) at depth $z = 2Z$ is the same as the surface velocity, *i.e.*, $v_2 = v_o$.

Hence—

The mean velocity $(U) > = <$ the surface velocity (v_o) when $Z > = < \frac{1}{3}H$, ... (29).

Single-velocity Approximations.—Writing down the general values of U, v from Eq. (6), (8),

$$v = v_o + 2mZz - mz^2, \ U = v_o + mZH - \tfrac{1}{3}mH^2, \ . \quad (30),$$

it is manifest that there is no value of z (taken as a function of the depth H only) which will make the general value of v either equal to U, or even proportional to U, in consequence of the presence of the variable and unknown Z. The flatness of the velocity-parabolæ is, however, in all cases so great that an approximation is possible. The closeness of this approximation depends on a prior rough knowledge of the range of $Z \div H$. Now a glance down the column (Tab. 3, 4) showing the values of $Z \div H$ in the 45 curves of the Roorkee Experiments will show that the range of this quantity is—except for verticals quite close to the vertical walls of the rectangular channel (*i.e.* for all verticals more than 5′ off the walls)—only from about 0 to $\frac{1}{3}$, and for this range of $Z \div H$, the value of $h_o \div H$ has been already shown to range from ·577 to ·667; with a mean value of about 0·625 = $\frac{5}{8}$.

Now the velocity corresponding to the value $z = \frac{5}{8}H$ is from (30),—

$$v_{\frac{5}{8}H} = v_o + m\left(\frac{5}{4}ZH - \frac{25}{64}H^2\right), \quad . \quad . \quad (31)$$

and the difference between this and the mean velocity is—

$$v_{\frac{5}{8}H} - U = \frac{1}{4}m\left(ZH - \frac{11}{48}H^2\right),$$

which ranges from $-\frac{11}{192}mH^2$, when $Z = 0$,

$$\text{to } +\frac{5}{192}mH^2, \text{ when } Z = \frac{1}{3}H.. \quad . \quad (31a).$$

In the other case. Near the margin of the rectangular channel the limiting values of the quantity $Z \div H$ are $\frac{1}{3}$ and $\frac{1}{2}$, and the table of values of $h_o \div H$ already given shows that there are two sets of values of $h_o \div H$ corresponding, viz., one between 0 and ·211, and one between ·667 and ·789, with mean values of about ·105 and ·728. The former is the better for practical velocity-measurements on account of the greater accuracy of work near the surface.

Now the velocity corresponding to the value $z = \frac{1}{10}H$ is—

$$v_{\frac{1}{10}H} = v_o + m\left(\frac{1}{5}ZH - \frac{1}{100}H^2\right) \quad . \quad . \quad (32),$$

and the difference between this and the mean velocity is—

$$v_{\frac{1}{10}H} - U = \frac{1}{5}m\left\{-4ZH + \frac{97}{60}H^2\right\},$$

which ranges from $+\frac{17}{300}mH^2$, when $Z = \frac{1}{3}H$,

$$\text{to } -\frac{23}{300}mH^2, \text{ when } Z = \frac{1}{2}H, . \quad . \quad (32a).$$

Now, in consequence of the flatness of all the curves the quantity m (=reciprocal of parameter) is always a very small quantity; so that 'the several discrepancies

$$-\frac{11}{192}mH^2, \frac{5}{192}mH^2, \frac{17}{300}mH^2, -\frac{23}{300}mH^2,$$

just shown are always very small quantities,' . (33),

and:

'The two velocities $v_{\frac{3}{5}H}$ (*i.e.*, at $\frac{3}{5}$ depth) in general, and $v_{\frac{1}{10}H}$ (*i.e.*, at $\frac{1}{10}$ depth) near margin of a rectangular channel are probably the best approximations obtainable from velocity-measurement at a single point,' . (34).

Mid-depth-velocity, ($v_{\frac{1}{2}H}$).—Writing $z=\frac{1}{2}H$ in the general expression (8) for v, the mid-depth-velocity is seen to be,—

$$v_{\frac{1}{2}H}=v_0+mZH-\tfrac{1}{4}mH^2, \quad . \quad . \quad . \quad . \quad . \quad (35),$$

whilst $U=v_0+mZH-\frac{1}{3}mH^2$, (by (6)),

so that the difference $v_{\frac{1}{2}H}-U=\frac{1}{12}mH^2$ is always a positive quantity . . . . (36).

Thus in the velocity-parabola—

'The mid-depth-velocity is always > the mean velocity by a small quantity, viz., $\frac{1}{12}mH^2$, not depending on the position of the axis,' . . . . (36a)

It will be seen also that the discrepancy $\frac{1}{12}mH^2$ is always > the greatest possible discrepancies with the two approximations last proposed.

[The property just proved, viz., that the 'mid-depth ordinate exceeds the mean ordinate by a small quantity' is a property in no way peculiar to the parabola. All experiment agrees in showing that as a rule—

'The average vertical velocity-curves are everywhere convex down-stream; and are always very flat curves.'

These two properties involve the property in question; for in any convex curve whatever the tangent at the point M where the middle ordinate mM meets the curve lies wholly without the curve, so that the curve falls wholly within the circumscribing trapezoid; also the middle ordinate = area of circumscribed trapezoid ÷ depth; and the mean ordinate = area of curve ÷ depth (by definition); so that the middle ordinate always > the mean ordinate; also, when the curve is very flat, it is clear that the excess of the former over the latter must be a small quantity.]

This is fully borne out by the Roorkee Experiments: the value of the quantity $(v_{\frac{1}{2}H} - U)$ is given for every series in Abstr. Tab. 3, 4, Col. 9, and it will be seen from them that its value is positive in 40 out of the 46 Series, and zero in 2 more. The only cases in which $v_{\frac{1}{2}H} < U$ are shown in following table:—

Serial Number	Number of Sets	Value of $(v_{\frac{1}{2}H} - U)$	Remarks
9	14	−·07	Several very low velocities about the mid-depth (*i.e.*, at 4′ and 5′ depth).
21	16	−·01	An unimportant difference.
44	5	−·11	These two curves on the exceptional vertical, close to the 4′ drop-wall are of exceptional shape (not wholly convex), so that the property (47) of a convex curve could not be expected.
45	6	−·06	

It may hence be concluded that 'the difference $(v_{\frac{1}{2}H} - U)$ is always a small quantity, and usually +, so that $v_{\frac{1}{2}H}$ usually exceeds U,' . . . . . . (37).

Ratio $U \div v_{\frac{1}{2}H}$.—This ratio has acquired quite exceptional importance of late years from the assertion, at p. 294 of the Mississippi Report, of its approximate constancy under all circumstances at the same site, and the proposal therein to utilise this supposed property in discharge-measurement.

From the result $v_{\frac{1}{2}H} = U + \frac{1}{12} mH^2$, Eq. (36), it is clear that the ratio $U \div v_{\frac{1}{2}H}$ is—in the velocity-parabola at any rate—not a constant quantity (unless mH^2 be proportional to U), nor a function of U only (unless indeed mH^2 be a function of U). The value of the ratio is in fact—

$$\frac{U}{v_{\frac{1}{2}H}} = \frac{U}{U + \frac{1}{12} mH^2} = \frac{1}{1 + \frac{1}{12} \cdot \frac{mH^2}{U}} . \qquad . \quad (38).$$

Now from the admitted smallness of the quantity $\frac{1}{12} mH^2$ (the same as $v_{\frac{1}{2}H} - U$) it is clear that this ratio will be tolerably constant (<1, of course) at any rate as a rough approximation.

The conclusion advanced by the Mississippi Report is that this ratio depends chiefly on the mean velocity (V) of the whole channel, at any rate in a deep channel.

But the argument is based (see Mississippi Report) upon the assumed value for the parameter $\frac{1}{m}$ or $p = H^2 \div \sqrt{\beta V}$, and upon a further *assumed* relation that $U = \cdot 93 V$ approximately (*i.e.*, with sufficient approximation for the purpose of proving the dependence of the ratio $U - v_{\frac{1}{2}H}$ on V). Applying these two Results, the ratio $v_{\frac{1}{2}H} \div U$ indeed becomes—

$$v_{\frac{1}{2}H} \div U = 1 + \frac{1}{12 \times \cdot 93} \sqrt{\frac{\beta}{V}}, \text{ where } \beta = \frac{1 \cdot 69}{\sqrt{H + 1 \cdot 5}}, \quad (39),$$

which depends in deep channels at any rate (in which β varies very little) chiefly on V; and this result is proposed, at p. 293 of the Mississippi Report, as 'the absolute numerical value of the ratio for any curve of actual observations.'

But the argument is inconclusive on account of the uncertainty (and probable incorrectness as general truths) of the two assumptions $p = H^2 \div \sqrt{\beta V}$ and $U = \cdot 93V$ approximately. The assumption $U = \cdot 93V$ approximately is obviously not true at all parts of a channel, for it is equivalent to assuming that—

'The mean velocity past a vertical (U) is approximately the same right across a channel,'

which is true enough throughout great part of the width, but very far from true regarding velocities near the banks. Thus result (39) is not a general truth, but is at the utmost limited in application to those parts of a cross-section, the mean velocity past the verticals of which is nearly the same.

In fact the real evidence of the proposed law for this ratio must be held to depend, not on the argument which led to it, but, on the numerical comparisons exhibited (Mississippi Report, p. 294) showing—

1st, the values of the ratio $U \div v_{\frac{1}{2}H}$ (computed direct from the velocity-data).

2nd, the values of its proposed equivalent, viz., of

$$1 \div \left(1 + \frac{1}{11 \cdot 16}\sqrt{\frac{\beta}{V}}\right).$$

3rd, the discrepancies between the above values.

These are shown in the Mississippi Report for 15 cases, viz., 8 Mississippi curves, 2 of Capt. Boileau's curves from small canals, and 5 curves on the Rhine. The discrepancies shown are certainly surprisingly small in the 8 Mississippi curves, in which they do not exceed $\frac{8}{10}$ per cent.; whilst in 4 of the European curves they rise to 2 to 3 per cent.

Upon this evidence the important conclusion is drawn (*ib.*) that—

'The ratio of the mid-depth velocity to the mean velocity in any vertical plane is practically independent of the depth and the width of the stream, of the mean velocity of the river, of the mean velocity of the vertical curve, and of the locus of its maximum velocity. In other words, it is a sensibly constant quantity for practical purposes.'

And upon this conclusion it is proposed that the field-work for computing the total discharge of a large channel should in future be limited to mid-depth velocity-measurements.

The practical value of this conclusion depends chiefly on the amount of error likely to be made in its application. Now the value of the ratio (39) proposed involves unfortunately the unknown quantity V (=mean velocity of the whole channel). If an approximate value of this were known *a priori*, it would give the value of the ratio in question with sufficient approximation.

It was apparently supposed (Mississippi Report) that the ratio in question varied within such small limits *under all circumstances whatever* (even in different channels) that it might be assumed sensibly constant for all practical purposes of discharge-measurement of large channels. The additional evidence now available by no means confirms this hypothesis: the ranges of average values of the ratio in question—*i.e.* of the average experimental values of $U \div v_{\frac{1}{2}H}$—are given below from all the known published cases.

Experiments	Reference to Original	Number of Curves	Range of Average Values of the ratio $U \div v_{\frac{1}{2}H}$
Mississippi . .	Miss. Report, p. 294 .	8	·9868 to ·9624
Rhine . . .	" " .	5	·9569 to ·9322[1]
Small Canals, Capt. Boileau . .	" " .	2	·9640 to ·9417
Bazin . . .	Bazin Experiments .	?	not given
Lake Survey . .	Reports of 1868–70 .	?	not given
Irrawaddi . .	Report of 1875, Appx. C.	14?	1·092 to ·976
Connecticut . .	Report of 1878, p. 350	27?	·961 to ·918
Roorkee . .	Roorkee Expts., Tab. 3, 4	16	1·045 to ·961

Thus it appears that—

'The ratio $U \div v_{\frac{1}{2}H}$ is liable to range from about 1·082 to ·918, *i.e.*, about 16 per cent.' . . . (40),

an amount not fairly negligible even in the rough process of discharge-measurement of large channels.

9. Discharges of Rivers.

To determine with accuracy the discharge of any ordinary or large river, independently of velocity-observation, is at present impossible. To this general truth there is only one exception, the case of a long straight and uniform reach of river, whether canalised artificially or naturally; then it may be treated nearly as a canal.

If it be required to determine approximately the discharge of a river from its section, slope, and condition as regards roughness of bed surface and irregularity; the section may be sounded, and the hydraulic slope ascertained by levelling, but the required coefficient (n) of

[1] Printed ·0322 in Mississippi Report.

roughness and irregularity must be guessed by an experienced hydraulician from comparison with other rivers and their coefficients. (See Kutter's local values of n for natural channels in Table XII.) This being done, the value of c may be calculated by the formula or obtained from Table XII., and the calculation of discharge can be effected through the general formula

$$Q = A.V = A.c.100\sqrt{RS}.$$

It is obvious that it is preferable to take at least a few velocity-observations. (See Gauging, Chapter II.)

There are also two other theories of flow, or modes of approximating to river-discharges without velocity-observation, that are of some practical value under certain conditions; besides a large number of formulæ whose merits are demonstrated by comparison (in Chapter III., Hydrodynamic Formulæ) to be very inferior.

Of the two former the first is that of Dupuit; it neglects friction on the sides of the section of flow, thus considering motion in all vertical planes to be the same, and dealing with horizontal laminæ only; the surface lamina is considered to be in the condition of a solid gliding over an inclined plane, and each lamina below, except the bottom one, is urged on by its own weight and its cohesion to the upper lamina; the bottom fillet is retarded by its adhesion to the bed. Putting this in the form of an equation, summing, rejecting certain terms, integrating and applying three numerical coefficients, Dupuit obtains a result, which for English feet is—

$$v = \frac{S.RA}{0{\cdot}08\,W} - 0{\cdot}082 + (0{\cdot}0067 + 0{\cdot}9114\,RS)^{\frac{1}{2}}.$$

It is this formula that has produced more correct practical results generally than any one of the formulæ having fixed coefficients; next to it, in order of correctness, coming the Chezy formula, with a fixed coefficient $c=1$. This theory assumes that the uppermost lamina moves invariably with the maximum velocity, which is not the case; the neglect of the friction of the banks might not vitiate results if applied to large rivers or shallow channels; it is probable, therefore, that a modification of this formula in accordance with correct data of the relations between maximum and mean velocity, might render it very useful and practical. Hitherto the formula has been generally treated as a pipe-discharge formula, and as a modification of the Chezy type; the theory, however, is one pre-eminently adapted to wide rivers, and the results (see Article in Chapter III., Hydrodynamic Formulæ) are undeniably correct as good approximations. For more information, refer to Dupuit's 'Etude Théorique et Pratique sur le Mouvement des Eaux courantes' (Paris, 1848), and Claudel's Tables, which contain extracts therefrom.

The second theory is that of the Mississippi Survey, mentioned in the Mississippi Report, Philadelphia, 1861, which deduces the new formula, mentioned as giving the most correct results of all yet known; it is, however, unfortunate in its formulæ being rather inconvenient in some respects. While, therefore, the investigation and deduction of the formula is valuable on account of the experimental data applied to it, the result is not practically useful; as the formula was virtually set aside by the Mississippi Survey, whenever careful river-gauging was carried out, in favour of other equations deduced from velocity-observation.

In a work of this scope, it is impossible to go beyond the mere outlines of the demonstration adopted. Adopting the notation of the Mississippi Survey given at pages 11 and 12, it may be stated as follows.

The theory accepts uniform motion and the usually accepted application of the laws of uniform motion, but, in retarding force, denies the stability of position of maximum velocity, and makes allowance for the resistance of the air on the water surface, as well as for the effect of wind.

The process of reasoning pursues the following equations obtained for the forces:—

$$(1.)\ lGgAS = l(p+w)\,\phi\frac{U_s W + U_r p}{W+p}$$

dividing both sides by Ggl,

putting $U_s = 0{\cdot}93v + (0{\cdot}016 - 0{\cdot}06f)\,(bv)^{\frac{1}{2}}$

$U_r = 0{\cdot}93v + (0{\cdot}06f + 0{\cdot}35)\,(bv)^{\frac{1}{2}}$

(2.)

$$\frac{AS}{W+p} = \phi\left\{\cdot 93v + \frac{(bv)^{\frac{1}{2}}\left(W\left(\cdot 333 - \frac{d_1}{r}\right) + p\left(\frac{d_1}{r} - \cdot 667\right)\right)}{W+p}\right\}$$

putting $W = qp$, where q practically $=1$ for large rivers.

$$(3.)\ \frac{AS}{W+p} = \phi\,(0{\cdot}93v + {\cdot}0167\,(bv)^{\frac{1}{2}} = \phi\,(z) = C\,z^2.$$

$$(4.)\ C = \frac{AS}{(p+W)z^2};$$

by practical observation $C = \frac{S}{195}$, hence

$$(5.)\ z = \left(\frac{195\,AS}{p+W}\right)^{\frac{1}{2}}$$

In this equation there are practically only four variables, A, $p+W$, S and z, and for ordinary natural channels p nearly $=1{\cdot}015\,W$; hence if the values of any three are given, the fourth may be obtained, the transpositions of the equation being—

$$(6.)\quad S=\left(\frac{(p+W)z^2}{195A}\right)^2$$

$$(7.)\quad A=\frac{(p+W}{195S^{\frac{1}{2}}}$$

$$(8.)\quad p+W=\frac{195\,AS}{z^2}.$$

Now z is a variable, of which only two absolute values are known, viz., that for a rectangular cross section, and that for an ordinary river section, which are—

$$z=v+0{\cdot}167\,b^{\frac{1}{4}}\,v^{\frac{1}{2}}$$

$$z=0{\cdot}93v+0{\cdot}167\,b^{\frac{1}{4}}\,v^{\frac{1}{2}}.$$

Substituting these in (5) and solving, we get for rectangular channels

$$(9.)\quad v=\sqrt{0{\cdot}0064b+(195R_1S^{\frac{1}{2}})^{\frac{1}{2}}-0{\cdot}08b^{\frac{1}{2}})^2}.$$

For ordinary river channels,

$$(10.)\quad v=(\sqrt{{\cdot}0081b+(225R_1S^{\frac{1}{2}}-{\cdot}09b^{\frac{1}{2}})^2};$$

For large rivers, where $R>12$ feet, and where $b=\dfrac{1{\cdot}69}{(R+1{\cdot}5)^{\frac{1}{2}}}=0{\cdot}1856$, the first term may be neglected, and this latter equation becomes—

$$(11.)\quad v=([225R_1S^{\frac{1}{2}}]^{\frac{1}{2}}-{\cdot}0388)^2;$$

If the discharge is known, and also two of the four variables in equation (5), provided they are not A and v, the other two variables may be computed by eliminating the unknown variable in the second member of that one of the transpositions of equation (11) whose first member is the variable sought, by substituting for it its value deduced from the equation (12).

$$v=\frac{Q}{A}.$$

No difficulty will be found in performing the calculation, except when S and $p+W$ are the known variables, in which rate an equation of a higher degree than the second cannot be avoided, and successive approximation must be adopted as follows:—

Assume a value of A, and find two values of v, one from equation (12), the other from (10) or (9), as the case may require; these values of v will not agree, hence continue assuming new values for A, until the resulting values of v are identical.

The above-mentioned Mississippi formulæ apply only to the discharges of very large rivers; their adoption is not to be recommended in any other cases.

10. Bends and Obstructions.

The irregularities of a river materially affect its velocity; the following remarks on this subject, by Captains Humphreys and Abbot, are instructive on this point.

'Even on a perfectly calm day, there is a strong re-'sistance to the motion of the water at the surface, inde-'pendent of, and not mainly caused by the friction of the 'air; the principal cause being the loss of force, arising 'from the upward currents or transmitted motion caused 'by the irregularities at the bottom. There is also an 'almost constant change of velocity at various depths, re-'sulting from the wind in a great measure; and eddies 'changing their position and magnitude cause variations 'in the velocity of the river at a given point, and these 'again are influenced in intensity by the wind.'

Such irregularities are of course beyond calculation; others again may, in some instances, have their results approximated to, and allowances made for them, by considering a certain portion of the head on the stream as neutralised by them; and these are known as bends or obstructions whose effects are within the range of calculation. Generally the disturbing effects of lateral bends and curves, and of shoals and obstructions, constituting vertical bends, as well as alterations of section, cannot be calculated with any practical accuracy. It is, therefore, best entirely to avoid such difficulties; but when this cannot be done, the following formulæ may be used in preference to neglecting the allowance.

The old general formula for loss of head, h_1 due to a bend in a canal, river, or water-pipe, is of very doubtful value; it is

$$h_{,}=\frac{c.\sin^2 a \,.\, V^2}{\sqrt{R}}$$

where c is an experimental coefficient generally taken at the fixed value 0·5184;

a = the arc of any bend, not exceeding 90°;

$h_{,}$ and R the radius of bend are in feet, and V is in feet per second.

The total loss of head, due to the bends for which allowance is to be made throughout a course, is then the sum of all such values $h_{,}$ obtained.

River bends.—A more modern formula suited to rivers is that adopted by the Mississippi Survey, it is—

$$h_{,}=\frac{V^2 \sin^2 a}{134};$$

where a=angle of incidence of the water in passing round the bend:—it is, however, always assumed that each angle is one of 30°, and the effect is estimated as due to the number N whether integral or fractional of such bends or deflections of 30°; and this enables the formula to be put into the simpler form—

$$h_{,}=\frac{N\ V^2}{536}=N\ V^2 \times 0{\cdot}001865.$$

The values of this formula, for various velocities and bends, are given in Part 2 of Table IX., and an explanatory example is attached.

Pipe-bends.—A formula more suited to bends of pipes is that of Weisbach; it is for cylindrical pipes—

$$h_{,}=\frac{a}{180}, \frac{V^2}{2g} \times \left\{0{\cdot}131+1{\cdot}847\left(\frac{r}{R}\right)^{\frac{7}{2}}\right\}$$

and for rectangular tubes—

$$h_{,}=\frac{a}{180^{\circ}}, \frac{V^2}{2g} \times \left\{0{\cdot}124+3{\cdot}104\left(\frac{d}{2R}\right)^{\frac{7}{2}}\right\}$$

but as the bends of pipes, known as quarter bends, are generally taken as 90°; the value of the factor in either case

$$\frac{a\ V^2}{180^{\circ} \times 2g} \text{ then becomes}=\frac{V^2}{128{\cdot}8}=0{\cdot}007764\ V^2.$$

In this formula r and R are the radii of the pipe and of the bend, and the other terms are as before. The loss of head due to bends in pipes is, however, generally quired in relation with discharges, not with mean velo ties of discharge. The values approximately given this formula have, therefore, been tabulated in this for and are given in Part 1 of Table IX.; an explanato example is also attached to it.

Obstructions.

While the above formulæ may be thus employ for the present, it must be noticed that they are mere approximately correct, and that extensive and numero careful experiments are yet required before an accura determination of the head, representing the loss of effe caused by a bend of every sort and condition, will arrived at.

The ordinary formula for calculating the rise in f resulting from an obstruction in the section of a riv channel is that of Dubuat; it is—

$$h_{\prime\prime}=\left(\frac{V^2}{o^2.\,2g}+S\right)\left\{\left(\frac{A}{a}\right)^2-1\right\}$$

where A, a, are the normal and the reduced sectio areas of flow.

S is the sine of the hydraulic slope of the river,

and o is the experimental coefficient for discharge throu the bridge opening taken as a sluice or orifice.

Now, as in most cases S is less than 0·001, that te may be neglected, and taking $o=0{\cdot}96$, $o^2=0{\cdot}92$, and formula becomes—

$$h_{\prime\prime}=0{\cdot}0169\ V^2\left\{\left(\frac{A}{a}\right)^2-1\right\}$$

For other values of o, suitable to any special case, corresponding value of o^2 must be applied in the origi formula.

The values of this are given in Part 3 of Table IX., and an explanatory example accompanies it.

11. DISCHARGES FROM ORIFICES AND OVERFALLS.

The discharge from orifices and overfalls, which to the practical man generally resolve themselves into sluices, weirs, and water-cocks, is a subject that was fully entered into by hydraulicians of past times, and to which very little information has been added by recent experimentalists. Nor is it by any means likely that further contributions will be soon made to this branch of hydraulic science, as there have recently been to that of channel-discharge; the practical interest attaching itself to the exact determination of discharge of a sluice or a weir not being in excess of the amount of exactitude already attained. As all accepted information on this subject is to be found, with but little variation, in the older books, the author had little choice left to him, in compiling from them; much of the following was reduced from Bennett's translation of d'Aubuisson's hydraulics, for want of a copy of the original.

Setting aside the experiments of the more ancient philosophers, it may be assumed that the discharge from any orifice under theoretically constant pressure is

$$Q=A\,V=A.o\,\sqrt{2g\,H}$$

where H = the head of pressure of the orifice,

o = the coefficient of reduction obtained by experiment on such orifice,

V = the mean velocity of discharge.

The first of the more modern hydraulicians to obtain experimental values of *o*, on a scale larger than the previous very petty experiments, was Michelotti: his experiments conducted at Turin in 1767, under heads of pressure up to 22 feet, determined coefficients of reduction varying from 0·615 to 0·619, for circular orifices, up to 6½ inches in diameter, and coefficients varying from 0·602 to 0·619 for square orifices, up to 3 inches in length of side. The next important experiments did not so much include increase of head as increased dimension of opening. Messrs. Lespinasse and Pin, Engineers of the Languedoc Canal, 1782 to 1792, made experiments on rectangular openings, or sluices 4·265 feet broad, and having heights varying from 1·575 to 1·805 feet, under heads on their centres of from 6·2 to 14·5 feet; the coefficients deduced varied from 0·594 to 0·647, the mean being 0·625; they also observed that the discharge from two sluices opened at one time side by side was not double that from one sluice. In 1826 at Metz, MM. Poncelet and Lesbros deduced a law for the determination of coefficients of discharge of rectangular orifices under various proportions of head of pressure and depth of opening to width; these coefficients, ranging from 0·572 to 0·709, are given in Table XII. The next important experiments recorded were those conducted by M. George Bidone, at Turin, in 1836, on orifices on parts of which the contraction was suppressed, the extreme of suppression being a case in which the whole of the contraction was suppressed by fitting an interior short tube to the mouth of the orifice: his resulting formula of discharge was for rectangular orifices—

$$Q=o\,.\,A\,\sqrt{2gH}\left(1+0{\cdot}152\,\frac{p}{P}\right)$$

and for circular orifices,

$$Q=o \, . \, A \sqrt{2gH}\left(1+0{\cdot}128\frac{p}{P}\right)$$

where p is the portion of the perimeter P whose contraction is suppressed.

About this time also some further experiments were made by Castel and d'Aubuisson; and some by Borda on orifices in sides not plane, but of compound formation.

In small orifices generally.

The results of all these experiments show that the extreme limits of the value of o are 0·50 and 1·00 for orifices in all sorts of sides, and under all conditions, and are 0·60 and 0·70 for orifices in plane sides; also that the general mean value of o for orifices in a thin plate is 0·62; this, however, is perhaps more true for small circular orifices than for any other class of them. In this case therefore

$$V=0{\cdot}62 \times 8{\cdot}025 \sqrt{H}=4{\cdot}975 \sqrt{H},$$

and for rectangular orifices of a similar class, the special values of o, ranging from 0·572 to 0·709, given in Table XII., must be applied to the general formula

$$V=o \times \sqrt{2gH}$$

in order to determine the mean velocity of discharge, which when multiplied by the sectional area gives the quantity discharged per second.

Effect of initial velocity.—In the special case in which the reservoir of supply, still being kept at a constant level, is seriously affected by the velocity of the water supplying it, the discharge of the orifice will be augmented on this account, and then

$$V = o\sqrt{2g\left(H+\frac{W^2}{2g}\right)} = o\sqrt{2gH+W^2}$$

where W = the initial velocity of entrance.

Attached channel.—When an open channel is attached to the orifice at its exit, in such a manner that the sides and bottom of the channel are continuations of those of the orifice, the coefficient of contraction remains the same, except when the head on the orifice is less than 2½ times the height of the orifice; in this latter case the coefficient may have to be materially reduced. An extreme case given by Poncelet and Lesbros, being one of a discharge through an orifice 0·164 feet high, under a head of 0·118, gave a value of $o = 0{\cdot}452$, while without an attached channel the value of o was $= 0{\cdot}612$; further, when the level of the attached channel was exactly at the same level as the floor of the reservoir of supply, the value of o was reduced to 0·443. The law of reduction of coefficient necessary for these cases is not yet given in a definite form. The inclination of the attached channel when less than one in 100 did not affect the coefficients in any way, but when increased to one in 10 had the effect of increasing the coefficient from 3 to 4 per cent.

Orifices with mouthpieces attached were even in the time of the Romans known to have a greater discharge than those without them. In order to effect this increase it is, however, necessary that the length of the attached or additional tube should be twice or three times the diameter of the orifice, otherwise the fluid vein does not entirely fill the mouth of the passage. The experiments of Michelotti and Castel determined a mean coefficient ischarge for cylindrical mouthpieces of 0·82, the emes being 0·803 and 0·830; the singular effects duced under some circumstances by the application cylindrical mouthpieces are more curious than useful. nical converging mouthpieces increase the discharge ore highly: the experiments on them of Castel, engineer of the waterworks of Toulouse, are exceedingly interesting; they demonstrated that under varied heads the coefficients of discharge and of velocity were practically constant for the same mouthpiece, and that for the same orifice of exit the coefficient of discharge increased from 0·83 for a cylindrical mouthpiece in proportion to the increase of the angle of convergence of the mouthpiece employed up to 0·95 for an angle of $13\frac{1}{2}°$; and that beyond this angle the coefficient of discharge diminishes to 0·93 for 20°, and afterwards decreases more rapidly. The length of mouthpiece employed in these cases as well as in the former was $2\frac{1}{2}$ times the diameter of the orifice. Some experiments by Lespinasse on the canal of Languedoc showed the enormous increase of discharge effected by using converging mouthpieces: his mouthpieces were truncated rectangular pyramids 9·59 feet long, the dimensions at one end $2·4 \times 3·2$ feet, at the other $·44 \times ·62$ feet, and were used in mills to throw the water on to water-wheels; their opposite faces were inclined at angles of 11° 38′ and 15° 18′, and the head employed was 9·59 feet; the experiments resulted in determining a coefficient of discharge varying from 0·976 to 0·987.

Conical diverging and trumpet-shaped mouthpieces still further increase the discharge from an orifice: the experiments of Bernouilli, Venturi, and Eytelwein have thrown much light on this subject, and showed the coefficient to lie between 0·91 and 1·35. Venturi concluded that the mouthpiece of maximum discharge should have a length nine times the diameter of the smaller base, and a flare of 5° 6′, and that it would, if properly proportioned to the head of pressure, give a discharge 1·46 times the theoretic unreduced discharge through an orifice in a thin side.

Sluice gates, large openings, &c.

It may be observed, however, that although the minutiæ of discharges under certain experimental conditions have been sedulously preserved, there is yet considerable doubt what coefficients should be used for large sluices and wide openings of different sorts. It may be unfortunate that experimentalists should differ, but at the same time the circumstances, under which the amount of discharge from a sluice is an important consideration, only occur generally to those who are capable and have the opportunity of determining it accurately by experiment themselves.

The ordinary coefficient for a sluice of moderate size, for small lock or dock-gates, or mill-gates, is generally taken at 0·62; that for a narrow bridge-opening, which may be considered as a large sluice, at 0·82; and that for very large well-built sluices, very wide openings out of reservoirs level with the bottom of the reservoir, and large bridge-openings of the modern type, at 0·92.

The term H, representing the effective head of pressure, is differently estimated in various cases: in ordinary cases of sluices, supplied from a reservoir above them, the head is the difference of level between the surface of the water in the reservoir and the centre of figure of the sluice; but when the sluice is drowned, that is, has a perceptible depth of water in the tail race standing above the sluice itself, the head is the difference of level of the water above and of that below it; in bridge-openings also, the head is the difference of water level on the up-stream and down-stream sides of the bridge.

The most recent experimental determination of coefficients of discharge for head-sluices supplying small channels is that of d'Arcy and Bazin; the results of these operations will be given, with the account of the mode of gauging adopted by them, in Chapter II.

The above includes all the general deductions about orifices that are likely to be of any use to the engineer; a more practical collection of coefficients of discharge for orifices is given in Part 4 of Table XII.; and the value of the expression $V = o\sqrt{2gH}$ is given in Table X., for various heads, and for all the values of o that are commonly used; some explanatory examples also follow that table.

The discharge of pipes under pressure.

This subject may be treated as one closely allied to the discharge of orifices in one respect. If at any point in a pipe or series of pipes under pressure the continuity of the pipe be cut off, the discharge at that point will obviously be that of an orifice under pressure, provided the necessary free fall be allowed; the dimensions of the orifice will be those of the section of the pipe at the exit, and the head will be the statical pressure, less a reduction of head representing the friction throughout the whole course of the series of pipes of supply, and another for contraction at entry and at exit.

[illegible]

[illegible] used [illegible]

[illegible] which [illegible]

[illegible] are [illegible]

[illegible] may b[illegible]

very l[illegible]

[illegible]

In actual practice, this method could alone be conveniently applied at the extremity of a series of pipes for direct determination of discharge; but having obtained by this or any other method the discharge at any one point in a line of pipes, the discharge at any other point along the same line may be relatively determined by making allowance for the friction developed in the intermediate length by a representative head.

A more common mode of making calculations of discharge, pressure, and diameter of pipes under pressure has been in accordance with mean inclinations of the various general lines of pipes in a series, and by applying the ordinary formula for flow (transformed for diameters of cylinders) as before given

$$Q = c \times 39{\cdot}27 \sqrt{Sd^5}$$

$$\text{or } H = \frac{0{\cdot}0648 Q^2}{c^2 d^5}.$$

It is, however, evident that this method of assuming a mean hydraulic slope taken from a point where the pressure is zero to the point of contemplated discharge, and treating the discharge according to the principles of flow, from a summit due to that hydraulic slope, is an inexact method; for it is very evident that the same data as bases of calculation might apply to two very different conditions of length of pipe, thus neglecting considerable amounts of friction.

Overfalls and Weirs.

An overfall may be treated as a wide rectangular orifice in an ultimate position, where the head on the upper edge is zero; and its discharge may be therefore computed in the same manner as that of an orifice.

The discharge of an orifice is according to the parabolic theory—

$$Q=o\times\tfrac{2}{3}\sqrt{2g}\times w(h_1\sqrt{h_1}-h\sqrt{h})$$

where h and h_1 are the heads on the top and bottom edge, and w is the width of the orifice; but if H=mean head on the centre of the orifice, and d is its depth when the orifice becomes an overfall, this formula becomes

$$Q=o\times\tfrac{2}{3}\sqrt{2g}\times w\left\{\left(H+\frac{d}{2}\right)^{\frac{3}{2}}-\left(H-\frac{d}{2}\right)^{\frac{3}{2}}\right\}$$

developing this, and putting $wd=A$, the sectional area,

$$Q=oA\tfrac{2}{3}\sqrt{2gH}\left(1-\frac{d^2}{96h^2}\right)$$

and as d is comparatively small, the last term may be neglected, hence

$$Q=oA\tfrac{2}{3}\sqrt{2gH}\text{; and }V=o\tfrac{2}{3}\sqrt{2gH}$$

where H is the head on the sill of the overfall.

The value of the coefficient, o, varies according to the conditions of the overfall. It was determined by M. Castel, at Toulouse, by a large series of experiments; and also by Francis, in the Lowell experiments referred to in Chapter II. on Gauging. (For obstructed overfalls see also a paragraph following.)

The experiments of M. Castel showed that, for the accurate employment of a general coefficient the dimensions and conditions of an overfall should fall within one of the three following classes.

1st. When the length of the overfall sill extends to the entire breadth of the channel, and the head on the sill is less than one-third the height of the dam or barrier, the coefficients remain remarkably constant, varying only from 0·664 to 0·666. Hence generally for this case, $o = 0·666$.

2nd. When the length of the overfall sill is less than the entire breadth of the channel of supply, but is greater than a quarter its breadth, the coefficient lies between the two extremes of 0·666 and 0·598, and is strictly dependent on the ratio of the length of sill to breadth of channel; hence it is for the following relative lengths of sill :—

Relative lengths of sill	Coefficient	Relative lengths of sill	Coefficient
1·00	0·666	0·50	0·613
0·90	0·658	0·40	0·609
0·80	0·647	0·30	0·600
0·70	0·635	0·25	0·598
0·60	0·624		

3rd. If the length of the overfall sill be equal, or even only nearly equal, to one-third the breadth of the channel, the coefficient remains very constant, varying only between 0·59 and 0·61. Hence generally for this case, which is particularly favourable for gauging small streams, $o = 0·60$.

In other cases, that is, when the length of the sill is less than a quarter the breadth of the channel of supply, the coefficient depends on the absolute length of sill, and requires determining specially; it increases from 0·61 to 0·67 in direct proportion to the diminution of absolute length of sill.

Velocity of approach.—With reference to the three cases suitable for practical purposes, the experiments of M. Castel showed that when the sectional area of the overfall was less than one-fifth of that of the normal section of the channel of supply, the effect of velocity of approach in the channel did not modify the value of the coefficient; for other conditions, the modification necessary was not determined in a very satisfactory form :—the new equation for mean velocity of discharge being changed from

$$V=o\tfrac{2}{3}\sqrt{2gH}$$

into

$$V=o\tfrac{2}{3}\sqrt{2g(H+0{\cdot}035\,W^2)},$$

where $W=$ the surface velocity of approach, not determined from observation, but from its assumed ratio to the mean velocity. Perhaps therefore it is preferable to modify the coefficient, o, into a new coefficient o_1, comprising the allowance, thus

$$o_1=o\left\{\left(1+\frac{h}{H}\right)^{\frac{3}{2}}-\left(\frac{h}{H}\right)^{\frac{3}{2}}\right\}$$

where h is the head due to the velocity of approach, and H is the head on the weir sill.

Attached channels.—For the special cases in which channels are attached in continuation of the sides of the overfall, the coefficients in the experiments of Poncelet and Lesbros were reduced by 18 to 33 per cent. If, however, the fall to the channel is more than 3 feet, no reduction is generally made in the coefficients.

It may be noticed that the head on the sill used in the above expression is that in the centre of the overfall, which is independent of the rising of the water at the wings, a phenomenon to be observed in almost all cases of weir discharges.

In all the above cases, it is supposed that thin edges as of metal sheets, or one-inch waste-boards, are used; for broad or round-lipped crests, the coefficients will require reduction. See the coefficients given in Part 5 of Table XII.

Obstructed Overfalls.—When obstacles occur on the sill of an overfall, as dwarf pillars or blocks, a deductio in the discharge over the sill is made not only on accoun of the reduction of section, but on account of the con tractions resulting. Francis's formula is applicable t these circumstances in cases where the length of weir si equals or exceeds the head ;—it is

$$Q=\tfrac{2}{3}o\sqrt{2g}.(l-0{\cdot}1\,n\,H)H^{\frac{3}{2}},$$

where n = the number of end contractions,
(note that $n=2$, when there is no central obstruction,
l = length of weir sill,
$lH=A$ the sectional area of discharge,
and $o=0{\cdot}6228$.

In case the weir sill has the same breadth as t channel of supply, $n=0$; and in that case

$$Q=3{\cdot}332\,l\,H^{\frac{3}{2}}.$$

This, it will be observed, varies from that of Castel, whi under the same conditions, when $o=0{\cdot}666$, gives

$$Q=3{\cdot}563\,lH^{3}.$$

Partly Drowned Overfalls.—When a weir has its water above the edge of the sill, it may be treated a combination of an overfall with an orifice; the up portion down to the level of the lower water as an ov fall, and the lower portion from that down to the level as a rectangular orifice, and the discharges calcula separately for each. The same value of H is used both cases, H being the head due to the overfall, t is, down to the level of the tail-race.

Some further values of coefficients of weir discha are given in the accounts of gauging in Chapter II. aid in the computation of discharges from overfalls, velocities of discharge due to various heads and various coefficients may be obtained from those given in Table X., by reducing the velocities there given by one-third; the results multiplied by the section of overfall are then the required discharges. The method thus adopted enables the same table to be used in computing the discharges of both orifices and overfalls. A table of weir coefficients is given in Table XII., and some explanatory examples accompany Table X.

12. Efflux or Discharge from Prismatic Vessels, Locks, Basins, Reservoirs, or Tanks.

The following formulæ given by d'Aubuisson may be considered useful for reference in the cases in which they are required in engineering practice:—

First Case.

Simple discharge from a reservoir.

(1st.) When the reservoir empties itself through an orifice or sluice with free exit.

Velocities.—The ratio between the velocity at the orifice of discharge and that of the water in the reservoir is in the inverse ratio of their sectional areas.

Head.—If H = actual height of water in the reservoir; h = the height due to and generating the velocity of discharge, and A and a are the sectional areas of the reservoir and the orifice respectively.

Then $$h=\frac{HA^2}{A^2-c^2a^2}$$

Discharge.—A reservoir emptying itself through an orifice in a given time would discharge a volume equal to half that due to the head at the commencement, kept constant during the same time. For such examples applied to locks, see Table X.

Time.—The time in which a prismatic reservoir empties itself is double that in which the same volume would be discharged if the initial head had remained constant.

The time of descent, t, to a given depth, $d=H-h$,

$$t=\frac{2A}{oa\sqrt{2g}}(\sqrt{H}-\sqrt{h});$$

and the quantity discharged in a given time, t,

$$\text{is } Q=A\,(H-h)=\frac{t.o.a\ \sqrt{2g}}{A}\left(\sqrt{H}-\frac{toa\sqrt{2g}}{4A}\right),$$

and the mean hydraulic head, H_1 under which the same quantity would be discharged in the same time is—

$$H_1=\left(\frac{\sqrt{H}+\sqrt{h}}{2}\right)^2$$

where H and h are the heads at the beginning and end of the time of discharge, the reservoir receiving no supply during that time.

(2nd.) When the basin or reservoir receives a constant supply during the time of discharge.

If q=quantity supplied per second,

t=time in which the surface will descend the depth, $x=H-h$.

$$t=\frac{2A}{(oa\sqrt{2g})^2}\left\{oa\sqrt{2g}\,(\sqrt{H}-\sqrt{h})+q.hyplog\ \frac{oa\sqrt{2gH}-q}{oa\sqrt{2gh}-q}\right\}$$

when there is no supply, or $q=0$, this equation resolves itself into that previously given.

(3rd.) In the case of there being no supply, but the discharge instead of being effected through an orifice is conducted over an overfall, having a length of sill $=L$,

$$t=\frac{3A}{oL\sqrt{2g}}\left\{\frac{1}{\sqrt{h}}-\frac{1}{\sqrt{H}}\right\}$$

Non-prismatic reservoirs are extremely difficult to deal with, and the investigation of any special case here would be comparatively useless.

Second case.

When one reservoir empties itself into a partly filled reservoir.

(1st.) When each of the two reservoirs being exceedingly large practically preserves its own level, the communicating sluice being below the lower surface of water; then if H, h, are the heads; a the sectional area of the sluice,

$$\text{the discharge } Q=oa\sqrt{2g\,(H-h)}.$$

(2nd.) When the upper reservoir being exceedingly large preserves its own level, and the lower reservoir having a definite area (A), receives the supply through a sluice of a section (a), required the time t in which the surface of the lower basin will rise to a certain height.

If H, h, be the heads on the lower surface at the beginning and end of the time, t,

$$\text{then } t=\frac{2A}{oa\sqrt{2g}}(\sqrt{H}-\sqrt{h}),$$

this formula, like that previously given, is useful for determining the time necessary to fill a lock chamber; when $h=0$, or the levels become the same, the case is that of canal locks, and the sectional area of the sluice may be determined from this equation.

(3rd.) When neither reservoir receives any supply and both are limited in size, if the surfaces are originally at different levels, and the communication sluice is opened, the surface of one will rise and the other fall.

If A, B, are the sections of the two vessels,

H, x, the heads at the beginning and end in A,

h, y, the heads at the beginning and end in B,

a = the sectional area of the pipe or sluice,

t = time during which the sluice is open,

then

$$t=\frac{2A\sqrt{B}}{ca(A+B)\sqrt{2g}}\left\{\sqrt{B(H-h)}-\sqrt{(A+B)x-AH-Bh}\right\}$$

and if it be required to know the time t' in which the two surfaces will be level; in that case, $x=y=\frac{AH+Bh}{A+B}$

and then

$$t'=\frac{2AB\sqrt{H-h}}{ca(A+B)\sqrt{2g}}.$$

This formula is convenient for determining the time occupied in bringing the water in the two chambers of a double lock to the same level, by means of a sluice of known dimensions.

CHAPTER II.

ON FIELD OPERATIONS AND GAUGING.

1. Direct measurement of discharge. 2. Gauging by rectangular overfalls. 3. Appliances and instruments for the measurement of velocities. 4. Baldwin and Whistler's gauging by means of surface velocities. 5. Francis's gauging canals and streams with loaded tubes. 6. The Mississippi field operations for gauging very large rivers. 7. Field operations in gauging crevasses: and computation of coefficients. 8. Captain Humphreys' improved system of gauging rivers and canals, and General Abbot's mode of determining a discharge on any given day. 9. The experiments of d'Arcy and Bazin on the Rigoles de Chazilly et Grosbois. 10. Velocity observations on great rivers in South America, by J. J. Révy. 11. Captain Cunningham's experiments on the Ganges Canal. 12. General remarks on systems of gauging, and conclusions therefrom.

1. DIRECT MEASUREMENT OF DISCHARGE.

THE direct measurement of the discharge of a channel or stream can be obtained by means of gauge-wheels. The channel is widened until the water flows at a moderate depth, less than five feet, over a horizontal and carefully constructed apron which is divided by piers into a number of equal openings. At each of these openings a gauge-wheel is placed, which fits the opening every way within a quarter of an inch. Sheet piling is driven across the head of the apron and along the banks approaching it for some little distance, so as to force the whole of the water of the stream to pass between the piers and drive the wheels. The measurement of the water is determined by the number of revolutions of the wheels, which should be all coupled on t one shaft and be made self-recording on a dial-face, an by the dimensions of the wheels, or spaces betwee their blades, as well as by the depth of water passin over the apron, which is observed at intervals of abou five minutes on gauges erected for the purpose. Thi method of obtaining a discharge is expensive, interfer with navigation as well as the passage of the water, an is therefore very rarely adopted.

2. Gauging by Rectangular Overfalls.

The water of a canal or stream is made to dischar itself over a single horizontal dam, or over a series small overfalls specially constructed for the purpos The discharge over overfalls of certain dimensions, ar under certain circumstances, is known by many seri of experiments to be correctly expressed by a formul containing the required data and dimensions, known Francis's formula; it is

$$Q=o\times\frac{2}{3}\sqrt{2g}\left[l-0{\cdot}1nH\right]H^{\frac{3}{2}}$$

where l=length of weir-sill.
H=head on the weir from still water.
n=number of end contractions.

If the weir-sill is of the same length as the breadth the channel of approach, $n=0$; if less than it, and the is no central pier or obstacle, $n=2$; each pier or obst cle involving two additional end contractions.

Taking $\sqrt{2g}=8{\cdot}025$ and $o=0{\cdot}6228$,

$$Q=3{\cdot}33198\left[l-0{\cdot}1nH\right]H^{\frac{3}{2}}.$$

This gives results within one per cent. of absolute exactitude. The dimensions in this formula being taken in feet, the discharges will be in cubic feet per second.

The following conditions should be observed in gauging by rectangular overfalls.

As regards form of construction :—

1. The dam in which the overfall or series of overfalls is placed should have the sills truly horizontal, and the sides of the overfalls truly vertical : the dam itself should be vertical all along on the up-stream side, but the sills should all be sloped off on the down-stream side at an angle of 45° or more with the horizon ; all the edges of discharge should be sharp and true, after passing which the water should discharge itself unobstructed.

2. In order to obviate the necessity of allowing for the velocity of approach in the channel, the area of the overfall—*i.e.*, the quantity $l \times H$, must not exceed one-fifth the area of the channel ; otherwise an allowance must be made on this account, as given in the paragraph on Weirs, Chapter I., Section 11.

3. Should the velocity in the channel of supply not be uniform in all parts of its section, arrangements must be made to make it so ; this can be done by placing gratings, having unequally distributed apertures, all across the channel, and as far from the overfall as possible, and letting the water pass through them under a small head.

4. In addition to the above it is absolutely necessary that the air under the falling sheet of water should have free communication with the external air.

With regard to dimensions :—

5. Should the overfall not extend to the entire width

of the channel of supply, there should be at least a difference at each end equal to the depth on the overfall, so as to produce complete end contraction.

6. When the breadth of the overfall is equal to that of the stream, and even under all circumstances, the depth on the weir should be less than one-third the height of the barrier.

7. The depth on the weir must be always less than one-third of the length of the sill.

8. The head on the overfall, H, should never be less than 0·2 feet; it is better, also, to make it more than 0·5 feet and less than 2 feet.

9. The fall from sill to tail-water should not be less than half the depth on the weir, in order to ensure a free fall.

The following practical directions suitable to streams and moderate rivers are given as examples, where ordinary care and accuracy is required.

First case.—When the discharge is supposed to be less than 40 cubic feet per second :—

First, according to the above rules, make H greater than ·2 feet; and $H \times l$ less than one-fifth of the channel section; let l be greater than ·3 feet, but less than one-third the width of the channel; and, to ensure a free fall, arrange so that the lower edge of the sill may not be less than half a foot above the tail-race. Under these conditions the coefficient of discharge to be used will be $o = 0·623$, and any error should not be more than one per cent.

Before constructing the weir, observe the surface velocity in the channel (V_s) and the transverse section (A); the approximate discharge will then be $Q_s = V_s \times A$, and assuming a value for l as before mentioned, obtain a value for H by means of the ordinary formula, making use of the approximate discharge for this purpose. H should be from 1 to 3 feet, and should such a value not result, from the application of the previous conditions, use another value for l, so as to secure this condition, as well as to retain the other conditions before mentioned. When this is gained, the opening may be cut of the required dimensions in one-inch plank, and the dam well puddled; and as, in practice, the dimensions are not likely to be very closely adhered to, they should be measured again when the orifice is completed, and applied in the formula before given.

Second case.—When the supposed discharge is more than 40 cubic feet per second, but is manageable:—

Find the approximate discharge at the spot from the section and velocity, when the surface of the stream is level with a fixed mark on a post or stone, at from 100 to 200 feet below the intended site of the weir. Having previously selected a place where the stream is regular in width and inclination, construct the dam so that the weir-sill may be equal to the full breadth of the channel, and square the ends of the opening with planking. Put a gauge at each end, with the zero at the level of the upper edge of the sill of the overfall, which should be from 1 to 5 feet above the fixed bench-mark.

When the water is up to the mark, read the height on either scale; take their mean, and use it as a value for H in the weir formula before given to obtain the velocity and amount of discharge. If necessary, obtain the surface velocity of approach W, and make suitable allowance for it as before mentioned under the head of weir discharges in Chapter I. In this case $o = 0{\cdot}666$.

3 APPLIANCES AND INSTRUMENTS FOR VELOCITY MEASUREMENT.

There are many cases when it is not advisable to construct a dam or gauge by overfalls, and also cases where the simple calculation of discharge due to the hydraulic slope, and the terms of its cross-section, does not give sufficiently accurate results. Under these circumstances velocity observations must be made, and other data correctly obtained, so as to obtain from them the required discharge, which, when divided by the sectional area, gives the mean velocity of discharge.

In all cases where velocity must be observed it is advisable to choose a straight reach of channel having a tolerably uniform section; it is also advantageous that the bank should admit of the measurement of a straight line parallel to the general direction of the channel, and at right angles to the line of intended river section of observation, to serve as a base for triangulation, and location of courses, and sections.

To obtain perfect uniformity of channel, a flume or timber lining to the reach of well-joined plank may be constructed, giving about two hundred feet of perfectly uniform section; this gives the means of accurately measuring the dimensions of the stream, the whole of the water of which is forced to pass through it by means of sheet piling at its upper entrance. It should not produce any sensible disturbance in the flow of the water, and not interfere with the navigation or passage of water. Velocity observations are then made either at the middle section or on a measured length along the flume, at such intervals that the variation of served velocity in section shall never be very marked. The summation of the products of these representative velocities by their corresponding portions of sectional area gives the required discharge. A long and accurately constructed open aqueduct in perfect order answers all the purposes of a flume.

Failing all such opportunities, the channel itself must be employed in its natural state; in this case the effect of various velocities on the bed and banks should be noted from time to time during the observations. Should any exact determination of the water section be impossible it becomes necessary to resort to soundings. These may either be taken by means of a surveyor's 100-feet chain, with a suitably heavy leaden weight attached to one of the handles, or with a sounding line. The determination of the position of each sounding can in narrow reaches be best made by stretching a rope across, and measuring the distances of the sounding points from one bank along the cord. In wide reaches where this is impracticable, the sounding points have to be fixed by angular observation and connected with the base line of triangulation at the moment of sounding either by an observer with a theodolite on the shore, or with a pocket-sextant in a moored boat.

The fall of the water surface at all states of the channel is one of the data generally required. To determine this, a gauge-post is erected, driven into the ground at each sounding section, and the heights of the water shown on them continually recorded so as to show all variations of depth; the connection of level between the two or more gauge-posts is made by levelling either from one post to the other, or from both to a fixed bench-mark. In many cases the fall of the water surface is so slight that the ordinary level and staves cannot give sufficiently exact results; instruments of greater precision must then be used.

An ordinary gauge-post may also be too coarse for indicating the slight variation of the water surface during the period of gauging; in that case a superior appliance, a hook-gauge or a tube-gauge, is necessary.

Boyden's hook-gauge.—It is well known that the capillary attraction of water about any simple rod-gauge for determining water level will falsify readings. To obviate that defect this gauge has a hook at its lower end, which can be raised or lowered by turning a screw; when the point of the hook is even a thousandth part of a foot above the water surface, the water around it is sensibly elevated by the capillary attraction, and obviously distorts the reflection of light from the surface; when the hook is lowered just sufficiently to cause this distortion to disappear, the point of the hook must coincide with the water surface; a true reading, exact within 0·001 of a foot, can then be read, by means of a vernier attached to the rod of this gauge which is graduated to hundredths of a foot. As this instrument can only be effectively used in still water, it is held in a box, the inclosed water communicating with the external water only by means of a hole; or, if the depth at some distance off is the object, by a pipe leading from that place to the hole in the box; any oscillation of the water surface in the box may then be diminished or nearly removed by partially obstructing the hole or communication at will. Should perfect rest not be attainable, a good mean position of the point of the hook may be obtained by adjusting it to a height at which it will be visible above the water surface for half the time. It is convenient to have also a hook made with a small semispherical knob on it, so that a level-staff can then be held on it for taking a sight with an instrument.

Bazin's tube-gauge is, unfortunately, not described in sufficient detail, nor are drawings of it given in his 'Recherches Hydrauliques.' It seems, however, to have been a glass tube having a mouthpiece of only a millimètre in diameter, and that it enabled variations of water level of one millimètre to be easily read; it is hence extremely probable that it resembled in some respects the velocity gauge-tube of d'Arcy, used for taking velocity measurements, hereafter described. It is, in fact, evident that an instrument on this latter principle, capable of indicating variations of velocity with precision, would also indicate with exactness the moment of the withdrawal from, or submersion of its mouthpiece in, the water, and that this motion could be easily manipulated with a clamping and a tangent screw.

The following are the different instruments and appliances for measuring velocity; but most if not all of these involve the application of a special coefficient of reduction due to the particular appliance, in order to obtain the *actual* velocity of the water in feet per second.

1. *Surface floats.*—Surface velocity may be very simply measured by observing the time of transit over a known distance or length of a reach of a river, of any light floating body, a wafer, a ball of wood or cork, or a partly filled bottle. This method is coarse, and fallacious; a later float may outrun an earlier one, when there is much local variation of velocity.

2. *Loaded rods and tubes.*—Mean verticalic velocity, being the mean velocity past any vertical axis, or the

mean of all the velocities from water surface to th bottom under any point in a vertical plane, is measure by a loaded wooden rod or hollow tube placed verticall having a length nearly equal to the depth of th channel. The time of transit of such a rod will the give approximately the mean velocity of the vertic plane of the water in which it moves. These tubes ar generally weighted inside and capped, as the painte metal tubes of the Lowell experiments hereafter mer tioned, thus obviating the necessity of attaching weight

The loaded tubes and rods used in the velocit observations on the Ganges Canal by Captain Cunnin ham will be described hereafter in Section 11 of th chapter, which is devoted to those experiments.

Another recognised mode of observing mean vertical velocity consists in lowering from the surface to tl bottom, and raising again to the surface any accumul tive self-recording current meter. This is an operatio requiring extreme care; the meter must be sufficientl weighted, and, if necessary, also managed by a cord fro an additional boat moored up stream so as to ensure i moving vertically up and down; the lowering and raisir of the meter must also be evenly and steadily manage so that the results may not be falsified.

3. *Floated frames.*—Mean sectional velocity can l approximately obtained in small streams and canals one operation only by making a light covered framewo nearly the size of the whole cross-section of the strear and so arranging it by floats and weights that it w assume a vertical position at right angles to the threa of the current; its time of transit can then be note and this will be the approximate mean velocity of tl section.

4. *Double floats.*—These are used for sub-surface velocities.

A weighted float, consisting of ball, or cube of wood, or hollow tin weighted with lead, is sunk to the required depth, being attached by a cord or thread to a small upper float on the surface of the water; the upper float being made of cork, light wood, or hollow tin, carrying a vertical stick, or wire, for convenience of observation, and the length of cord being so adjusted as to prevent the weighted float from sinking lower than the depth at which the current velocity is required. The time of transit of this double float, over a measured or a calculated distance, is observed, and is supposed to represent the velocity of the stream at that depth, independently of any coefficient of reduction.

Another form of double float is a pair of equal hollow balls connected or linked together, the upper one on the surface, and the lower one weighted sufficiently to keep it at the certain depth; the velocity of this double float, as observed on a measured distance, is supposed to be that of the current at half the depth of the lower ball.

The double-floats invariably used in the Mississippi Survey were kegs without top or bottom, ballasted with strips of lead, so as to sink and remain upright; they were 9 inches in height, and 6 inches in diameter; the surface floats, when of light pine, $5{\cdot}5 \times 5{\cdot}5 \times {\cdot}5$ inches, when of tin, ellipsoids, axes 5·5 and 1·5 inches, the cord one-tenth of an inch in diameter; for observations more than 5 feet below the surface, the kegs were 12 inches high by 8 inches in diameter, and the cord nearly two-tenths of an inch. It was believed that neither the weight of the surface float nor the force of the wind directly affected their velocities to any appreciable amount.

5. *Instruments of angular measurement.*—A quadrant having a graduated arc has a string attached to its centre, and a ball attached to the string, which is immersed in the stream. The current moving the ball produces an angular change from verticality in the position of the string; the velocity is then equal to the square root of the tangent of this angle multiplied by a coefficient, which is constant for the same ball only.

6. *The tension balance.*—A ball is immersed in the stream and attached by a wire to a balance, which registers the amount of pull. Another very similar method requires a small plate instead of a ball, which is connected with the balance, and which is directly opposed to the current.

The tachometer of Brünings is the best known instrument of this type. It consists of a plate fixed at one end of a horizontal stem, which moves in the socket of a vertical bar, by means of which the instrument either rests on the bottom of the channel or is suspended from above. A cord of fixed length is fastened to the other end of the stem, and, passing under a pulley, is attached to the short arm of a balance, on whose other arm a weight is suspended, being placed in such a position that the equilibrium is established with regard to the force of the current under observation. The position of the weight on the graduated arm of the balance indicates the velocity observed.

7. *The rotary screw.*—A light metal screw, similar to that of a ship's patent log, will, when submerged in a current, rotate at a velocity approximate to that of the water in which it is placed. If on the axle

of the screw a thread is set turning one or more worm-wheels, the number of revolutions of the worm-wheel will indicate the approximate velocity of the water, from which, by applying a coefficient of reduction applicable to the particular instrument, thus including all allowances for friction and other causes, the true velocity of the current may be obtained. There are several current meters of this type: Saxton's, Brewster's, and Révy's, hereafter described, are all modifications of this form. Some of these instruments are not suited to great depths and high velocities; others are made self-recording in such a way as to make allowance in the indicated number of revolutions for the loss of velocity by friction; the latter is a great disadvantage, as it is always practically necessary to test each particular instrument, and make use of a coefficient, however small it may be, in order to obtain accurate results.

The earliest now known instrument of this type is the hydrometric mill of Woltmann, used by him in 1790. The wings on its axle resembled those of a windmill, and were square copper plates, set at an angle of 45°, having their sides ·082 feet and their centres at ·164 feet from the axis of rotation; for small velocities the size and distance of the wings was doubled. In great depths this instrument was attached to a bar and lowered from a platform between two boats, and the instrument put in gear or out of gear by means of a cord at any depth. This type of current meter, from its convenience of use in observing velocity at any depth, has been re-invented many times.

On the gauging of the Paranà and La Plata, by Mr. Révy, the screw current meter, with some alterations and improvements made by him, was invariably adopted.

For ordinary currents the screw used by Mr. Révy consisted of two long thin blades of German silver, having a diameter of 6 inches, and a pitch of 9 inches; the thread of its axis worked on two worm-wheels of 3 inches in diameter, one wheel having 200, and the other 201 teeth; each revolution of the screw moved the first wheel one tooth onwards, the second wheel moving one tooth onwards for each complete revolution of the first wheel; this allowed of the continuous reading of 40,000 revolutions; the two worm-wheels had graduated divisions around their circumferences, corresponding to the teeth in number and position, which were read off at an index through a glass plate covering them. A nut was also used for clearing the worm-wheels from the thread of the axle of the screw, by means of which the instrument was either put in gear or out of gear by hand; a wire attached also enabled this to be done from above when the instrument was at any depth.

For strong currents, the screw-blades were shorter and stronger, and made of steel. Some of the screws used were only 4 inches in diameter. The divisions on the circumferences of the wheels were found to be too near for convenient reading; 100 and 101 divisions would have been preferred to the existing arrangement of 200 and 201.

These meters were generally used for observing velocities of more than 10 feet per minute, their corrected results being absolutely correct within 1 inch per minute of velocity. They required extreme care and continual watching: the slightest bend or damage to a screw-blade, or any clogging or accidental tightening of a screw being liable to vitiate results.

When in good order, exposure to a gentle breeze is sufficient to keep the instrument revolving;—failing this, cleaning and oiling, or readjusting carefully, is absolutely necessary. In order to keep a check on the observations, a second current meter should always be at hand.

The principal advantage of current meters of this description is the convenience with which they can be worked, and their unvarying utility in observations at any depth of water.

8. *The differential tube.*—Pitot's tube is a glass tube bent at the lower end; it is sunk to the required depth and its lower orifice directed against the current: the velocity is deduced from the difference of water-level in this tube and that in another free from the effect of the current. The first improvement of this instrument is that of Dubuat, who gave the orifice of the tube a funnel shape, and closed it by a plate pierced with a small hole, thus considerably reducing the objectionable oscillations of the water in the tube. The next is by Mallet, who terminated the horizontal branch of the tube by a cone, having an opening of 2 millimètres, and made the tube itself of iron with a diameter of 4 centimètres; he also introduced a float and stem which, elevated by the force of the current, indicated heights on a graduated scale. The last improvement was that of d'Arcy, hereafter described.

In the experiments of d'Arcy and Bazin, on the Rigoles of Chazilly and Grosbois, the gauge-tube of d'Arcy, a development of the tube of Pitot, was generally used for taking velocity observations.

Pitot's tube, used in 1732, demonstrated the principle that the difference of water-level, h, shown by the two tubes, one vertical and the other curved, and directed against the current, was that due to the velocity, and that the latter could be obtained from the former, by making use of the formula $V^2 = 2gh$.

The error in this was caused by the fact that the water in a vertical tube immersed in a current stands lower than the water surface outside; the difference being a quantity dependent on the square of the velocity immediately below the orifice. In addition to this Pitot's tubes had a serious disadvantage in that the oscillation of the water within the tubes, whose orifices were of the same diameter as the tubes themselves, did not allow the difference of level to be correctly observed.

These objections are entirely removed in the improved tube of d'Arcy, which has an orifice 1·5 millimètres in diameter for a tube one centimètre in diameter; in addition to this the lower portions of the tube to which the orifices are attached have a small diameter, and are made of copper: besides this, two cocks are introduced which add greatly to convenience of manipulation. The lower cock, which can be worked by a wire and lever, enables the orifices to be opened or closed at any moment from above, and thus allows the difference of water-levels of the tubes to be read off at leisure, after withdrawing the instrument from the water. The upper cock, after the water in the tubes is drawn up by the breath at an upper orifice, shuts off the air, and enables the difference of water-level in the tubes, which is not affected by dilatation or compression of the atmosphere, to be read off above against a scale.

This gauge-tube is described in 'Les Fontaines Publiques de la Ville de Dijon, 1856,' and drawings of it are given in the 'Recherches Hydrauliques' of d'Arcy and Bazin, 1865.

the latter the vertical glass tubes are 1·25 m. long, o small copper tubes below them being inclosed copper casing, 0·77 m. long, 0·06 m. broad, and m. thick, terminating in a sharp wedge-shaped to reduce the effect of the perturbation of the cur- The tubes themselves are affixed to an upright of t boxwood, which is graduated and supplied with a nier; the whole instrument being attached to an iron ndard on which it slides, and to which it can be fixed screws at any height; a handle turning the instru- ent directs the orifices in any required direction; and additional movable wooden arm is used to enable e instrument to rest by means of it on any crossbeam timber from which the observations are being taken.

In taking an observation with the instrument it is sual to take a mean of three maxima and minima.

The following is the theory of the determination of e coefficient of reduction μ in the formula $V=\mu\sqrt{2gh}$ r any instrument.

If a single curved Pitot tube be placed in a current, st, with its orifice directed against it, and recording a ight h', above the natural water surface; secondly, hen directed with it, and recording a loss of level, h'', elow that of the natural water surface; and thirdly, hen directed at right angles to the current, recording a ss of level h''', then—

$$\frac{V^2}{2g}=m'h'\,;\ \frac{V^2}{2g}=m''h''\,;\ \frac{V^2}{2g}m'''h'''\,;$$

nd hence—

$$V=\sqrt{\frac{m'm''}{m'+m''}}\sqrt{2g(h'+h'')}=\mu\sqrt{2g(h'+h'')}$$

$$V=\sqrt{\frac{m'm'''}{m'+m'''}}\sqrt{2g(h'+h''')}=\mu'\sqrt{2g(h'+h''')}$$

and finding from tables the values of velocities V' and V'' corresponding to the heights $h'+h''$ and $h'+h'''$; the above equations become—

$$V=\mu V' \text{ ; and } V=\mu' V'' ;$$

hence there is a constant relation between the theoretic height $\frac{V^2}{g}$ due to the velocity of the fillet under consideration, and the quantities h', h'', h'''; and the coefficient of reduction can therefore be obtained for any sort or form of orifice by means of a few experiments; also, when once the coefficient of reduction for the instrument is determined, it is unnecessary while observing velocities to make further use of the level of the water, in which the instrument is plunged.

9. *Grandi's Box.*—A box, having a small hole in the side towards the current, is sunk to a certain depth and withdrawn after a certain time; the amount of water in the box indicates the velocity at that depth.

10. *Boileau's Air-Float.*—A glass tube of fixed length is immersed in a position parallel to the current; the upper end of the tube has a conical mouthpiece fitted to it of any convenient size; the velocity of passage of a globule of air through the tube indicates the velocity of the current.

11. *Jackson's Current-meter.*—This instrument, designed by the author in Berar in 1870, is a spring indicator, or an adaptation of the principle of the spring-balance or weighing machine to measuring a sub-surface velocity at any point excepting at the exact surface or at the perimeter: it admits of convenient testing and verification by direct application of weights.

12. *De Perrodil's Torsion Current-meter.*—The principle of this instrument is the estimation of current

effect on the twisting of a wire: it reads to minute fractions of a foot per second.

Some of these modes of measuring velocity have for the present practically fallen into disuse, on account of the very limited range of their applicability; others, on the contrary, have been severally adopted by various hydraulicians in modern times, to the entire exclusion of the rest. It may be noticed more especially that some of them merely afford a mean of a velocity varying throughout an extended time, and from this cause falsify any deduced velocity for any special moment of time; others are inconvenient to manipulate, and a few yield inaccurate results whatever coefficient of reduction may be applied to the special instrument. The accounts of gauging operations given in the following sections of this chapter illustrate the use of some of these appliances.

4. Gauging Channels by means of Surface Velocities only.

The experiments of Messrs. Baldwin and Whistler on discharges of canals of rectangular section are worthy of notice. They obtained discharges on the canals by means of surface velocities and flume measurement, and simultaneously gauged the actual discharges by gauge wheels, with the view of determining practically the relation between surface velocity and mean velocity, for channels of a certain size conveying water at certain velocities.

In one case the flume was 27·22 feet wide, with depths of water from 7·52 to 8·14 feet, having surface velocities from 3·07 to 3·34 feet per second; the observations deduced a mean coefficient of velocity ·857, the extremes being ·838 and ·856. In the other case, the flume was 29·94 feet wide, with depths of water from 7·67 to 8·85 feet, having surface velocities from 1·91 to 2·77 feet per second; the observations deduced a mean coefficient for the surface velocity of ·814, the extremes being ·797 and ·846.

In other cases, the data of which are not forthcoming, the coefficients of surface velocity were ·835, ·830, ·810; and taking ·829 as the mean of the five results, it can be favourably compared with De Prony's coefficient ·816, obtained from experiments on wooden troughs 18 inches wide, having depths of water from 2 to 10 inches, and velocities varying from 5· to 4·25 feet per second. Another point which Messrs. Baldwin and De Prony agreed in determining was that their coefficients should be slightly reduced for lower velocities and increased for higher. The result is that the proportion between the surface velocity and the mean velocity of discharge for rectangular channels in plank, and within certain limits of velocity and proportions of cross-section, may be said for practical purposes to lie between ·8 and ·85. Under similar local conditions, therefore, the discharge of a canal of rectangular section can be rapidly obtained by a few surface velocity observations, the inclination of the water surface, and the measurement of its section. Recent experiments, however, show that the above law of velocity does not hold generally; hence this mode of gauging does not admit of extensive application.

5. Gauging Canals with loaded Tubes; by Francis.

Under the then existing arrangements at Lowell, a daily account was usually kept of the excess of water, if any, drawn by each manufacturing company over and bove the quantity it was entitled to under its lease. In ordinary times, occasional measurements were sufficient; but when water was deficient, frequent measurements were made. In the latter case, the following was the usual course of proceeding:—

A gauging party, consisting of one or more engineers with assistants, was assigned to each flume where measurement is necessary; and arrangements were so made that the observations for a single gauging occupied about an hour, the intervals during the day being occupied in working out the results, which were immediately communicated to the manufacturers, so that the machinery might be adjusted to the amount of water they were entitled to draw.

The following are the dimensions of the measuring flumes used, and the quantities of water usually gauged in them; the depth of water in the flume generally varying from 6 feet to 10 feet.

Merrimac	100′ long by	50′ wide,	1500	cub. ft.	per sec.
Appleton	150	50	1800	,,	,,
Lowell, M. C.	150	30	500	,,	,,
Middlesex	150	20	200	,,	,,
Prescott	180	66	2000	,,	,,
Boott	100	42	800	,,	,,

The loaded tubes used were cylinders 2 inches in diameter made of tinned plates soldered together, with a piece of lead of the same diameter soldered to the lower end, having sufficient weight to sink the tube nearly to the required depth, thus leaving generally about 4 inches above the water surface. A red-paint mark was made to show the amount of immersion required, leaving a space between the bottom of the tube and the bottom of the canal of 1 foot. The tubes were of thirty-three different lengths, varying from 6 to 10 feet; six of each length were provided for this purpose.

In order to adjust the tube precisely, it was placed in a tank made for the purpose, and small pieces of lead were dropped into the top of the tube, and rested on the mass of soldered lead, and more were added until the tube was sunk to the required depth, when the orifice at the top was closed by a cork. The tubes were allowed to remain floating for some time in the tank in order to discover any leak. If they leaked, they were taken out and filled with water to discover the position of the leak, when the leak was soldered and the tube adjusted again. The centres of gravity of the tubes adjusted were 1·78 to 1·90 feet from their bottom ends; and thus being low, the tubes had a strong tendency to remain vertical.

The tubes were put into the water by an assistant standing on a bridge below the upper end of the flume, a thing requiring a little practice to do well; he stood with his face up-stream, with the tube in hand, the loaded end directed downwards, but slightly up-stream, holding it at an angle with the horizon, greater or less, depending upon the velocity of the current. At a signal he pushed the tube rapidly into the water at the angle at which he previously held it, until the painted mark near the upper end of the tube reached the surface of the water; he retained his hold of the upper end of the tube until the current brought it to a vertical position, when he abandoned it to the current.

There were three transit timbers placed across the flume, the middle one equidistant from the other two, their up-stream edges vertical, and distinctly graduated in feet from left to right. An assistant stood at each transit timber to note the transits, and the assistant at the middle transit timber observed the depth of water in the flume at each transit in a box close to him between the lining planks and the wall of the canal, which communicated with the flume by a pipe about 4 feet above the bottom. The box contained a graduated scale, divided to hundredths of a foot, the zero point being at the mean elevation of the bottom part of the flume between the upper and lower transit timbers. The bottom of the flume was very nearly horizontal; the elevations to obtain the mean were taken at 32 points, giving an extreme difference observed of ·027 feet in one case. The course of the tube, denoted by the distance in feet from the left side of the flume when the tube passes the transit timbers, was also observed and called out by the assistants; the mean course being obtained by adding the distances at the upper and lower transit timbers to twice that at the middle, and dividing the result by four for a mean distance.

The usual method of observing the transits was by means of an assistant carrying a stop-watch beating quarter-seconds, who walked down and recorded every transit himself; but when greater exactness was required, an electric telegraph made for the purpose was used, by which the transit observers communicated transits to a seated observer from their stations, the times of signals being noted by him to tenths of seconds according to a marine chronometer placed before him beating half-seconds:—an assistant was also required to carry back the tubes to the up-stream station. In the usual method before stated, a party of five was sufficient for all purposes. The observations were made at distances apart about 1·5 feet in the cross-section, as may be seen in the following gauge record for one set of observations; the mean velocities of the tubes for these mean distances were calculated and plotted on a diagram of

Gauge record of the quantity of water passing the Boott m... flume, May 17, 1860, between 10·30 and 11·30 A.M. ... between transit timbers, 70 feet; breadth of flum... feet; length of immersed part of tube, 8·4 feet.

Position of tube at starting	Mean velocity of transit	Position of tube at upper transit	Position of tube at lower transit	Mean position	Depth of water in flume	Products of m... velocity and w...
0·0	2·102	·3	·8	·55	8·510	2·073 × 1
1·5	2·258	1·8	1·6	1·70	8·481	2·193 × 1
3·	2·318	3·2	2·1	2·65	8·450	&c.
4·5	2·473	4·4	4·5	4·45	8·470	
6·	2·373	6·2	5·4	5·80	8·445	
7·5	2·593	8·2	10·1	9·15	8·438	
9·	2·672	9·7	10·4	10·05	8·440	
10·5	2·800	10·5	8·8	9·65	8·470	
12·	2·713	12·3	10·9	11·60	8·483	
13·5	2·778	13·8	15·5	14·65	8·490	
15·	2·800	15·2	18·0	16·60	8·500	
6·5	2·373	17·0	20·4	18·70	8·498	
18·	2·593	18·0	17·8	17·90	8·505	
19·5	2·431	19·7	19·0	19·35	8·505	
21·	2·280	21·1	20·9	21·00	8·522	
22·5	2·201	23·4	29·3	26·35	8·533	
24·	2·077	23·7	22·1	22·90	8·510	
25·5	2·071	26·5	29·7	28·10	8·495	
27	2·258	27·0	25·2	26·10	8·483	
28·5	2·258	28·6	26·5	27·55	8·495	
30·	2·414	31·0	34·3	32·65	8·550	
31·5	2·500	32·1	30·0	31·05	8·630	
33·	2·258	32·5	28·1	30·30	8·610	
34·5	2·672	34·6	36·7	35·65	8·625	
36·	2·431	36·5	35·0	35·75	8·632	
37·5	2·458	37·5	35·5	36·50	8·612	
[illegible]	2·500	40·1	40·5	40·30	8·578	
[illegible]	2·500	39·0	39·6	39·30	8·578	
[illegible]	2·507	41·2	40·6	40·90	8·560	
[illegible]	—	—	—	—	—	
[illegible]	[illegible]	·5	·4	·45	8·471	
[illegible]	[illegible]	9·8	8·7	9·25	8·580	
[illegible]	[illegible]	[illegible]	19·9	20·40	8·605	&c.
[illegible]	[illegible]	[illegible]	33·8	33·65	8·635	2·504 × 1
[illegible]	[illegible]	[illegible]	40·6	41·00	8·610	2·417 × 1
[illegible]	—	—	—	—	—	2·264 × ·7
				Mean	8·5204	Sum
						Mean 101·52... / 41·76

Products of each foot of breadth

section paper having the mean widths in feet of the flume scaled on one side, and the other calculated velocities for those widths scaled on the other: a curve joining these points was then drawn on the diagram, from which the mean velocity for each foot in width of the flume was scaled off and entered in the record; from these the mean velocity due to the total width was obtained. In this case it was 2·4311 feet per second; and since the mean section of waterway between the upper and lower transit timbers was $= 41·76 \times 8·5294 = 356·188$ square feet, the approximate discharge $= 2·4311 \times 356·188 = 865·929$ cubic feet per second.

To obtain the true discharge from this approximate result, an empirical factor, depending on the difference (d) between the depth of water in the flume, and the depth to which the tube was immersed, divided by the depth of water in the flume, was applied: the expression of correction being $1-0·116\ (d^{\frac{1}{2}}-0·1)$. The value of this expression for various values of d is given in the table following at p. 148.

In this case d, the quantity before mentioned,

$$=\frac{8·5294-8·4000}{8·5294}=0·0152\ ;$$

and hence the true discharge

$$Q=865·929 \times \left\{1-0·116\,(\sqrt{0·0152}-·1)\right\}=863·59.$$

Remarks.—These observations were made in a flume placed below a quarter bend in the canal, which caused the velocity to be much greater on one side than the other. To obviate this, an oblique obstruction was placed near the lower end of the bend, which removed

Table of correction for Discharges obtained from Tube Velo servations, being values of the expression 1 − 0·116 (d *for different Values of* d *(from the Lowell Experimen*

d	Correction	d	Correction	d	Correction	d	Correction	d
·000	1·01160	·020	·99520	·040	·98840	·060	·98319	·080
·001	1·00793	·021	·99479	·041	·98811	·061	·98295	·081
·002	1·00641	·022	·99439	·042	·98783	·062	·98272	·082
·003	1·00525	·023	·99401	·043	·98755	·063	·98248	·083
·004	1·00426	·024	·99363	·044	·98727	·064	·98225	·084
·005	1·00340	·025	·99326	·045	·98699	·065	·98203	·085
·006	1·00261	·026	·99290	·046	·98672	·066	·98180	·086
·007	1·00189	·027	·99254	·047	·98645	·067	·98157	·087
·008	1·00122	·028	·99219	·048	·98619	·068	·98135	·088
·009	1·00060	·029	·99185	·049	·98592	·069	·98113	·089
·010	1·00000	·030	·99151	·050	·98566	·070	·98091	·090
·011	·99943	·031	·99118	·051	·98540	·071	·98069	·091
·012	·99889	·032	·99085	·052	·98515	·072	·98047	·092
·013	·99837	·033	·99053	·053	·98489	·073	·98026	·093
·014	·99787	·034	·99021	·054	·98464	·074	·98004	·094
·015	·99739	·035	·98990	·055	·98440	·075	·97983	·095
·016	·99693	·036	·98959	·056	·98415	·076	·97962	·096
·017	·99648	·037	·98929	·057	·98391	·077	·97941	·097
·018	·99604	·038	·98899	·058	·98366	·078	·97920	·098
·019	·99561	·039	·98869	·059	·98342	·079	·97900	·099
								·100

he trouble in measurement due to the original irre-arity; the other remaining irregularities may be seen plotting a diagram of the velocities. It is hence dvisable in all cases to equalise the velocities on each ide of the axis, should they require it.

In gauging a branch canal it is best to put the flume in it near its off-take from the main canal, with its axis nearly parallel to that of the branch canal. Its section may be determined by roughly calculating the expected discharge, and making it so as to suit a velocity of from 1 to 3 feet per second; its length should not be less than 50 feet, allowing 20 feet above the upper transit timber to enable tubes to attain the same velocity as the water, and 5 feet below the lower timber, the transit course of 25 feet, run over in $7\frac{1}{2}$ or 10 seconds, can be then noticed by a practised observer with a quarter-second stop-watch.

In gauging rivers by means of loaded tubes, flumes are dispensed with, and marked cords may be substituted for the graduated transit timbers, being supported from the bottom if necessary, so as to be always visible; in large rivers triangulation observations are necessary. The reach should be 50 to 100 feet long, and the bottom irregularities may be removed or filled in to a certain extent beforehand, so as not to interfere with the poles, which should, when immersed, reach to about six inches from the bottom. Boats will be required to convey the poles. As the cross-section may be irregular, it will be necessary to divide it into several parts, finding the area and mean velocity for each division, and calculating the corrected discharge for each division separately; the sums of these corrected discharges will then be the true discharge for the river at that spot.

6. Field Operations for Gauging the Mississippi River and Tributaries, by Captains Humphreys and Abbot in 1858.

Soundings.—The strength of the current, the depth and width of the river, and the floating driftwood, all combined to render an accurate measurement of the dimensions and area of cross-sections a difficult operation on the Mississippi. After various experiments, the following system was adopted, by which accurate work was done even in the highest stages of the river. The middle stages were usually selected for this purpose, being preferable to the low stages, during which there would have been exposure to oppressive heat and disease, and more favourable than the high stages, when the difficulties attending accurate measurement were greatest.

Preparatory to making a cross-section of the river, whether for general purposes of comparison or for determining a discharge, a base line, varying in length from 400 to 1 000 feet, was measured along the bank near the water's edge; an observer with a theodolite was stationed at each extremity of this line. The one directed the telescope of his instrument across the river, so as to command the line on which the soundings were to be made; the other prepared to follow the boat with his telescope, in order to measure its angular distance from the base line when each sounding was taken. The boat, a light six-oared skiff, contained a man provided with a sounding chain, a recorder with a flag, and three oarsmen. The strongest kind of welded jack-chain was employed, to which bits of buckskin were attached at intervals of 5 feet, smaller divisions being measured with a rod in the boat. The sinker, varying from 10 to 20 pounds in weight according to the force of the current, was a leaden bar whose bottom was hollowed out and armed with grease, in order to bring up specimens of the bed of the river. The patent lead was also used for the latter purpose. The boat was rowed some little distance above the proposed section line, and allowed to drift down with the current, the sounding lead being lowered nearly to the bottom. By this precaution, the deflection of the line by the force of the current was prevented. When the first observer, stationed opposite the proposed section line, saw that the boat had nearly reached it, he waved a flag as a signal to take a sounding, and then carefully turned his instrument so as to keep the vertical hair of his telescope upon the point where the chain crossed the gunwale of the boat. The recorder in the boat, seeing the signal, waved his flag to the second engineer to follow the boat carefully with his telescope. The man with the sounding chain allowed it to slip rapidly through his hands until the lead struck the bottom, when he grasped the chain at the water surface, and instantly rose to a standing position. This motion was the signal for arresting the movement of each telescope, and recording the angles. The recorder in the boat noted the depth of the water, and the nature of the bottom soil adhering to the lead. By the angles measured at the base line, the exact position of the sounding, which was never more than a few feet above or below the proposed section line, was ascertained. The process was repeated until soundings enough had been taken to give an accurate cross-section of the river. Careful lines of level were then run up each bank from the water surface to points above the level of the highest floods, when such points existed, or to other convenient bench-marks. Generally, the triangles were computed, and the work plotted before leaving the place, in order to fill by additional soundings any gaps which might appear on the diagram.

At places where a series of daily velocity observations was to be made, additional precautions were taken, and two independent sections, 200 feet apart, were sounded with the greatest care. Soundings, repeated from time to time upon these lines, uniformly showed that no sensible changes took place in the bed of the river. The mean of all such sections, when reduced to the same stage of the river, was accordingly always taken for the true cross-section at the locality. The change in area produced by any change of level in water surface could then be readily computed from the plotted section. To determine the daily changes of this level, a gauge-rod, graduated to feet and tenths, was observed daily, its correctness of adjustment being frequently tested by comparison with secure bench-marks. An accurate knowledge of the area of the cross-section on any given day was thus obtained. The tables of soundings for each cross-section, which were all numbered, also denoted the distance of the sounding from the base line, the depth of high water during that year, and the nature of the bottom.

Velocity Measurements.—Narrow and straight portions of the river, where the form of its cross-section approximated most nearly to that of a canal, where the waters of the highest floods were confined to the channel by natural banks or by levées, and where the river at all stages was free from eddies, were selected for the permanent velocity stations.

The depth and violence of the river rendered the measurement of its velocity, especially below the surface, exceedingly difficult. Of all the methods known for determining this quantity, that by double floats was found to give the best results. The method of conducting these observations was as follows:—Two parallel cross-sections of the river having been made as already explained, 200 feet apart, a base line of the same length was laid off upon the bank from one to the other, being of course at right angles to both. This length was sufficient to ensure accuracy without being too great either for observing many floats in a day, or for avoiding local changes in velocity. An observer with a theodolite was stationed at each extremity of the base line. It is evident that, when the telescopes were directed upon the river, with their axes set at right angles to the base line the vertical cross hairs marked out the lines of sounding upon the water surface, and that the time of passage of a float between these lines was that consumed in passing 200 feet. Also, that if the angular distance of a float from the base line when crossing each line of sounding was measured, its distance in feet from the former could readily be computed, and its path fixed. Upon these principles the observations were conducted. Two skiffs were stationed on the river, one considerably above the upper, and the other below the lower section line, the former being provided with several keg floats. At a signal from the engineer at the upper station, whose telescope was set upon the upper section line, a float was placed in the river. The keg immediately sank to the depth allowed by its cord, and the whole float moved down toward the lower line. The observer at the lower station followed its motion, keeping the cross hair of his telescope directed constantly upon the flag. At the word 'mark' uttered by his companion, when the float crossed the upper line, he recorded the angle shown by his instrument, and then, setting his telescope upon the lower line, watched for the arrival of the float. In the meantime, the observer at the upper station, whose theodolite supported a watch with a large seconds hand, recorded the time of transit of the float across the upper line, and then followed the flag with his telescope. At the word 'mark' given by his assistant, when the flag crossed the lower line, he recorded the line and angular distance from the base line. The float was picked up by the lower boat. By this method, the exact point of crossing each section line, and the time of transit, were ascertained. When the velocity was not too great, the time was noted by the engineer at the lower station also, to guard against error. A stop-watch was sometimes used. As it was evidently impossible to observe floats daily in all parts of the cross-section, the best practical method found was to adopt a uniform depth of 5 feet for all the floats, distribute them equally across the entire river, and afterwards divide the resulting velocities into groups or divisions within which the variation of velocity was but slight; a mean relative velocity, and a mean relative discharge, for each division was then computed, the sum of the latter being an approximate mean discharge of the river, which, when divided by the area of the whole river section, gave a mean relative velocity for the whole river. The resulting discharge, when multiplied by the ratio of the velocity at the assumed depth (in this case 5 feet) to the mean velocity for the whole vertical curve, gave an accurate mean discharge of the river for that place and day.

Computation of Discharge.—A separate plot of each day's velocity measurements was made in the following manner:—Lines were drawn upon section paper to represent the section lines, the base line, and the water edges. The distances from the base line to the points where each float crossed the section lines were then computed by a table of natural tangents, and the points laid down on the plot. Straight lines connecting the two corresponding points indicated the paths of the floats, which were of course nearly perpendicular to the section lines. The time of transit in seconds and the depth of the float were inscribed upon these plotted paths.

The diagram resulting showed that the velocities in different parts of the section increased gradually and quite uniformly with the distance from the banks until the thread of the current was reached, and, since these velocities were found to vary but very slightly for distances of 200 feet apart except in the immediate vicinity of the banks, the diagram of the daily velocity floats was divided by parallel lines 200 feet apart, the first being the base line, and the mean of all the velocities of floats in each division taken as the mean relative velocity for that division and recorded. For the shore divisions, unless the floats happened to be well distributed through them, the mean relative velocity was assumed to be eight-tenths of that in the outer edge; a rule deduced from a subdivision and study of the velocity when thoroughly measured in these divisions.

For checking and making interpolations among defective observations of any day in a division, the day's work was also plotted in a curve whose ordinates were the mean velocities of the different divisions, and whose abscissæ were the distances of their middle points from the base line.

The river channel being of a natural form, the sectional areas of all the divisions were unequal, and again the ratios of these areas were not constant for different stages of the river. Each divisional area was therefore multiplied by its mean relative velocity, and the sum of the products was then the mean relative or approximate discharge of the whole section; dividing this discharge by the total area of the whole section, the approximate mean velocity of the river was determined. This computation was made by logarithms, and simplified by the use of a table constructed for the purpose. In order to correct these discharges, which were those due to the velocities five feet below the surface, it was necessary to determine the value of the ratio,[1]

$$\frac{U_m}{U_5} = \frac{U_m}{U_m + \left[\frac{1}{3} + \frac{(\cdot 317 + \cdot 06f)(10r - r^2) - 25}{r^2}\right]\sqrt{bv}}$$

and multiply them by it, thus getting the true discharges, which, when divided by their corresponding areas of cross-section, gave the final and correct mean velocity. The numerical values of the above expression or ratio were obtained in the following way, and put into the form of the table given.

The days on which observations were made were grouped according to even feet of the computed approximate mean velocities, it being assumed that the effect upon the desired ratio, produced by changes in mean velocity of less than one foot, might be neglected. Each group was then examined in connection with the

[1] See Mississippi velocity notation, page 12, Chapter I.

d record, and days were rejected until only calm days those on which the wind blew directly across stream, those on which when combined the wind effects balanced each other, were left. The resulting mean day in each group was then equivalent to a calm day, so far as wind effect was concerned. The following mean quantities were then deduced for each mean day by dividing the sum of the quantities by the number of days going to make up the mean day, viz., an approximate mean velocity of the river (v), a gauge reading, and hence a mean radius (r), and a mean velocity five feet below the surface (U), found by taking a mean of the tabulated velocities of all the different divisions.

These values being substituted in the equation,

$$U=U_{d_{\prime}}-(0{\cdot}1856\,v)^{\frac{1}{2}}\left(\frac{d-d_{\prime}}{r}\right)^2$$

putting also $d=5$, making $d_{\prime}=0{\cdot}317r$, and $b=\dfrac{1{\cdot}69}{(D+1{\cdot}5)^{\frac{1}{2}}}$ $=0{\cdot}1856$ when $D \mathrel{7} 30$; the value of $U_{d_{\prime}}$ was computed and obtained.[1]

Next this value of $U_{d_{\prime}}$ was introduced into the same equation again to obtain new values of U, first for a value $d=0$, secondly for a value of $d=r$, thus getting the surface and bottom velocities denoted by U^0 and U_r. Substituting for these their values in the following equation, together with those computed for $U_{d_{\prime}}$, $d_{\prime}$, and r, the value of U_m was obtained

$$U_m=\frac{2}{3}U_{d_{\prime}}+\frac{1}{3}U_r+\frac{d_{\prime}}{r}\left(\frac{1}{3}U-\frac{1}{3}U_r\right)$$

[1] N.B.—The general value of b is $\dfrac{1{\cdot}69}{(R+1{\cdot}5)^{\frac{1}{2}}}$.

Table of Ratios for correcting the approximate discharges of Mississippi.

Locality	Approximate mean velocity of river	Wind down 4	Wind down 3	Wind down 2	Wi… do… 1
	Feet				
Columbus .	1·6826	·90759	·92250	·93791	·95…
	2·4440	·92202	·93519	·94874	·96…
	3·6548	·93719	·94826	·95917	·97…
	4·5097	·94400	·95407	·96428	·97…
	4·3426	·94908	·95829	·96809	·97…
	6·6496	·95406	·96261	·97131	·98…
	7·4282	·95751	·96550	·97365	·98…
	8·3162	·95983	·96747	·97523	·98…
Vicksburg .	3·6038	·93881	·94854	·95846	·96…
	4·4110	·94544	·95458	·96423	·97…
	5·5571	·95161	·96017	·96895	·97…
	6·7363	·95631	·96440	·97264	·98…
	7·0529				
Natchez . .	4·6901	·94566	·95501	·96454	·97…

Locality	Approximate mean velocity of river	Calm	Wind up 1	Wind up 2	Wind up 3	W…
	Feet					
Columbus .	1·6826	·97040	·98750	1·00521	1·02357	1·0…
	2·4440	·97737	·99192	1·00721	1·02294	1·0…
	3·6548	·98302	·99521	1·00767	1·02048	1·0…
	4·5097	·98546	·99641	1·00760	1·01903	1·0…
	4·3426	·98723	·99727	1·00689	1·01793	1·0…
	6·6496	·98918	·99837	1·00773	1·01727	1·0…
	7·4282	·99035	·99891	1·00762	1·01648	1·0…
	8·3162	·99112	·99927	1·00756	1·01598	1·0…
Vicksburg .	3·6038	·97895	·98956	1·00037	1·01142	1·0…
	4·4110	·98310	·99300	1·00307	1·01337	1·0…
	5·5571	·98693	·99613	1·00557	1·01518	1·0…
	6·7363	·98952	·99823	1·00706	1·01604	1·0…
	7·0529	·99006				
Natchez .	4·6901	·98420	·99433	1·00466	1·01522	1·0…

A calm or wind at right angles to the current = 0 ; a hurricane = 1…

sing the resulting value of U_m, also the values already educed for v and r and b, and giving f its value successively for each of the various forces and direction of the wind, in the following equation :—

$$\frac{U_m}{U_s} = \frac{U_m}{U_m + \left[\frac{1}{3} + \frac{(0{\cdot}317 + 0{\cdot}06f)(10r - r^2) - 25}{r^2}\right](bv)^{\frac{1}{2}}}$$

the table of ratios for the stations was computed.

The approximate discharge for each day at each station was multiplied by the ratio in the table most nearly corresponding to its approximate mean velocity to obtain the true discharge, from which the true mean velocity was then obtained.

7. Field Operations in Gauging Crevasses by Captains Humphreys and Abbot.

The phenomena observed in the discharge of water, through crevasses, or breaks in levées at seasons of high water, were—

1. That the effect of every crevasse, even though as large as 327 feet wide and 15 feet deep, along the line of levée, extends only for a short distance from the bank ; in the above instance, it did not affect the line of motion of floating bodies passing 200 feet from the natural bank, or 300 feet from the break in the levée.

2. Between the crevasse and the outer limit of its influence there is always a movement of the water towards the break from all points below and above, which increases towards the break, and rapidly diminishes on

reaching the ground in rear of the levée, where it spreads in every direction, but mostly towards the swamps.

3. There is a sensible slope along the course of this movement.

4. In passing the break, whether by a cascade or not, the water is higher in the middle of the opening than at either side.

The following was the ordinary method of computing a discharge. Knowing, from measurements made after the cessation of the flow, the high-water depth of the given crevasse, which was estimated on the line of levée, if no material excavation was made there, and on the batture in front of the levée, if holes were dug on the line of the break; the depth on the given day was found by subtracting from this high-water depth the stand of the river below high-water mark—a quantity which was always known either from local information or from a comparison of the nearest river gauges. Taking D to represent this depth, and w the maximum width of the crevasse after cessation of flow; and knowing from exact information the date of breaking of the levée, and that of the cessation of flow, the width of crevasse of any desired day could be computed; and the required discharge per second was then assumed to be equal to the continued product of this width w_i, the depth D, and the velocity (v); or $Q = w_i \times D \times v$; the velocity when D was less than 3 feet was taken $= 2{\cdot}818 \sqrt{D}$ (Castel's weir formula); and when D was greater than 3 feet, v was taken $= 10 - \frac{17}{D}$; the general formulæ for discharge corresponding to each case being

$$Q = (100 + \overline{w - 4}) \left(\frac{w - 100}{N - 5}\right) D (2{\cdot}818 \sqrt{D})$$

$$Q=(100+\overline{n-4})\left(\frac{w_{,}-100}{N-5}\right)D\left(10-\frac{17}{D}\right)$$

where n = numbers of days of discharge which have preceded the given day, and N = total number of days of discharge.

Coefficient of correction for special cases of crevasses.

There are cases in which the conditions of the flow of water were considerably modified; such as when the levée was so far distant from the river that the depth at the edge of the natural bank was much less than that at the base of the levée; or when trees, a growth of saplings, or other obstacles existed in front or in rear of the break, both of these causing a diminution of discharge. So when the reported depth of crevasse included that of previously existing excavations on the line of levée, in these cases the resulting calculated discharge would be too high, and it then became necessary to apply in each case a special coefficient of correction. The coefficient for crevasses flowing into the Yazoo bottom was thus determined. The areas of these bottom lands and their watersheds were as follows, in square miles:—

		Total.
Yazoo bottom	7110	
Yazoo watershed	6740	
St. Francis' bottom	6900	34 600
St. Francis' watershed	3600	
Tennessee and Kentucky bottom	750	
Tennessee and Kentucky watershed	9500	

The yearly rainfall in feet was—

At New Harmony, Indiana	3·92	
At West Salem, Illinois	4·02	
At St. Louis, Missouri	5·18	
Mean downfall at head of region		4·38
At Memphis, downfall for middle of region		4·42
At Jackson, downfall for foot of region		4·99

	feet
Mean for whole region	4·60

Giving total yearly downfall,

$=34\,600\times4\cdot6\times(5280)^2=4\,437\,126\,144\,000$ cubic feet.

To obtain the total yearly drainage, the discharge at Columbus, together with that of the Arkansas and White Rivers, was deducted from the discharge at Vicksburg; and from this also a deduction was made an account of the river during the year between Columbus and Vicksburg being lower by a mean difference of 6·8 feet throughout a mean width of 3 300 feet for 589 miles in length; thus getting the drainage

	4 372 572 757 200
Channel drainage	69 786 604 800
Total yearly drainage	4 302 786 152 400 cubic ft.

And ratio of drainage to downfall is hence

$$=\frac{4\,302\,786\,152\,400}{4\,437\,126\,144\,000}=0\cdot96 \text{ nearly.}$$

Next, the total rainfall for the Yazoo basin, area 13 850 square miles, for from December 1, 1857, to July 15, 1858 $=3\cdot64$ feet $\times 13\,850\times(5\,280)^2=1\,405\,461\,657\,600$ cubic feet; the mean rainfall 3·64 during that time being determined from the mean of the registered falls at Memphis, and at Jackson, 3·19 and 4·08 feet; applying to this rainfall the coefficient of drainage before determined, the drainage from the Yazoo basin = 1 349 243 191 300 cubic feet.

The area of the Yazoo bottom was dry on December 1, 1857, but at high water July 15, 1858, it had a mean depth of water of 3·08 feet over an area of 6 800 square miles; having received between those dates $6800\times$

$(5\,280)^2 \times 3{\cdot}08 = 583\ 885\ 209\ 600$ cubic feet, and the discharge of the channel of the Yazoo, the sole outlet, was measured during this time $= 1\ 408\ 665\ 600\ 000$ cubic feet. Hence, 1 992 550 809 600 cubic feet represented the total quantity which, entering the Yazoo basin between those dates, eventually drained off into the Mississippi; and the total amount of overflow from the Mississippi basin into the Yazoo basin was $1\ 992\ 550\ 809\ 600 - 1\ 349\ 243\ 191\ 300 = 643\ 307\ 618\ 300$ cubic feet; this quantity as computed by the uncorrected crevasse formula was—

$$1\ 758\ 153\ 600\ 000\,;$$

hence the required coefficient of correction for the formula equals the former divided by the latter = nearly $\frac{1}{3}$. This, therefore, holds good for the crevasses in the district for which it is obtained, and the same principle may be applied to other districts.

8. System of Gauging by Mid-depth Velocities, Proposed by Humphreys and Abbot.

The details of field operation to be adopted differ according to the size of the river. 1st. If the river be small and considerable exactness be required, the boat should be anchored at various equidistant stations, the banks being considered two of them, and the station actual mid-depth velocities measured by any of the known methods; the number of stations being sufficient to prevent the velocity of the water between any two of them from varying materially. 2nd. In the case of a large river, if the depth is uniform, sufficient accuracy may be obtained by observing the times of transit of a large number of double floats well distributed across the river section, the kegs being uniformly sunk beneath the surface to a depth equal to half the hydraulic mean radius of the river. Should it happen that the cross-section is not sufficiently uniform and symmetrical to admit of this, the site or reach is ill chosen for the purpose. The results should then be plotted and grouped into divisions of equal width, and the mean result for each division calculated, including, of course, interpolated velocities should any be missing.

The depth of water in the river should be noted on a permanent gauge-post during the observations, or before and after. By this method the results obtained will be in the first case absolutely, and in the second case nearly, unaffected by the wind, no matter what its direction or force may be.

The method of computing the discharge from these observations will vary according to the accuracy required.

First method.—A close approximate result may be obtained by taking a mean of all the different station or division mid-depth velocities, and applying a coefficient of 0·95 for large, and 0·93 for ordinary rivers, to obtain the mean velocity of the river. In this method there are two causes of error which very nearly balance each other, namely, the inequality in area of the different divisions and the difference between the mid-depth and mean velocities in any vertical plane, and the above coefficient meet those errors. For a rectangular cross-section, no coefficient is required.

Second method.—If greater precision be required, a more accurate mean velocity of discharge of the river

V) may be computed by substituting the grand mean of all the station mid-depth or division velocities for $U_{\frac{1}{2}r}$ in the following formula,

$$v=[(1.08\, U_{\frac{1}{2}r}+0.002b)^{\frac{1}{2}}-0.045b^{\frac{1}{2}}]^2$$

This formula is deduced by substituting for U_m its value 0.93v in the general expression,

$$U_{\frac{1}{2}r}=U_m+\frac{1}{12}(bv)^{\frac{1}{2}}$$

and reducing the resulting equation.

As has been already stated, when the mean radius exceeds 12 feet, $b=0.1856$, and under any circumstances $b=\dfrac{1.69}{(r+1.5)^{\frac{1}{2}}}$. The formula therefore gives at once v the mean velocity of the river; and this simple method is quite exact in ordinary river sections, though not applicable to rectangular sections.

Third method.—Should, however, a very high degree of accuracy be required for testing formulæ, or constant coefficients, an amount of exactitude affected only by instrumental errors of observation may be secured by substituting the different observed division mid-depth velocities successively for $V_{\frac{1}{2}D}$ in the formula

$$V_m=V_{\frac{1}{2}D}-\frac{1}{12}(bv)^{\frac{1}{2}}$$

and the results will be true values of the mean velocities of the different divisions in terms of $v^{\frac{1}{2}}$ and known quantities. The sum of the products of these expressions, by the corresponding division areas, should be placed equal to the product of v by the total area of the cross-section;

and this equation, involving v and $v^{\frac{1}{2}}$ and known quantities, will give two positive values of v; the less of which, corresponding to the actual case when the velocity is greater at the axis, is the value of the true mean velocity of the river. This method, though accurate in principle, is probably not so good for ordinary purposes as the previous more simple one, which neglects the latter attempt at extreme accuracy and involves less observation, and consequently less instrumental error, as well as less labour.

General Abbot's Method of determining on any given day the discharge of a large river that has been previously surveyed and gauged.

The previous field operations consist of a survey and numerous soundings of a straight and regular portion of the channel between two bench-marks, A and B, fixed permanently near the water, whose relative levels are accurately known. An accurate plan of the river between these points is necessary, the mean cross-section derived from the soundings, and a series of careful gaugings of the river on permanent gauge-posts. It is desirable that the course of the river between A and B should be as straight and regular as possible, in order to eliminate to the utmost the effect of bends, although allowances almost invariably must be made on that account. The points A and B should be well chosen, as far apart as practicable, and distant from any eddy, and be placed where the current on the bank flows with equal velocities. The latter condition is necessary, because water in motion exerts less pressure than when at rest, and if it moves rapidly past one bench-mark, and is nearly stationary at the other, a difference of level independent of the motive power of the stream would vitiate the observations.

On the required day the water surface at each end of the reach, A and B, has to be simultaneously referred by accurate levels to the bench-marks, to obtain the difference of level of water surface and the gauge depths Nothing more is required. A calm day should be selected.

The formula to be used is that given in the paragraph on velocities:

$$v=[\sqrt{0{\cdot}0081b+(225\, r_{,}\, \sqrt{s})^{\frac{1}{2}}}-0{\cdot}09b^{\frac{1}{2}}]^{\frac{1}{2}}$$

the terms of which have been already explained, excepting s; in this case s is the sine of the slope of the water surface corrected for bends, and is obtained numerically by subtracting the value of h'', due to effect of bends (*vide* Paragraph on Bends) from the total fall between the level stations, and dividing the difference by the total distance between them, measured on the middle line of the channel.

The method of successive approximation must be adopted to find the value of v in this formula. The following formulæ give the value of each variable in the above equation in terms of the others and known quantities. Taking $Z=0{\cdot}93v+0{\cdot}167\sqrt{bv}$, and assuming $p=1{\cdot}015\ W$, should it not have been measured,—then

$$s=\left(\frac{Z^2}{195r_{,}}\right)^2;\quad a=\frac{(p+W)\,Z^2}{195\sqrt{s}};\ r_{,}=\frac{a}{p+W};$$

and $p+W=\dfrac{195\,a\sqrt{s}}{Z^2}$.

For small streams.—General Abbot modifies the above formula into the following, where v' is the value of the first term in the expression for v—

$$v=\left\{\sqrt{0\cdot0081b+(225r_{,}\sqrt{s})^{\frac{1}{2}}}-\cdot09\sqrt{b}\right\}^{2}-\frac{2\cdot4\sqrt{v'}}{1+p}$$

or putting $M=0\cdot0081b$ and $M_{,}=\frac{2\cdot4}{1+p}$

$$v=\left\{\sqrt{M+225\,r_{,}\sqrt{s}}-\sqrt{M}\right\}^{2}-M'\sqrt{v'}$$

in which the term involving M' may be neglected, for streams larger than 50 or 100 feet in cross-section; and for large rivers exceeding 12 or 20 feet in mean radius, M' but not $\sqrt{M}$ may be neglected. The following table facilitate the application of the formula.

r	M	$\sqrt{M}$	p	M'	Log. M'
1	0·0037	0·0930	5	0·400	9·602060
2	0·0073	0·0855	6	0·343	9·535294
3	0·0065	0·0803	7	0·300	9·477121
4	0·0058	0·0764	8	0·267	9·426511
5	0·0054	0·0733	9	0·240	9·380211
6	0·0050	0·0707	10	0·218	9·338456
7	0·0047	0·0685	12	0·185	9·267172
8	0·0044	0·0666	14	0·160	9·204120
9	0·0042	0·0649	16	0·141	9·149219
10	0·0040	0·0634	18	0·126	9·100371
12	0·0037	0·0610	20	0·114	9·056905
14	0·0035	0·0590	22	0·104	9·017033
16	0·0033	0·0573	24	0·096	8·982271
18	0·0031	0·0558	26	0·089	8·949390
20	0·0029	0·0544	28	0·083	8·919078
30	0·0024	0·0494	30	0·078	8·892095
50	0·0019	0·0437	50	0·047	8·672098
100	0·0013	0·0369	100	0·024	8·380211

9. THE EXPERIMENTS OF D'ARCY AND BAZIN ON THE RIGOLES DE CHAZILLY AND GROSBOIS IN 1865.

These experiments, in small channels under various conditions, were made with the principal object of obtaining coefficients of reduction due to various surfaces of bed and banks; their details cannot fail to be interesting to those intending to gauge channels of any description.

The canal of supply was Bief No. 57, of the Canal de Bourgogne, from which the water was taken into a receiving chamber through four iron sluices, 1^{m} wide, and being capable of being raised $0{\cdot}40^{m}$, having their sills $0{\cdot}60^{m}$ below ordinary water level of the canal. This chamber was $5{\cdot}40^{m}$ wide by $14{\cdot}00^{m}$ long, having its bottom $0{\cdot}80^{m}$ below the entrance sills; the gauge-sluices opening from it into the channel of experiment were of brass, twelve in number, each having a section of passage when opened of $0{\cdot}20 \times 0{\cdot}20^{m}$, and having their sills $0{\cdot}40^{m}$ above the bottom of the chamber, and $0{\cdot}40^{m}$ below the sills of the entrance sluices before mentioned. These orifices resemble those of the type employed by Poncelet and Lesbros, and would, according to them, require a coefficient of reduction of discharge of 0·604, provided that the effect of the velocity of approach be neglected; in this case, however, it augmented the discharge, and an allowance had to be made on that account. The water in the chamber was constantly kept at a level of $0{\cdot}80^{m}$ above the centre of the gauge-sluices; an appliance for showing the slightest variation of its level being continually watched by a sluice-keeper.

The channel of experiment was 450^m long before it commenced to bend towards the river Ouche; it was water-tight, and was lined with planks of poplar: its fall for the first 200^m was 0·0049 per mètre, and for the next 250^m was 0·002 per mètre up to the bend, after which its fall to the river for the remaining 146^m was 0·0084 per mètre. The different provisional constructions for employing various inclinations, and sections of different forms, were made in plank within this channel, the spaces being filled with rammed stiff earth. Nails were driven into the bottom of the channel at various points to serve as bench-marks, from which every variation in depth of water could be obtained with exactitude. Most of the experiments were made by successively opening the twelve gauge-sluices, having one fixed section and amount of supply in each case, and thus twelve results were obtained for comparison in every experiment conducted.

The velocities were principally observed with d'Arcy's current-meter, but in some cases also with floats. The latter were sometimes simple wafers, and sometimes pieces of wood or cork weighted with lead, $2\frac{1}{2}$ inches in diameter, and 1 inch thick; their times of transit over distances of from 40 to 50 mètres were noted with chronometers indicating fifths of seconds, and the mean of five or more observations, in which the float following the course of the àxis of the channel was adopted as finally correct.

The following was the mode of determining the measurement of discharge at the off-take.

The coefficient of discharge at the four entrance sluices was determined by closing the lower sluices and noting the time in which the former filled the chamber to a certain height; in this way the following coefficients were obtained for a head on the sill of from 0·55^m to 0·70^m, when one single sluice was opened at a time.

Sluice raised.	Coefficient.
0·10^m	0·645
0·20^m	0·639
0·30^m	0·631
0·40^m	0·621

When the four sluices were opened at once to the full height 0·40^m, the coefficient was 0·637, instead of 0·621.

It was hence evident that, in order to obtain a sufficiently constant discharge, the use of the second set of twelve sluices became absolutely necessary. The conditions of construction of the latter did not, however, render the contraction complete, and hence the coefficients of Poncelet and Lesbros were not applicable to them. In order to have effected this, a chamber large enough to entirely annihilate all velocity would have been necessary, the sluices should have been farther apart, and their sills should have been at least 0·60^m above the bottom of the chamber. It was hence necessary also to determine the coefficients of discharge for these sluices by direct observation.

In June 1857, experiments were made with this object; a portion of the channel was closed up, and filled by opening one, two, three, &c., up to twelve sluices at a time, and the volumes thus discharged in a certain time carefully measured. The discharges per second were in these cases from 0·103 to 1·242 c.m.; and when each sluice was opened separately the discharges varied between 0·1022 and 0·1057 c.m., giving coefficients varying from 0·645 to 0·658. The irregularity of the latter was considered due to the irregularity of form of the bottom of the portion of channel filled not allowing exact volume to be calculated: hence a mean coeffici of 0·650 was adopted provisionally for any number sluices open at one time. In 1860, it was determined obtain this coefficient with greater exactitude, further experiments were made: all the practical det were carefully reinvestigated: the influence of the va tions in depth of the bief or canal of supply was even ally found to exercise no effect on the irregularities; gauge used was supplanted by a glass tube havin mouthpiece of 1 millimètre in diameter, by mean which variations in depth of water as small as 1 m mètre could be easily read. The results under th conditions were thus :—

For a discharge from	1 sluice, the coefficient was	0·633
	2 sluices, ,,	0·642
	3 ,, ,,	0·646
	4 ,, ,,	0·649
	5 ,, and upwards to 12	0·650

For a sluice raised only $0·10^{m}$ instead of being f opened, the coefficient was found to depend on number of other sluices open, thus :—

When 1 other is opened full, the coefficient for the partly opened one is	0·650
2	0·657
3	0·660
4	0·662
5 and upwards	0·663

The determination of the coefficient for reduction for current-tube.

This was effected by three methods—

1st.—By comparing the velocities obtained by m of the tube with the surface velocities shown by fl

The data according to the floats were obtained in channels two mètres wide, having a discharge furnished by five sluices open at a time: the results gave a coefficient varying from 0·981 to 1·039 as extremes, and 1·006 as the mean of all.

2nd.—By moving the instrument at a known velocity in a mass of still water. The floats and the current-tube were drawn by men for a distance of 450 mètres, each 50 mètres furnishing a set of observations; the obliquities of the course of traction furnished the principal obstacle to arriving at a very exact result. The velocities employed varied from 0·609 to 2·034 mètres, giving coefficients of reduction varying from 1·015 to 1·053 as extremes, the general mean of all being 1·034: this was considered far too high, and the results of this set of observations were therefore entirely discarded.

3rd.—By measuring by means of the current-tube the velocities at a great number of points in the transverse section of the channel, and comparing the discharge calculated from these velocities with that determined by the experiments previously described; the points referred to were distributed rectangularly in vertical and horizontal lines; the discharge of each rectangle was calculated, and the sum of these discharges was employed to obtain an approximate discharge of the canal. These comparisons gave results varying from 0·968 to 1·029 as extremes, the general mean of all being 0·993.

The mean of the means obtained by the first and third methods gave a coefficient of nearly unity, which was therefore adopted for the instrument under trial.

Having thus securely determined the amount of discharge passing down the canal of experiment at any time, the levels of the water surface and its inclination being attainable also at any time with exactitude, the sectional area at any point being also known, and the coefficient of reduction for the current-tube being determined so exactly that any velocity observed by means of it was absolutely correct, the experiments for obtaining coefficients of discharge under different conditions, and for obtaining the ratio of the maximum velocity in a section to that of the mean velocity of discharge in open channels were undertaken.

The principal results of these experiments.

The first was the determination of the coefficient A in the formula $A=\frac{R\,S}{V^2}$ where R is the mean hydraulic radius, S the inclination of the water surface, or sine of its slope in one mètre, and U is the mean velocity of discharge.

The coefficient was considered to vary in four categories of channel.

1st.—When the bed and banks of the channel are made of well-planed plank, or of cement :

$$c_{,}=0{\cdot}00015\left(1+\frac{0{\cdot}03}{R}\right)$$

the data on which this was based are those of series No. 2 of Bazin's experiments, those of the Aqueduc des fontaines de Dijon of d'Arcy, and those of Baumgarten on the Canal Roquefavour.

2nd.—For bed and sides of ordinary plank, brickwork, or ashlar :

$$c_{,,}=0{\cdot}00019\left(1+\frac{0{\cdot}07}{R}\right)$$

the data on which this was based were, for plank twelve series of experiments of Bazin, and twenty-nine of Dubuat; for brickwork, the series of experiments No. 3 of Bazin; for ashlar, those of the Rigole Marée de Tillot, the Aqueduct of Cran, and the series No. 3 of experiments of Bazin.

3rd.—For channels of rubble:

$$c_{,}=0\cdot00024\left(1+\frac{0\cdot25}{R}\right)$$

this was based on Bazin's experiments on the Rigoles de Grosbois, and the Marseilles Canal.

4th.—For earthen channels:

$$c_{,}=0\cdot00028\left(1+\frac{1\cdot25}{R}\right)$$

the experiments on which this was based were those of d'Arcy and Bazin on the Rigoles of Chazilly and Grosbois, on the Marseilles Canal, the Canal du Jard, those of Dubuat on the Hayne, of Funk on the Weser, and those of various engineers of the French Ponts et Chaussées on the Seine and Saône.

The second result was the following formula for velocity:

V = the mean velocity of discharge.

V_x = the maximum velocity observed in the section.

$\frac{V_x}{V}=1+14\sqrt{c_{,}}$; or $V_x-V=14\sqrt{RS}$;

or in the form most useful in the cases in which maximum velocities are observed as data for gauging,

$$V=V_x-14\sqrt{RS}.$$

Using values of $c_{,}$ from 0·00015 to 0·003 the corresponding values of $\frac{V_x}{V}$ become thus:—

$c_{\prime}$	$\frac{v}{V_x}$
0·00015	0·854
0·0005	0·762
0·001	0·693
0·002	0·615
0·003	0·566

The above expression, involving terms not included in that of De Prony for the ratio of maximum to mean velocity of discharge, does not admit of comparison with it; but is evidently calculated to supersede it entirely.

The reduction of both of these results to English measures is given in Chapter I.

10. The Gauging of Great Rivers in South America, by J. J. Révy.

The account of the most recent operations in gauging very large rivers conducted by J. J. Révy, given in Révy's 'Hydraulics of Great Rivers' (London, 1874), includes a description of the method he adopted in current observations on the Paranà, La Plata, Paranà de las Palmas, and the Uruguay, from which the following brief *résumé* of operations is taken.

It seems to have been a work of some time and difficulty to find a reach of the Paranà sufficiently straight for conducting gauging operations and velocity measurements; a hundred miles of the river were searched unsuccessfully, but at last a reach straight for many miles was found. Here the river was about a mile in breadth, and the soundings showed from 5 to 71 feet of water; a gauge fixed in the stream did not show a variation of n the water surface of as much as a quarter of an n twenty-four hours; and the inclination of the surface in one mile was very nearly nothing. ll observed by levelling for one mile with a 14- vel, on equidistant staves placed 300 feet apart, s than 0·01 of a foot; it was therefore practically ible under the existing state of the river bank, was not adapted for levelling, and with the instru- at hand, to carry out levelling operations with any e result; as it would have involved ten miles of g on passable ground, and probably required also of superior instruments.

as found that for the surveying and triangulation ither calm weather or clear weather with a gentle was absolutely necessary;—for current observa- lm days only allowed of operations being carried

ase line of 3 000 feet was measured on the low- ft bank of the river, with a steel tape of 300 feet; es were set out at right angles at each end of it, the direction of a river-section-line for soundings; minent points in the neighbourhood and on the nk were triangulated and tied into this base line.

ndings.—Those on the lines of section were taken e lead and cord; the length of cord was measured tape at each sounding, each of these measure- taking one minute; the position of each sounding ed by angular observation, with a 3-inch pocket- giving readings to one minute, on the two flags each end of the base line. The angles were ob- in from three to ten seconds each. The number dings taken in the section varied with the neces- them: it was necessary to show, and hence also to find the points in the river bed where there was a change of lateral slope, however many they might be, but in places where this slope was regular and gradual, the soundings were not considered necessary at closer distances than from one-twentieth to one-tenth of the breadth of the river. The section of the Paranà, where its breadth was more than 4 800 feet, was sounded in two hours and sixteen minutes, after all the preliminary arrangements, drilling of the men, &c., had been properly carried out. In plotting the section, the position of each sounding was fixed both by means of the complements of the angles observed at those points, and the calculated distances from the base.

Velocity measurements.—These were made with the screw current-meters previously described. As the velocities had sometimes to be observed at great depths, the ordinary method of lowering the meter to its position by sliding it on an iron standard was utterly impracticable, and the following mode was adopted. The current meter was attached to one end of a horizontal iron bar, 9 feet long, 2 inches wide, and half an inch thick, which was suspended by chains passing through rings attached to it from a boat moored over the required spot; in order also to prevent the current from moving the bar from its proper position, cords from the rings of the bar were also attached to other two boats, one moored 100 yards up stream, the other 100 yards down stream. By these means the current-meter could be used with good effect in water up to 100 feet in depth, and in currents up to 5 miles an hour. Four sailors were necessary in taking current observations in this way. The observations of velocity were generally taken by an immersion of the current-meter for about five minutes, the time observed by the watch being generally a few seconds more or less, which were allowed for in the resulting calculated velocity per minute; a second checking observation was also generally made by an immersion of one minute. The instrument was put in or thrown out of gear by means of a wire leading from it up to the boat, thus allowing or preventing the revolutions of the screw from recording themselves on the dial faces at any moment.

In the gaugings carried out, observations of mean verticalic velocity, giving the mean velocity in any plane from the surface of the water to the bottom, seem to have been preferred wherever practicable. For these cases, in which it was necessary that the current-meter should be steadily and evenly lowered to near the bottom and raised again to the surface, it was found advisable always to work it from a platform between two boats, placed 12 feet apart, moored by four anchors, and to have the two suspending cords marked at every 3 feet with alternately red and white marks, as guides to those lowering and raising them; the cord attached to the down-stream boat was not, however, considered necessary in this operation, the up-stream cord preventing the instrument from going far out of the vertical direction. In these operations the instrument was put in gear by hand by tightening a nut on immersion, and put out of gear again in a corresponding manner on withdrawal from the water. In taking surface velocity observations, the current-meter was screwed on to a wooden staff, 3 inches wide and half an inch thick; the revolutions of the screw continuing after withdrawal from the water being at once stopped by hand so as not to vitiate the record on the dial-face.

The determination of the equation of correction for each current-meter was conducted in the following way. It was tested at a low velocity by drawing it through a distance of 189′ 6″ in the still water of a reservoir in a time of 2′ 30″ giving a velocity of 75·9 feet per minute; the average of these trials gave a recorded number of revolutions of 172, or 68·8 per minute: in the same way also it was tested at a high velocity, and showed 176·13 revolutions per minute for a speed of 183·64 feet per minute. The equation of correction being that of a straight line, two points alone are necessary to determine it: on referring these to rectangular co-ordinates on a diagram, and joining them, the true velocity corresponding to any number of revolutions of the instrument could be scaled off from the rectangular co-ordinates to the resulting straight line. Or taking it algebraically, if x and y, x_1 and y_1, be the corresponding pairs of co-ordinates for low and for high velocity,

$$\text{then } y=ax+b, \text{ and } y_1=ax_1+b;$$

$$\text{where } a=\frac{y_1-y}{x_1-x}=0{\cdot}9962,$$

$$\text{and } b=\frac{1}{2}(y_1+y-ax_1+x)=-6{\cdot}811;$$

$$\text{hence } y=0{\cdot}9962\,x-6{\cdot}811,$$

or in the form more useful for obtaining the true velocity, x, from the number of revolutions, y,

$$x=1{\cdot}00381y+6{\cdot}837.$$

On applying to this equation a value of $y=0$, we obtain as a result that this particular instrument would cease to record revolutions for a velocity of less than 6·137 feet per minute.

Hourly Observations.—In consequence of the rivers observed being tidal, and having a variable current, it was necessary to moor a permanent observatory at a convenient point in the deep part of the river on the line of section, and make hourly observations of the current from it throughout the day and night. The tidal rise and fall was also registered at every quarter of an hour; barometric, thermometric, and wind observations were also recorded.

The current observations, both surface, mean, and sub-surface, were taken with Révy's current-meter from a small boat moored temporarily fore and aft on the line of section already sounded, its position in each case being determined by angular measurement with a pocket sextant on the extremities of the base line, which fixed it within a few inches. For this work two sailors, two anchors, and several hundred yards of line were necessary. The current observations were taken at the surface, and at depths of 4, 7, 10, 16, and 23 feet, the latter being one foot above the bottom. The mean current observations were made three times in each case, and were found to check each other within 1·6 foot per minute in observations giving 80 feet per minute. The time of day of the current observations was always noted, and check observations were also taken from a fixed level, so that the observed tidal variation might be applied, and the effect of the tidal wave—a disturbing cause far greater than that due to the inclination of the water surface in the cases of these rivers—thoroughly investigated.

A convenient mode was adopted for testing the straightness of the reach of the river at the section in which the velocities were observed. The centre of gravity of the river section was found and marked on the drawing, and also the centre of gravity of a section whose depths represented the surface currents in any convenient mode, either feet per minute or per second; the horizontal distance apart of these two centres of gravity indicated the amount of effect of a bend in the reach at that section. In the Rosario section of the Paranà this was $\frac{1}{273}$ of the width of the river, and the section was considered favourable; in the Palmas section it was as much as $\frac{1}{25}$ the width of the river, and this was not considered favourable. In cases where a very straight reach is not to be obtained, the position of a section of observation is recommended to be taken at the point of contrary flexure of two reaches curving in opposite directions.

Conclusions.—The conclusions arrived at by M. Révy from his study of the current observations on the La Plata, Paranà, Paranà de las Palmas, and Uruguay, were—

1st. That at a given inclination surface currents are governed by depths alone, and are proportional to the latter. 2nd. That the current at the bottom of a river increases more rapidly than at the surface. 3rd. That for the same surface current the bottom current will be greater with the greater depth. 4th. That the mean current is the actual arithmetic mean between that at the surface and that at the bottom. 5th. That the greatest current is always at the surface, and the smallest at the bottom; and that as the depth increases, or the surface current becomes greater, they become more equal, until in great depths and strong currents they practically become substantially alike.

Remarks.—The consideration of the foregoing *résumé*, as well as the study of the original books, leads to the further conclusions—that these observations and experiments on tidal rivers have yet thrown no light whatever on the laws of velocity in ordinary rivers unaffected by tidal currents, the two matters being distinct and separate; that a more complete account of the tidal action on these South American rivers might have rendered the records valuable and useful; and that the further perfection of the Woltmann meter or water-mill by M. Révy proves its suitability to gauging operations on a large scale.

11. Captain Cunningham's Experiments on Large Canals.

The sites at which the experiments were made were those mentioned in the Table on the next page, this Table also describing generally their conditions, and mentioning the period over which the experiments were conducted at each.

An examination of the longitudinal sections at these reaches shows extreme irregularity of bed, deep scouring and high silting in various places, and considerable departure from the original bed slopes; in this respect the conditions were extremely unfavourable. The cross sections, however, were moderately regular in form, and portions of reaches in which no general depression occurred were invariably selected. The supply of the canals was very variable; the requisite control over the water was effected at the falls at the tail of each reach by raising or lowering the crest with balks of timber. Gauges, either permanent or temporary, were set up at each site, and soundings taken at each cross-section of observation. The sections in earth were mostly rough trapezoids, or coarsely formed sections; those in the aqueduct were either simple or stepped approximate

Table of Sites of Observation on the Ganges Canal and its branches.

Site	Bed Width	Maximum Depth	Maximum Discharge	Channel		Season of Experiment
				Bed	Banks	
	ft.	ft.	cub. ft. per sec.			
Fifteenth mile . .	160	12	7000	Earth	Earth	March to May, 1878; November and December, 1878; April, 1879
Solani embankment sites	150	12¼	7000	Clay and boulders	Masonry steps	August, 1876, to December, 1878; April, 1879
	150	11¾	7000	,,	,,	December, 1874, to January, 1875
Solani twin aqueducts	85	10	3500	Masonry	Masonry vertical	December, 1874, to April, 1875; February, 1877, to December, 1878; April, 1879
	85	10	3500	,,	,,	February, 1875; December, 1875, to December, 1878; April, 1879
Bebra . .	180	11½	6500	Earth	Masonry slope	January to March, 1879
Jaoli . .	185	10½	6500	,,	,,	,,
Kamhera .	55	6	980	,,	Earth	,,
Right Jaoli	16	4½	190	,,	,,	March, 1879
Mansurpur	10	4	80	,,	,,	,,
Miranpur .	11	3½	80	,,	,,	,,
Punora. .	9	5	85	,,	,,	,,

rectangles, the steps of 14-inch tread and 12-inch rise not continuing down to the bed, but terminating vertically.

The range of external conditions under which the observations were carried out at the two principal sites, main Solani embankment and the Solani right queduct, was extremely great—with high and low surface gradients, high and low water, and through great range of regulation at both the head and the tail of each reach; this rendered the results in these two cases highly valuable. The experiments on channels in earth were not carried out under such an extensive range of conditions, and afforded far less valuable results: extended experiment on them is yet a desideratum.

Proceeding to details and remarks on the velocity measurements: the terms adopted for velocities of various sorts by Captain Cunningham have the merit of great clearness. Taking x, y, z as co-ordinates of length along current, across it, and in depth respectively, h for depth, b for breadth, A for area, and t for time, the velocities of different sorts are thus distinguished:

1. Average velocity at any point:

$$v \text{ or } \int_0^t v\partial t \div t.$$

2. Float velocity, the mean of forward velocities or resolved parts of velocities parallel to the current axis through any point in a cross-section:

$$V \text{ or } \int_0^x v\partial x \div x.$$

3. Mean velocity past a vertical:

$$U \text{ or } \int_0^h v\partial z \div h.$$

4. Mean velocity past a transversal:

$$U \text{ or } \int_0^b v\partial y \div b.$$

5. Mean sectional velocity:

$$V \text{ or } \int_0^b\int_0^h v\partial y\partial z \div A.$$

In discussing the subject of instruments for m
ing velocity, the obliquity and crookedness of the
of a float is not considered objectionable, as its
motion gives a representative forward velocity ; bu
the opinion that all floats and many velocity-
afford a correct average of velocities during the t
actual observation may be correct, the objection t
result is not true for any single instant of time
noticed. Among the enumerated advantages o
are that they afford direct measurement of v
interfere little with the current, are not liable to
may be easily repaired, are cheap, and may be
streams of any size. The nearest approach to th
of a bank possible with floats was found to be
inches. The sites of the experiments being very
able to the use of floats, they were *exclusively us*
the systematic work.

At each site of observation an upper and
rope were strained across the channel, to mark
tremities of the reach under experiments, and co
dants were attached to these wire ropes at fixed d
suited to the intended paths of the floats ; th
velocities obtained were treated as actual veloc
the middle point of the float course. The d
admissible from the float course was, in channels
wide and upwards, 2 ft. ; in those of 70 ft. wide
wards, 1 ft. ; and in those of 25 ft., $\frac{1}{2}$ ft. ; the utmos
tion being allowed only about the middle of the
near edges and banks a less deviation was allowe
a third of the above. The dead run of the float
the upper rope to allow of relative equilibrium
established before timing was generally 100 ft. ;
narrow channels 50 ft. Moored boats were n

for casting and catching the floats, the number of men in each field-party with the boats and floats varied from thirteen to nine men.

The timing was managed by two thoroughly trained observers, a caller who watched the floats, and called as each float passed the upper rope, then ran to the lower rope, and called again just when each float passed the lower rope; the observer sat with a field-book and a loud half-seconds chronometer at a midway place, and recorded the times by ear alone. The maximum error admissible was half a second. In this respect there was a great improvement on the timing by watch adopted in the International Rhine observations. The usual length of run adopted was 50 ft.; in exceptional cases, where the tendency to deviation of the floats from their courses was greater, a 25 ft. run was preferred. Three timings were made and recorded, and the mean taken; all defective observations were rejected instantly in the field; the force of wind and the gauge-reading were invariably recorded with each set, as well as the distance of the float paths to right and left from the middle of the stream, the breadth of water surface, and the sizes of the floats or tinned tubes used. The speed of these timing observations was much affected by the number of float courses that turned out bad; as several floats were often used unsuccessfully in one set on one float course. The deduced velocities were taken out to hundredths of a foot per second, the hundredths being treated as approximately correct. The velocity of 5 ft. per second was considered unusually high; the maximum error in such high velocities, due to half a second in observation, was therefore one-twentieth or 5 per cent., and in low velocities of 1 ft. per second one per cent.

As to gauges, both still- and free-water gauges were adopted at various sites, and these were either permanent or temporary. In the permanent still-water gauges a pool with fine passages of communication afforded a good place for the gauge; for temporary still-water gauges, a 3 in. stand-pipe was erected in the bank, and made to communicate with the water by a $\frac{1}{4}$ in. lead pipe with a contracted nozzle; float sticks of 3 ft., 6 ft., and 10 ft., were used with indicators for convenience in reading. The oscillations of the water in free-water gauges were troublesome, especially in high wind; the practice was to observe the maximum and minimum reading in half a minute, and to use the mean; with temporary free-water gauges the difficulty was higher, the plan adopted was to make firm bench-marks less than a foot below the temporary water surface, and scale depth to surface with a brass rule having its thin edge directed up-stream. Free-water levels were proved to be slightly above still-water levels. The average of water-level at both banks of a section was invariably determined and used; the differences of level frequently being very marked and much affected by the wind. Gauge-readings were made at the beginning and end of each set of observations and the mean adopted.

Soundings were taken both along the cross-section and along the courses, and at distances 50 ft. apart in wide channels, and at 25 ft. apart in small channels; these had to be repeated after any presumed change in the bed and banks, and the average depths were made dependent on the mean water-level. The sounding rods were wooden rods $1\frac{1}{2}$ in. square, and from 11 ft. to 15 ft. long, protected by iron shoes and having rings above for convenience in withdrawal. The readings were seen by an observer on the bank and read to a tenth of a foot, occasionally even this could not be done with certainty.

Both the direction and the force of the wind was recorded at the beginning and end of each set of observations; but the anemometers did not compare favourably; and the wind data obtained can only be looked on as a rough estimate of the wind. The reduced levels were referred to the datum of mean sea level at Karachi; all special levelling was done twice over with an excellent 20 in. level, and no discrepancies exceeding 0·01 ft. were allowed. The computation of the final hydraulic elements from the observed data was exceedingly laborious; but that, as well as all work admitting of check, was verified by two persons independently.

Unsteadiness of motion producing variation in velocity was investigated, and a large series of experiments tabulated to demonstrate the effect; the conclusion being that the amount of velocity variation at one and the same point is liable to be at least 25 per cent. of the mean value. Under such circumstances single or detached velocity observations are nearly valueless; but the assumption that synchronous measurement cannot possibly be secured in actual practice is perhaps overstated; it would certainly be very expensive. Falling back then on average velocities, the conclusion is applied that averages should be formed from about fifty values; the course of the four years' experiments was accordingly entirely regulated on that basis, and the measurements done in groups.

The systematic float velocity-measurements were also made in as rapid a succession as possible on either a vertical or on a transverse axis, in groups of three at each point, thus:

On a vertical.	On a transversal.
At surface.	At the point near left bank.
At a depth of 1 ft.	At next point.
At a depth of 2 ft.	&c.
&c.	At point nearest right bank.
At the point near to the bed.	

Also six rod velocities, the whole forming a set. The only other systematic velocity work was central surface velocity measurements, which were done in groups of 48 in as rapid a succession as possible, thus forming a set of another sort. Sets were then taken up in succession under nearly similar external conditions, so long as the water-level remained nearly constant and the wind moderate, up to a limit of about sixteen sets. But if the water-level changed more than 0·1 ft., or the wind exceeded 15 ft. per second, the field work was usually closed.

Such sets as were executed in sequence were then combined into one series by tabulation on the same sheet, each series admitting a maximum range of water-level of 0·3 ft., irrespective of the state of the wind, and only to some extent irrespective of the surface slope at the site. This careful mode of combination is a great advancement on the method often adopted elsewhere of combining sets on different verticals in all depths of water, and sometimes even at different sites.

A conclusion drawn from the plotting of these sets is valuable. Notwithstanding unsteady motion, the average velocity at a point is probably constant under similar external conditions, any departures from this law shown in the velocity curves being due to insufficiency of velocity observations, to irregularity of contour of bed and banks at the site, or to irregularity of the channel above and below the site. The recognition, however, of unsteady motion being the ordinary normal condition of flow, and of the vertical interlacing of stream lines, is strongly insisted on.

With regard to longitudinal slopes. First, as the bed slopes were very irregular, an average bed slope, equal to the fall between two adjacent permanent floorings divided by the distance between them, became the only representatively useful quantity. Both the average surface slope of the water for a long distance above and below any site, and the local surface slope at the site, were always determined with great precision, the surface slope per 1 000 never exceeding 0·48; it was a matter of extreme delicacy, in which the reference to water-level was more important. This was done simultaneously by two observers in calm weather on each bank, in some cases only. The condition that the real surface slopes at opposite banks are not generally equal was not fully recognised till a late period. The amount of surface fall deduced from gauge readings above and below site, supplemented the slopes deduced by levelling, but was in many cases imperfect from the conditions of control of the reach. The conclusions derived from the diagrams of surface gradients are that the local surface slope depends jointly on the surface falls both above and below, but that the latter by no means suffice to indicate the former. It is also observed that the mean velocity and discharge at any site was more dependent on the value of the surface slope than any other element.

Surface convexity received the attention of Captain Cunningham. Noticing the theory that the pressure in a fluid in motion is always less than the mere hydrostatic pressure, and comparatively less with more velocity, and the opinion that lateral motion would sectionally enforce a convexity in the middle, and thus form an accumulative layer above the *locus* of maximum velocity of the section, he remarks that the above is true, excepting the sectional convexity, which is almost wholly wanting. The observations for convexity were exceedingly delicate and tedious; yet from a series of them, made at the Solani embankment main site, the conclusion was drawn 'that the surface of water in motion in a long straight reach with tolerably uniform bank is, on the average, nearly level across.'

Such a general law seems almost unaccountable by abstract reasoning, and may be true only for special conditions and circumstances, probably under peculiar irregularities of bed above and at the site; but the deduction is one that cannot be set aside, although it undoubtedly requires the light of further and extended special experiment under higher velocities, and with strictly uniform conditions of bed and of section.

While concluding this notice of the preliminary conditions under which the experiments were made—conditions sufficiently involved and irregular to deter the most arduous of hydraulic enthusiasts—we may notice that it seems surprising that the Government did not make some grant for largely improving and rendering regular the beds of the canal in the vicinity of the sites before experiment; also that a bolder comprehensive method of meeting the expenditure would have been conducive to continuous work. The straining against difficulties, as well as the labours of the undertaking, had to be met by the unsparing energies of the experimentalist; and though under such circumstances results redound more greatly to credit, it is much to be deplored that his efforts were thus fettered.

Continuing to verticalic velocity curves, or observations elocity past a vertical, it may be noticed that all sub-ace velocities were obtained by timing double floats. se were of two patterns, one a ball of acacia wood, in diameter, boiled in oil and loaded with lead; to a surface cork disc, 2 in. in diameter and $\frac{3}{8}$ in. thick, attached by a brass wire 0·012 in. thick; the other ell of copper 0·02 in. thick, $1\frac{5}{8}$ in. in diameter, loaded lead; to this a cork surface disc, 1 in. in diameter, thick, was attached by an oiled silk thread $\frac{1}{80}$ in. k. Velocities being observed at every foot of depth, any as ninety floats were used in a set, and three rvations were made at every point; defective courses made up by subsequent courses, and the mode of ng was that already described with surface floats and . The velocities were plotted to vertical axes, mostly ral verticals, on a scale exaggerated ten times for the city ordinates; the curves formed were approximate bolas, having general features agreeing closely with similar cases of Bazin on a smaller scale; the errors to the employment of floats are such as to produce es flatter than they should be. From these were com-d the mid-depth velocities $v_{\frac{1}{2}H}$, the bed velocities v_H the mean velocities V.

The mid-depth velocity at every vertical was found subject to great and rapid variation; thus disproving assumption of constancy asserted in the Mississippi ort, for which no proof was afforded by observations; its variability was proved to be less than that of either surface velocity or the bed velocity. It was also dis-red that any marked increase or decrease of either urface, the maximum, or the mean velocity was accompanied on the whole by increase or decrease of the whole of the velocities on the same vertical.

The calculation of the parabolic elements of the velocity parabolæ was thus effected:

Taking the two general formulæ, $Z^2 = p\ (V-v_0)$, $p(v_0-v)=z^2-2Z\,z$, where Z is the depth of maximum velocity, p is the parameter, z the depth to any point, the known values being $v_0, v_{\frac{1}{2}l}, v_l$, corresponding to $0, \frac{1}{2}l, l$; these were substituted for v and for z in the above and the equations solved for p, Z, and V. Thence

$$p=\frac{l^2}{2\ 2v_{\frac{1}{2}l}-(v_0+v_l)},$$

$$Z=\tfrac{1}{4}\,l+(v_{\frac{1}{2}l}-v_0).\frac{p}{l},$$

$$V=v_0+\frac{Z^2}{p}.$$

The parabolæ determined by each group of three data being usually different, the most probable parabola was determined by the method of least squares, a mode laborious but correct. An investigation of parameter variation showed that the data did not admit of sufficient accuracy in the determination of the value of p to enable its dependence on the external conditions to be traced. The depression of the line of maximum velocity is shown to be not sensibly affected by the wind but largely due to air resistance, and dependent on the surface slope near the site, but the quantitative connection cannot yet be traced.

The summation of velocity past a vertical was effected through various combinations of the trapezoidal, Simson's, cubic, and Weddle's rules, suited to the number (n) of equal spaces (k); of which the following are the general expressions.

$\frac{1}{2}k\{v_0+v_n+2(v_1+\&c.+v_{n-1})\}$

$\frac{1}{3}k\{(v_0+v_n)+4(v_1+\ \dots\ +v_{n-1})+2(v_2+\ \dots\ +v_{n-2})\}$

$\frac{3}{8}k\{(v_0+v_n)+2(v_3+v_{n-3})+3(v_1+v_2+v_4+v_5+\&c.+v_{n-2}+v_{n-1})\}$

$\frac{3}{10}k\{(v_0+v_2+\ \dots\ +v_{n-2}+v_n)+(v_3+\ \dots\ +v_{n-3})$
$\qquad+5(v_1+v_3+\ \dots\ +v_{n-3}+v_{n-1})\}$

The deductions with regard to mean velocity (U) past a vertical are that its line is always below mid-depth, but that it cannot be directly measured in practice by any single velocity observation; that the mean velocity past a central vertical is dependent on the surface fall in the upper sub-reach, but cannot be deduced from it better than from any primary velocity. It may be deduced from two velocities by the following formulæ:

$$U=\tfrac{1}{4}(v_0+3v_{\frac{2}{3}}\ );\ \text{or}\ U=\tfrac{1}{7}(3v_{\frac{1}{6}H}+4v_{\frac{3}{4}H});$$
$$\text{or}\ U=\tfrac{1}{7}(4v_{\frac{1}{4}H}+3v_{\frac{5}{6}H}),$$

of which the first is considered the most convenient.

The value of U may also be obtained from a single observation with a loaded rod in depths not more than 15 ft.

The rods preferred and mostly used were 1-in. tin tubes painted and marked for immersion, loaded with fixed iron, and adjusted with shot; they were made in sets of fixed length, but wooden rods were also used in shallow water. The bed and banks had sometimes to be dressed to admit of tube observation. The tube velocities were compared with double-float velocities for purposes of experimental test. An investigation of the theory of rod motion results in a conclusion that a proper rod length is from 0·945 to 0·927 of the full depth, when the maximum velocity is at within one-third depth from the surface, and from 0·927 to 0·950 of it when that is at between one-third depth and one-half depth.

Proceeding to transverse velocity curves, or
whose ordinates are the forward velocities at all po
a transverse base line in a transverse section, the f
ing is an abstract of the observations effected, whicl
made under varying conditions of water-level at eac

Surface velocities . .	10 series comprising	109 sets at		
Mid-depth velocities .	2	"	17	"
Bed velocities . . .	2	"	7	"
Mean velocities . .	100	"	581	" 1

The surface velocities were observed with pin
3 in. by $\frac{1}{4}$ in.; the mid-depth and bed velocities w
in. double floats; the mean velocities with 1-in. tir
rods generally, and with 1-in. wood rods in depth
than 1 ft. As the ordinate spacing required close
nates where the change of velocity was more rapi
transversals were divided into lengths or spaces,
each of which the sub-spacing was equal; the arrang
being symmetrical to the centre line of the bed in
case. The mode and order of the field work and t
were similar to those already described, so als
arrangement in sets and series. The average ve
observations were finally plotted as rough curves to
transversal, as also the resulting means of the pr
velocities, at surface, mid-depth and bed, an
sectional. The notation here used is: h=any d
b=surface breadth; R=hydraulic radius; H=c
depth; B=wet border; S=surface slope; an
values of these are given with the transverse ve
curves for each site. The causes and conditions ac
panying local peculiarities in these curves are
entered into; but the principal deductions made
the whole set of curves are the following:

1. That like curves are similar under similar external conditions. 2 That like curves with equal mean velocity are, *cæteris paribus*, equally flat on the whole. 3. Curves of low velocity are flatter than those of like kind of high velocity. 4. The flatness of a curve depends more on the mean velocity than on the general depth, as shown by comparing low-water and high-water curves. 5. Wide sides give flatter curves thoughout. 6. Sloping or stepped banks give rise to sharp curvature. 7. Vertical banks give rise to curvature also, but this is less than with the former. 8. In comparing unlike curves; of unlike curves under the same external conditions at the same site of rectangular section, the mid-depth curve is usually the outer, the mean velocity curve intermediate, and the bed curve the inner. The mean velocity curve is one of the flattest and the surface curve the most rounded, so much so, that near the banks the surface curve becomes one of the innermost. 9. The figure of a transverse velocity curve can be determined with equal precision at all parts excepting near the edge. 10. Edge velocity is assumed to be zero, but not plotted.

The attempt to arrive at a geometric figure for a transverse velocity curve generally was eventually given up as hopeless; but the sort of curve most nearly possessing the required properties is the elliptic curve of the type represented by the equation

$$\left(\frac{v}{v_o}\right)^n + m\left(\frac{y}{b}\right)^n = 1$$

The following were also general conclusions:

1. The figure of the transverse velocity curves is for given external conditions determined by the figure of the bed.

2. The velocity (v) should be expressed not only as

a function of the abscissa (y) but also of the depth (z); so that the equation should be of the form $v+V=f(y,z,$ &c.); it may also be a function of the average effective distance from the wet border.

In the calculation of discharges, the mode and notation adopted were as follows. The data used were:

A system of depth ordinates H_y in the cross-section.

A system of velocity ordinates u_y in the velocity curves.

A system of curve areas $D_y=H_y\ u_y$ with the same abscissæ $\pm\ y$; *i.e.*, at the same points of the transversal.

The quantities $D_y=H_y\ u_y$ were prepared by multiplying separately every rod velocity u_y by the average depth H_y along the float course. These so-called superficial discharges D_y past the several verticals whose abscissæ are y are then equally spaced quantities used in ordinary approximation formulæ, of which the prismoidal formula is one, to obtain the total or cubic discharge. The following were the four formulæ used; the quantities a, a_1, a_2, at equal spacing b to right or left of the centre line being distinctively dashed thus—a', a'', a_1', a_1'', &c.

1. Simson's

$$\tfrac{1}{3}b\,\{(a_2''+a_2')+4\,(a_1''+a_1')+2a_0\}$$

2. Cubic.

$$\tfrac{3}{8}b\,\{(a_3''+a_3')+3\,(a''_1+a_1')\}$$

3. Weddle's.

$$\tfrac{3}{10}b\,\{(a_3''+a_1''+a_0+a_1'+a_3')+5(a_2''+a_0+a_2')\}$$

4. Simson's modified.

$$\tfrac{1}{3}b\,\{(3\,E+e)+4\,(Q+M),$$

where q a missing quantity$=\tfrac{1}{2}(M+E)$ is between two adjacent quantities $M E$, these and e being all alike at equal spacing. This last was convenient for such cases.

With a rectangular cross-section the total discharge $=D_m H$; D_m being the superficial discharge past the mean velocity transversal, or area of mean velocity curve.

The conclusions arrived at with regard to total or cubic discharge were: That it is sensibly constant from instant to instant, but that at any site it increases and decreases rapidly with the rise and fall of water-level. It is liable to increase or deficiency from a cross wind blowing towards or from the gauge. Moseley's discharge formula meets with very strong condemnation, and its faultiness is clearly proved in a most lucid manner. For comparison of discharges at successive sites, the field work should be either simultaneous or in the same body of water at all the sites; and for those from successive observation at the same site, immediate succession is desirable. The discordance between successive comparable results under similar favourable conditions may be expected to be seldom over 3 per cent.

With regard to mean velocity, the following also are the conclusions of Captain Cunningham.

1. That the arithmetic mean of velocities past neighbouring points on a transversal is not the mid-distance velocity, but errs in defect.

2. The mean velocity past a transversal and the mean sectional velocity are less variable from instant to instant than most of the individual velocities, but the former varies sensibly.

3. The mean sectional velocity is constant from instant to instant, and more so than the discharge.

4. The chief source of variability in successive mean

velocity-measurements is that each single result is imperfect, and this is due to unsteady motion.

5. The mean surface and central surface velocities U_o, v_o, and also the mean sectional, central mean, and central surface velocities (V_o, U, v_o), and the quantity $\sqrt{RS}$ increase and decrease with either R or S.

6. In high up or down-stream wind, surface velocity observations are liable to be under or over-estimated, and are quite unsuitable for computation of discharge; but mean-velocity observation is but little affected by wind of any sort, and error is then attributable to an abnormal gauge reading.

7. The ratio $c = V \div U_o$ generally increases with increase of depth, and probably with decrease of velocity or surface slope; but its variation is obscure, perhaps owing to the effect of wind on U_o.

8. For rapid approximation to mean velocity a good average central mean velocity observation is at present the most reliable mode.

9. The ratio $c = V \div 100\sqrt{RS}$ increases and decreases generally with increase and decrease of R, depends in some complex manner on S, and also on the nature of the bed and banks at the site.

This last conclusion is obviously of the highest importance in its bearing on *calculated velocity formulæ*.

In a careful examination of these latter, Captain Cunningham states that these are all, with the sole exception of that of Herr Kutter, quite untrustworthy; and that Bazin's relation $c_b = 100\,C \div (100\ C + 25{\cdot}34)$ is fundamentally incorrect as a relation between $c = V \div v_o$ and C.

The rejected formulæ among the really old ones are those of Dubuat, 1786; Girard, 1803; De Prony, 1804;

Young, 1808; Dupuit, 1848; St. Venant, 1851; Ellet, 1851; and among newer ones, those of Bornemann, Hagen, Gauckler, Mississippi, and Gordon.

The only two formulæ of sufficient value to merit extended discussion were those of Bazin and Kutter. The results of their examination are:

1. That the form of the value of C in the Bazin formula is defective.

$$C_b=\left(a+\frac{\beta}{R}\right)^{-\frac{1}{2}}.$$

This was also Herr Kutter's conclusion.

2. That making K a constant in the expression:

$$V_s-V_m=K\sqrt{RS}$$

is not just, and K varies from 22·4 to 9·9 in 61 cases, and from 17·0 to 10·7 in 43 selected cases given by Bazin.

3. The effect of applying Bazin's coefficient c_b to central surface velocities v_0 is to produce too low values of mean velocity.

4. Bazin's ratio c_b increases with R, whereas the experimental values of$_b$ show no signs of this.

5. For earthen channels Bazin's ratio c is so low as to be of little use.

Next, regarding Kutter's coefficients (C_k);

1. The formula, though complex and laborious, is the best empirical formula yet proposed for calculated mean velocity (and hence for discharge).

2. When the surface slope measurement is a good average, done in calm air on both banks on a canal in good train, C_k will give results whose error will probably seldom exceed $7\frac{1}{2}$ per cent. in large canals.

3. The coefficient of rugosity must be experimentally determined for each site.

It may be here noticed that the books of the author were employed by Captain Cunningham to obtain values on the Kutter system suited to English purposes, and are referred to repeatedly; and that with reference to the liability to error of 7½ per cent. in these quantities, it is clear that as discharges under favourable circumstances of experiment are allowed to be liable to 3 per cent. of error, the former being about double, this proves a high degree of exactitude for a mere calculated velocity formula, and practically justifies the claim advanced in those books to an accuracy within about 5 per cent.

The above constitute the principal results of Captain Cunningham's experiments.

In addition, much care and experiment were devoted to fan current meters, Moore's and Révy's and to improving them by separating the recording portions from the fans; but from uncertainty of oriculation, of depth, of gearing, and of non-measurement of forward velocity, their employment was eventually considered simply useless. A series of observations on the effect of silt resulted in the following conclusions, that, 1. There is no obvious connection between the velocity and the silt density of different parts of a site; the silt density varies from instant to instant at one and the same point. 2. The silt density and silt discharge do not appear to depend sensibly either on the depth or the velocity at a site, but in the Ganges Canal they depend chiefly on the silt admitted with the supply.

The observations on evaporation produced the following conclusions: 1. The evaporation from a floating evaporameter on a large still-water surface or river is far less than from a small vessel on land. 2. The evaporation from the Ganges Canal at Rurkhi averages about $\frac{1}{16}$ inch daily out of the rainy season; and the loss by evaporation is about $\frac{1}{150}$th part of the full supply of the canal, or about ten minutes' full supply daily.

The main result of the whole may be expressed in a few words, 'That most of such hydraulic results as were previously accepted by only the few have now been so verified on a large scale as to command their acceptation by the many.'

12.—General Remarks on Systems of Gauging.

The foregoing brief accounts of the modes adopted by various hydraulicians in carrying out field operations form a far better guide to the engineer about to undertake the execution of gauging operations than any arbitrary advice, or set of rules, could possibly be; the author may, however, be permitted to make a few remarks in conclusion. It is, of course, assumed that the most advisable mode of proceeding in one case might not be applicable to another, and that the method of gauging should be suited to the general object, the place, and the circumstances. When the object is of an experimental nature, having scientific results in view, the experimentalist himself is the best judge of the mode most suited to his object. Most gauging operations, however, have for their purpose the determination of the discharge of a river, or of a canal, with as little labour and expense and in as short a time, as anything approaching to accuracy of result will admit; in these cases the amount of predetermined accuracy greatly affects the choice among modes to be adopted.

1. The most rapid and least accurate mode of determining the discharge of a river or canal at a certain place and time is that which dispenses with velocity observations, and makes use of a calculated velocity formula as a substitute. The dimensions of two parallel sections of a straight reach of the channel are measured, the inclination of the water surface between the two is levelled, and the nature and quality of the bed and banks are noted; these data enable the discharge to be calculated by the aid of the most modern and most correct formula with a certain amount of approximate truth. The point now to be considered is what amount of exactness may be reasonably expected from the practical application of this method.

The general formulæ for mean velocity of discharge and for discharge in open channels,

$$V=c\times 100\sqrt{RS}; \qquad \text{and } Q=AV;$$

where

$$c=\frac{\sqrt{R}}{100\,n}\left(\frac{m+1{\cdot}811}{m+\sqrt{R}}\right); \quad \text{and } m=n\left(41{\cdot}6+\frac{0{\cdot}00281}{S}\right);$$

seem theoretically to leave nothing more to be desired, except perhaps a simplification of form not attainable in the present state of hydraulic science. It is applicable to channels of all dimensions, from the smallest distributary or rigole to that of the Mississippi; and can be applied to channels of any material, from weed-covered earthen beds to cut stone and carefully planed plank, the data on which it is most carefully based being those of numerous experimentalists. The functions or terms involved are only three, R, S, and n.

f which the two former can in most cases be readily and sufficiently exactly observed in practice; the great difficulty, however, lies in the determination of the third function. An examination of the general and the local values of n, given in Working Table No. XII., will explain this. Among the general values suitable to beds of special construction, from well-planed plank to rubble, the value of n ranges from 0·009 to 0·017; and the gradations of roughness or quality of surface are clearly marked by the corresponding values of n, the greatest gap being the difference between 0·013 for ashlar and 0·017 for rubble, a difference that can be easily worked up to in practice without any likelihood of important error. It would hence appear that there would be no difficulty in practice of determining discharges with fair accuracy by means of the above calculated velocity formula for channels constructed in such artificial materials. It is, however, in the cases more usual in practice, namely, in those of canals having earthen beds and banks, and in natural river channels, that the values of n offer so wide a range of choice, that the calculated discharge might involve serious error as the result of the adoption of an unsuitable coefficient. For earthen canals the values of n range from 0·020 to 0·035, the gradations of which are far from being yet sufficiently definitely marked; and for local values the range is about the same. It would seem, therefore, that in these cases it would be necessary to determine by velocity measurement the discharge of the river or canal at the site under consideration, and thence deduce a value of n suitable to it before the above method could be applied for obtaining its discharge at any time or place with sufficient accuracy; or, in other words, a small amount of actual gauging must be done before this mode of procedure can be adopted. In the future we shall probably have the values of this function more definitely laid down, and we shall then be able to make use of this method more readily, and with greater confidence in the results; now we have only the present amount of information to guide us, and are hence unavoidably forced into a certain amount of velocity measurement as a means of correctly gauging canals and river channels in earth.

2. Assuming, therefore, that velocity measurement is absolutely unavoidable, the question next arises, what is the least amount of it necessary in determining a discharge? The results of Bazin, determining the relation between the maximum velocity in a section and its mean velocity of discharge, give the readiest solution of this problem for small canals. His formula is,

$$V_x - V_m = 25{\cdot}34 \sqrt{RS},$$

where V_x = the maximum velocity, and V_m = the mean velocity of discharge; and it is evident that by combining with this formula the more modern coefficients of Kutter, we can, with the aid of only a few observations of maximum velocity, arrive at a mean discharge with rapidity and a fair amount of accuracy, and may be afterwards able to determine a discharge at any time under the same local conditions by means of the ordinary calculated velocity formula and the Kutter coefficient already mentioned, without the need of more velocity observation. The reduction of these equations from French measures is given at page 38, Chapter I.

It is extremely probable that this mode of gauging will be more universally adopted in future, and that a large series of observations will throw more light on the relation of the maximum velocity to the mean velocity of discharge, and enable it to be determined with greater accuracy than is at present possible. Observers are therefore recommended to keep in view in all gaugings conducted on this principle, not only the sectional position of the maximum velocity in a section (which may be confined to a single point either in the middle of the channel at the surface, or at a few feet below it, around which the velocities may diminish in section rather suddenly, or may extend with but little diminution over an important portion of the section), but also the locus of maximum velocity, or its depth below the water surface, which may vary sensibly in a long reach of river. This inclination of the locus, as well as the amount of section of very high velocity, are data that will probably aid eventually in determining the ratio of maximum to mean velocity of discharge with greater precision than Bazin's formula now affords.

3. The next mode of gauging that seems most applicable to ordinary rivers is one of the modes recommended by Captains Humphreys and Abbot. This, however, involves a greater amount of velocity observation, and at the same time requires the velocities to be observed at a greater depth, for which all descriptions of current-meters are not applicable.

The velocities are all observed at a uniform depth equal to half the hydraulic radius of the section, and at equal distances judiciously chosen across the line of section; and the mean of these velocities $U_{\frac{r}{2}}$ is taken; —the mean velocity of discharge, V_m, is then obtained in the formula,

$$V_m = \left[\left(1{\cdot}08\,U_{\frac{r}{2}} + 0{\cdot}002b\right)^{\frac{1}{2}} - 0{\cdot}045\,\sqrt{b}\right]^2$$

where $b = \dfrac{1{\cdot}69}{(r+1{\cdot}5)^{\frac{1}{2}}}$; and r is the hydraulic radius.

This mode should, however, be limited to very large rivers; in fact, the application of any of the Mississippi data or formulæ to artificial channels or small streams cannot be recommended.

The defect of the above method in assuming the relation $U=0{\cdot}93\,V_m$ is sufficiently evident, so also is that of assuming the parameter of the parabolic curvature of mean verticalic velocity; but when these quantities are predetermined for any case under consideration, the same principles may be applied in gauging small streams or canals with quite as much success as in gauging the Mississippi.

4. If we accept the conclusions of Captain Cunningham, given at pp. 91 to 93, Section 8, Chapter I.; we may gauge any rectangular or approximately rectangular section of flow by single velocities taken at equal distances on a transversal; the depth of observation being $\frac{5}{8}$ the total depth generally, and $\frac{1}{10}$ the total depth at the points near the margins; these velocities will then be representative elementary mean velocities in their own portions of channel, from which the mean velocity for the whole section may be deduced with some degree of general correctness. Further correctness may be obtained by taking two velocity-observations on each vertical from which to deduce each mean verticalic velocity; the formula recommended for this is (see p. 87),

$$U = \tfrac{1}{4}\left(v_o + 3v_{\frac{2}{3}H}\right);$$

that is to say, the surface-velocity and the velocity at $\frac{2}{3}$ the depth, are sufficient.

The defect in these methods is evident; it consists in making the parabolic curvature dependent on one point or on two points, whereas three points are the least necessary. If, however, we apply the three-point method (see p. 86) and obtain values of U on each vertical through three synchronous observations on it, and make

$$U=\frac{1}{3}\left(2v_{\frac{1}{4}H}-v_{\frac{1}{2}H}+2v_{\frac{3}{4}H}\right),$$

we may deduce a mean sectional velocity that is theoretically almost unimpeachable, though based on a very moderate amount of velocity-observation.

5. The next further attempt at accuracy in river gauging involves a complete investigation of the whole of the velocities in the channel section; the velocity at every point in the cross-section should be known and plotted on a diagram, they can then be grouped into divisions of the section by vertical and horizontal lines within which the variation of velocity is not important: a mean velocity for each division is calculated and multiplied by the area of that division to obtain its discharge; the sum of these discharges is the discharge of the whole section. There are, however, two or three methods of treating and observing the velocities. When these fluctuate locally to a very small degree within a short space of time, any velocities observed at the same site within a day or even within a week may be grouped together to serve as a basis of calculation; similarly also when there is very little local variation of velocity in a reach, mean velocities observed over a portion of reach of from 50 to 200 feet in length will represent

mean velocities at the middle of that length. When both such advantages happen to be combined, the whole of the observation is much simplified, as the velocities must not then be necessarily confined to an exact sectional site, and need not be perfectly synchronous.

Preliminary observation is therefore necessary to determine the conditions under which the velocity-observations will yield correct results.

When the local variation of velocity along a reach is important, either a sufficiently favourable reach must be found, or the method of using loaded tubes and floats must be discarded in favour of other appliances that actually afford velocities at points of observation, or on vertical lines, at a single transverse section.

When velocities vary much at the same spot within a short time, synchronous or exactly simultaneous velocity observations at the given transverse section are absolutely necessary, and appliances must be used that will obtain these. Among them may be mentioned the d'Arcy gauge tube, and the author's current-meter.

Such detailed observations when carried out on an extended scale involve a large amount of labour, care, and skilled personal superintendence, but at the same time afford results not only valuable as regards the determination of the discharges of the river specially under consideration, but also as records of hydraulic experiment aiding in the progress of science.

CHAPTER III.

PARAGRAPHS ON VARIOUS HYDRAULIC SUBJECTS.

1. ON MODULES OR WATER-REGULATORS.

HYDRAULIC engineers not having yet arrived at a perfect module for regulating the amount of water drawn off in an open channel for irrigation or town supply from an open canal or reservoir under a varying head of pressure, it is a matter of some interest to examine the older types of design of modules that have been used at various times, and in various countries, before going on to those of more modern form. Such designs being necessarily simple, they will be found perfectly comprehensible by means of description without the aid of drawings or diagrams.

Piedmont appears to have been the birthplace of modules, for although irrigation is essentially Oriental in origin, owing to its extreme reproductive power in hot climates, and though it was introduced into Europe by the Moors, we do not find, either in India or in Spain, where portions of these works still exist, anything approaching to a module. The systems employed i carrying out irrigation almost prove that they had n such a thing at all. In India the practice seems t have been to turn water on to a field until either t landowner or the turner-on of water was satisfied, perhaps rather until the landowner was satisfied that h could get no more. No doubt this was the best pl to start with, as the object of irrigation was to wat the fields sufficiently; and the landowner being the be judge as regards how much water was required for h crop, this mode insured the observation of the prop persons. This plan was, however, open to one ve serious objection; when the landowners discovered th an extra amount of water beyond that strictly necessa for the crop was in some cases capable of increasing t amount of produce to a small degree, they would ta more water, either by stealth or otherwise; the amou of perpetual squabbling on this subject would then ha been very large, had it not been for the fact that Oriental countries irrigation works were made by raja emperors, or chiefs, whose despotic rule and despo institutions supplied a very practical limit in such m ters—moral or physical force.

In Spain, under Moorish rule, it is probable t this useful substitute for modules was also in vog but in the huertas or irrigated lands of Spain, in m modern times and under Christian rule, the water be the joint property of several villages that combined keep the works in order, and legislated for themsel about the distribution of the water, the first great st the just division of the water on a large scale among several villages, had to be regularly carried out. T canals being comparatively small, a proportional divis ted by equalising the size of a certain small of outlets from the main canal into the y channels, one village thus taking a fourth 1 of the total volume of water passing down the

iedmont the conditions were different; the eing hilly, and the water taken from streams nts having a considerable fall, water power was ly used for driving corn mills. It is probable e were a few water-driven corn mills both in l in Spain, but there such mills would be public ns, the miller being a servant of the community, living on a fixed income, or yearly pay, given kind or in money by all the neighbouring sing the mill. In Piedmont the mills were the roperty of individuals, as they are at the present urope; hence it was there that the first unit of asurement was arrived at—the amount of water o drive a corn mill, which was probably then of about the same size and requirements. unt of water then assumed a technical name, *d'acqua;* the same thing in Lombardy being *rodigine*, in Modena a *macina*, and in the a *moulan*—the same circumstances in various ading to the adoption of a similar unit of nent, which was naturally rather variable. In the amount was generally about 12 cubic feet d, and was supplied by an outlet about 1·60 re, the water issuing free from pressure at the vel. The next step was the introduction of a nit of measurement for purposes of irrigation arges under pressure, the Piedmontese *oncia;* s a rectangular outlet 0·42 ft. broad, 0·56 ft.

high, having a head of water 0·28 ft. above the upper edge of the outlet; its discharge was 0·85 cubic feet per second, and this was the immediate parent of the Piedmontese module, and, as far as we know, the ancestor of all modules.

Piedmontese Modules.—These, the most perfect type of which is that of the Sardinian code, were designed or intended to fulfil the following conditions: that the water should issue from the outlet by simple pressure, that this pressure should be maintained practically constant, that the outlet should be made square in a thin plate having vertical sides, that the issuing water should have a free fall, unimpeded by any back-water, and that the water of the canal of supply should rest with its surface free against the thin wall or stone slab in which the outlet was formed. The following is a description of the general type. The water is admitted through a sluice of masonry, having a wooden shutter working vertically, into a chamber in which the water is supposed to lose all its velocity and is kept to a fixed level mark by raising or lowering the shutter; the chamber is of masonry and has its pavement on the same level as the sill of the sluice, the regulating outlet from this chamber being an orifice 0·65 feet square, having its upper edge fixed at 0·65 feet below the fixed water-level mark of the chamber. Its discharge is 2·04 cubic feet per second. If a larger discharge at one spot be required, the breadth of the outlet is doubled or trebled, the other dimensions remaining unaltered. Such are the sole unalterable conditions or data of this module; all its others seem to have varied very greatly; its sill is sometimes at the level of the bed of the canal of supply, sometimes above it, and sometimes below it, in which case a slight masonry incline was made from the bed down to it; the length and breadth of the chamber vary greatly, the former from 15 ft. to 35 ft., its form being circular, oval, or pear-shaped; the side walls splaying outwards sometimes close up to the sluice, sometimes not till near the regulating outlet, the object being to destroy the velocity of the water within the chamber. The lower edge of the regulating outlet is generally, but not always, placed at 0·82 feet above the floor of the chamber. The paved floor of the chamber is in many cases, but not in all, continued at the same level beyond the outlet.

The practical advantages of this type of module consist, therefore, in having a chamber in which the water can be kept to a constant level, and from which the water can issue under a constant head of pressure through a regulating orifice of fixed dimensions.

Milanese Modules.—The *modulo magistrale* of Milan is the most improved type of Lombard modules, the *modulo* of Cremona and the *quadretto* of Brescia being very inferior to it in design. its principal advantage over the Piedmontese module being the fixity of dimension of almost all its parts; in other respects it resembles it very much, the principal differences being that the water chamber is always rectangular and covered with slabs, and is hence called the covered chamber, that its flooring has a reverse slope in order to deaden velocity, and that the masonry channel beyond the regulating outlet has fixed dimensions also, a portion of it being called the outer chamber. In its general arrangement, the sluice of supply has its sill invariably on a level with the bottom of the main canal, which is paved with slabs near it; the breadth of the sluice is the same as that of the regulating or measuring outlet; the sluice gate is worked by lock and level, being fixed and locked at any required height by catch lock and key. As to dimensions, the covered chamber is 20 ft. long, its flooring having a rise of 0·15 feet in that length, and its breadth is 1·64 ft. more than that of the sluice of supply, that is, 82 ft. more on each side; the lower surface of its covering of slabs or planks is fixed at 0·33 feet above the upper edge of the regulating outlet, which is the height to which the water must be kept to secure the fixed discharge. In order to gauge the water in the chamber, a groove is made in the masonry so as to allow a gauge rod to be introduced within at the sill of the sluice, which will read 2·29 feet of water above the sill, when the proper head of pressure exists; should it read more or less, the sluice gate must be raised or lowered. The outer chamber is 0·66 feet wider than the measuring or regulating outlet, its total length 17·79 ft.; its side walls, which like those of the covered chamber are vertical, have a splay outwards, so that the width at the farther end is 0·98 feet greater than at the outlet end, that is to say, it is there equal in width to the covered chamber. To insure a free fall, the flooring of the outer chamber is 0·15 feet below the lower edge of the outlet, and has besides a fall of 0·15 feet in its length of 17·72 ft.

The total length of the module is nearly 37·75 ft., but its breadth is variable, according to the amount of discharge required. If intended to discharge a Milanese *oncia magistrale*, the Milanese unit, which varies from 1·21 to 1·64 cubic feet per second according to different computations, averaging 1·5 cubic feet per second, the measuring outlet is 0·66 feet high and 0·33 feet broad, under a constant head of pressure of 0·33 feet; the breadth of the covered chamber being 2·13 feet and the breadths of the open chamber 1·15 feet and 2·13 feet.

It is essential to the effective operation of the regulating sluice that the difference of level between the water in the canal and that in the module be at least 0·65 feet; and as the height of water in the latter must be 2·29 feet, the depth of water in the canal must never be less than about 3 feet, in order to allow the module to work properly. The following are the relative levels of the parts of the module referred to the bottom of the main canal as a datum:

	Feet
Water surface in the interior of the module . . .	2·29
Upper edge of the measuring outlet . . .	1·96
Upper end of flooring of open chamber . . .	1·14
Lower end of the same	0·98

Such is the type of the Milanese modules, the dimensions being suitable for a discharge of 1·5 cubic feet per second; unfortunately, in point of fact, the type has been rarely adhered to rigidly, and thus its advantages as a universal, or even as a local water standard have been comparatively thrown away in practice. Its use, however, established a discovery that was at that time very important, viz., that larger outlets gave a greater discharge than that due to the proportion of their section for small ones; it was therefore determined that no single outlet of a module should be made for a discharge of more than eight oncia or 12 cubic feet per second; and when a greater discharge was required, two or more separate outlets were to be used side by side. A gauge post was also found to be necessary in order to enable the water guardians to adjust the sluice accurately.

The principal defect of the Milanese modules is that, owing to the rush of water from the canal, it is nearly impracticable to keep a constant head of pressure on the measuring outlet; besides this, sand and fine silt vitiate the accuracy of amount of discharge.

Such are the comparatively ancient modules, the Milanese *modulo magistrale* being the most improved one of them. Their type has been very much adhered to in modern times; that of Messrs. Higgin and Higginson on the Henares Canal may be considered as the greatest improvement that can be made on them, without departing from that type. In this module, the entrance by a sluice into a chamber for destroying velocity has been preserved, but the exit is an overfall, and hence more susceptible of exact measurement of discharge; the means applied to deaden the velocity of entrance are again different.

The entrance into the channel through a wall is a passage 1·96 feet (·6 mètre) square, regulated by a well-fitting cast-iron door raised by a screw; the chamber is rectangular, 10·37 ft. long, by 7·20 ft. wide below, 9·20 ft. above, the side walls having a batter of 1 in 6. The bottom of the chamber is horizontal and at a level 72 feet below the sill of the entrance sluice. To deaden the action of the water, a partition of masonry grating is built across the chamber at a distance of 4 ft. from the wall, and 5 ft. from the overfall wall of exit, it is 1·37 ft. broad, and has eight slits or vertical passages not cross-barred, each slit being 0·45 feet wide. The water having been deprived of all action by passing through this arrangement, enters the second portion of the chamber nd then passes over a weir having an iron edge 6·56 ft. 2 mètres) long, fixed nearly on a level with the top of he entrance sluice, or 2 ft. above its sill. The discharge equired for irrigation being never to exceed 176 litres r 6·22 cubic feet per second, the depth on the weir sill will therefore never exceed 0·5 feet, the sluice opening being 1·97 ft. square.

There are two small side walls having a batter from above on either side of the sluice entrance, these walls projecting into the main canal, in order to protect the entrance and prevent silt from accumulating there, which otherwise, and perhaps even in any case, would have to be dug out occasionally. In order to keep the chamber in proper working order, a keeper must be employed, and a gauge post erected in the canal, by reference to which he lowers or raises the sluice, and keeps the water in the chamber always at a fixed level.

It is evident that the changes may be rung on this species of module to a great extent without effecting great improvement, by increasing the number and altering the positions of the sluices and overfalls, and modifying the arrangement for deadening the action of the water. This has been done in many cases without much result; it is hence not worth while to bring forward other examples of this type.

Although some of these are complicated in form, as well as much varied in detail, the types are exceedingly simple; they all require the occasional attendance of a keeper for adjusting them according to the variation of pressure; they are made of brickwork and masonry, and consist of a series of open passages and covered chambers connecting orifices and overfalls. It is quite evident that, except under special circumstances, such modules are far behind the wants of an age that economises labour, attendance, and supervision wherever possible.

Self-acting Modules.—A module to be of much use now must in the first place be self-acting. Nor, indeed, is this all. A large number of self-acting apparatus for regulating the supply or flow of water have been designed and used, but three-quarters of them do not answer all the purposes required of them at present. Some are large, some expensive, others involve a large expenditure in protective or additional large chambers, others are complicated and liable to get out of order, and others involve a great loss of head, which, in the case of their application to irrigation canals of small fall, is an insurmountable objection. The worst of them may be said to be those that fail in their main object in producing practical invariability of discharge. With all these objections to deal with, it will not be necessary to do more than make passing comments on the greater number of them, and the principles involved in their design and construction.

We will, however, first mention the requirements of a good module. The first consideration is that under all ordinary circumstances the discharge may be practically constant and correct, that is, should not be liable to vary more than 5 per cent.; secondly, that it should be very simple in construction and application; thirdly, that it should not be liable to derangement; fourthly, that it be portable, easily applied and removed from any portion of the canal without involving much waste or loss; fifthly, that it should not involve much loss of head, and that it should be able to drain the main canal or basin of supply, down to a level of one foot above its bed, and deliver water if need be as high as within one foot of full level in the canal; sixthly, that it be inexpensive, not costing in England more than about 10*l*., and more than 5*l*. additional for its attachments, slabs, cisterns, or chambers, and setting it in place in working order.

There are perhaps only three modules yet designed that may be said to fulfil these conditions; these we will for the present term portable modules, and defer dealing with them until after commenting on the others, or ordinary self-acting modules, some of which have advantages or disadvantages worthy of notice, or have attracted special attention in any way.

Until recently, the power of flotation was the sole means adopted in self-acting modules for obtaining an equal discharge under varying heads in the canal or basin of supply. The simplest manner of applying this is perhaps in attaching or fixing the pipe or pipes of supply to the float itself, thus insuring a fixed head of pressure on their entrance, however much the surface level in the supplying basin may vary. So far as this, the modules depending on this principle appear excellent, but unfortunately all of these seem defective on account of other considerations. For instance, in '*the suspended opening*,' where the water enters through two horizontal pipes into the body of the float itself (which is kept submerged to a sufficient depth by weights) and passes out of it through a vertical pipe fixed on to the lower side of it, the vertical pipe has to slide up and down in a species of stuffing-box in a masonry platform below, so as to discharge itself clear of the water in the main canal, and prevent the latter from leaking through into the well below the platform, from which the moduled water alone should be drawn off. This is plainly a contrivance that would be defective for purposes of irrigation ; should the vertical pipe not slide easily into the stuffing-box, the power of flotation may be entirely neutralised ; should it be too easy, there will be leakage, and perhaps to a serious amount ; the loss of level is seriously great, the delivery level never being higher than 1 ft. above the bed level of the canal. Modifications of this contrivance, having in view the abolition of the loss of head, have been made by using syphons either erect or inverted, instead of the sliding vertical pipe. They certainly attain that object, but introduce new defects sufficient to render them less useful for purposes of irrigation than the original suspended opening ; they are expensive, and difficult to manage, the action of the syphons is liable to be stopped by accumulation of air, and their discharge is not only practically low in comparison with their theoretical calculated discharge, but also is variable, as they are very liable to foul ; their adjuncts, chambers around and attached, are expensive. The vertical pipe arrangement of the suspended opening is the principle on which many so-called water-meters, used by water companies for discharging water in large quantities, have been constructed.

The same principle has been adapted to purposes of irrigation in the module of M. Monricher, on the Marseilles Canal, constructed between 1839 and 1850 ; it is intended to supply irrigation channels having discharges of from 1·06 to 4·24 cubic ft. (30 to 120 litres) per second as a constant supply. The details of construction are as follows : A masonry reservoir 11·15 ft. by 14·76 ft., having its bottom at a level approximately 3 ft. below the bottom of the canal, is connected with it by a rectangular masonry passage having a horizontal masonry covering at the level of low-water surface in the canal; a transverse masonry wall stops the action of the water, which enters the reservoir afterwards by two passages, one on either side, the wall and passages taking up a portion of the reservoir space. Beyond two pairs of grooves for putting in stop-planks for shutting off the water entirely during repair, there is no other sluice or check to the free flow of the water. In the centre of the rectangular reservoir is a cylinder of masonry, having an internal diameter of 2·30 ft., being 1·00 ft. thick, the bottom of it being approximately 2·00 ft. below the bottom of the reservoir, and its top edge about 2·00 ft. below low-water canal surface. An iron cylinder is made to fit the internal masonry closely, and to slide up and down it, and to hang by a rod and adjusting screw to a wooden bar supported by two wooden floats placed clear of the masonry, each of which is 1·64 ft. deep, 1·31 ft. broad, and 5·24 ft. long. There are also two vertical bars in the reservoir outside the floats, up and down which the bar slides on rings. The adjusting screw enables the iron cylinder, which is about 5·8 ft. long, to be placed so that its upper edge may be set at any depth below the water surface, so as to produce any required discharge. This, when once fixed and checked, is never altered. The whole is inclosed in a locked building.

The water of the reservoir therefore enters the iron cylinder above, and flows out below; the lower water being divided from the rest of the reservoir above by masonry partitions, it rises through the masonry passage thus made into the masonry water-course or irrigation channel, the bottom of which is not more than 75 below that of the bed of the main canal; the chan section is 2·00 ft. by 1·31 ft., having a small enlar ment 3·28 ft. square at the commencement of the ch nel. Plans and details of the module here describ are given in Moncrieff's 'Irrigation in Southern Euro

In this module, therefore, the section of outlet, that of the iron cylinder, is constant; the edge of cylinder rises and falls by flotation; the loss of level as small as can be conveniently obtained in modules this principle of design, and if the cylinder could, wi out much care or superintendence, be made to w well in the masonry without leakage or friction to detrimental extent, as stated by the engineers of Marseilles canal, the amount of inaccuracy of discha cannot be great. It would doubtless be an impro ment were some arrangement applied to this mod for preventing silt from entering the reservoir, wh must be liable to interfere with the working of cylinder, and produce a greater deteriorating effect this module than in many others. The masonry port of the module would require good workmanship, the putting together of the whole in good working or considerable care. It is, therefore, rather expens and certainly has not the element of portability.

The suspended plug is, like the suspended openin principle that has been adopted for modules and app in a very large variety of ways, some of which inv complexity of parts and details. Its main principl probably slightly more modern than that of the lat both are decidedly old, but as these old contriva are perpetually being re-invented, a brief descriptio their principles may be of use to some, while comments on them may deter others from wasting their energies on an idea that appears to have been fully worked out.

The simplest case of the suspended plug is this. A circular orifice is fixed in a floor at the level of the bed or bottom of the canal or reservoir, and a plug of varying section is suspended in it, being attached to a float that rises and falls with the surface of the water; the annular water passage thus left open is made to discharge equal quantities under varying heads by proportioning the section of the plug throughout its length; the area of the annular opening being in inverse proportion to the velocity of discharge. To insure a free fall there is a well below the floor into which the water falls to a depth equal to that of the depth of the floor from high-water level of the canal. The depth of the float and its attachment to the plug prevent its acting at a depth of water of less than one foot in the canal. These two points, which are serious objections to the adoption of this module on irrigation canals, have been much modified in the more complicated modules constructed on this principle, which will hereafter be mentioned. As to the plug itself, it is either a conoid hung in a circular orifice, or a flat-sided conoid of equal thickness in one direction hung in an orifice which is rectangular laterally and of circular curvature transversely; in the latter case a fixed area is left open on the flat sides of the plug which has to be allowed for in the calculations for the section of the plug. The diameter of the plug in the case of the conoid is obtained by calculating the areas required to pass the required discharge for various heads of water, as, from 1 to 10 ft. for every three inches, and deducting these from the fixed area of the orifice, the remainders are then the areas of the circular sections of the plug for those depths from which the diameters are obtained. The flat conoid can be made of the same lateral section for all discharges, the thickness of the flat sides being increased in direct proportion.

The following is an example of a module designed on the suspended plug principle, and is perhaps the simplest application of it in actual practice. It was designed by Don Juan de Ribera, projector of the Lozoya canal, or canal of Isabella Segunda, and is used on that canal with good effect.

It is so arranged that the size of the outlet diminishes when the head of water increases. The module itself is a long tapering bronze plug, 0·524 ft. in diameter at its lower end, and is attached to a circular brass float above, which floats freely in the water of a masonry well 3·38 ft. by 3·94 ft. square and 4·16 ft. deep; at the bottom of this well, which is on a level with the bottom of the main canal and the rectangular masonry passage connecting them, is a circular orifice 1·56 ft. in diameter, within which the lower end of the module is made to work vertically, the plug and plate being of bronze to prevent rust. Below this well again is a second one, into which the water falls after having passed through the ring between the orifice and the plug. The entrance of the rectangular passage leading from the canal, which is only about 3 ft. long, is protected from silt by an iron grating, and is covered in at the top by slabs to the full level in the canal; the well is also covered in by a locked iron trap-door. In this module friction is reduced to a minimum; the module hangs freely from the centre of the float, and can be slightly raised or lowered in order o diminish or increase the discharge passing through the ing or space between the edge of the orifice and the lug; but when a constant discharge is required it is inally properly adjusted, and then entirely left alone. The float is about 2 ft. in diameter, having a thickness n the middle of about 0·9 ft., and at the edges of 0·6 ft.

This module discharges one cubic mètre (35·3166 cubic feet) per hour, and is hence styled an horamètre, he discharge being ·2777 litres, or ·0098 cubic feet per second. The curve of the module or bronze plug is such, hat the roots of the vertical abscissæ vary inversely as the differences between the squares of the radius of the orifice and of the horizontal co-ordinate. Hence, if the required discharge is given with a head of water of one mètre, when the diameters of the orifice and plug are respectively ·20 and ·1653 mètres, then, if the head of water be reduced to ·81 mètres, the diameter of the plug at the level of the orifice must be ·1610 mètres, as

$$\sqrt{1} : \sqrt{\cdot 81} :: (20)^2-(\cdot 1610)^2 : (\cdot 20)^2-(\cdot 1653)^2.$$

The lengths corresponding to the different diameters of the taper of the plug will, for a constant diameter of orifice of ·20, be as follows:—

Depths from water surface	·10	·12	·16	·41	·77
Diameters of plug	·00	·0585	·0912	·1211	·1374
Depths from water surface	1·26	1·90	2·71	3·71	
Diameters of plug	·1480	·1554	·1610	·1653	

The principle being that the velocity of discharge through an orifice varies with the square foot of the head of water; thus, taking $R\ r$ to represent the radii of the orifice and plug respectively, the discharge per second

$$Q = c.\pi(R^2-r^2)\ \sqrt{2gH},$$

H being the head of water, the value of the experimental coefficient, *o*, being for this case deduced, from a series of experiments of Don Juan de Ribera, to be ·63, in accordance with similar results obtained in ordinary practice in parallel cases. This is probably the module in most perfect accordance with theory yet designed; it is, however, of small dimensions, and hence likely to be much affected by even the very small proportion of silt that would pass through the grating. Its principal defect is, that the loss of level necessarily involved in it in order to obtain a free fall would render it inapplicable in a very great number of cases, where even a few inches of fall are of extreme importance.

The modifications of this type of module consist in putting the float in a separate chamber, which thus becomes a silt trap, and relieves the orifice from being affected by silt, the connection between the float and the cone being either a chain passing over two runners or a lever: in these cases the plug is reversed, having its broader end upwards; the friction involved affects the working of the module and its accuracy of discharge, and, in the case of levers, the lengths of the arms modify the quantities employed in the calculations of sections of discharge. In some cases the form of the lower well assumes various forms, having for their object the reduction of the loss of level existing in the more simple type. It is extremely doubtful whether any of these modifications can be considered advantageous on the whole.

Rising and Falling Shutters.—Contrivances of this type are generally suited for large quantities of water where great accuracy is not required. The falling shutter, as used on canals in England or Scotland, is an oblique shutter hinged below, and raised or lowered in front of an opening in the side of the canal by two floats in recesses, the water passing over the upper edge of the shutter in a tolerably uniform volume. The rising shutter is a vertical shutter in front of an opening in the side of and down to the bottom of the canal; it is raised or lowered by means of a float attached to it by a chain passing over a runner, the float being in a separate chamber, and having trunnions and friction rollers running in curved grooves or recesses on each side of the chamber; these curves require very accurate construction in order that the discharges may not vary under different heads. Shutters of this description having pressure on one side only are very liable to stick, and get out of order; they are hence very inferior in practice, although new ones under favourable conditions can be made to work very accurately.

The above three types comprise the whole of the non-portable self-acting modules that have been much used in practice to good effect.

Portable Self-acting Modules.—In this class we comprise such modules as could be removed or replaced without much difficulty or loss. There are three such modules that have attracted attention, though there are probably others not so well known.

Carroll's Module.—The first is that of Lieutenant Carroll, of the Royal Engineers; its principle is exactly that of the well-known draught regulator: the pressure of the water is made to regulate the opening in the one case in the same way as an increased draught of air is made to partially close the opening in the other; and the application of the principle is excellent for the intended purpose—it can be made almost entirely of iron, is simple, effective, and admits of removal without causing much loss or expense. Drawings of this module are given in the Rurkhi Professional Papers.

Anderson's Module.—The second is a modification of the hydraulic lift regulator, invented by the late Mr. Appold, used to regulate the descent of hydraulic passenger-lifts under a variable load; it has been applied to its new object by Mr. W. Anderson, of the firm of Eastons and Anderson, and in some respects resembles the module of Lieutenant Carroll: the velocity through the pipe of discharge is, however, in this case made to move a suspended plate of curved form, in front of an opening also fixed inside the pipe, and the opening is therefore reduced by increase of velocity.

In December 1866 some experiments were made with a 6-inch Appold regulator at the request of Col. Smith, consulting engineer to the Madras Irrigation Company, and of Mr. Clark, hydraulic engineer to the Municipality of Calcutta.

In one experiment, in which the regulator was used to discharge water from a tank 7′ 7″ square internally during 13 minutes, the surface of the water in the tank sank as follows, in one-minute intervals: $3''\frac{3}{16}$, $3\frac{1}{4}$, $3\frac{1}{\ }$ $3\frac{1}{4}$, 3, $3\frac{3}{16}$, $3\frac{1}{8}$, 3, $3\frac{1}{16}$, 3, $3\frac{1}{16}$, $3\frac{1}{8}$, $3\frac{3}{8}''$;—the total quantity discharged in 13 minutes was

$$=7'\ 7'' \times 7'7'' \times 3'\ 5\tfrac{1}{2}'' = 197{\cdot}22 \text{ cubic feet,}$$

or about 15 cubic feet per minute.

In the second experiment, the surface of the water in the tank sank as follows, in one-minute intervals: $3''\frac{5}{16}$, $3\frac{6}{16}$, $3\frac{3}{8}$, $3\frac{1}{2}$, $3\frac{6}{16}$, $3\frac{11}{32}$, $3\frac{3}{8}$, $3\frac{3}{8}$, $3\frac{3}{8}$, 3, $3\frac{5}{16}$, $3\frac{1}{4}$, $3\frac{3}{16}$ $3\frac{1}{4}$, $3\frac{3}{8}$, $3\frac{3}{16}$, $3\frac{9}{16}$, $3\frac{11}{16}$, $3\frac{5}{8}$, $3''\frac{5}{8}$; the total quantity discharged in 20 minutes was

$$=7'\ 7'' \times 7'\ 77'' \times 5'\ 8'' = 323 \text{ cubic feet,}$$

or about 16·13 cubic feet per minute.

In the latter case the heads at the beginning and the end of the discharge over the centre of the pipe were 22·8 feet and 12·24 feet.

In each case the same regulator or module was used; its square aperture on the delivery side was $5''\frac{11}{32}$ high, and $3''\frac{11}{16}$ broad, or a section of $20''\cdot35$; the swinger was $3''\frac{1}{8}$ wide, nearly touching at top and bottom; the case $5\frac{1}{4}$ wide, and the area for water passage $8\frac{9}{16}'' \times 1\frac{3}{8}''$ $=11''\cdot77$ in section.

Two of these Appold's modules are it is believed in use on the Tumbaddra canals of the Madras Irrigation Company. From the convenience of form that this module possesses, being self-contained, and externally a simple iron tube, with an enlargement like a box in the middle of it, that admits of being attached or detached from an orifice very rapidly, it would appear to be preferable to that of Lieut. Carroll, and less liable to damage in transit.

The equilibrium module.—The third portable self-acting module is the design of the author of this work, and is named the Equilibrium Module. It consists in the first place of a box or chamber, having an entrance and an exit orifice, and one or two air-holes above; within this box is the pipe leading horizontally from the entrance orifice for a short distance and then turning vertically upwards; this is terminated by a dead end, but has two or four slits or narrow vertical openings in the sides, through which the water passes when the module is open and working. There is at all times enough water within the chamber to rise above the level of these openings, and to work a float above them; this float, working vertically, raises or lowers the cap that slides over the head of the pipe, and gradually opens or closes the slits in accordance with the variation of the level of water in the chamber; which is below the low-water surface of the canal or tank of supply. The form of construction adopted reduces to a minimum the depth from the water-level within the chamber to the openings, which discharge above the sliding collar, and thus causes the loss of head to be unimportant.

This is also a small module, possibly only a quarter larger than the Appold module before mentioned, and equally convenient as regards portability; it is simple in design, being actually little more than one of the old types of equilibrium steam valve applied as a module in a chamber under pressure: it could, however, be made of any size, the adjustment of the sizes of the orifices of entrance, of exit, and of the slit-openings being the only important points of variation. It might also, for rough purposes, be made generally of stone-ware, and the pipe would then be square in section and have only two slits, the other two sides forming part of the box. This module slightly resembles the old cylinder sluice, which is also a modification of a double beat steam valve; the latter, however, is not so simple, being far more liable to choke or get out of order, one of its valves working within the pipe, and it is therefore not so effective in constant use as any of the three already mentioned.

Modules have been here treated as principally intended for regulating irrigation; the reason of this is that the requirements are then more stringent in many particulars. A module for water supply of other kinds, (frequently termed a water-meter, although possessing regulating power) generally acts under greater head and freedom from silt, and may hence be of coarser design.

2. THE CONTROL OF FLOODS.

The prevention of the submergence of land by inundations from overcharged rivers, and the drainage from marshes and submerged land of the water that has been allowed to accumulate over it, are kindred engineering problems that appear at first sight to present but little difficulty. Their theoretical solution, when merely on a small scale, is ready and simple; on a larger one, however, the practical details brought into these problems affect them to such a degree, that, although the principles involved cannot be said to be subverted, their carrying out is forced into a comparatively new form.

Land liable to submergence from a river is lower than the extreme flood-level, and in open communication with it; the remedies consist, therefore, either in lowering the extreme flood-level in the channel by providing other passages for the water, partially diverting it, or dredging out a deeper channel, or by warping up the land liable to submergence, or by cutting off possible communication in flood stages between the river and the land by means of embankments. Submerged land, again, remains in that condition for want of sufficient natural outfall; an outfall has, therefore, to be cut, tunnelled dredged, or enlarged to a sufficient extent to allow gravity alone to do the work, should that be possible or economically sufficient; in other cases pumps are indispensable.

Imagining, then, the case to be one of an area of a few hundred acres, liable to inundation from a river with a moderate declivity, the application of these principles involves generally but little difficulty as regards engineering, and becomes a local economic question, rather than an engineering practical problem. Putting the case again on a large scale, a vast tract submerged by the floods of a river having a very small declivity—the usual condition when large areas are submerged—the dimensions entering into the works that would be necessary in adhering rigidly to the above principles become so large, that their complete execution is positively impossible in most cases. Let us adduce the embankments of the Ganges, the Mahanaddi, the Po, and the levées of the Mississippi, which are not and never can be complete and sufficiently developed to insure, by means of themselves alone, the absolute protection of all the lands on their banks from the devastating effects of extreme floods.

To this it might, though perhaps rather thoughtlessly, be replied, that very extensive works may be so costly as to be impossible, but that the application of the principles need not vary. It is, however, in point of fact also a matter of modification of the application of principle.

The case of a comparatively small river supplying the flood, very nearly, and in most cases totally, limits the consideration of the flood to its principal point, the extreme flood-level; the catchment area of a small river being tolerably uniform supplied throughout the rainfall, its upper portions do not require very special consideration; the declivity of the small river being tolerably rapid, the condition of the lower ranges of the river does not affect the matter to any very important degree. Remote local conditions being comparatively disregarded, and it being possible to cope with the flood at the required point both successfully and economically, the works involved are necessarily small.

On a large scale, on the contrary, the extreme flood level, the nature, causes, and duration of the flood may be greatly affected by any of the physical conditions of the entire catchment area of the region watered by the river and its tributaries, from the loftiest hill on the watershed down to the currents of the ocean, miles beyond the river's mouth; and as these physical and meteorological conditions vary greatly throughout large countries, a perfect knowledge of them as regards the country under consideration is absolutely necessary in order to arrive at sufficient information to enable one to propose measures for the mitigation of the effects of the flood. In other words, the natural drainage of the whole region under any state or circumstances, as well as everything that practically affects it in any way, must be thoroughly known in detail.

It will be unnecessary to dilate on the physical laws and conditions of our sphere, matters best understood from studying the larger works on physical geography to be found in any good library: and a knowledge of these will hence be assumed. The detailed knowledge, however, of the special physical conditions and rainfall of the region under consideration, may possibly not be obtainable from any book whatever. It is not sufficient to possess meteorological statistics of observations taken at a few towns in the valley of the river, and at one or two points or villages on the hills; it is needful to know definitely what is the greatest amount of rain that ever falls in the region, the greatest area in it over which rain falls at any one time, and which portions of the area they are likely to be at any time; or generally how much water, when, and where, so that it may be practically accounted for. Detailed observations taken for many years at a very large number of meteorological stations are therefore requisite, and it is almost painful to reflect in how very few instances are even a moderately small number forthcoming. As a notable exception to this apparent apathy, may be noticed the large number of meteorological stations in the United States of America, and the large sum annually spent by their Government in obtaining such information. Besides the meteorological data, a correct detailed topographical and hydrographical knowledge of the whole of the catchment of the river, based on engineering surveys and velocity observations, is necessary in order to determine the discharge and the flood level of the river at any time, and under any possible meteorological condition. Having all this information we are enabled at any time to state what will be the results in rise and amount of discharge of the river, corresponding to and resulting from any special rainfall lasting for any usual or unusual time over an area, or detached portions of area within the catchment basin, and the evils to be contended with are then fully known before commencing to deal with them and attempting to mitigate their ill effects by means of engineering works of any sort.

To this it may be replied, that the expense of c taining all these data, and especially those of a hydrographical and topographical nature, which cannot be done except by skilled hydraulic engineers, must necessarily be very large; and if after all this it should be discovered that under any circumstances no engineering works could remove the evils, or even moderate them to an important extent, the expense would have been uselessly incurred.

Not entirely so. Even should no works be attempted, the information can be made use of in the protection of human life, and in thus mitigating the fearful effects produced by sudden and devastating floods. The extent of land liable to submergence under certain conditions of rainfall in any part of the country being known to a practical certainty, the telegraph can be employed to warn the inhabitants of an impending flood, and allow them to save at least their own lives, and perhaps also that of their cattle and movable valuables. It may be urged that the terrible catastrophes resulting in large loss of life generally commence with the bursting of an embankment, which happens before the flood overtops it; doubtless it is so, but it would be an important part of the topographical knowledge to ascertain to what height of flood these embankments, which, when in sound condition, are in most cases only sufficient protection against very moderate floods, are practically safe. Timely warning could, therefore, be afforded in any case, and the inhabitants would be spared the terrible infliction, in case of flood, of watching the waters rising, and not knowing either how much higher they might rise, or to what height of flood their dams might be safe.

But to proceed to the main object, the protection of

...arge the w
into the rivers by
doubt, a certain a
certain height of t
sufficiently evident
established in practi
to be a remedy, and
the cause of disaste
pressure on the em
channels of the rive
allowed to silt themse
also the flood level cor
discharge, is allowed to
of the evil. Beyond t
these circuitous emban
ceedingly costly. These
have sufficiently demons
the means that are occas
works to those of large e

Before entering into
better principles, let us fi
a flood under circ...

ason, has set in tolerably mildly; the river swells, creases in depth and velocity, and is discoloured at st; this afterwards passes away, and the water then ns steadily, tolerably clear. The rain increases in the ains, and the sky gives prospects of a heavy storm in e direction of the uplands of the river. Let us watch e effect. The rainfall of the plains, in fact the down-our all around us, increases the depth and the velocity f the river, but its colour is unchanged, in fact it seems early pure. Suddenly a roaring of waters, like that elow an overtopped mill weir, is heard, and up stream e notice a white line of foam approaching; three or four minutes, and a flood sweeps by on the surface of the river, like a wall of water 3 or 4 feet in height; all this water is muddy and dark with detritus. The waters after this again rise still higher for twenty-four hours, but are yet muddy; the low-lying lands near the river are submerged. We learn afterwards that a considerable fall of rain has taken place in the uplands of the river, and that towns and villages in the plains have been inundated.

Such is the flood, its subsidence is a matter of less moment; and such is the type of flood to which those causing serious catastrophes generally belong. In this case we fully satisfy ourselves of the rationale of the flood; the lowland water rises steadily and clear, going perhaps one mile an hour; the upland water comes down with a velocity of nearly six miles an hour and charged with silt—for where else is this velocity and this silt to come from except from its course in the hills?—and tops the lowland water; the combination of waters gradually decreasing in speed spread themselves out over the land in the first locality, where the form of channel and banks admit of it, and perhaps in more than one, extending even for miles beyond the natural bed of the river.

How is such a flood to be controlled? Apart from the Dutch principle, already shown to be fallacious on a large scale, there are only two methods, either or both of which can be adopted. The first, the improvement of the whole of the natural drainage lines of the country to such an extent that the velocity of the waters may under such circumstances be increased throughout the whole course of the river, and a little beyond it, into the sea or next large river, and so that the natural bed, thus improved, may be sufficiently large to carry off any previously known flood, without being exceeded. The second, any means of separating the upland from the lowland waters, holding or retarding either the one or the other, or portions of either one or the other, and providing for their discharge either separately in different courses, or at different times in the same watercourse.

Let us first indicate the nature of the works requiring execution, when the former principle alone is adopted: the perfecting of the natural lines of drainage.

The ultimate free delivery of the water into the sea, or any way entirely free of the river, is perhaps the most important point of all, the low-lying lands on the lower ranges of the river being there more extensive than elsewhere; to insure a free delivery, the main outlet of the river should be carried out to deep water protected on both sides by banks or jetties, against the shore currents, and so directed as to avoid as much as possible the retarding influence of sea storms; through the delta, also, a single direct channel of properly determined dimensions should be made and protected by embankments; by these means the mass of water will, in forcing its way in this course to the sea, scour for itself a deeper bed at the outfall and throughout the lower ranges of the river, and carry off floods more rapidly, improving the river continually. A further advantage from confining the river to one channel is that of the reclamation of a large amount of land previously occupied by marshes, as well as by the numerous old channels of the delta.

In the middle ranges of the river the works to be adopted are all such as will promote a more rapid discharge: the enlargement of the bed wherever it is contracted or narrowed; the removal of obstacles, rocks, small islands, silt deposits, shoals, or anything that impedes velocity; the straightening of the course wherever it can be done to good effect; the prevention of the deposit of silt in such places as would be objectionable; the deepening or dredging of the bed in the requisite places: the whole course to be put under a regimen that would remain constant generally, and besides continue to improve itself by scouring in contra-distinction to its former habits of silting up and causing its flood levels to rise.

In the uplands, all the works which should be constructed are those that have for their object the control of the detritus washed down, and the prevention of its deposit at unfavourable spots. If the silt could by any means be entirely prevented from being carried down into the middle ranges of the river, or into the plains, it would be a great achievement; but this being hardly possible, palliative measures are perhaps all that can be adopted. Besides this, the hills might be covered with thick plantations, which, catching the rainfall, would

[illegible]

[illegible] separate the low and [illegible] as [illegible] as possible. In order to [illegible] drainage [illegible] of the plains [illegible] such [illegible] [illegible] and improving [illegible] cut off from [illegible] and [illegible] of the main [illegible] some point where it may be advisable to discharge [illegible] through regulating sluices, or if preferable some artificial reservoirs or lakes. These latter would insure the additional advantages of perfect entire drainage of the country, and of having a water-supply for irrigation

The adoption of the two principles thus described would insure a perfect remedy and an effective control of floods under any practicable circumstances. That such works would necessarily be expensive there is no doubt whatever, but they would still be less costly and more effective than the continuous lines of embankment designed on the fallacious principles before quoted; the works again would improve the rivers instead of deteriorating with lapse of time, and the gain by reclamation and irrigation would, apart from other collateral advantages, yield a profitable return.

3. TOWAGE.

Recent experiments show that the pull on the tow-rope of a barge is, within practical limits, proportional to the square of the speed, and that it varies widely according the form of the barge; assuming then a general formula,

$$R = b\,T\,V^2$$

where R is the resistance in lbs.,

$T =$ the displacement of the barge in tons,
$V =$ the velocity through the water in miles per hour,

and b is a coefficient depending on the form of the barge.

It has been found that for the small and bluff barges of about 70 tons employed on the Thames, and for limits of speed not exceeding 5 miles an hour, the coefficient $= \frac{1.5}{\sqrt[3]{T}}$ or generally about 0·369; and that for well-formed barges of medium size,

$$b = \frac{0{\cdot}75 \text{ to } 1{\cdot}00}{\sqrt[3]{T}} \text{ or generally about } 0{\cdot}170\,;$$

and for the best ship-shaped barges with good lines, as those employed on the Danube wire-rope system, which have a length about eight times their beam, and are about [illegible] tons' displacement,

$$b = \frac{0{\cdot}5 \text{ to } 0{\cdot}6}{\sqrt[3]{T}} \text{ or generally about } 0{\cdot}109.$$

The limit of speed for ships will be about 10 miles an hour, and beyond these limits the resistance *R* would vary with the fourth power of *V*; but within the assumed limits, calculations may be made on the above data.

The number of horses required to draw a train of barges may hence be readily deduced. The best performance of a draught-horse working 8 hours a day, is assumed to be at the speed of 2½ miles per hour, when he will exert an average pull of about 120 lbs.; substituting this value in the above formula, we obtain for the tonnage that one horse will pull at the speed of 2·5 miles an hour in still water,

$$T = \frac{R}{0{\cdot}17\,V^2} = \frac{120}{0{\cdot}17\,(2{\cdot}5)^2} = 113 \text{ tons.}$$

In a current the resistance or the pull upon the tow line will increase as the square of the speed through the water, but the horse in this instance moving over the ground is going at a less speed than that of the boat through the water; and this is an important distinction which must not be overlooked in estimating the effect of a current. The mode in which the necessary correction must be effected will be best illustrated by an example.

Referring to the last example, let us assume that the barge of 113 tons' displacement encounters an adverse current of 1 mile an hour, and it is required to know the reduced speed at which the horse will then go, assuming him to be performing the same average work per hour.

In the last case, the said work in mile-pounds was $120 \times 2{\cdot}5 = 300$ mile-pounds per hour; in the present case the pull upon the rope will be proportional to the square of the velocity through the water (V), and the pull the horse is capable of pulling will be inversely proportional to the velocity at which he is travelling (v); and the difference between these two velocities will be the speed of the current (v_1); we have therefore

$$V = v + v_1 \text{ where } v_1 = 1 \text{ mile per hour}$$
$$R = {\cdot}17\ T\ V^2$$
$$\text{and } Rv = 300 \text{ mile-pounds per hour}$$
$$V^2 (V \pm v_1) = 15{\cdot}4$$
$$\text{whence } R = 19{\cdot}4\ V^2, \text{ and } V^3 - V^2 = 15{\cdot}4.$$

Solving which we obtain $V = 2{\cdot}86$ miles per hour, the speed of the boat through the water; and the speed past land, or rate at which the horse is going, will be $2{\cdot}86 - 1 = 1{\cdot}86$ miles an hour.

It will be observed from this example that the influence of the current is relatively less important when horses are employed, than when steam-tugs, either paddle or screw, are used, the reason being that in the latter case the reaction operates upon the moving current, whilst in the first case against the immovable tow-path. Thus in the present example, if the power, instead of being an animal moving on the tow-path, had been a steam horse in a tug, the speed through the water would be the same, whether the water was still, or ever so rapid

a current. In this instance 2·5 miles an hour the sp
past the land, which is the useful result, would be redu
to 1·5 miles an hour in the case of the tug, instead of
1·86 when horses are used.

The difference of conditions will be more stron
marked if we assume the current to be 2·5 miles an h
because then it is obvious that the steam tug, capabl
moving through still water at that rate, would sim
simply maintain its position if it encountered such a c
rent; and although the paddle-wheels or screw wo
be revolving at the same rate as before, the only re
of their effects, namely, the maintenance of position
the boat, would be equally attained if she drop
anchor; in short, the whole power exerted would
thrown away. In the instance of the barge towed
horses, on the other hand, the whole power exer
would be utilised; and it may be shown by the sa
reasoning as in the last example, that the 113 ton ba
would be towed by one horse against a current of
miles an hour, at the rate of $1\frac{1}{6}$ miles an hour.

Obviously the same reasoning would apply, whet
the motive power on the tow-path were horses c
locomotive, or whether the tow-path were dispen
with, and a rope were laid down in the bed of the ri
and coiled round a drum in a steam-barge in the man
now generally admitted to be the most economical m
of conducting heavy traffic at a slow speed in river
rapid current and on still-water canals.

From the above we may conclude that, in orde
tabulate for the effect of a current on the diminutio
increase of speed of a horse, we have to calculate
increased or diminished value of V_1 the velocity thro
the water, and apply it in the general formula—

$$R = bT\,V^2$$

inserting different values for the constant b, which lie between ·109 and ·369, according to the form of the barge.

In the above case R = 120 lbs. for a draught horse; but for other animals corresponding values of R, with reference to their best continuous speed, can be applied.

Assuming a case of a current of 3 miles an hour, and that the ordinary limits for the speed of the horse in towing a load with and against stream, are 4 and 1 mile an hour respectively, the velocity through the water becomes 1 and 4 miles an hour, and the loads 706 and 44 tons, the horse performing the same average work, but executing the average pull of 75 lbs. with stream, and 300 against it.

The values required are given for the limits in the following form.

For barges having 113 tons' displacement, and a coefficient b = 0·17, the results are as follows:—

With a current v_1			In still water	Against a current v_1		
v_1 = 3·0	2·5	1·0	0	1·0	2·5	3·0
V = 1·79	1·88	2·2	2·5	2·86	3·66	3·97
v = 4·79	4·38	3·2	2·5	1·86	1·16	·97
V_1 =	5·00	3·5	2·5	1·5	0	−0·5

Here v_1 is the velocity of the current, whether favourable or adverse.

V is the velocity of the barge through the water.

v is the speed of the horse.

V_1 is the velocity through the water for the case in which a steam-barge is used, and is given to illustrate the comparison. The foregoing formulæ on towage were denounced by a reviewer in 'The Engineer;' apparently the critic had confounded formulæ for resistance with those for horse-power; yet a reply forwarded to the denunciation was not published in the paper referred to. A more important paper would have been great enough to acknowledge a blunder: the attempt to shelve it has not succeeded.

4. On Various Hydrodynamic Formulæ.

The results of the various formulæ given for determining discharges, according to various authors, vary very greatly; and it is hence interesting to examine them in a tabulated form in comparison with measured discharges.

The following data of comparison are given by Mr. David Stevenson, and by Captains Humphreys and Abbot; they apply to four cases of river discharge, from a small stream up to the Mississippi; thus including all limits within which such formulæ are required.

1. For a small stream of 24 cubic feet per second. Mr. David Stevenson made careful measurements, and velocity observations, and compared the deduced results with the results of formulæ, thus:

1. Deduced discharge	24·22
2. By Dubuat's formula	32·50
3. By Robinson's formula	36·90
4. By Ellet's formula	46·40
5. By Beardmore's tables	38·92
6. By Downing's formula, coefficient 1·00 .	41·23
7. By Leslie's formula, coefficient 0·68 . .	28·04

2. For a river of 2424 cubic feet per second.

vid Stevenson and Dr. Anderson made velocity ervations on the Tay, at Perth, and the comparisons thus:

1. Deduced discharge	2423
2. By Dubuat's formula	2987
3. By Robinson's formula	2560
4. By Ellet's formula	2033
5. By Beardmore's tabular formula . .	2609
6. By Downing's formula, coefficient 1·00 .	2769
7. By Leslie's formula, coefficient 0·68 . .	2083

It is unfortunate that in these two cases the hydraulic ta, which would enable us to extend the comparison other formulæ, are not given.

3. For a large river of 31 864 cubic feet per second; e data of the Great Nevka, measured by Mr. Destrem re as follows:

Area of section	15 554 sq. feet;	width	881 feet;
discharge	31 864 c. feet;	perimeter	893 „ ;
mean velocity	2·0486 ft. per sec.;	max. depth	21 „ ;
hydraulic slope	0·000 014 87:		

The following are the results due to these data callated by various formulæ and compared with the tual discharge:

1. Deduced discharge	31 864
2. Young's coefficient	21 102
3. Eytelwein's coefficient . . .	23 389
4. Downing's coefficient . . .	25 031
5. Dubuat's formula	16 931
6. Girard's formula	22 491
7. De Prony's canal formula .	22 357
8. Young's formula	19 777
9. Dupuit's formula	23 456

10.	St. Venant's formula . . .	21 811
11.	Ellet's formula	13 807
12.	Humphreys' formula . . .	39 938

4. For a very large river, the Mississippi at Carrolton, the measured data at high water in 1851, were,

Area of section	193 968 sq. ft.;	width	2653 feet;
discharge	1 149 948 c. ft.;	perimeter	2693 " ;
mean velocity	5·9288;	maximum depth	136 " ;
hydraulic slope	0·000 020 51;		

and the corresponding results, which are kept in terms of mean velocity to lessen the figures, were,

1.	Deduced mean velocity . .	5·9288 feet per second
2.	Young's coefficient . . .	3·2400 " "
3.	Eytelwein's coefficient . .	3·5898 " "
4.	Downing's coefficient . .	3·8434 " "
5.	Dubuat's formula . . .	2·7468 " "
6.	Girard's formula . . .	4·8148 " "
7.	De Prony's Canal formula .	3·7271 " "
8.	Young's formula . . .	3·2741 " "
9.	Dupuit's formula . . .	4·8752 " "
10.	St. Venant's formula . .	3·4907 " "
11.	Ellet's formula . . .	3·0451 " "
12.	Humphreys' formula . .	5·8903 " "

A careful examination of these results in four cases of rivers cannot fail to be instructive.

In the fourth case, a very large river, Humphreys' formula is by far the most correct, and then come in order of correctness, Dupuit, Girard, and Downing, while Ellet and Dubuat are again the worst. In the third case, Downing is most correct, then Dupuit, afterwards Humphreys' formula, and Ellet and Dubuat again the worst. In the second case Ellet and Dubuat

ıe worst, and the best are Robinson, Beard-
d Downing. In the first case Leslie and
ıre best, and Downing worst.
l be understood that the formula mentioned as
's, being more familiar to many under that
really that of d'Aubuisson, applied to English
, without any modification.
cting the results, the formulæ may be thus
l :—

		Worst Formulæ	Best Formulæ
ream	24	Downing	Leslie and Dubuat
ver	2 424	Ellet and Dubuat	Robinson, Beardmore, and Downing
ver	31 864	Ellet and Dubuat	Downing, Dupuit, and Humphreys
ge	1 149 948	Ellet and Dubuat	Humphreys, Dupuit, Girard, and Downing.

nevitable conclusion from all these comparisons
ɔt one of these formulæ is correctly applicable
of different sizes, nor holds its own equally as
correctness throughout. For the few and special
which the discharge of an extremely large river
ed, the Humphreys formula might be used
eously, in spite of its form being rather un-
and in the same way Dupuit's formula for a
er. But for ordinary general purposes the
t the practical hydraulic engineer requires is a
tolerably well suited to all cases and of a
rm, so as to admit of easy rapid calculation.
st simple formula having a fixed coefficient is
Downing or d'Aubuisson, which gives for mean
of discharge

$$V = 100\,(RS)^{\frac{1}{2}}$$

where R = mean hydraulic radius
and S = mean hydraulic slope;

and this, too, is the formula shown to have been generally the most correct throughout all the comparisons and discrepancies, failing only in the very smallest streams, and evidently worse according as the stream or discharge is less. This then is the best basic formula for general purposes, though it requires modification by experimental coefficients to answer ordinary requirements in canals or canalised rivers.

The formulæ of Young, Eytelwein, Beardmore, Stevenson, and Leslie, all belong to this type, merely using other fixed numerical coefficients instead of 100.

Putting the basic formula into the general form

$$V = c \times 100\,(R\,S)^{\frac{1}{2}}$$

where $c = 1$ according to Downing,

the values of c, according to the other formulæ of the same type are thus:

	c
Young, for large streams	0·843
Neville, rivers, velocity $< 1·5$ feet	0·923
,, ,, ,, $> 1·5$ feet	0·933
Eytelwein, generally	0·934
Beardmore, open channels	0·942
Stevenson, for rivers of 30 cubic feet	0·690
,, ,, 2500 cubic feet	0·960
Leslie, small streams	0·688
,, large streams	1·
Downing, Taylor, d'Aubuisson, for open channels	1·

By comparing results through formulæ containing these coefficients, we may then tabulate a series of variable values of c that will be practically correct, when suitably applied into the general formula. The comparisons before mentioned show that Downing's coefficient 100 small results in cases when the area exceeds are feet, with a mean velocity of 2·5 ft., or a e of 17 500 cubic feet per second, and too large or cases of smaller data ; that the Eytelwein nt ·934 in the same way is too small above and below discharges of about 2000 cubic feet per and the Young coefficient ·843 is incorrect for ng above 900 cubic feet per second ; also that streams of 25 cubic feet per second, a coefficient ·600 is tolerably correct.

evident then that with a very large number of carefully measured discharge, this principle of ing practical coefficients in relation to approxi- lume or velocity might be carried out to further ss ; allowances for irregularities, lateral bends, forth, being either comprised in or made inde- of this coefficient.

er's coefficients comprise *all such* allowances, oduce a subsidiary variable coefficient of rugosity, applied in the general formula, to canals and every sort.

author's coefficients (c) are analogous to Kutter's, ependent on fixed surface-rugosity coefficients ated differently, but do not comprise irregu- or bends ; they apply to canals and are not d for rivers.

e the above was written, the large hydraulic ents of Captain Allan Cunningham on the Canal have also indisputably demonstrated that le of the old hydraulic formulæ, including the cent formula of Bazin, utterly fail in general ion. The variable coefficients, adopted with the modifications in the author's Canal Tables, are declared to be the sole coefficients of general applicability, yielding results within $7\frac{1}{2}$ per cent. of quantities determined by experiment ; while these latter are admittedly liable to an error of 3 per cent. in the cases of the Ganges Canal. The errors due to the old formulæ above proved to amount to 50 per cent., and even more, will, it is hoped, not find now any supporters.

To apply the same method of comparison to discharges through pipes, taking the same general formula,

$$V = c \times 100\,(R\,S)^{\frac{1}{2}}.$$

This formula being more convenient in practice in terms of the diameter of the pipe (d), it becomes for full cylindrical pipes, where $R=\frac{1}{4}d$; $V=c\times 50\,(d\,S)^{\frac{1}{2}}$.

And again as the actual discharge is the quantity most often wanted, this is

$$Q=Av=c\times 0{\cdot}7854\,d^2\times 50\,(S\,d)^{\frac{1}{2}}=c\times 39{\cdot}27\,(S\,d^5)^{\frac{1}{2}};$$

and transposing this, we have $d=\frac{1}{c^{\frac{2}{5}}}\,0{\cdot}23\left(\frac{Q^2}{S}\right)^{\frac{1}{5}}$.

Taking an example to compare the results of the various formulæ, let $Q=18{\cdot}57$ cubic feet per second, when $S=1$ in 1276 ; the results then are for diameter :

1. By Dubuat's formula	33·74
2. By Neville coefficient ·228 . . .	36·80
3. By the above formula, coefficient 0·23 .	37·12
4. Young's modification of Eytelwein . .	37·17
5. Beardmore, coefficient ·235 . . .	37·92
6. Hawksley (in Box's tables) . . .	39·59
7. De Prony and d'Arcy	47·71
8. De Prony's modification of Dubuat . .	48·16
9. Gerney	48·84

les these, there are very many authors that ;ive results for diameter very much below that g; it appears also that none of these formulæ qually well to both high and low velocities of ge, although it is unfortunate that a sufficiently umber of data are not forthcoming to determine y the limits at which it would be advisable to the coefficient.

above comparisons, while showing the merits of ious formulæ in certain cases, also point to the ident conclusion that a variable coefficient of ge is necessary for rivers, canals, and pipes; it it must be suitable both to the dimensions, the the fall, and conditions of irregularity of each lar case. The best *mode* now known of doing this s of canals, artificial channels, culverts, and pipes, ied in Chapter I. of this Manual. With rivers, r, some velocity-observation is indispensable.

5. THE WATERING OF LAND.

following is the usual mode of classifying crops gard to their special treatment under irrigation. ss meadows, or natural meadows of gramineæ. 2. ain crops or cereals. 3. Leguminous crops. 4. rops. 5. Those specially requiring more water: ndigo, tobacco, sugar, bamboo, water-nuts. 6. or fruit crops. 7. New plantations, and trees. uliarities of climate, soil, and water will generally he amount of water required for irrigation pro- more than the species of crop. In England vs of grass land, or Italian rye-grass, are those that generally profit most from irrigation. The usual plan is to keep the land flooded to a depth of two inches during the months of October, November, December, and January, for twenty days at a time, and then to let the water drain off from it for five days, before putting it again under water. In frosty weather however, the field should always remain flooded. In February and March the fields are flooded for eight days at a time at night only; at the end of March the land is left dry; and in May the grass-crop is cut. Irrigating fields in England in the hot weather is liable to produce rot in sheep, but does not harm cattle.

There are two methods of laying out the courses or channels in English fields:

1. The bedwork system, applicable to flat land.
2. The catchwater system, applicable to steeper country.

According to the former, the land is made into a series of very flat ridges, having a general direction nearly at right angles to the channel of supply, and being never more than 70 yards long and about 40 feet wide, the inclination of the ridge itself having a fall of about 1 in 500, and the inclinations of the sides of the flat ridges varying with the retentive power of the soil, from 1 in 100 to 1 in 1000; the crown of the ridges is not necessarily, therefore, in the middle of the breadth of the base of the ridge. The feeding and drainage channels are generally from 20 inches wide at their junctions to 12 inches at their ends.

The catchwater system used in Devonshire and Somersetshire consists of a series of ridges made across the general course of the water, which hold the water retain it over successive long strips, the water slowly round the end of one ridge to the lower ve the next ridge, and so on. This is neces- cheaper than the other system—about half, and arried out at the cost of about five pounds an

ughout the world generally, there may be said nly four methods of distributing water on or ut surfaces, of which all others are mere tions. In all cases it is best that the land ave one general slope throughout, the irrigation running along the head of this slope, the main nt drain along the bottom.

first method is that to which the English system belongs, the field being prepared in and ridges alternately from the head to the foot ope, either in the direction of the fall or making e with it, according as the quality of the soil general slope of the land may require; these ws, being from 10 feet to 50 feet wide and only inches in depth, receive the water from the g channel, which will then cover the land nearly he crests of the ridges, or in fact entirely if

second method is very similar to the first, but r, instead of flowing in the furrows, runs in little cut along the crests of the ridges, overflows the aters the slopes, and drains off in the furrows the main catchment drain. The ridges used in em are generally wider than those of the first and have a greater lateral inclination.

third or commonest method for applying water all scale is to distribute the water in little trenches around small squares and rectangles of land, allowing it to permeate throughout the surface inclosed, which must be very nearly level with the water in the trenches.

The fourth method, most commonly adopted in Spain, Portugal, and India, in cases where it is required that a large quantity of water should remain on the land for some time (as on rice-crops, and several grain and other crops in their early stages, that could not thrive on hard baked soil), consists in levelling the land into a number of nearly flat squares and rectangles, divided from each other by small ridges or dwarf mud walls, to hold the water on them. The number of rectangles depends on the fall of the ground; the water is allowed to flow in at some corner or temporary break, and flow out in the same way on to the next rectangle when it has remained sufficiently long.

As to soil:—For the surface, the most permeable is best, being most easily warmed, and allowing the water to arrive at the roots of the grass most quickly; a retentive surface-soil causes evaporation, and cools the land, which is generally a disadvantage, though not so under some circumstances;—a subsoil of clay, being retentive, is an advantage in very dry climates, as it economises water. In hot climates the nature of the soil is of inferior importance to the quality of the silt transported and deposited.

As to the quantity of water required for irrigating a certain area:—In Piedmont and Lombardy one cubic foot per second waters 50 to 100 acres of marcite or grass-land, or only 40 acres of rice; in England the amount required is generally also 1 cubic foot per second per 50 to 100 acres; in the Madras Presidency and in the North-West Provinces 1 cubic foot per second waters in ordinary seasons 100 acres of rice, or other very wet cultivation, but in very dry seasons the duty is as low as 50 acres. Taking all the crops watered throughout, counting single waterings in all, the duty per cubic foot per second is 200 acres both in Northern and in Central India;—the highest duty actually performed being about 270. In Northern India one cubic foot per second waters $4\frac{1}{2}$ to $5\frac{1}{2}$ acres for 24 hours. But details as to amount necessary in Spain, Italy, France, for Orissa, the Panjab, and India generally, will be found in the Hydraulic Statistics.

As to quality:—Pure water is bad for rice cultivation, and is always far inferior to that which brings fertilising particles with it. The best water for irrigating land may be said to be that which brings with it a fertilising matter most suitable to the improvement of the land under irrigation. As a rule, water containing much hydrous oxide of iron is very bad; so also the water that comes from forest or peat-moss is inferior. The water that comes from a granite formation, holding potash, is good; so also is water that comes from pure carbonate of lime; if the water is brackish, it is no objection; salt-water meadows are highly productive. A good method of foretelling the effects of the water is by observing the natural products of the irrigating water, such as the grasses and plants that grow on its borders.

With regard to the temperature of the water, very cold spring-water is not generally good, and crops require careful preservation from the effects of frost in winter. Warmed water is generally advantageous, and causes rapid growth; it is partly for this reason that water that has been long exposed to air, soil, and sun is

more fertilising than it was in its previous condition
Morning and evening are the best times for watering
The long exposure of the water is much affected by the
inclination of the land; the inclination of the main
channels in Lombardy is about 1 in 3600, in Piedmont
1 in 1600, in Provence 1 in 1000, in Tyrol 1 in 500 to
1 in 300, in Northern India it is generally kept between
1 in 1000 and 1 in 2000. In India generally it is usual
so to arrange the inclinations that the resulting mean
velocity of current may never exceed three feet per
second.

In connection with the watering of the land, the management of its drainage is a matter of the highest consequence. Modes and styles of drainage are necessarily varied, according to local circumstances; but they all have one main object, to keep the circulation of the water and the air through the soil under perfect command, so that the periods of intermission may be so managed as to suit the soil, the crop, and the circumstances. Any want of good management on this point is liable to cause most deplorable results; stagnation, causing decomposition and malarious effects in the neighbourhood, and even, in the case of sewage irrigation, making the very crops grown to be useless as food for man or beast.

For the healthy support of crops, a certain amount of water and of stimulant may be used advantageously (*see* Hydraulic Statistics: Watering of Crops in France); beyond this, any addition is worse than a loss—it is positive source of injury—clogging the soil, an preventing it from fulfilling its necessary functio With regard to the period of intermission advisable, probably varies greatly; recent experience in Engla would, however, seem to show that equal intervals of watering, and of draining off, for twelve hours at a time, afford the most rapid way of utilising in irrigation as much sewage as possible: further experience, however, is perhaps likely to show that this is not by any means a rule to be followed generally in all soils and conditions.

Assessment of Water-rate.—There are three principles on which water-rate may be levied on land.

1. By fixed outlet, or by module.

The small channel of supply being constantly full and of a certain section, the rate may be charged at so much per square inch or square foot of section, independently of the amount of pressure, for a certain time, as by the hour or day of 24 hours. This has been adopted in Italy, but has not been found to act well.

A further development of this method is to regulate by module all the water when distributed; a mode more likely to be adopted at present, now that modules are less expensive and more effective than formerly.

2. By area of land irrigated, or by crop.

This has the following disadvantages; the land to be irrigated is always varying in amount, and this cannot be watched in detail continually, nor can the landowners be trusted to state truthfully the amount of acreage over which water has been distributed. The crop can also be varied, so as to use more or less water, and the payment by crop also would be useless against cheating. Again, in a good rainy season the cultivator might try under these circumstances to do without the canal water, thus causing the water-rate to be precarious.

3. Water distribution by rotation.

An irrigating channel of fixed dimension, giving a constant fixed discharge, passes through the lands of several proprietors; a period of rotation is fixed for this channel, from 6 to 16 days according to the crops, the former for rice and the latter for meadow land, as, for instance, in Italy. Each landowner can then have the whole volume of the channel turned on to his land once in the total period of rotation for a certain number of hours, as from two to forty or fifty according to the amount of land he owns.

For example. Let ten days be the period of rotation, and let him require twelve hours' supply once in that period. His name is placed on the list, say sixth, and he gets his supply turned on at a fixed hour and turned off at a fixed hour also. If the channel gives twenty cubic feet per second, his amount of water is equivalent to a continuous discharge of $\frac{20 \times 12}{240} = 1$ cubic foot per second. In this way intermittent supplies admit of mutual comparison.

Last with regard to the cultivators themselves:— Whether on the Continent, or in England, the farmer is generally a grumbler under any state of affairs. In India the cultivator invariably complains, although his assessment is very small by comparison with the local circumstances; if he grow two very moderately good crops in the year, it would only amount to about two and a half per cent. per annum on the value of the produce, and he can therefore well afford to pay high water-rates, especially since both the yield and the number of crops produced on irrigated land is doubled, and the highest water-rate is small in comparison with the expense of making wells and raising the same amount of water by animal power throughout the year; he enjoys also the advantage of living under a tenure that remits the land assessment, and distributes food gratis in years of famine, while not demanding more assessment in years of plenty. If the water-rate is in some just proportion to the increase of produce and saving of expense resulting from the irrigation, it matters not how high per acre the rate may appear to be. If the irrigation is applied to suitable land in such a way that the natural drainage of the country is not interfered with, there can be no detriment to the health of the cultivator; this can, however, be rarely carried to perfection in actual fact. To this it can be replied, that the population will thrive on the whole and increase largely, which may be considered as a set-off on that account, and that landowners who prefer going away can always do so and part with their land at a premium; land always commanding a ready sale. A compulsory water-rate on land that is under water command cannot be considered a hardship by any one that considers the subject in a fair, unprejudiced manner; the privilege of being able to obtain water should be paid for, and since the same principle has always been applied to town supply of water, for which every inhabitant has to pay whether he uses it or not, there is no reason for leaving the payments of water-rate in the country to be optional. Whether both the landowner and the occupier should pay separately for the advantages they both receive is a point dependent on the local tenure of land; under ordinary circumstances they doubtless should do so, the occupier being benefited by increase of produce, the landowner by increase of rent; but in any case the whole of the advantages should be paid for.

6. Canal Falls.

That a fall of water at the headworks, or at any part of a canal, should be allowed to remain unutilised, appears, in these days of expensive fuel and costly motive power, to be a very painful waste of a valuable advantage. One's natural tendency is to devise means and ways of using everything, and to imagine that there could hardly exist circumstances under which it would be necessary to arrange for the destruction of the power and velocity generated by a fall of water. Grinding corn, pressing sugar, or extracting oil, are requirements even in semibarbarous countries, by which such motive power could be easily utilised, even if it were available for only four months in the year. In spite of this, however, it seems rather frequently to occur, that in distant countries the engineer has to devise means for destroying the effect of a fall of water; this occurs, generally, either at the headworks of a canal, where the water entering the canal in flood seasons has a great head of pressure, or at certain points in a canal where, owing to the inclination of the country being steeper than that due to a convenient velocity of canal current, it has been found necessary to concentrate the superabundant fall: the Ganges Canal and the Bari Doab Canals have many such examples. In either case, as the fall is independent of navigation of any sort, which has to be conducted in a special channel of détour, the problem is one of economy. The natural means would be to break up the force of the water by both lateral and vertical breaks and angular obstacles, and to oppose the remains of the velocity by a pierced breakwater, beyond which e water would issue with so small a current as not be able to cause any damage to the bed and sides of e canal, or to cause any prejudicial effect to navigation.

The breakwater, involving an enlargement of the idth of the channel, and, if a rock foundation be not vailable, requiring artificial and carefully made foundaions carried to some depth, is necessarily expensive, nd is hence generally dispensed with, except under avourable circumstances.

The fall itself is generally a modification of one of the four following types:—

1. A uniform, or a broken general incline.
2. A vertical fall with gratings.
3. A vertical fall with a water-cushion.
4. An incline or fall with a talus of boulders, &c.

The most primitive mode of managing such falls of water was to conduct it down an incline, made as gradual as possible, and break up the velocity by a series of steps. A long reach of rocky bed offers a convenient opportunity for such a construction, which could be hewn in the solid rock. In other cases, where it would require building on artificial foundations, the expense would be very great; and, even if the incline were so made that the resulting velocity were not high, the edges of the treads of the steps, even in good stonework, would soon wear, and the maintenance of the fall would also become an important item of expense. Apart from these objections also, this type is unsatisfactory. Although the treads of the steps may be set with a correct reverse inclination, so as to oppose more directly the inclined direction of motion of the momentum of the water; and, although a further improvement may be made in giving a more considerable reverse inclination to the treads, and by allowing a large proportion of the water to run off laterally and wind down the steps; yet under all circumstances the inherent defects remain; the steps cannot accommodate themselves to the variation of the quantity of water passing down the fall; if the steps are small, they fail to receive effectively the over-falling water when the amount increases, and become then comparatively valueless; if the steps are very large, the rise and tread of each step causes the velocity acquired from each step (which, it must be remembered, increases in the ratio of the square of the height of the step) to be very much increased, and to become very destructive to the stonework.

The next improvement on the inclined type of fall is the ogival fall used on the canals of Northern India; in this the general slope of descent from the head to the foot of the double curve is from one to six to one in nine; the upper one-third of the slope being the chord of the upper or convex curve, which is tangentia to the surface of the water in the upper reach; and the lower two-thirds of the slope being the chord of th concave curve, which is tangential to the convex curv above, and tangential to the horizontal line at its lowe extremity. The height and length of the fall applicabl to any special case is determined by equating the di charge of the open channel above with the dischar over a weir. The principle which this form of constru tion asserts is that the water at the foot of the desce being deprived of all vertical action and delivered ho zontally, will not cause any damage to the bed of t channel in the lower reach.

In canals where it is required that the discharge should remain perfectly uniform and unaffected by its fall down the weir or incline, an ogival fall must necessarily have its sill raised above the level of the channel-bed of the upper reach; as would also a fall of uniform slope.

Curves on more carefully eliminated principles have also been tried with the object of effecting some improvement, but the advantages resulting appear comparatively small. These curves generally effect, no doubt, some saving of masonry in comparison with that for a single uniform slope, and probably deliver the water with less destructive result than the latter; they are, however, still expensive, and the action of the water delivered is rather concentrated, and hence destructive. An attempt at economy on such falls has been made by narrowing the fall, and thus diminishing the amount of masonry; but the results, caused by the increase of action as well as irregularity of effect of the water, require greater expenditure in repair; they present also the additional disadvantage that during repair the whole fall instead of a part has to be stopped.

In the above cases of inclined falls it is supposed that it has been found convenient to concentrate the fall in a comparatively short length; in other cases, where it is spread over a long reach, it is usual to attempt to annihilate the velocity resulting at the foot of the incline by introducing a reach of canal having a reverse slope; and in cases where a greater length still can be allowed for the incline, to break it up into portions of descent, each followed by a portion with a reverse slope and then a short horizontal length, thus opposing the accelerating effect in detail without allowing its results to accumulate. In such work the bed of the channel must necessarily be paved; if the velocity do not exceed 10 feet or 12 feet per second, large rough convex boulders, laid dry, form the most suitable paving; and even up to 15 feet per second the same method may be adopted if very large boulders alone are used; beyond that velocity the boulder work requires packing with shingle and pebbles, and grouting with good hydraulic mortar.

While the above arrangements may destroy a great deal of the velocity, there is perhaps almost always a certain amount of it still remaining at the foot of the incline, and should the channel at this place happen to be in soft soil, further arrangements, tail-walls, brushwood spurs, or piles, are also necessary.

The Bari Doab Canal tail-walls offer an example illustrating such a case, the arrangement being generally as follows: At the foot of the incline the bed of the channel is made horizontal for some distance, and the banks are then splayed outwards in a curved form until the top width of the channel at water level is one-half wider than before: this, giving additional water-way, reduces the velocity; the channel is then narrowed to nearly its normal width by walls of dry boulders on each side, which project into the stream at an inclination of 1 to 5, and slope longitudinally with a fall of 1 in 20 from their commencement, where their height is up to full supply-level, down to the level of the bed; these are, of course, totally submerged at full supply, and produce the effect of concentrating and directing the current to the middle of the channel. The objections raised to these tail-walls as employed on the Bari Doab Canal is that they do not appear to answer their purposes sufficiently completely, and it is supposed that by giving the whole arrangement, both the enlargement and the reduction of section, a greater length, it would fully answer all purposes; this, however, would add greatly to the expense.

Vertical falls with gratings.—This is one of the most economic and convenient modes of dealing with a canal-fall. The sill of the fall is not raised above the bed of the upper channel and the whole section of passage is hence unimpeded by reduction; the grating, which may be placed at any slope from 1 in 3 to 1 in 10, presents a large perforated surface to the action of the water, thus keeping the upper water up to its proper level, and distributing the effect of the falling water passing through it on a long portion of the bed, diminishes the action to such an extent as to render it harmless. The gratings are supported on cross bearers, which again rest on masonry piers or iron stanchions, erected at about 10 feet intervals along the edge of the fall or weir. The higher a fall of this description is, the more truly the water falls and the more manageable it is. These gratings require clearing occasionally, and hence necessitate the attendance of a man; but as frequently there is a lockman to attend to the neighbouring lock, for the navigation passage near the fall, there is no additional expense incurred on this account, as one man can attend to both. This type of fall admits of comparatively little variation in design.

Vertical falls with water-cushions.—This is the form generally adopted by nature in discharging water down a fall; the action of the water scours for itself a basin, which fills and forms a natural water-cushion, the scour continuing until an equilibrium is established between the force of the descending water and the resistance offered by the depth of water in the basin. The fall itself has a tendency to approximate to the vertical, the force of wind and spray from the falling water making it slightly overhanging, and in some cases even causing a retrogression of fall, and coincidently also a retrogression of water-cushion, thus giving it an elongated form; the scoured silt, or debris, is deposited in the bed of the stream lower down.

The most natural mode of designing a vertical fall with water-cushion for a canal would perhaps depend on a consideration of what sort of fall nature would make for herself under the special circumstances and conditions of the case, and what improvements or modifications of that would be necessary. The objections to allowing nature to make her own fall and water-cushion are these:—first, it requires time, and this, in some, though not in all cases, is an objection in itself; second, any want of homogeneity of the soil or rock would result in an irregular form of basin, which might become almost unmanageable; third, the scour and silt deposited in the channel below would be a serious injury to it; fourthly, the retrogression of the fall might eventually undermine the weir or dam, and cause its entire destruction. But this latter objection might be very easily counteracted by protective measures.

In cases, then, where these four objections can be removed or are unimportant in result, there is no reason why a natural or a slightly modified natural fall should not be adopted. When the soil is firm or of homogeneous rock, a great deal of the objection disappears, a certain amount of excavation and trimming can then be so made as to aid in the natural action, and lateral encroachment may be easily provided against; a tolerably regular basin can then be economically made.

As to the form of basin best suited for a water-cushion, the breadth in plan should be rather wider than the extreme breadth of the falling water, as the wind may bear the latter considerably to one side; the length, again, will probably vary from $1\frac{1}{2}$ to 5 times the breadth, although it would hardly be advisable to make it quite rectangular in form, as the corners would be filled with useless water; the pear shape, therefore, is perhaps the best, and is certainly that most generally met with under natural conditions of homogeneity of soil. There would probably be no advantage, even if it were economic, to make the basin longer; the full or extreme depth may be terminated by a reverse slope at once, the deflected velocity thus obtained producing a greater degree of stillness than the passive effect of a longer continued full depth.

The main point, however, is to determine what depth of water is necessary in a water-cushion. The velocity of delivery is evidently dependent on the depth on the weir sill or fall above, and the height of fall down to the surface water in the basin: the resistance is the depth of water in the basin, and the quality of the material of which its bottom is composed. If, then, the depth be calculated by equating the forces for a depth producing equilibrium just clear of the bottom, we obtain an expression, involving also an assumption that the bottom is perfectly indestructible. It seems therefore, impossible at present to determine absolutely the actual depth necessary; and hence the practice is to assume an approximate calculated depth, and see how this answers its purpose, altering or adding afterwards until it appears to be satisfactory.

The formula generally used for this purpose on the canals of Northern India is—

$$d=1{\cdot}5\sqrt{h_1}\times\sqrt[3]{h_2}$$

$d=$ the depth of water in the basin ;
$h_1=$ the total height of fall, including h_2;
$h_2=$ the depth or head on the weir sill.

This is probably very limited in its range of application; for, in applying it to the well-known case of the projected Mahsur reservoir dam, designed by the engineers of the Madras Irrigation Company, it yields results very small in comparison to that allowed by the engineers: thus, for values of $h_1=43{\cdot}5$ and $h_2=6$ feet, the calculated value of d, suitable to a brick bottom, is about 18 feet, while the engineers have allowed for a hard rock bottom a depth of water-cushion of 33 feet in this instance.

In a second instance of the same case, the formula gives for values of $h_1=16{\cdot}81$, $h_2=8{\cdot}56$, $d=12{\cdot}54$, which is very much less than that allowed, 16·19 feet; this was also in hard rock.

Major Mullins, the Consulting Engineer to the Madras Irrigation Company, when commenting on these cases in the Proceedings of the P. W. D., for April 1868, refers also to a well-known natural fall as an illustration of the insufficiency of the above formula. The Rajah Fall at Gairsappa, with values of $h_1=8{\cdot}29$ and $h_2=15$ feet, would, according to that formula, require a depth of water-cushion of only 108 feet for brickwork, or 72 for stone, a depth nearly a half less than the actual depth, 130 feet.

In a smaller natural case, in hills in Berar, coming under the observation of the author, for values $h_1=26$ and $h_2=1$, the depth, according to the above formulæ, would be for a brickwork bottom 7·65 feet, and for stone 5·6 feet; whereas, in the soundest of basalt, the actual depth was as much as 8 feet, or more than a quarter more than that calculated.

It would, therefore, appear that the above formula, apart from its varied coefficients for brickwork and stone, is generally defective, and that, until a very much wider range of experiments and observations is made, it would be more advisable to approximate to such depths as are obtained under natural conditions, than to follow any formula for determining the depth of a basin serving as a water-cushion.

In practice it would rarely be necessary to construct a water-cushion of very great depth, the fall, if over a weir, being generally easily broken into three or four portions, and it being advantageous to do so, as the catch channels are convenient for affording a supply at various levels; probably, therefore, the above-mentioned case of 43·5 feet of artificial fall may be considered as the extreme for which a water-cushion would be required. In the future, too, the waste of such a large amount of useful motive power will be deemed a barbarism, an additional reason that there is not much probability of the above case being exceeded.

Inclines and falls with a talus of large blocks.—Under some circumstances it is not advisable to terminate an incline with a long reach of ogival tail-walls, or a basin, nor to apply any of the foregoing methods to the foot of a vertical fall. The velocity of the water having to be counteracted, presuming that it cannot be utilised, an alternative method is to allow the velocity to destroy itself by impinging on a large number of huge boulders and masses of stone of considerable weight. This mode was that adopted by Messrs. Fowler and Baker in the improvement of the Nile Barrage; a most unfortunate dam constructed by the French at an immense expense, which failed to effect its purpose, otherwise than to serve as a bridge, until it was entirely remodelled by English engineers.

7. THE USUAL THICKNESS OF WATER-PIPES.

The thickness of a water-pipe is a matter depending on practical considerations, being comparatively little affected by the theoretical determination of what it should be in order to resist the pressure brought on it, and is, like a very large number of the so-called calculations of the engineer, made almost entirely dependent on prescribed custom. The following notes on the formulæ in vogue are, hence, not given so much with the object of elucidating the principles as that the formulæ themselves, valueless as they seem, should be available for reference.

The largest scale on which a water-pipe to resist extreme internal pressure is made is that of the cylinders of hydraulic presses: in these the extreme working pressure is limited to 4 tons per square inch, the extreme permanent strain allowed in actual working being only one half of that; and the thickness of the cylinder or pipe is determined by the formula of Barlow—

$$t=\frac{r.P}{C-P};$$

re t and r are the thickness and internal radius of cylinder or pipe,

C is the cohesive strength of the material, and

P is the internal pressure, both being in tons:

e general principle asserted in this mode of calculation eing that the strain on the material is greatest at the nternal surface, and less beyond, the extension varying ith the square of the distance from the centre.

An example of the application of this formula, to a 0-inch cast-iron water-pipe, is given in Box's 'Hydraulics,' the results of which are as follows:—

Assuming the cohesive strength of cast iron to be 7 ons per square inch breaking weight; the extension E, n the inside ring at the moment of rupture, for a ength = 1,

$$E = \cdot000\ 165\ W + \cdot000\ 010\ 3\ W^2 \times L = \cdot001\ 659\ 7\ ;$$

nd the extension at any distance from the centre is in he ratio of the square of that distance to that of the nside ring.

The strain, at any distance from the centre, is then btained from the extension by the formula—

$$W = \sqrt{\left(\frac{E}{\cdot000\ 010\ 3 \times L} + 64\cdot16\right)} - 8\cdot01$$

nd the mean strain on each theoretical concentric ring f metal is the average between that at its external and ts internal circumference; the bursting pressure has hen the same ratio to the mean strain as the thickness f the pipe has to its radius; and tabulating these for 10-inch cast-iron pipe, they are:—

Thickness of Metal	Strain on the Metal			Bursting Pressure
	Max.	Min.	Mean	
1″	7·0	5·26	6·130	1·226
2	7·0	4·09	5·402	2·161
3	7·0	3·26	4·827	2·896
4	7·0	2·65	4·359	3·485
5	7·0	2·20	3·972	3·972
6	7·0	1·85	3·647	4·337
7	7·0	1·60	3·373	4·722
8	7·0	1·37	3·137	5·019
9	7·0	1·19	2·931	5·275
10	7·0	1·05	2·749	5·499

The practical empirical rule, however, that is usually given for the thickness of water-pipes is—

$$t=\left(\frac{\sqrt{d}}{10}+0{\cdot}15\right)+\left(\frac{Hd}{25\,000}\right);$$

where H is the head of pressure, and d is the diameter of the pipe, and it is according to this that most tables are calculated.

The theoretical mode of arriving at the thickness of a water-pipe is, therefore, about the most unsatisfactory of processes; and it would probably be useless to enlarge on the topic. In English practice, the dimensions of cast-iron water-pipes are about those given by this formula, or have a thickness of one-fifth the square root of the diameter, and a little more to allow for defects in casting, and inexactitude of bore.

The dimensions of the pipes used at Glasgow by Mr. Bateman (see Appendix) have been treated as English standards for some time. In Continental practice thinner large pipes are used; those designed under restrictions by the author for Rio de Janeiro, when Hydraulic Engineer in charge of the waterworks, were partly in accordance with such practice. See Appendix.

While in the case of cast-iron pipes of all sorts, there has always been a tendency to theorise, and to base a thickness on the laws of pressure, and extension of material; in stoneware pipes, this has been almost entirely disregarded, and a thickness is generally given them that is established entirely on practice or usual custom, and often varies according to the caprice of the potter or manufacturer. This is generally accounted for by saying that earthenware or stoneware is a very variable material as regards strength, while cast iron is homogeneous, and is very much alike in substance: a little reflection, however, will show that this is hardly a sufficient reason. Carefully-made stoneware, after a very careful selection, may be, and often is, exceedingly equable, while the variety of qualities of cast iron—more especially since its high price has brought such a large amount of very inferior material into use—is now very marked; some cast iron being known occasionally to fall to pieces from its own weight. In spite of this, the manufacturers of stoneware pipes still consider them as unsuited to the discharge of water under pressure, or for drainage in cases where the outlet is liable to be stopped; and although they can make pipes that will easily bear a head of 40 feet, yet do not recommend them, alleging that the joints cannot be made to stand any pressure at all. There is, however, no reason to doubt that under skilled superintendence and management, stoneware and fire-clay pipes, as well as their joints, may be well enough made to serve most efficiently for the distribution and drainage of water under low heads, and that a considerable saving of expense may be effected by dispensing with iron in such cases.

8. FIELD DRAINAGE.

The drainage of the surface water of a field, fo part of the general drainage of the valley or catc in which it is situated, is necessarily partly depe on the conditions of that general drainage, the d sions and fall of the watercourses, ditches, channel rivers, their straightness, and distribution of de also on the position of the field with reference to land in the same catchment, the drainage from may pass over or through it in various ways.

In the second place, the drainage of a single fi dependent on the geological formation at the pla distribution and superposition of pervious and i vious strata, their undulations, configuration, ar tentive qualities.

Any interference with the general drainage country by proposed works of improvement is a requiring the professional aid of the hydraulic en while in the same way any intended alteration subterranean flow and conditions of moisture by operations of marsh, bog, or spring drainage as ta strata, boring, intercepting deep drains, small tu &c., require that the hydraulic engineer should b a hydro-geologist.

The drainage of any single field may be so en altered or modified by works or operations of kinds, that any special drainage or series of drai the field itself may be entirely unnecessary, as i may be thus rendered thoroughly fit for all the pu of the agriculturist.

Treating for the present all engineering work hydro-geological operations as external matters, which might be either impracticable, not beneficial, or excessively costly, and supposing that the actual state of the general drainage and hydro-geological condition is moderately good, and incapable of much improvement, it may yet happen that a particular field may suffer from insufficient drainage, or may be improved by local drainage, or simple field-drainage.

The condition of good cultivable soil.—As the object of such drainage is to put the cultivable soil in the best possible condition, the first consideration is the quality of the soil. Should the soil be exceedingly porous and light, it may be deficient in retentive power and require consolidation, top-dressings of clay or marl and careful management; under such circumstances drainage would be hurtful, and deep-ploughing should be avoided, unless with the special object of subsoiling, or improving the soil by admixture with the subsoil turned up. Such soil benefits by irrigation, and the accompanying infiltration of clayey particles, and liquid manure in the soil. If on the contrary the soil should be exceedingly retentive and clayey, water or rain lodges in the soil, chills and binds it, rendering it unfertile and hard to cultivate. Such a soil would benefit greatly from field-drains and deep-ploughing, admixture of porous soil or burnt clay.

These are the two extremes of condition of cultivable soil, the one profiting least from drainage and most from irrigation, the other most from drainage. Apart from the composition of the soil itself, the climatic conditions, and the amount of rainfall, snow, dew, and atmospheric moisture affect the greater or less demand for drainage.

In a hot dry country, a retentive soil is favo
to the growth of rice and many wet crops that lu
in a semi-marshy state, and require very slow dra
in a moist chilly climate the same soil would
the most thorough drainage in order to grow c
roots, or pulses. Between the extremes both of
of soil and of local moisture there is an infinite
in degree, and the agriculturist has therefore t
his requirements as regards drainage in accordan
the conditions and the crops he wishes to grow.
lute stagnation is invariably fatal to crops. Eve
rice crops in India, rot will result; a certain deg
circulation is necessary everywhere. In England
is a large amount of land that is, either natur
through repeated deep-ploughing, sufficiently o
admit of full permeation of rain-water to a great
and thus capable of growing the ordinary crops
country without special drainage; the greater
the land, however, is less favourable, allowing w
lodge in it within a few feet of the surface, an
necessitating field-drains.

The condition of soil aimed at is an imitation
which is naturally most fertile; the retention
moderate amount of moisture, a free permeat
irrigation-water or of rain-water downwards
sufficient depth in wet weather, and a corresp
free capillary upward movement of moisture
weather or in the periods when irrigation is susp
the dispersion throughout the soil of air, m
volatile gas, and the soluble ingredients of accomp
fertilising manure, whether natural, chemical o
ficial.

Depth of active soil and of humus.—Such bei general condition requisite, the first and most natural question arises, how deep should such a soil be, and to what depth is drainage advantageous?

The depth of active aërated *humus* that will support crops advantageously is a most variable unit; it is generally believed that the greater the depth, the more fertile the land, that crops augment in yield by every additional inch and foot of humus. It may be so; but, taking an extreme case coming under my personal observation in a province entrusted to my charge, a depth of from eighty to ninety feet of soil on the banks of the Purna in Berar did not yield markedly better crops than in other places where the depth was half of that. Also in other cases, frequently noticed by myself in the earlier days of my experience in irrigation as exceptional, but afterwards considered very common-place—where cereals were grown under irrigation on pure sand, and on very nearly pure sand. A large extent of such land is irrigated, and at the end of the year, a thin surface crust of half-formed humus is formed; the crop of that year is zero in one respect, usually consisting of grass seeds, &c., that on growing form a spongy layer of roots and verdure, useful in arresting and binding the humus. But in the second year, under the powerful sun of India, and by the aid of careful irrigation and good management, a very inferior first crop of cereals may be grown. In the third year a moderately bad crop is the result, and afterwards excellent crops of wheat and of other kinds of produce, that can exist without throwing very deep roots.

In such cases, the depth of humus and spongy crust together can hardly exceed three inches or perhaps four; yet splendid crops are grown.

At Danzig on the sewage farm, excellent crops of vegetables were grown under rather similar conditions; it is not necessary to mention many such well-known cases on English sewage farms, Aldershot, Edinburgh, &c. It may hence be considered that world-wide experience has disproved the old theory about depth of humus being the main source of fertility. It is really, therefore, only one of the sources, and its importance is frequently outweighed by other conditions, more especially by the depth of active soil.

In England moderate crops may be grown in six inches of soil on stiff land, but for really good crops, a depth of three times that, or eighteen inches, of active aërated soil may be considered a suitable minimum. The maximum may be determined by the extreme depth to which roots of grass and grain crops are found to penetrate, about seven feet in thoroughly-drained active soil.

Depth of field-drains.—Taking the two extremes of eighteen inches, and seven feet, as suitable to firm soil in England generally; the minimum depth for field-drains, out of reach of the plough and not affecting the crop, by reducing the productive area, should be 2½ feet, and in strong clay lands four feet. It may be noticed that water does not permeate truly horizontally, in a lateral direction from the bottom of the active soil to a field-drain; but in perfect drainage should descend slightly in its lateral movement to the bottom of the field-drain; hence the necessity for placing the drains lower than the bottom of the active soil. Local conditions, depth of soil and subsoil, and economic considerations form the guide to determining the greatest depth at which field-drains might be put;

apart from them it would be difficult to say what would be the extreme depth that could not be advantageously exceeded under special circumstances.

Very strong clay-lands, with drains cut in the subsoil, would certainly be worse for having them very deep; but, keeping in view future improvement of the sub-soil by disintegration—as well as economy of labour, it appears seldom necessary to drain beyond five or six feet in depth unless in boggy retentive land, and even then a few extra deep drains may be cut without interfering with the ordinary field-drains. The limits thus lie between 2½ and six feet. Such general limits can, however, constitute merely a rough guide in connection with the special objects to be achieved, and the local circumstances. Drainage pure and simple has for its main object the removal of sub-surface water down to some or any practicable depth; but another object is often blended with it, the further improvement of the subsoil, and the increase of depth of active soil, in the clayey and stiff lands to which drainage is most frequently applied. Some stiff subsoils are so impervious and hard as not to admit of improvement by drainage; in such cases the field drains are perhaps best placed with their bottom just on the subsoil. Much good clay subsoil will, however, under drainage, alternately wash and contract, and gradually break up; a most desirable change that may be much aided by extra deep trenching with steam-power; in such cases the field-drain-soles may be sunk to a foot and a half in the subsoil, or even more when accompanied with subsoiling operations.

Distances between field-drains.—The closeness of the field-drains to each other must be determined so as to afford sufficient active permeation of moisture throughout the whole of the intervening breadth of land; this will depend on the qualities of the soil and subsoil down to the level of the sole of the field-drain, the drains being closer in stiff soil and under conditions of heavy local rainfall and further apart in more open soil, and a drier climate. In England the distances between the parallel lines of field drains usually adopted vary from fifteen to forty feet; in any special case the distance should be based either on the evidence afforded by actual drainage in the neighbourhood under similar conditions, or on partial experiment on the spot. The size or dimensions of the field-drains may be determined in the same way, but this is naturally dependent to a certain extent on the sort of field-drain adopted.

The alignment and length of field-drains.—A field may consist of several planes, or several fields may lie in one general plane or nearly uniform slope; but under all circumstances the field-drains, being set to some certain depth either below the surface, or below subsoil surface, lie in a plane or planes nearly parallel to those of the fields. Each plane has therefore to be treated separately as regards the alignment of the field-drains. The main drains, into which the field-drains run, are necessary at the bottoms or lower edges of these planes, and afterwards unite and run into some watercourse or general drainage-line of the country, at a point sufficiently low to secure sufficient outfall.

There are three modes of aligning field-drains, which under all circumstances are arranged in parallel lines in each separate plane, and besides at uniform or approximately uniform inclinations. The regularity of the fall may in rather steep ground be attained by setting out the soles of the field-drains with the aid of boning staves, the A level, or some rough spirit-level; but on slight inclines a small Gravatt level is absolutely necessary. The first and most common mode of alignment is to direct them on the lines of greatest slope from the top of a plane to the bottom; such lines may be long even as much as 300 yards, while the distances apart may be from fifteen to forty feet as before mentioned in accordance with the soil and conditions: the drainage-action is then entirely lateral and works by permeation into the field-drains, which transport the filtered water into the main drains. The second mode is termed cross-drainage, the parallel field-drains running across the lines of greatest slope, that is being nearly horizontal, having a slight fall towards the main drains: in this case the permeation is aided by gravity, and may be more rapid; the field-drains intercept the filtered water, and conduct it to the main drains at a comparatively slow velocity. The third mode, generally preferable to either, is the slightly oblique method; the field-drains are only slightly inclined to the direction of greatest slope, that is from ten to twenty degrees, and are supplemented at long intervals, of about one hundred feet, by cross-drains that are nearly level. In this case both the preceding modes of drainage-action are employed; gravity assists both in the lateral and in the transverse permeation, and interception is adopted to a small extent.

In comparing these three methods, it may be noticed that the first is that most usually adopted in England, and is generally far preferable to the second. The permeation is, no doubt, the least rapid part of drainage action; the filtered water on arriving at the field-drain, when in good order, rapidly runs into them through the joints, and still more rapidly is conveyed away. Keeping this in view, any check in the permeation due to any accidental circumstance or shortcoming will evidently produce a check in the drainage of a whole plot. For instance, the distance between the drains may be slightly too great, the depth may be slightly in excess, the soil may in certain places be less permeable than in others, a drain may become rather clogged. Now when the first method is adopted, the plots are very long narrow strips, half of the water from each strip going laterally into each field-drain, one on either side of it; and should the permeation be accidentally retarded, a middle portion, perhaps the middle third, of the strip remains in an inactive condition. The length of the strip may be so long (200 or 300 yards) that permeation, aided by gravity in the direction of the main drain, is almost out of the question; and here lies the defect in the first method.

The second method has no drains along the direction of greatest slope, but places the whole of the field-drains as intercepters, but putting them at the same distance apart as in the first method. It is true that with this method gravity aids the permeation, but as the permeation in each strip has to act over the whole of the breadth of each plot, instead of over half of it each way, nothing is gained; in fact it is rather the reverse. The action of gravity is an aid, but not a very large one, as from many observations we may see permeation acting successfully against gravity, as in the lines of damp on sides of ditches, the rise of damp in walls based on damp foundations, &c.

In order to make this method as efficacious generally as the former, the distance between the field-drains should be reduced by about one-third, and this means having half as many drains again, and adding one half more to the cost of the drainage.

Experience has proved not only the truth of this deduction, but also that, even when the field-drains are placed still closer, the drainage effected has not always been thorough, and re-drainage on the first or longitudinal method had to be substituted in the end after the dearly-bought experience.

Cross-drainage on this generally unfortunate method is, however, specially applicable and advantageous when the upper strata contain much water and either crop out across the line of greatest slope, or discharge their water in natural furrows existing on the surface of the subsoil; in that case the cross-field-drains act as intercepters to the fullest extent, and collect water readily as it comes forth, although not perhaps setting up a draining permeation in the strict sense, as their influence on permeation in the subsoil cannot be very large.

The slightly-oblique method preserves the advantages of the longitudinal method as regards lateral permeation, and remedies its defect in longitudinal permeation by the obliquity, which also aids in interception; the occasional cross-drains at about 100 feet apart still further aid the longitudinal permeation, and assist in rendering the whole action complete and effective even under the incidental shortcomings that may occur anywhere and in anything.

The various sorts of field-drains.—The object, the disposition, and the depth of field-drains has been dealt with in the preceding paragraphs, independently of their actual form, sort, or construction, under the premise that they are sufficiently large, porous, and well-constructed to carry off any effluent drainage, or filtered water, that may arrive and enter into them. The sort of drain adopted is necessarily in accordance with local circumstances and economy.

The oldest method was one of simple ridge and furrows, for carrying off surface-water, subsequently deepened to carry it off from a lower depth, and filled with porous soil or porous material. Such shallow drains interfered with ploughing, and reduced the effective cultivable area. Deeper sub-surface drains, covered with good soil, and leaving a flat surface equally productive everywhere, have long supplanted the old method. More latterly, porous cylindrical drain-pipes from 2 to 6 inches in diameter, with collars, have been usually adopted, in preference to other means; and these, placed at the required depth, and covered to a sufficient height with porous soil, and finally with a good top soil, have been considered the most effective ordinary method. This may therefore be considered the typical English method for many years past, though not the most modern one. It is well suited to clayey lands in England, and to the condition that the pipes can be cheaply made or bought, and the clay dug out of the drains can be profitably burnt to form manure, or made useful locally.

Previous to the general adoption of cylindrical porous pipes, large drain-tiles, horse-shoe shaped in section, 4 inches high by 3 wide, with flanges, sometimes resting on separate tile-soles about 5 inches wide, and sometimes merely on the clayey bottom of the trench, were commonly used; this arrangement developed into the flat-bottomed cylinders made in one piece, that are still used.

In some places, tiles of dried compressed peat may be made effective in field-drains, but the peat must be tough and fibrous to resist the action of water. In others, thorns and brushwood form a field-drain of an economical sort in fen-lands, where the material is cheap, and the flow of water is slow.

Stone drains, of rough stone, so arranged as to give large interstices below, and filled up above or covered with smaller stones above, are also economical in some localities; but the method is inferior, and the damage to land by carting stone over it forms a strong objection. For slow drainage, cinders, gravel, or other porous materials are far preferable, from being more effective for a longer time and from being lighter to transport.

Many of these modes, though lacking permanence, are effective for a considerable time, and, being inexpensive, admit of renewal after a few years without prejudice to economy. One of the most important considerations is the extent to which they become deleterious or hurtful after becoming ineffective in lapse of time. Such inert matter as broken tiles, stones, &c., cannot be of any advantage in cultivable soil; originally they are perhaps placed in the clayey or stiff subsoil; but if effective drainage and deep ploughing and subsoiling be adopted, the subsoil becomes disintegrated, and the active soil may then reach down to near the level of the field drain; the stones and inert matter are then out of place.

Stiff soils being those to which drainage and subsoil improvement is most applicable, the most modern mode of effecting drainage, by the deep drain-plough, is also best suited to them. The drain-plough cuts a mere gash in the surface of ground, but forms a cylindrical burrow or drain in the clay four feet below the surface. In less stiff soil, drain-pipes can be laid in the passage to keep it permanently open; the whole being effected by machinery in lengths of about 100 feet at a time.

The drain made, being parallel to the ground-surface, will not be on a regular incline in undulating ground; the process is hence more adapted to level and evenly-inclined land. The advantages of this method are very great; drainage becomes a more ordinary agricultural operation, the surface of the ground is not seriously interfered with, the process is inexpensive, and may be renewed every five or six years, and finally in stiff soil no inert matter, stones, or old pipes, are necessary, and hence are not allowed to accumulate.

The main-drains.—The system of field-drains, however constructed, constitutes the principal and effective portion of the drains; they draw off sub-surface water, increase the depth of active aërated soil, put it into a condition for assimilating manure, and for supplying sustenance to the crops through their roots, at any moderate depth; thus causing warmth in the soil and an intermittent hygrometric action beneficial both to the crop, shown by augmented produce, and to the husbandmen by diminution of heavy labour. The main-drains are mere collecting drains supplied from lower extremities of the field-drains and conveying the drained water into the arterial watercourses of the country.

There is generally but little choice as regards the alignment and length of the main-drains; they run along the lowest lines in any field, or along water-course lines at the bottoms of the various planes making up the field, and through any hollows that may exist. They are made as straight as the lowest edges of the fields and of the planes, or as the directions of the watercourse lines will conveniently admit. When several fields to be drained happen to be in one plane, and intervening hedges can be removed, one main-drain may be made to serve for all, though enlarged to do so efficiently. The removal of needless fences is very advantageous, not only for convenience in draining, but also from saving useful land; irregular fences and crooked boundaries may be straightened with similar good effect. Main-drains are generally covered so as to protect the ends of the field-drains from injury; their fall or inclinations need not necessarily be very regular, although these as well as the sections should be sufficient to convey away rapidly all water that may arrive under extreme conditions, as after heavy rainfall, when the watercourses of the country are in flood.

Utilisation of the effluent.—The various modes of utilising the water are necessarily dependent on its amount, the available fall, and the local circumstances; it may be dammed, stored, and used either as a cattle pond, for irrigation, or as the motive power for preparing food for cattle, thrashing corn, or other operations connected with husbandry.

When sufficient ready outfall is not available, as in low fen-lands, or on the banks of watercourses and streams of small fall, a long channel may have to be made to conduct the effluent parallel to the watercourse until a sufficient fall is obtained; and its discharge may also require tide-valves, to protect it from return-water during floods.

Time and expense.—The most favourable time for field-drainage is when the land is unoccupied and during dry weather; in England during autumn and winter, after the cutting of a white crop, or a clover crop, or when the land is in pasture or in stubble, and immediately before a summer fallow or a green crop. The work has necessarily to be suspended during severe frost; but any intervals of slightly wet weather are advantageous opportunities for drain-ploughing or drain-cutting in stiff clay. The expenses of ordinary field-drainage in England vary from about 1*l.* to 20*l.* per acre or even more, 30*l.* to 40*l.* The justifiable cost will in any case be considered in its ratio to the eventual value of the yield per acre, or enhanced yield after thorough drainage is completed. The expenses will necessarily have to be borne by an additional rent-charge on the land for several years until the improvement effected is comparatively exhausted. In some cases the expenses are repaid in yield in two or three years, as the increase of *weight* of wheat grown per acre may amount to from half as much again up to nearly double, and the same for potato crops. Perfect draining, accompanied by good management and followed by good culture, is, however, generally necessary for such achievements.

Wet lands in England, that really require drainage, and will not repay the cost of thorough drainage, may generally be considered hardly worth the expenses of mere cultivation.

The drainage of irrigated fields is a matter most frequently distinct from ordinary field-drainage, and hence usually treated in connection with irrigation. The drainage of marshes and bogs and the diversion and control of springs is also a separate branch of draining requiring hydro-geological knowledge and special treatment, before ordinary field-drainage can be conveniently applied to the land afterwards available for cultivation.

9. THE RUIN AND DETERIORATION OF CANALS OF IRRIGATION.

IN canals purely intended for navigation, the velocity of the water has to be kept below a fixed maximum; below that it may be anything down to still-water without causing serious harm; but in irrigation canals, which are continually receiving fresh supplies of water, and distributing it over the land through minor channels, the velocity of the water must be regulated with extreme nicety and care, in order to avoid many evils; the two extremes of which result either in making the cnaal utterly unremunerative from not carrying sufficient water for purposes of irrigation, or in the eventual ruin and destruction, from deterioration, of the canal itself. Such canals cannot be maintained like roads, by merely repairing and trimming worn places; they also require that their suitable velocities should be perpetually watched and regulated, even in the case that the intended velocities were originally correctly determined, and the designs and works made in accordance with them.

One of the most important causes of ruin to works of irrigation is that the velocities were never originally well determined, but were faulty and unsuitable, if not throughout the whole of the works, then at least in portions of them, the result of which eventually affects the whole. This is the case with a great many Indian canals, and is likely to be so on many others, as the matter of hydraulic velocities is one on which knowledge has been very deficient.

The next cause in point of importance is faulty engineering design and defective construction of the works themselves, but this admits of remedy, without going in most cases to such an enormous expense as the former class of error entails. Even under this head, the apportionment of the velocities at intakes, outlets, bridges, and such works, is of extreme importance.

Thirdly, even if we assume the comparatively unusual case of the original intended velocities and the works themselves having been correctly designed in the abstract, and of the works having been constructed to perfection, the canal itself may yet follow the steady course to ruin. For whenever rain falls on the canal, or freshets or floods occur in any of the streams, rivers, or sources of supply, which then increase the supply of the canal, the depth of water in the canal is increased at certain places; and besides, the hydraulic gradient is increased, thus causing a very large increase of velocity taken in proportion to the adjustable correct limits. Under the same circumstances, too, a certain amount of silt is washed into the canal from its banks, and silt-bearing water may also, from want of early precautions, enter from the streams of supply. A high wind may also increase these evils; while, again, the velocity of the canal water may again be increased by the augmented velocity of the water entering the canal.

The practical adjustment of the velocity, or its regulation, becomes, under such circumstances, a matter of extreme care and refinement, even with the aid of all the hydraulic science the world now affords, and the assistance of good instruments and appliances for determining velocities; while without both of these aids it is nearly impossible in most instances.

Setting aside the extreme cases in which the excess of water admitted may be so large that it becomes necessary to let it out over the country by breaking down a bank, and assuming the very moderate one of the velocity being increased by only one-fifth, this alone is amply sufficient to cause scour and erosion of bed and banks to a very appreciable extent; and if this recurs at rainy seasons for years, it becomes positive ruin, not merely on account of the erosion itself, but because also the scoured matter is transported by the water in the form of silt and deposited at other parts of the canal. The whole regimen of the entire canal thus gets out of order, the velocities are redistributed unsuitably or in ill proportion; such errors augment very rapidly, and a partly worn and partly silted-up canal is the result. This is ruin, which cannot be set right except by extraordinary repairs costing half as much as the original cost of the canal; and this is the principal cause of ruin on works of the very best design.

Other causes of deterioration are the admission of silt-bearing water at intakes, neglect of petty repairs, and non-removal of such an average amount of sediment as may be deposited in the canal and channels from causes apart from the preceding. It may also be mentioned that neglect of repair in one year is not compensated for by double the amount in the next, under similar circumstances; but that all such results are cumulative, from increase of interference with the strict regimen of the canal, and its suitably apportioned velocities in various parts of its course.

The consideration of these causes, and more especially of the principal ones, leads to the inevitable conclusion that a careful adjustment, measurement, and regulation of the velocities of the water in canals and works of irrigation is the basis of almost all measures for preventing or deferring eventual ruin.

That considerable refinement is necessary is evident from the fact that the maximum velocities permissible in canals are :—

2·5	feet per second for		very sandy soil.
2·75	"	"	sandy soil.
3·	"	"	loam.
4·	"	"	gravel and very firm soil.

While with low velocities of 1·5 and 1·75 feet per second, any suspended silt may be deposited, and vegetation springs up—the other source of extreme damage. The interval between the extremes is comparatively small and very easily overstepped.

Our present knowledge of velocities, their calculation, determination, and measurement is extremely coarse at present (not long ago it was altogether erroneous), hence the necessity for more knowledge and greater refinement which should be based on extremely careful experiments, carried out under the most advantageous circumstances, with all the aid that improved instruments and appliances of every sort can give and civilised assistance can furnish. The results of greater refinement in dealing with velocities may therefore, if correctly made use of and applied, prevent the lamentable ruin to canals which is illustrated by so many nearly obliterated ancient works in several formerly well-irrigated countries.

The causes of deterioration, and the remedy for them, having been previously explained, the next point to be considered is whether it is worth while to go to the expense involved in applying a more refined knowledge of hydraulic velocities, and in the methods of dealing with them. The amount actually invested in India in canals and works of irrigation, including distribution done at all times, is certainly not less than twenty millions of capital, clear of all working expenses. (For figures in detail, see 'Hydraulic Statistics,' Allen, 1875.)

Now in dealing with statistics of this description, for purposes of argument, it is absolutely necessary that no exceptional case, rates, or figures should be used ; this rule will therefore be rigidly adhered to, and instead of dealing with any special case of canal, a theoretical canal under conditions that average well among actual statistics will be dealt with. Let us suppose a completely developed irrigation canal to have cost one million pounds, the irrigated area to be half a million acres annually, and the net annual profit 10 per cent. on the capital. (The Eastern Jumna Canal yields 22, the Western Jumna Canal 31, and the Kalerun 24 per cent., and these are the three completely developed canals of India, while it is evident that half-developed canals do not afford a fair basis of calculation, any more than partly opened lines of railway.) Now although the duration of a canal, or its lifetime, cannot be actually rigidly estimated, it is perfectly fair to assume that a canal relieved from the wear and tear of excessive velocities and from large deposits of silt, retrogression of levels, and so forth, which are all solely due to the causes previously explained, will last for a duration exceeding by a quarter the period that a less carefully managed canal will last ; in other words, let us assume that if such a canal in one case will last fifty years, in the other it will only last forty years with the same prosperity, full average irrigated and full returns; while after that period they may steadily dwindle down from prosperity to ruin in a similar ratio. Taking the canal thus only at its climax, the total profits in either case will be in proportion to the number of years of duration; for the actual time when the 10 per cent. annual profit dwindles down to below zero, or the canal is worked at what is called a loss, is a different corresponding period in each case. Thus the compared profits on a capital of one million pounds will be about as follows:—

1. *In case of more gradual deterioration.*

			£
10 per cent.	for 50 years=	. .	5 000 000
8 "	10 "	. .	800 000
6 "	10 "	. .	600 000
4 "	10 "	. .	400 000
2 "	10 "	. .	200 000
1 "	10 "	. .	100 000
Total profits during a century		. .	7 100 000

2. *In case of more rapid ruin.*

			£
10 per cent.	for 40 years	. . .	4 000 000
8 "	8 "	. . .	640 000
6 "	8 "	. . .	480 000
4 "	8 "	. .	320 000
2 "	8 "	. . .	160 000
1 "	8 "	. .	80 000
0 "	8 "	. . .	nil.
Loss during 12 years to be deducted at 1 per cent.		. . . .	120 000
Total profits during a century		. .	5 560 000

The difference of total profits, apart from either simple or compound interest on them, is about one million an half pounds sterling, or half as much again as the riginal capital expended on one canal. Taking twenty ıch completed canals to represent the capital invested ı India of twenty millions sterling, the loss due to the ıore rapid deterioration becomes thirty millions sterling, r half as much again as the capital invested, if ex-ended over a full century in each case. Over half a entury the loss is simply equal to the value of the apital invested, and this seems a probable and fair stimate of the anticipated loss in that period, or lamage done.

To this estimated loss, or to something very near to t, there is only one alternative, and that is, the expen-diture of the same amount in extraordinary repairs; which might be set down in the returns either as added to the capital account, or as included in the ordinary repairs. But, however accounts may be managed, the amount estimated must either be lost, or spent in making head against the destruction occurring more rapidly in one case than in the other.

It is useless to ignore that there is a lifetime to everything; the principles of dilapidation cannot be controverted. It may, however, be asserted that under any circumstances instructions may be given that the canals shall be kept in perfect repair, that every care shall be taken, and so forth. This is the very point; the care cannot be taken to prevent such damage unless a higher knowledge of velocities enables a more refined care and a real prevention to be exercised. No doubt the damage, instead of being allowed to accumulate over so many years into absolute ruin, may be stopped by incurring more expense annually; but this is merely spreading the bill for damage over a number of years, the expense is not prevented in that case, but merely divided; and if this form of account be preferred, instead of dealing with a total loss of twenty millions in fifty years, it becomes a waste, loss, or combination of both, of 400,000*l.* yearly over the whole of the irrigation canals and works of distribution of India, which is simply due to the coárseness of our knowledge about velocities. Comparing this annual waste, or even merely a quarter, or a tenth of it, with the relatively small cost of a thoroughly well-conducted series of hydraulic experiments, we may easily see whether the latter are worth while from a financial point of view, as a just and remunerative investment or expenditure on public works.

The principle involved cannot be avoided by drawing any analogy between canals and railways. All improved modes and principles, and increased knowledge, experiments, and so forth, on railways, may have cost India nothing. As railways in their perfection were first required in England where they are still being improved at the expense of skill, money, and thought, all such ideas may be borrowed gratuitously. But there are no large irrigation canals in England, and India must necessarily work out its own improvements in that branch at its own expense, and effect permanent economies for itself, if at all; although it may, and perhaps should, bring to bear on them the highest English skill available in every respect, and make use of it both at home and in India.

In following up, or copying in practice, any clearly defined thoroughly-worked-out principles, as those of roads, railways, and navigable canals, a routine system of the marionette type may be sufficient for the purpose:

ut when practical improvement has to be gained by xperience, experiment, and skill, such a system is in-pplicable without further aid.

The method hitherto adopted of following up and using the hydraulic experience and formulæ devised in France and Germany, and of applying their errors as well as their principles on a very magnified scale, thus saving expense in experiments, has had the most disastrous effect on the irrigation works of India; this point hardly requires exemplification. Latterly the large-scale experiments of Captain Allan Cunningham have demonstrated the immense amount of error involved in using the French and American formulæ and have pointed out the correct method. This, however, is not all that is required; the correct principles must be applied in practice. Any dispensing with the application of improved knowledge in a branch of science that pre-eminently affects the permanent benefit of large and extensive works of irrigation seems therefore perfectly indefensible either on financial or on any other grounds.

10. On Water-Meters.

The term water-meter being frequently used with little discrimination, it becomes necessary to notice briefly the distinction between water-meters and modules or water-regulators. A module actually regulates the supply of water passing into a channel or into a pipe, or makes it practically constant, although both the amount of water and the pressure in the main canal, main pipe, or reservoir, supplying the branch canal or pipe, may be variable. A water-meter does not regulate supply it simply measures or registers supply under corresponding circumstances. Such is the broad distinction; yet water-companies frequently use modules for regulating their supplies, when in large quantities, and call them water-meters; also real water-meters have sometimes auxiliary regulating appliances attached to them. In the former case there is an habitual blunder in language; in the latter there is a constructive difficulty, apparently affecting the term used.

A module is undoubtedly the more perfect appliance as it both regulates and enables the amount of supply passing in any time to be arrived at by calculation, that is to say, it also answers the purpose of a water-meter. A registering or chronographic apparatus may be attached to a module, but it still remains a module. A simple water-meter or registering machine does not regulate supply with practical exactitude (or if it does so, it then is really a module); but, if it has an auxiliary regulator, this merely controls either pressure or quantity, or both, between two limits, convenient to the action of the mechanism, and the machine still remains a water-meter from the fact of its not possessing the complete qualities of a module.

The notion that all such appliances may be distinguished as regulators or meters, according as they are attached to reservoirs and canals or to pipes of supply, is erroneous.

For various types of module, see the paragraph devoted to that subject.

As to water-meters, nominally so-called, we may expect to find that some of them are really modules.

Trough-meters.—The earliest of the English water-meters dates from the time when iron pipes came into use in England for conducting water, and was known as Crosley's water-meter. [It is said that Samuel Clegg, a mechanical engineer in charge of some pumps at Liverpool, in 1802, was the inventor of a gas-meter (See William Matthews's 'Hydraulia,' of April 1835), and of the stand-pipe, and that his ideas gave rise to the water-meter, but there is much doubt about this.] Samuel Crosley's first liquid-meter was a rotating drum inclosed in an air-tight vessel, and certainly was the converse of a gas-meter, as regards action. Crosley's second liquid-meter was a rotating trough, in pattern very like the first. (See p. 304, Matthews's 'Hydraulia.') This latter is the common one, and is well known to this day; it has been re-invented several times, and is sometimes known as Parkinson's, on account of some error (in the Minutes of Proceedings of the Institution of Civil Engineers, January 1851) having intentionally or undesignedly conveyed that this meter was his invention. But in this case neither favouritism, wealth, nor combination have sufficed to obscure the past. Crosley's liquid-meter is a good one, as regards exactitude of measurement; one of its defects is the loss of all pressure at points beyond it, or after the water has passed through it; hence, when applied to the supply of a single house, it must be placed at the top or at the highest level in that house where water is required. It has a ball-valve regulator for maintaining a constant level in the supply-trough

Piston-meters.—Brunton's meter (see copy of patent in 'Repertory of Arts,' &c., for July 1829) was a piston-meter; the water passed through a cylinder with packed piston and rod, nozzle, and valve, or cock; its principle consisted in applying the static fluid pressure on the piston to move it with sufficient force to raise a weight on an inclined plane during the whole range of impulse; the power generated is, at the termination of the impulse, capable of moving the valves or four-way cock, and reversing the pressure on the piston, by which the weight is again raised; the motion is therefore continuous, and expresses the quantity of discharge, which is registered by wheelwork attached to the machine. This meter has been re-invented, with more or less improvement, by Kennedy (see 'Proc. Inst. C. E.' for 1856). The defects of meters of this type are, that the reversals of pressure cause shocks in the mains, and allow some water to pass unregistered; also either the packed piston, the reversing cock, or the balance may be seriously affected by friction, so much so as to get jammed.

Frost's meter is also a piston meter, hardly preferable to the other two; its reciprocating mechanism is not better, though it has a three-way valve moving an auxiliary piston and working another three-way exhaust valve; its piston moves leather buckets within the cylinder, and the whole is liable to stick. (For drawings see 'Proc. Inst. C. E.' for 1857.)

Among the modern piston-meters is Galaffe's; it has two cylinders and two slide-valves, working in cross action, thus neutralising much defect, or rather perhaps keeping it out of view. It is much used in Belgium, and is perhaps the best piston-meter now well known. The compensation of defect that it affords must not, however, make us lose sight of its inherent qualities. Richards' water-meter is the most recent piston-meter, and has some advantages in simplicity; it seems to be a development of the gas-meter of the same inventor. All piston-meters appear to require supervision, and o be generally unsuited to low speeds and small discharges.

Turbine-meters.—Water-meters on this principle are perhaps older than those of the preceding two classes, although it is impracticable to assign definite dates to their introduction. Their applied object is to register the velocity of supply through a fixed opening, but, as some friction must exist, they actually record a less velocity, and, when very defective from wear or rust, become utterly untrustworthy. There have been turbine-meters of several kinds, the modern form is the reaction turbine in common use; Siemens' turbine-meter is one of these. The peculiarity of this meter consists in the drag-boards attached to the rotating drum, which ensure that its velocity shall not exceed that of the water at any time, and thus within certain limits maintaining a constant speed of revolution under a supply that does not vary in amount; in other words, the effect of slight variation in the velocity of the water of supply is entirely annulled. This is a marked advantage, but the appliance suffers from the before-mentioned defects, inseparable from its class of water-meter.

Fan-meters.—These light fans, constructed with the object that the effect of all passing water shall be registered, are the water-meters of the most modern sort. They are much used in Germany, Russia, Italy, and France, but are not popular in England. Siemens' fan-meter has drag-plates to moderate velocity, as in his turbine-meter, and these constitute its chief advantage.

Tylor's fan-meter (described in a paper read before the Institution of Mechanical Engineers) has the same advantage as Siemens': its wheel is of indiarubber, its openings for entrance-water are well arranged, it is not easily choked by sediment at the points of exit, and is generally a much-improved fan-meter. A special improvement in it is an appliance for regulating the speed of the fan by a counter-current of water, so arranged that it is adjustable from the outside of the case. This is of great convenience in testing, as any error in registration due to long use or accident can be remedied without taking the meter to pieces. On the whole, Mr. Tylor's fan-meter is perhaps the best of its kind; it has been thoroughly tested by Mr. Anderson, who has a high opinion of it, and it is much used already in the Colonies.

The objections to fan-meters, or their defects, consist in allowing unregistered water to pass, in slowness in getting into motion at starting, and in spinning on after the supply has been cut off; these defects do not compensate each other, but they may be much reduced by management and care.

General Remarks.—In order to arrive at a just and full comprehension of any particular meter or module, the thing itself should be inspected or examined during action under various conditions; illustrations fail to convey the information that may be obtained in this manner.

It may be noticed that house-meters for registering small supplies of water must necessarily be more delicate in many respects than the large supply-meters of water-companies; they should demand little or no supervision, and be so arranged as not to permit of being easily tampered with, either by the consumer or by the water-officials or agents. Probably some type of module, ensuring constant head during action, with a chronographic apparatus, admitting of independent check on time, would best answer such purposes (see Modules, section 1, Chapter III.).

For exact measurement of supply through pipes under variable pressure, a good pressure-gauge and a chronographic apparatus are necessary; besides this, the outlet must be free, and a considerable length of the pipe must be made of some exact diameter, less than the ordinary varying diameters above the point of observation: all the conditions require much precision and competent management.

part 2

HYDRAULIC WORKING TABLES.

ITY.

HMENT.

AGE AND SUPPLY.

D DISCHARGE.

RAULIC SECTIONS.

RAULIC SLOPES.

VII. CHANNELS AND CANALS.

VIII. PIPES AND CULVERTS.

IX. BENDS AND OBSTRUCTIONS.

X. SLUICES AND WEIRS.

XI. MAXIMUM VELOCITIES.

XII. HYDRAULIC CO-EFFICIENTS.

ADDITIONAL AND MISCELLANEOUS TABLES.

bles can be used either with tradesmen's units or with the units of the English decimal scientific series.

Table I.—GRAVITY.

Calculated Values of the Force of Gravity in Feet at Different Latitudes and Elevations, being a Tabulated Application of the formulæ

$$g = 32{\cdot}1695\ (1 - 0{\cdot}00284\ \cos 2l)\left(1 - \frac{2e}{r}\right).$$

$$r = 20887540\ (1 + 0{\cdot}00164\ \cos 2l).$$

Values of the force of gravity in feet at differ

Elevation in feet	Latitude			
	0°	5°	10°	15°
0	32·0781	32·0795	32·0836	32·0904
100	32·0778	32·0792	32·0833	32·0901
200	32·0775	32·0789	32·0830	32·0898
300	32·0772	32·0786	32·0827	32·0895
400	32·0769	32·0783	32·0824	32·0892
500	32·0766	32·0780	32·0821	32·0889
600	32·0763	32·0777	32·0818	32·0886
700	32·0760	32·0774	32·0815	32·0883
800	32·0757	32·0771	32·0812	32·0880
900	32·0754	32·0768	32·0809	32·0877
1000	32·0751	32·0765	32·0806	32·0874
2000	32·0721	32·0735	32·0775	32·0843
3000	32·0690	32·0704	32·0745	32·0813
4000	32·0660	32·0674	32·0715	32·0783
5000	32·0630	32·0644	32·0685	32·0753

Elevation in feet	Latitude			
	40°	45°	50°	55°
0	32·1536	32·1695	32·1854	32·2008
100	32·1533	32·1692	32·1851	32·2005
200	32·1530	32·1689	32·1848	32·2002
300	32·1528	32·1686	32·1845	32·1998
400	32·1524	32·1683	32·1842	32·1995
500	32·1521	32·1680	32·1839	32·1992
600	32·1518	32·1677	32·1835	32·1989
700	32·1515	32·1674	32·1832	32·1986
800	32·1512	32·1671	32·1829	32·1983
900	32·1509	32·1668	32·1826	32·1980
1000	32·1506	32·1665	32·1823	32·1977
2000	32·1473	32·1633	32·1793	32·1947
3000	32·1442	32·1603	32·1762	32·1916
4000	32·1411	32·1572	32·1731	32·1885
5000	32·1382	32·1541	32·1700	32·1854

titudes and elevations above mean sea level.

ELEVATION IN FEET	LATITUDE			
	20°	25°	30°	35°
0	32·0995	32·1108	32·1238	32·1383
100	32·0992	32·1105	32·1235	32·1380
200	32·0989	32·1102	32·1232	32·1377
300	32·0986	32·1099	32·1229	32·1374
400	32·0983	32·1096	32·1226	32·1371
500	32·0980	32·1093	32·1223	32·1368
600	32·0977	32·1090	32·1220	32·1364
700	32·0974	32·1087	32·1217	32·1361
800	32·0971	32·1084	32·1214	32·1358
900	32·0968	32·1081	32·1211	32·1355
1000	32·0965	32·1077	32·1208	32·1352
2000	32·0934	32·1047	32·1177	32·1322
3000	32·0904	32·1017	32·1146	32·1291
4000	32·0874	32·0986	32·1115	32·1260
5000	32·0843	32·0955	32·1084	32·1229

ELEVATION IN FEET	LATITUDE			
	60°	70°	80°	90°
0	32·2152	32·2395	32·2554	32·2609
100	32·2149	32·2392	32·2551	32·2606
200	32·2146	32·2389	32·2548	32·2603
300	32·2143	32·2386	32·2545	32·2600
400	32·2140	32·2382	32·2541	32·2596
500	32·2136	32·2379	32·2538	32·2593
600	32·2133	32·2376	32·2535	32·2590
700	32·2130	32·2373	32·2532	32·2587
800	32·2127	32·2370	32·2529	32·2584
900	32·2124	32·2367	32·2526	32·2581
1000	32·2121	32·2364	32·2523	32·2578
2000	32·2090	32·2332	32·2491	32·2546
3000	32·2059	32·2301	32·2460	32·2515
4000	32·2028	32·2270	32·2429	32·2483
5000	32·1997	32·2239	32·2397	32·2452

Table II.—CATCHMENT.

rt 1. Total quantities of water resulting from a given effective rainfall run off from any unit of catchment area.

rt 2. Supply in cubic feet per second throughout the year, resulting from a given effective rainfall run off from one square statute mile of catchment area.

rt 3. Supply in cubic feet per second, resulting from an effective daily rainfall for 24 hours over catchment areas.

rt 4. Equivalent supply.

PART I.—*Total quantities of water resulting from a gi*
tive rainfall run off from any unit of catchment ar

Rainfall in feet	Cubic feet per square chain	Cubic feet per century	Cubic rods per square league	Rainfall in inches	Cubic feet per acre	Cubi squ
1	10 000	1 000 000	100 000	12″	43 560	27 8
0·9	9 000	900 000	90 000	11″	39 900	25 5
0·8	8 000	800 000	80 000	10″	36 300	23 2
0·7	7 000	700 000	70 000	9″	32 670	20 9
0·6	6 000	600 000	60 000	8″	29 040	18 5
0·5	5 000	500 000	50 000	7″	25 410	16 2
0·4	4 000	400 000	40 000	6″	21 780	13 9
0·3	3 000	300 000	30 000	5″	18 150	11 6
0·2	2 000	200 000	20 000	4″	14 520	9 2
0·1	1 000	100 000	10 000	3″	10 890	6 9
				2″	7 260	4 6
				1″	3 630	2 3
				″		
0·09	900	90 000	9 000	0·9	3 267	2 09
0·08	800	80 000	8 000	0·8	2 904	1 85
0·07	700	70 000	7 000	0·7	2 541	1 62
0·06	600	60 000	6 000	0·6	2 178	1 39
0·05	500	50 000	5 000	0·5	1 815	1 16
0·04	400	40 000	4 000	0·4	1 452	92
0·03	300	30 000	3 000	0·3	1 089	69
0·02	200	20 000	2 000	0·2	726	46
0·01	100	10 000	1 000	0·1	363	23

N.B.—1 square statute mile = 640 acres = 27 878 400 square f
1 square league = 4 sq. London miles = 100 centuries = 10 000 sq.
(Ramsden's).
1 square chain = 100 sq. rods = 10 000 square feet.

PART 2.—*Supply in cubic feet per second throughout the year, resulting from a given effective annual rainfall run off from one square statute mile of catchment area.*

Annual rainfall in feet	Supply in cubic feet per second	Annual rainfall in feet	Supply in cubic feet per second	Annual rainfall in feet	Supply in cubic feet per second
0·1	·0883	2·1	1·8550	4·1	3·621
0·2	·1766	2·2	1·9433	4·2	3·7100
0·3	2650	2·3	2·0317	4·3	3·7983
0·4	·3533	2·4	2·1200	4·4	3·8866
0·5	·4417	2·5	2·2083	4·5	3·9750
0·6	·5300	2·6	2·2966	4·6	4·0633
0·7	·6183	2·7	2·3850	4·7	4·1517
0·8	·7066	2·8	2·4733	4·8	4·2400
0·9	·7950	2·9	2·5617	4·9	4·3283
1·0	·8833	3·0	2·6500	5·0	4·4166
1·1	·9717	3·1	2·7383	5·5	4·8583
1·2	1·0600	3·2	2·8266	6·	5·3000
1·3	1·1483	3·3	2·9150	6·5	5·7417
1·4	1·2366	3·4	3·0033	7·	6·1833
1·5	1·3250	3·5	3·0917	7·5	6·6250
1·6	1·4133	3·6	3·1800	8·	7·0666
1·7	1·5017	3·7	3·2683	8·5	7·5083
1·8	1·5900	3·8	3·3566	9·	7·9500
1·9	1·6783	3·9	3·4450	9·5	8·3917
2·0	1·7666	4·0	3·5333	10·	8·8333

Similarly from 1 foot of effective annual rainfall, the supply per second is—

From 1 square league . .	3·170 979 2	cubic feet per second
,, 1 century . . .	0·031 709 8	,, ,,
,, 1 square chain . .	0·000 317 1	,, ,,

PART 3.—*Supply in cubic feet per second, resulting from effective daily rainfall for 24 hours over catchment areas.*

FOR CATCHMENT AREAS IN SQUARE STATUTE MILES.

Catchment in sq. miles	For an effective daily rainfall in feet and decimals of								
	0·1	0·09	0·08	0·07	0·06	0·05	0·04	0·03	0·02
	Cubic feet per second								
1	32·27	29·04	25·81	22·59	19·36	16·13	12·91	9·68	6·45
2	64·53	58·07	51·62	45·16	38·72	32·26	25·81	19·36	12·90
3	96·80	83·52	74·24	64·96	55·68	48·40	37·12	27·84	18·56
4	129·1	116·1	103·2	90·30	76·40	64·50	51·60	38·70	25·80
5	161·3	145·2	129·0	112·9	96·80	80·64	64·50	48·40	32·25
6	193·6	174·2	154·8	135·4	116·1	96·78	77·40	58·06	38·70
7	225·9	203·2	180·6	158·0	135·5	112·9	90·30	67·73	45·15
8	258·1	232·2	206·4	180·6	154·8	129·0	103·2	77·40	51·60
9	290·4	261·4	232·3	203·3	174·3	145·2	116·2	87·13	58·10
10	322·7	290·4	258·1	225·9	193·6	161·3	129·1	96·80	64·60

Catchment in sq. miles	For an effective daily rainfall in inches and decimals of								
	1·0	0·9	0·8	0·7	0·6	0·5	0·4	0·3	0·2
	Cubic feet per second								
1	26·89	24·20	21·51	18·82	16·13	13·44	10·76	8·07	5·38
2	53·78	48·40	43·00	37·64	32·26	26·89	21·50	16·13	10·75
3	80·67	54·60	64·53	56·47	48·40	40·33	32·26	24·20	16·13
4	107·56	96·75	86·00	75·25	64·50	53·78	43·00	32·25	21·50
5	134·4	120·9	107·5	94·08	80·64	67·22	53·75	40·32	26·87
6	161·3	145·1	135·0	112·9	96·78	80·67	67·55	48·39	33·77
7	188·2	169·3	150·5	131·7	112·9	94·11	75·25	56·45	[illegible]
8	215·1	193·6	172·1	150·5	129·0	107·5	86·05	64·50	43·02
9	242·0	217·8	193·6	169·4	145·2	121·0	96·80	72·60	48·40
10	268·9	242·0	215·1	188·2	161·3	134·4	107·56	80·67	53·78

Similarly from 1 foot of day's rainfall, the supply is—

From 1 square league	. .	1157·40740	cubic feet per second
" 1 century	. .	1·15741	" "
" 1 square chain	. .	0·01157	" "

(continued).—Supply in cubic feet per second, resulting effective daily rainfall for 24 hours over catchment areas.

FOR CATCHMENT AREAS IN ACRES.

For an effective daily rainfall in feet and decimals of								
0·09	0·08	0·07	0·06	0·05	0·04	0·03	0·02	0·01
Cubic feet per second								
1·13	1·01	0·88	0·76	0·63	0·50	0·378	0·252	0·126
2·27	2·02	1·77	1·51	1·26	1·01	0·756	0·504	0·252
3·40	3·03	2·65	2·27	1·89	1·51	1·134	0·756	0·378
4·54	4·03	3·53	3·03	2·52	2·02	1·513	1·008	0·504
9·08	8·07	7·06	6·05	5·04	4·03	3·025	2·017	1·008
13·61	12·10	10·59	9·08	7·56	6·05	4·538	3·025	1·513
18·15	16·13	14·12	12·10	10·08	8·06	6·050	4·033	2·017
22·69	20·17	17·65	15·13	12·61	10·08	7·563	5·042	2·521
27·22	24·20	21·17	18·15	15·13	12·10	9·075	6·050	3·025
29·04	25·81	22·59	19·36	16·13	12·91	9·680	6·453	3·227

For an effective daily rainfall in inches and decimals of								
0·9	0·8	0·7	0·6	0·5	0·4	0·3	0·2	0·1
Cubic feet per second								
0·95	0·84	0·74	0·64	0·53	0·42	0·315	0·210	0·105
1·89	1·68	1·47	1·28	1·05	0·84	0·630	0·420	0·210
2·83	2·52	2·20	1·92	1·58	1·26	0·945	0·630	0·315
3·78	3·36	2·94	2·56	2·10	1·68	1·260	0·840	0·420
7·56	6·72	5·88	5·12	4·20	3·36	2·521	1·681	0·840
11·34	10·08	8·82	7·68	6·30	5·04	3·781	2·521	1·260
15·12	13·44	11·76	10·24	8·40	6·62	5·042	3·361	1·681
18·91	16·81	14·71	12·80	10·50	8·40	6·302	4·202	2·101
22·69	20·17	17·65	15·36	12·60	10·08	7·562	5·042	2·521
24·20	21·51	18·82	16·13	13·44	10·76	8·067	5·378	2·689

effective rainfall is the measured rainfall, after deduction for eva-, absorption, and all losses.

PART 4.—*Equivalent supply.*

Cubic feet per second, per minute, and per day, into Gallons p
second, per minute, and per day.

Per second		Per minute		Per day of 24 hours	
Cubic feet	Gallons	Cubic feet	Gallons	Cubic feet	Gallons
0·01	0·06	0·6	3·74	864	5 384
0·02	0·12	1·2	7·47	1 728	10 768
0·03	0·19	1·8	11·21	2 592	16 152
0·04	0·25	2·4	14·95	3 436	21 536
0·05	0·31	3·	18·69	4 320	26 920
0·06	0·37	3·6	22·43	5 184	32 304
0·07	0·44	4·2	26·17	6 048	37 688
0·08	0·5	4·8	29·90	6 912	43 072
0·09	0·56	5·4	33·64	7 776	48 456
0·1	0·62	6·	37·39	8 640	53 844
0·16	1·04	10·	62·32	14 400	89 741
0·33	2·08	20·	124·64	28 800	179 842
0·5	3·12	30·	186·96	43 200	269 223
0·66	4·16	40·	249·28	47 600	358 964
0·83	5·20	50·	311·60	72 000	448 704
1·	6·23	60·	373·92	86 400	538 446
1·16	7·27	70·	436·24	100 800	628 187
1·33	8·31	80·	498·56	115 200	717 928
1·5	9·35	90·	560·88	129 600	807 669
1·66	10·39	100	623·20	144 000	897 408
1·15	7·21	69·4	432·7	100 000	623 200
1·93	14·42	115·7	865·4	200 000	1 246 400
3·47	21·63	208·3	1298·1	300 000	1 869 600
4·63	28·84	277·7	1730·8	400 000	2 492 800
5·78	36·05	346·8	2163·5	500 000	3 116 000
6·94	43·26	416·6	2596·2	600 000	3 739 200
8·10	50·47	486·	3028·9	700 000	4 362 400
9·26	57·68	555·5	3461·6	800 000	4 985 600
10·41	64·89	624·9	3894·3	900 000	5 608 800
11·57	72·10	694·4	4327·5	1 million	6 232 000

PART 4 (*continued*).—*Equivalent supply.*

ons per second, per minute, and per day, into Cubic Feet per second, per minute, and per day.

er second		Per minute		Per day of 24 hours	
s	Cubic feet	Gallons	Cubic feet	Gallons	Cubic feet
	0·016	6	0·96	8640	1385
	0·032	12	1·92	17280	2772
	0·048	18	2·88	25920	4158
	0·064	24	3·84	34560	5543
	0·080	30	4·80	43200	6929
	0·096	36	5·76	51840	8315
	0·112	42	6·72	60480	9701
	0·128	48	7·68	69120	11087
	0·144	54	8·64	77760	12473
	0·160	60	9·62	86400	13858
66	0·027	10	1·60	14400	2310
33	0·053	20	3·21	28800	4619
	0·080	30	4·81	43200	6929
66	0·107	40	6·42	57600	9239
33	0·134	50	8·02	72000	11549
	0·160	60	9·62	86400	13858
66	0·187	70	11·23	100800	16168
33	0·214	80	12·83	115200	18478
	0·241	90	14·44	129600	20788
66	0·267	100	16·04	144000	23097
5	0·186	69·4	111·4	100000	16040
3	0·371	115·7	222·8	200000	32079
7	0·557	208·3	334·2	300000	48119
3	0·742	277·7	445·6	400000	64159
8	0·928	346·8	556·9	500000	80199
4	1·114	416·6	667·3	600000	96239
0	1·299	486·	779·7	700000	112278
6	1·485	555·5	891·1	800000	128318
1	1·670	624·9	1002·5	900000	144358
7	1·856	694·4	1113·9	1 million	160398

Table III.—STORAGE AND SUPPLY.

Part 1. Capacity of reservoirs and supply from catchment.
Part 2. Utilisation of a continuous supply of water.
Part 3. Equivalent of continuous supply.

Examples.

PART I.—*Capacity of reservoirs and supply from catchment.*

FOR A NINE MONTHS' SUPPLY.

Supply afforded during 270 days or nine months	Contents of reservoir to hold that supply	Surface of that reservoir if 3 feet deep on the average	Catchment necessary to fill that reservoir in three months; with 1 foot available rainfall in that time
Cubic feet per second	Cubic feet	Square feet	Square miles
1	23 328 000	7 776 000	0·83678
2	46 656 000	15 552 000	1·67355
3	69 984 000	23 328 000	2·51033
4	63 312 000	31 104 000	3·34711
5	116 640 000	38 880 000	4·18388
6	139 968 900	46 656 000	5·02066
7	163 296 000	54 432 000	5·85743
8	186 624 000	62 208 000	6·69422
9	209 952 000	69 984 000	7·53099
10	233 280 000	77 760 000	8·36775
1·1951	27 878 400	9 292 800	1
2·3901	55 756 800	18 585 600	2
3·5852	83 635 200	27 878 400	3
4·7802	111 513 600	37 171 200	4
5·9753	139 392 000	46 464 000	5
7·1704	167 270 400	55 756 800	6
8·3654	195 148 800	65 049 600	7
9·5604	223 027 200	74 342 000	8
10·7555	250 905 600	83 635 200	9
11·9506	278 784 000	92 928 000	10

NOTE.—The reduction of similar quantities in decimal scientific units is so simple as not to require the aid of tables.

T 1 (*continued*).—*Capacity of reservoirs and supply from catchment.*

FOR AN EIGHT MONTHS' SUPPLY.

fforded 40 days months	Contents of reservoir to hold that supply	Surface of that reservoir if 3 feet deep on the average	Catchment area necessary to fill that reservoir in four months, having one foot available rainfall in that time
eet per nd	Cubic feet	Square feet	Square miles
	20 736 000	6 912 000	·7438
	41 472 000	13 824 000	1·4876
	62 208 000	20 736 000	2·2314
	82 944 000	27 648 000	2·9752
	103 680 000	34 560 000	3·7190
	124 416 000	41 472 000	4·4628
	145 152 000	48 384 000	5·2066
	165 888 000	55 296 000	5·9504
	186 624 000	62 208 000	6·6942
	207 360 000	69 120 000	7·4380
444	27 878 400	9 292 800	1
888	55 756 800	18 585 600	2
333	83 635 200	27 878 400	3
777	111 513 600	37 171 200	4
222	139 392 000	46 464 000	5
666	167 270 400	55 756 800	6
100	195 148 800	65 049 600	7
555	223 027 200	74 342 000	8
999	250 905 600	83 635 200	9
4444	278 784 000	92 928 000	10

NOTE.—See explanatory examples following Table III.

PART I (*continued*).—*Capacity of reservoirs and supply from catchment.*

FOR A SIX MONTHS' SUPPLY.

Supply afforded during 180 days or six months	Contents of reservoir to hold that supply	Surface of that reservoir if 34 feet deep on an average	Catchment necessary; with 1 foot available rainfall in 180 days
Cubic feet per second	Cubic feet	Square feet	Square miles
1	15 552 000	5 184 000	0·55785
2	31 104 000	10 368 000	1·11570
3	46 656 000	15 552 000	1·67355
4	62 208 000	20 736 000	2·23140
5	77 760 000	25 920 000	2·78926
6	93 312 000	31 104 000	3·34711
7	108 864 000	36 288 000	3·90496
8	124 416 000	41 472 000	4·46281
9	139 968 000	46 656 000	5·02066
10	155 520 000	51 840 400	5·57851
1·7926	27 878 400	9 292 800	1
3·5852	55 756 800	18 585 600	2
5·3778	83 635 200	27 878 400	3
7·1704	111 513 600	37 171 200	4
8·9630	139 392 000	46 464 000	5
10·7556	167 270 400	55 756 800	6
12·5482	195 148 800	65 049 600	7
14·3407	223 027 200	74 342 000	8
16·1333	250 905 600	83 635 200	9
17·9259	278 784 000	92 928 000	10

[P]ART I (*continued*).—*Capacity of reservoirs and supply from catchment.*

FOR A FOUR MONTHS' SUPPLY.

Supply afforded during 120 days or four months	Contents of reservoir to hold that supply	Surface of that reservoir, if 3 feet deep on the average	Catchment necessary; with 1 foot available rainfall in 240 days
Cubic feet per second	Cubic feet	Square feet	Square miles
1	10 368 000	3 456 000	0·3719
2	20 736 000	6 912 000	0·7438
3	31 104 000	10 368 000	1·1157
4	41 472 000	13 824 000	1·4876
5	51 840 000	17 280 000	1·8595
6	62 208 000	20 736 000	2·2314
7	72 576 000	24 192 000	2·6033
8	82 944 000	27 648 000	2·9752
9	93 312 000	31 104 000	3·3471
10	103 680 000	34 560 000	3·7190
2·6889	27 878 400	9 292 800	1
5·3777	55 756 800	18 585 600	2
8·0666	83 635 200	27 878 400	3
10·7555	111 513 600	37 171 200	4
13·4444	139 392 000	46 464 000	5
16·2000	167 270 400	55 756 800	6
18·8200	195 148 800	65 049 600	7
21·5111	223 027 200	74 342 000	8
24·1999	250 905 600	83 635 200	9
26·8889	278 784 000	92 928 000	10

PART 2.—*Utilisation of a continuous supply of water.*

Cub. feet per second	At 5 gallons per head daily	At 7½ gallons per head daily	At 10 gallons per head daily	At 15 gallons per head daily	At 20 gallons per head daily	At 25 gallons per head daily	At 30 gallons per head daily
	Population supplied						
1	107732	71820	53866	35910	26933	21546	17955
2	215464	143640	107732	71820	53866	43093	35910
3	323196	215410	161598	107730	80799	64639	53865
4	430928	287280	215464	143640	107732	86186	71820
5	538660	359100	269330	179550	134665	107932	89775
6	646392	430920	323196	215460	161598	129278	107730
7	754124	474740	377062	237370	188531	150825	118685
8	861856	574560	430928	287280	215464	172371	143640
9	969588	646380	484794	323190	242397	193917	161595
10	1077320	718200	538660	359100	269330	215464	179550

Cub. feet per second	At 1 cub. foot per head daily	At 1⅓ cub. feet per head daily	At 2 cub. feet per head daily	At 2½ cub. feet per head daily	At 3 cub. feet per head daily	At 4 cub. feet per head daily	At 5 cub. feet per head daily
	Population supplied						
1	86400	57600	43200	34560	28800	21600	17280
2	172800	115200	86400	69120	57600	43200	34560
3	259200	172800	129600	103680	86400	64800	51840
4	345600	230400	172800	138240	115200	86400	69120
5	432000	288000	216000	172800	144000	108000	86400
6	518400	345600	259200	207360	172800	125600	103680
7	604800	403200	302400	241920	201600	151200	120960
8	691200	460800	345600	276480	230400	172800	138240
9	777600	518400	388800	311040	259200	194400	155520
10	864000	576000	432000	345600	288000	216000	172800

NOTE.—See explanatory examples following Table III.

PART 2.—(*continued*).

At 50 acres per cub. foot per sec.	At 75 acres per cub. foot per sec.	At 100 acres per cub. foot per sec.	At 150 acres per cub. foot per sec.	At 200 acres per cub. foot per sec.	At 250 acres per cub. foot per sec.	At 300 acres per cub. foot per sec.
Number of acres irrigated						
50	75	100	150	200	250	300
100	150	200	300	400	500	600
150	225	300	450	600	750	900
200	300	400	600	800	1000	1200
250	375	500	750	1000	1250	1500
300	450	600	900	1200	1500	1800
350	525	700	1050	1400	1750	2100
400	600	800	1200	1600	2000	2400
450	675	900	1350	1800	2250	2700
500	750	1000	1500	2000	2500	3000

At 200 sq. chains per cub. foot per second	At 300 sq. chains per cub. foot per second	At 400 sq. chains per cub. foot per second	At 600 sq. chains per cub. foot per second	At 800 sq. chains per cub. foot per second	At 1000 sq. chains per cub. foot per second	At 1200 sq. chains per cub. foot per second
Number of square chains (Ramsden) irrigated						
200	300	400	600	800	1000	1200
400	600	800	1200	1600	2000	2400
600	900	1200	1800	2400	3000	3600
800	1200	1600	2400	3200	4000	4800
1000	1500	2000	3000	4000	5000	6000
1200	1800	2400	3600	4800	6000	7200
1400	2100	2800	4200	5600	7000	8400
1600	2400	3200	4800	6400	8000	9600
1800	2700	3600	5400	7200	9000	10800
2000	3000	4000	6000	8000	10000	12000

PART 3.—*Equivalent of continuous supply.*

Continuous supply in cubic feet per second into total quantities and vice versâ.

Total quantity in cubic feet	Continuous supply in cubic feet per second.					
	For 2 months	For 3 months	For 6 months	For 8 months	For 9 months	For 12 months
315 360	·06	·04	·02	·015	·013	·01
630 720	·12	·08	·04	·030	·027	·02
946 080	·18	·12	·06	·045	·040	·03
1 261 440	·24	·16	·08	·060	·053	·04
1 576 800	·30	·20	·10	·075	·067	·05
1 892 160	·36	·24	·12	·090	·080	·06
2 207 520	·42	·28	·14	·105	·093	·07
2 522 880	·48	·32	·16	·120	·107	·08
2 838 240	·54	·36	·18	·135	·120	·09
1 million	·1903	·1268	·0634	·0476	·0423	·031710
2 millions	·3805	·2537	·1268	·0851	·0846	·063420
3 ,,	·5708	·3805	·1903	·1427	·1268	·095129
4 ,,	·7610	·5074	·2537	·1902	·1691	·126839
5 ,,	·9513	·6342	·3171	·2378	·2114	·158549
6 ,,	1·1416	·7610	·3805	·2854	·2537	·190259
7 ,,	1·3318	·8879	·4439	·3119	·2960	·221969
8 ,,	1·5221	1·0147	·5074	·3405	·3382	·253678
9 ,,	1·7123	1·1416	·5708	·4280	·3805	·285388
10 ,,	1·9026	1·2684	·6342	·4756	·4228	·317098

PART 3 (*continued*).—*Equivalent of continuous supply.*

Continuous supply in cubic feet per second throughout a month of 30 ys that is equivalent to a certain number of waterings in a month.

mounts given at each atering to one acre	At 30 waterings per month	At 15 waterings per month	At 10 waterings per month	At 4 waterings per month	At 2 waterings per month	At 1 watering per month
Cubic feet	Monthly supply in cubic feet per second					
10000	·1157	·0579	·0386	·0154	·0077	·0039
9000	·1041	·0520	·0347	·0139	·0069	·0035
8000	·0926	·0463	·0309	·0123	·0062	·0031
7000	·0810	·0405	·0271	·0108	·0054	·0027
6000	·0694	·0347	·0231	·0092	·0046	·0023
5000	·0579	·0289	·0193	·0077	·0039	·0019
4000	·0463	·0231	·0154	·0062	·0031	·0015
3000	·0347	·0173	·0116	·0046	·0023	·0011
2000	·0231	·0116	·0077	·0031	·0015	·0008
1000	·0116	·0058	·0039	·0015	·0008	·0004
8640	·1	·050	·0333	·0133	·0066	·0033
7776	·09	·045	·0300	·0120	·0060	·0030
6912	·08	·040	·0267	·0107	·0054	·0027
6048	·07	·035	·0233	·0093	·0046	·0023
5184	·06	·030	·0200	·0080	·0040	·0020
4320	·05	·025	·0167	·0067	·0032	·0016
3456	·04	·020	·0133	·0053	·0026	·0013
2592	·03	·015	·0100	·0040	·0020	·0010
1728	·02	·010	·0067	·0027	·0014	·0007
864	·01	·005	·0033	·0013	·0007	·0003

Example I.

A supply of 18·234 cubic feet per second is wanted during eight mon of the year from a reservoir which is to be supplied by a catchm area yielding an available rainfall of 1·32 feet during the remaining f months; required the contents of the reservoir, and the size of the cat ment area.

Obtain from the Table the quantities due to 1 foot of rainfall,

Supply, cubic feet per second.	Contents of reservoir cubic feet.	Catchment area, square miles.
10	207 360 000	7·4380
8	165 888 000	5·9504
·2	4 147 200	·1488
·03	622 080	·0223
·004	82 944	·0030
18·234	378 100 224	13·5625

Catchment area for 1·32 feet of fall = $\frac{13{\cdot}5625}{1{\cdot}32}$ = 10·274 sq. miles.

Example II.

A catchment area of 21·963 square miles, having an available rai of 1·32 feet in four months of rainy season, supplies a reservoir which hold water for eight months' supply; what should be the full conten the reservoir, and the supply in cubic feet per second during the months?

The proportionate catchment area for an available rainfall of one will = 21·963 × 1·32 = 29·001 square miles.

Catchment area	Contents of reservoir cubic feet	Supply, cub. ft. per second
20	557 568 000	26·888
9	250 905 600	12·0999
·001	27 878	·0013
29·001	808 501 478	38·9892

Example III.

A combined irrigation and water-work scheme yields 18·234 cubic feet [per] second; what amount of land and of population could it supply, at the [ra]tes of 150 acres per cubic foot per second, and of $7\frac{1}{2}$ gallons per head [p]er diem, if one-fourth is to be used for the water-works?

The supply available for irrigation will be $= 18 \cdot 234 - 4 \cdot 558 = 13 \cdot 676$ [c]ubic feet per second; and from Table III., Part 2, we obtain the required [r]esults, thus—

Cubic feet per second.	Population.	Cubic feet per second.	Acres.
4·	287 280	10·	1500
·5	35 910	3·	450
·05	0 591	·6	90
·008	574	·07	10·5
4·558	327 355	·006	·9·
		13·676	2051·

Example IV.

A town has a population of 40 000, requiring water supply at 3 cubic feet per head daily, and has suburbs to the extent of 1 400 acres requiring irrigation at 150 acres per cubic foot per second of supply:—what catchment area will be necessary to provide this, if the annual rainfall is 60 inches, out of which a half can be utilised?

According to Table III., Part 2, the supply necessary will be

For population. Persons.	Cub. ft. per sec.	For irrigation. Acres.	Cub. ft. per sec.	Total cubic feet per second.
28 800	1·	1 350	9·	10·721
8 640	0·3	50	0·333	
2 304	0·08			
230	0·008			
28	0·0001			
40 000	1·3881	1 400	9·333	

According to Part 2, Table II., 30 inches of effective annual rainfall is equivalent to a supply of 2·2083 cubic feet per second from one square mile, hence the minimum catchment area necessary will $= \dfrac{10 \cdot 721}{2 \cdot 208} = 4 \cdot 86$ square miles.

TABLE IV.—FLOOD DISCHARGE.

Part 1. Table of flood discharges in cubic feet per second, due to catchment areas in square miles, and corresponding to a coefficient $k = 1$ in the formula—

$$Q = k \times 100\ (K)^{\frac{3}{4}}.$$

Part 2. Flood discharges in cubic feet per second due to catchment areas, with values of k from 1 to 20

Part 3. Flood waterway for bridge-openings under coefficients $k = 8{\cdot}25$; and $k = 12$.

TABLE IV.—FLOOD DISCHARGE.

Part 1. Table of flood discharges in cubic feet per second, due to catchment areas in square miles, and corresponding to a coefficient $k = 1$ in the formula—

$$Q = k \times 100\,(K)^{\frac{3}{4}}.$$

Part 2. Flood discharges in cubic feet per second due to catchment areas, with values of k from 1 to 20

Part 3. Flood waterway for bridge-openings under coefficients $k = 8{\cdot}25$; and $k = 12$.

PART 2.—*Flood discharges in cubic feet per second du*

Catch-ment in square miles	$k=2$	$k=3$	$k=4$	$k=5$	$k=6$
0·05	22	33	44	55	66
0·1	36	54	72	90	108
0·2	60	90	120	150	180
0·3	82	123	164	205	246
0·4	100	150	200	250	300
0·5	118	177	236	295	354
0·6	136	204	272	340	408
0·7	152	228	304	380	456
0·8	170	255	340	425	510
0·9	184	276	368	460	552
1·	200	300	400	500	600
2·	336	504	672	840	1 008
3·	476	714	952	1 190	1 428
4·	566	849	1 132	1 415	1 698
5·	668	1002	1 336	1 670	2 004
6·	766	1149	1 532	1 915	2 298
7·	860	1290	1 720	2 150	2 580
8·	952	1428	1 904	2 380	2 856
9·	1040	1560	2 080	2 600	3 120
10	1124	1686	2 248	2 810	3 372
20	1802	2838	3 784	4 730	5 676
30	2564	3846	5 128	6 410	7 692
40	3180	4770	6 360	7 950	9 540
50	3760	5640	7 520	9 400	11 280
60	4310	6465	8 620	10 775	12 930
70	4840	7260	9 680	12 100	14 520
80	5350	8025	10 700	13 375	16 050
90	5844	8766	11 688	14 610	17 532
100	6324	9486	12 648	15 810	18 972

at areas, with other values of the coefficient k.

	$k=2$	$k=3$	$k=4$	$k=5$
0	6 324	9 486	12 648	15 810
0	10 636	15 954	21 272	26 590
0	14 416	21 624	28 832	36 040
0	17 888	26 832	35 776	44 720
0	21 148	31 722	42 296	52 870
0	24 246	36 369	48 492	60 615
0	27 218	40 827	54 436	68 045
0	30 084	45 126	60 168	75 210
0	32 864	49 296	65 728	82 160
0	35 566	53 349	71 132	88 915
0	59 814	89 721	119 628	149 535
0	81 072	121 608	162 144	202 680
0	100 594	150 891	201 188	251 485
0	118 920	178 380	237 840	297 300
0	136 346	204 519	272 692	340 865
0	153 058	229 587	316 116	382 645
0	169 180	253 770	338 360	422 950
0	184 804	277 206	369 608	462 010
0	200 000	300 000	400 000	500 000
0	336 358	504 537	672 716	840 895
0	476 570	714 855	953 140	1 191 425
0	564 710	847 065	1 129 420	1 411 775
0	668 740	1 003 110	1 337 480	1 671 850
0	766 732	1 150 098	1 533 464	1 916 830
0	860 704	1 291 056	1 721 408	2 151 760
0	951 366	1 427 049	1 902 732	2 378 415
0	1 039 230	1 558 845	2 078 460	2 598 075
0	1 124 682	1 687 023	2 249 364	2 811 705

PART 2 (*cont.*).—*Flood discharges in cubic feet per*

Catchment in square miles	$k=8$	$k=10$	$k=12$	$k=16$	$k=$
0·05	88	110	132	176	
0·1	144	180	216	288	
0·2	240	300	360	480	
0·3	328	410	492	656	
0·4	400	500	600	800	1
0·5	472	590	708	944	1
0·6	544	680	816	1 088	1
0·7	608	760	912	1 216	1
0·8	680	850	1 020	1 360	1
0·9	736	920	1 104	1 472	1
1·	800	1 000	1 200	1 600	2
2·	1 344	1 680	2 016	2 688	3
3·	1 904	2 380	2 856	3 808	4
4·	2 264	2 830	3 396	4 528	5
5·	2 672	3 340	4 008	5 344	6
6·	2 904	3 830	4 596	5 808	7
7·	3 440	4 300	5 160	6 880	8
8·	3 808	4 760	5 712	7 616	9
9·	4 160	5 200	6 240	8 320	10
10	4 496	5 620	6 744	8 992	11
20	7 568	9 460	11 352	15 136	18
30	10 256	12 820	15 384	20 512	25
40	12 720	15 900	19 080	25 440	31 8
50	15 040	18 800	22 560	30 080	37 6
60	17 240	21 550	25 860	34 480	43 1
70	19 360	24 200	29 040	38 720	48 4
80	21 400	26 750	32 100	4[illegible] 800	53 9
90	23 376	29 220	35 064	46 752	58 4
100	25 296	31 620	37 944	50 592	63 2

ue to catchment areas with other values of the coefficient k.

Catchment in square miles	$k=8$	$k=12$	$k=16$	$k=20$
100	25 296	37 944	50 592	63 240
200	42 544	63 816	85 088	106 360
300	57 664	86 496	115 328	144 160
400	71 552	107 328	143 104	178 880
500	84 592	126 888	169 184	211 480
600	96 984	145 476	193 968	242 460
700	108 872	163 308	217 754	272 180
800	120 336	180 504	240 672	300 840
900	131 456	197 184	262 212	328 640
1 000	142 264	213 396	284 528	355 660
2 000	239 256	358 884	478 512	598 140
3 000	324 288	486 432	648 576	810 720
4 000	402 376	603 564	804 752	1 005 940
5 000	475 680	713 520	951 360	1 189 200
6 000	545 384	818 076	1 090 768	1 363 460
7 000	632 232	918 348	1 264 464	1 530 580
8 000	676 720	1 015 080	1 353 480	1 691 800
9 000	739 216	1 108 824	1 478 432	1 848 040
10 000	800 000	1 200 000	1 600 000	2 000 000
20 000	1 345 432	2 018 148	2 690 864	3 363 580
30 000	1 906 280	2 859 420	3 812 560	4 765 700
40 000	2 258 840	3 388 260	4 517 680	5 647 100
50 000	2 674 960	4 012 440	5 349 920	6 687 400
60 000	3 066 928	4 600 392	6 133 856	7 667 320
70 000	3 442 816	5 164 224	6 885 632	8 607 040
80 000	3 805 464	5 708 196	7 610 928	9 513 660
90 000	4 156 920	6 235 380	8 313 840	10 392 300
100 000	4 498 728	6 748 092	8 977 456	11 246 820

PART 3.—*Flood waterway for bridge openings under a* *coefficient* k=8·25.

(By Colonel Dickens.)

Catchment area	Flood discharge	Assumed velocity	Flood waterway	Number of square openings	Span
Square miles	Cubic feet per second	Feet per sec.	Square feet	Number	Feet
·0016	6·5	5	1·5	1	1½
·0031	11	5	2·25	1	2
·0047	15	5	3·	1	2
·0078	22	5	4·5	1	3
·0125	31	5	6·	1	3
·0250	52	5	10·5	1	4
·0625	103	6	18·	1	6
·1250	173	6	29·	1	7
·2500	292	6	49·	1	10
·5000	490	6	81·	1	12
1	5	7	137	2	12
2	1 388	7	200	3	12
3	1 881	7	270	3	14
5	2 760	7	400	3	16
7	3 550	7	507	3	18
10	4 640	7	663	3	20
20	7 804	8	975	5	20
30	10 577	8	1 322	5	24
50	15 605	9	1 734	5	30
100	26 094	9	2 899	5	40
200	43 884	10	4 388	7	40
300	59 481	10	5 948	9	40
500	87 255	10	8 725	9	50
1 000	146 737	10	14 673	15	50
2 000	246 780	11	22 434	15	60
3 000	334 487	11	30 408	20	60
5 000	490 636	12	40 886	20	75
10 000	825 000	12	68 750	30	75
20 000	1 385 746	13	106 749	40	75
30 000	1 870 962	13	143 920	45	80
50 000	2 695 690	14	190 256	50	90
100 000	4 639 274	15	306 285	60	100

3 (*cont.*).—*Flood waterway for bridge-openings under a coefficient* k=12.

(By the Author.)

…hment …rea	Flood discharge	As-sumed velocity	Flood waterway	No. of sq. open-ings	Span	Height
…re miles	Cub. feet per sec.	Feet per sec.	Square feet	No.	Feet	Feet
·0016	9·6	5	2	1	2	1
·0031	15·8	5	3	1	3	1
·0047	21·5	5	4	1	3	1½
·0078	31·5	5	6	1	3	2
·0125	44·9	5	9	1	3	3
·0250	75·4	5	15	1	4	4
·0625	150	6	25	1	5	5
·1250	252	6	42	1	9	5
·2500	424	6	71	1	12	6
·5000	708	6	118	2	10	6
1·	1 200	7	172	3	10	6
2·	2 016	7	288	3	12	8
3·	2 856	7	408	3	16	9
5·	4 008	7	573	5	14	9
7·	5 160	7	738	5	15	10
10·	6 744	7	964	5	19	10
20	11 352	8	1 694	5	28	12
30	15 384	8	1 924	5	30	13
50	22 560	9	2 508	5	40	13
80	37 944	9	4 216	7	40	15
…00	63 816	10	6 382	9	40	18
…00	86 496	10	8 650	9	50	20
…00	126 588	10	12 660	11	60	20
…00	213 396	10	21 340	15	60	25
…00	358 884	11	32 626	17	80	25
…00	486 432	11	44 222	23	80	25
…00	713 520	12	59 460	20	100	30
…00	1 200 000	12	100 000	25	100	40
…00	2 018 148	13	155 244	26	150	40
…00	2 859 420	13	219 956	28	200	40
…00	4 012 440	14	286 604	29	250	40
…00	6 748 092	15	449 874	45	250	40

Table V.—SECTIONAL DATA.

Sectional Areas (A) and Hydraulic Radii (R),

- Part 1. For Rectangular Canal Sections
- Part 2. For Trapezoidal Canal Sections having side-slopes of one to one.
- Part 3. Dimensions of Channel Sections of equal discharge.
- Part 4. Values of A and R for Cylindrical and Ovoidal Pipes and Culverts.

for use in the General Formulæ,

$$Q = A \cdot c \cdot 100\sqrt{RS},$$
$$V = c \cdot 100\sqrt{RS}.$$

This Table may be used with any unit of measurement.

PART I.—*Sectional Areas* (A) *and Hydraulic Radii* (

Corresponding to vario

d	b=2		b=3		b=4		
	A	R	A	R	A	R	A
0·5	1·	0·333	1·5	0·375	2	0·4	2·5
0·75	1·5	0·429	2·25	0·5	3	0·545	3·75
1·	2·	0·5	3·	0·6	4	0·666	5·
1·25	2·5	0·555	3·75	0·682	5	0·769	6·25
1·5	3·	0·600	4·5	0·750	6	0·857	7·5
1·75	3·5	0·636	5·25	0·808	7	0·933	8·75
2·	4·	0·666	6·	0·857	8	1·	10·
2·25	4·5	0·692	6·75	0·9	9	1·058	11·25
2·5	5·	0·714	7·5	0·937	10	1·111	12·5
2·75	5·5	0·733	8·25	0·971	11	1·158	13·75
3·	6·	0·750	9·	1·	12	1·200	15·
3·5	7·	0·777	10·5	1·050	14	1·273	17·50
4·	8·	0·800	12·	1·091	16	1·333	20·
5·	10·	0·833	15·	1·154	20	1·428	25·

d	b=14		b=16		b=18		
	A	R	A	R	A	R	A
1·	14·	0·875	16	0·888	18	0·900	20
1·25	17·5	1·061	20	1·080	22·5	1·098	25
1·5	21·	1·244	24	1·262	27	1·286	30
1·75	24·5	1·397	28	1·434	31·5	1·468	35
2·	28·	1·555	32	1·600	36	1·636	40
2·25	31·5	1·701	36	1·757	40·5	1·800	45
2·5	35·	1·841	40	1·904	45	1·953	50
2·75	38·5	1·971	44	2·050	49·5	2·109	55
3·	42·	2·100	48	2·182	54	2·250	60
3·25	45·5	2·230	52	2·311	58·5	2·387	65
3·5	49·	2·333	56	2·346	63	2·520	70
3·75	52·5	2·447	60	2·556	67·5	2·646	75
4·	56·	2·545	64	2·666	72	2·768	80
4·25	59·5	2·644	68	2·774	76·5	2·892	85
4·5	63·	2·741	72	2·880	81	3·	90
4·75	66·5	2·833	76	2·979	85·5	3·109	95
5·	70·	2·917	80	3·080	90	3·214	100
5·5	77·	3·080	88	3·256	99	3·416	110
6·	84·	3·230	96	3·429	108	3·600	120
7·	98·	3·500	112	3·733	126	3·938	140

Rectangular sections of Channels, Canals, and Aqueducts.

[Wid]ths (b) and Depths of Water (d).

$b=6$		$b=8$		$b=10$		$b=12$	
A	*R*	*A*	*R*	*A*	*R*	*A*	*R*
6·	0·750	8	0·800	10·	0·833	12	0·857
7·5	0·882	9	0·857	12·5	1·	15	1·035
9·	1·	12	1·091	15·	1·154	18	1·200
10·5	1·106	14	1·218	17·5	1·295	21	1·357
12·	1·200	16	1·333	20·	1·429	24	1·5
13·5	1·286	18	1·440	22·5	1·553	27	1·636
15·	1·364	20	1·538	25·	1·666	30	1·764
16·5	1·436	22	1·628	27·5	1·777	33	1·887
18·	1·5	24	1·714	30·	1·875	36	2·
19·5	1·560	26	1·794	32·5	1·970	39	2·106
21·	1·615	28	1·866	35·	2·058	42	2·209
22·5	1·666	30	1·938	37·5	2·143	45	2·304
24·	1·714	32	2·	40·	2·222	48	2·4
30·	1·875	40	2·222	50·	2·500	60	2·727

$b=25$		$b=30$		$b=35$		$b=40$	
A	*R*	*A*	*R*	*A*	*R*	*A*	*R*
25·	0·925	30	0·938	35·	0·945	40	0·952
37·5	1·338	45	1·364	52·5	1·382	60	1·398
50·	1·725	60	1·764	70·	1·792	80	1·818
56·25	1·901	67·5	1·957	78·75	1·994	90	2·023
62·5	2·083	75·	2·143	87·5	2·187	100	2·222
68·75	2·255	82·5	2·326	96·25	2·377	110	2·418
75·	2·422	90	2·500	105·	2·562	120	2·610
81·25	2·579	97·5	2·672	113·75	2·741	130	2·795
87·5	2·734	105	2·835	122·5	2·919	140	2·982
93·75	2·884	112·5	3·	131·25	3·071	150	3·099
100·	3·030	120	3·156	140·	3·162	160	3·333
106·25	3·166	127·5	3·312	148·75	3·421	170	3·505
112·5	3·308	135	3·456	157·5	3·579	180	3·672
118·75	3·327	142·5	3·608	166·25	3·737	190	3·838
125·	3·571	150	3·750	175·	3·944	200	4·
137·5	3·820	165	4·026	192·5	4·177	220	4·314
150·	4·050	180	4·286	210·	4·473	240	4·614
162·5	4·274	195	4·544	227·5	4·739	260	4·906
175·	4·480	210	4·773	245·	5·	280	5·180
200·	4·880	240	5·220	280·	5·491	320	5·714

[redacted]

r Rectangular Sections of Channels, Canals, and Aqueducts.

idths (b) and Depths of Water (d).

	$b=90$		$b=100$		$b=120$		$b=140$	
	A	R	A	R	A	R	A	R
	90·	0·978	100	0·980	120	0·984	140	0·986
	180·	1·915	200	1·923	240	1·936	280	1·944
5	202·5	2·143	225	2·153	270	2·169	315	2·180
	225·	2·369	250	2·381	300	2·400	350	2·414
5	247·5	2·592	275	2·606	330	2·629	385	2·646
	270·	2·813	300	2·830	360	2·857	420	2·877
5	292·5	3·031	325	3·052	390	3·083	455	3·106
	315·	3·245	350	3·271	420	3·307	490	3·333
5	337·5	3·461	375	3·488	450	3·529	525	3·560
	360·	3·672	400	3·704	480	3·750	560	3·784
25	382·5	3·883	425	3·917	510	3·969	595	4·007
5	405·	4·091	450	4·128	540	4·186	630	4·228
75	427·5	4·296	475	4·338	570	4·402	665	4·448
	450·	4·500	500	4·545	600	4·615	700	4·667
25	472·5	4·701	525	4·751	630	4·828	735	4·883
5	495·	4·900	550	4·955	660	5·038	770	5·100
75	517·5	5·098	575	5·157	790	5·247	805	5·313
	540·	5·292	600	5·357	720	5·455	840	5·527
25	562·5	5·488	625	5·555	750	5·659	875	5·738
5	585·	5·679	650	5·752	780	5·865	910	5·948
75	607·5	5·870	675	5·947	810	6·068	945	6·156
	630·	6·057	700	6·140	840	6·269	980	6·364
25	652·5	6·244	725	6·332	870	6·468	1015	6·569
5	675·	6·429	750	6·522	900	6·667	1050	6·775
75	697·5	6·611	775	6·720	930	6·863	1085	6·977
	720·	6·792	800	6·897	960	7·059	1120	7·179
25	742·5	6·972	825	7·082	990	7·253	1155	7·380
5	765·	7·150	850	7·265	1020	7·445	1190	7·579
75	787·5	7·325	875	7·445	1050	7·637	1225	7·778
	810·	7·505	900	7·627	1080	7·826	1260	7·976
25	832·5	7·672	925	7·805	1110	8·015	1295	8·171
5	855·	7·844	950	7·983	1140	8·201	1330	8·364
75	877·5	8·013	975	8·159	1170	8·387	1365	8·559
	900·	8·182	1000	8·333	1200	8·571	1400	8·750
	990·	8·839	1100	9·017	1320	9·295	1540	9·510
2	1080·	9·472	1200	9·677	1440	10·	1680	10·244

[illegible]	[illegible]	
2·0	[illegible]	
2·25	[illegible]	
2·5	400	2
2·75	440	2
3·	480	2
3·25	520	2
3·5	560	3
3·75	600	3
4·	640	3
4·25	680	3
4·5	720	4·0
4·75	760	4·2
5·	800	4·4
5·25	840	4·7
5·5	880	4·9
5·75	920	5·14
6·	960	5·36
6·25	1000	5·58
6·5	1040	5·79
6·75	1080	6·011
7·	1120	6·225
7·25	1160	6·437
7·5	1200	6·648
7·75	1240	6·857
8·	1280	7·057
8·5	1360	7·273
9·	1440	7·684
9·5	1520	8·090
10·	1600	8·492
11·	1760	8·858
12·	1920	9·167
13·	[illegible]	10·435

tangular Sections of Channels, Canals, and Aqueducts.

) and Depths of Water (d).

b=2[illegible]		b=260		b=280		b=300	
A	R	A	R	A	R	A	R
480	1·967	520	1·969	560	1·971	600	1·974
600	2·449	650	2·453	700	2·456	750	2·459
720	2·927	780	2·932	840	2·937	900	2·941
780	3·164	845	3·170	910	3·176	975	3·181
840	3·401	910	3·408	980	3·414	1050	3·420
900	3·636	975	3·645	1050	3·652	1125	3·659
960	3·871	1040	3·880	1120	3 889	1200	3·896
020	4·104	1105	4·115	1190	4·125	1275	4·132
080	4·337	1170	4·349	1260	4·360	1350	4·369
140	4·569	1235	4·582	1330	4·594	1425	4·604
200	4·800	1300	4·815	1400	4·827	1500	4·839
260	5·030	1365	5·045	1470	5·060	1575	5·073
320	5·259	1430	5·277	1540	5·291	1650	5·305
380	5·487	1495	5·508	1610	5·522	1725	5·537
440	5·714	1560	5·735	1680	5·754	1800	5·769
500	5·940	1625	5·963	1750	5·983	1875	6·
560	6·167	1690	6·192	1820	6·212	1950	6·230
620	6·391	1755	6·416	1890	6·439	2025	6·460
680	6·614	1820	6·643	1960	6·666	2100	6·689
740	6·836	1885	6·869	2030	6·894	2175	6·916
800	7·060	1950	7·090	2100	7·119	2250	7·144
860	7·274	2015	7·314	2170	7·343	2325	7·370
920	7·500	2080	7·536	2240	7·567	2400	7·596
040	7·938	2210	7·978	2380	8·013	2550	8·055
160	8·372	2340	8·417	2520	8·457	2700	8·492
280	8·803	2470	8·852	2660	8·895	2850	8·935
400	9·230	2600	9·286	2800	9·333	3000	9·375
520	9·654	2730	9·716	2940	9·767	3150	9·807
640	10·076	2860	10·142	3080	10·198	3300	10·250
760	10·494	2990	10·565	3220	10·627	3450	10·681
880	10·909	3120	10·986	3360	11·052	3600	11·111
000	11·321	3250	11·404	3500	11·475	3750	11·538
120	11·728	3380	11·818	3640	11·895	3900	11·961
360	12·546	3640	12·639	3920	12·727	4200	12·793
600	13·333	3900	13·448	4200	13·549	4500	13·635
840	14·116	4160	14·247	4480	14·359	4800	14·458
800	17·143	5200	17·333	5600	17·500	6000	17·646

0·5	1·25
0·75	2·06
1·	3·
1·25	4·06
1·5	5·25
1·75	6·56
2·	8·
2·25	9·56
2·5	11·25
2·75	13·06
3·	15·
3·5	19·25
4·	24·
5·	

d	=1…	
	A	
1·	15·	0…
1·25	19·06	1…
1·5	23·25	1·…
1·75	27·56	1·…
2·	32·	1·…
2·25	36·56	1·7…
2·5	41·25	1·9…
2·75	46·06	2·1…
3·	51·	2·2…
3·25	56·06	2·4…
3·5	61·25	2·5…
3·75	66·56	2·7…
4·	72·	2·84
4·25	77·56	2·98
4·5	83·25	3·11
4·7…		

Trapezoidal Sections of Canals with Side Slopes of One to One.

widths (b) and Depths of Water (d).

d	b=6		b=8		b=10		b=12	
	A	*R*	*A*	*R*	*A*	*R*	*A*	*R*
0	7·	0·793	9·	0·831	11·	0·858	13·	0·877
25	9·06	0·950	11·56	1·002	14·06	1·039	16·56	1·066
5	11·25	1·098	14·25	1·164	17·25	1·211	20·25	1·246
75	13·56	1·238	17·06	1·318	20·56	1·375	24·06	1·420
	16·	1·373	20·	1·464	24·	1·533	28·	1·586
25	18·56	1·502	23·06	1·606	27·56	1·684	32·06	1·746
5	21·25	1·626	26·25	1·742	31·25	1·831	36·25	1·901
75	24·06	1·747	29·56	1·873	35·06	1·972	40·56	2·051
	27·	1·864	33·	2·002	39·	2·110	45·	2·197
25	30·06	1·979	35·56	2·069	43·06	2·244	49·56	2·339
5	33·25	2·091	40·25	2·249	47·25	2·375	54·25	2·477
75	36·56	2·201	44·06	2·368	51·56	2·502	59·06	2·612
	40·	2·311	48·	2·486	56·	2·628	64·	2·745
	55·	2·731	65·	2·936	75·	3·107	85·	3·252

d	b=25		b=30		b=35		b=40	
	A	*R*	*A*	*R*	*A*	*R*	*A*	*R*
0	26·	0·934	31·	0·944	36·	0·952	41·	0·957
5	39·75	1·359	47·25	1·380	54·75	1·395	62·25	1·407
	54·	1·761	64·	1·795	74·	1·820	84·	1·840
25	61·31	1·954	72·56	1·995	83·81	2·026	95·06	2·050
5	68·75	2·144	81·25	2·172	93·75	2·228	106·25	2·257
75	76·31	2·328	90·06	2·384	103·81	2·426	117·56	2·460
	84·	2·509	99·	2·573	114·	2·622	129·	2·661
25	91·81	2·684	108·06	2·758	124·31	2·815	140·56	2·838
5	99·75	2·858	117·25	2·939	134·75	3·001	152·25	3·051
75	107·81	3·028	126·56	3·141	145·31	3·197	164·06	3·242
	116·	3·193	136·	3·291	156·	3·368	176·	3·431
25	124·31	3·358	145·56	3·464	166·81	3·547	188·06	3·615
5	132·75	3·519	155·25	3·633	177·75	3·724	200·25	3·798
75	141·31	3·677	165·06	3·800	188·81	3·898	212·56	3·977
	150·	3·831	175·	3·965	200·	4·070	225·	4·155
5	167·75	4·136	195·25	4·286	222·75	4·406	250·25	4·504
	186·	4·432	216·	4·599	246·	4·733	276·	4·844
5	204·75	4·720	237·25	4·903	269·75	5·053	302·25	5·177
	224·	5·000	259·	5·201	294·	5·365	329·	5·501
	264·	5·541	304·	5·776	344·	5·968	384·	6·132

PART 2 (*cont.*).—*Sectional Areas* (A) *and Hydraulic Radii* (R), *for*

Corresponding to Various Bed-

d	b=50		b=60		b=70		b=80	
	A	R	A	R	A	R	A	R
1·0	51·	·964	61·	0·971	71·	0·975	81·	0·978
2·0	104·	1·868	124·	1·889	144·	1·903	164·	1·915
2·25	117·56	2·086	140·06	2·110	162·56	2·129	185·06	2·143
2·5	131·25	2·300	156·25	2·330	181·25	2·352	206·25	2·369
2·75	145·06	2·511	172·56	2·546	200·06	2·572	227·56	2·592
3·	159·	2·719	189·	2·760	219·	2·790	249·	2·814
3·25	173·06	2·927	205·56	2·971	238·06	3·006	270·56	3·034
3·5	187·25	3·126	222·25	3·180	257·25	3·220	292·25	3·251
3·75	201·56	3·326	239·06	3·386	276·56	3·431	314·06	3·466
4·	216·	3·523	256·	3·590	296·	3·640	336·	3·680
4·25	230·56	3·717	273·06	3·791	315·56	3·847	358·06	3·891
4·5	245·25	3·910	290·25	3·991	335·25	4·052	380·25	4·101
4·75	260·06	4·100	307·56	4·188	355·06	4·256	402·56	4·308
5·	275·	4·287	325·	4·384	375·	4·457	425·	4·514
5·25	290·06	4·473	342·56	4·577	395·06	4·656	447·56	4·719
5·5	305·25	4·656	360·25	4·768	415·25	4·853	470·25	4·921
5·75	320·56	4·838	378·06	4·957	435·56	5·049	493·06	5·122
6·	336·	5·017	396·	5·145	456·	5·243	516·	5·321
6·25	351·56	5·195	414·06	5·330	476·56	5·435	539·06	5·519
6·5	367·25	5·371	432·25	5·515	497·25	5·626	562·25	5·715
6·75	383·06	5·544	450·56	5·697	518·06	5·815	585·56	5·909
7·	399·	5·716	469·	5·877	539·	6·002	609·	6·102
7·25	415·06	5·887	487·59	6·056	560·06	6·188	632·56	6·295
7·5	431·25	6·056	506·25	6·234	581·25	6·373	656·25	6·484
7·75	447·56	6·223	525·06	6·409	602·56	6·555	680·06	6·672
8·	464·	6·389	544·	6·584	624·	6·736	704·	6·860
8·25	480·56	6·553	563·06	6·757	645·56	6·917	728·06	7·048
8·5	497·25	6·716	582·25	6·928	667·25	7·095	752·25	7·230
8·75	514·06	6·877	601·56	7·098	689·06	7·272	776·56	7·414
9·	531·	7·037	621·	7·267	711·	7·448	801·	7·595
9·25	548·06	7·196	640·56	7·434	733·06	7·623	825·56	7·777
9·5	565·25	7·353	660·25	7·600	755·25	7·797	850·25	7·956
9·75	582·56	7·509	680·06	7·765	777·56	7·968	875·06	8·134
10·	600·	7·665	700·	7·929	800·	8·140	900·	8·312
11·	671·	8·273	781·	8·572	891·	8·812	1001·	9·009
12·	744·	8·863	864·	9·197	984·	9·467	1104·	[illegible]

Trapezoidal Sections of Canals with Side Slopes of One to One.

widths (b) and Depths of Water (d).

	b=90		b=100		b=120		b=140	
	A	*R*	*A*	*R*	*A*	*R*	*A*	*R*
	91·	0·980	101·	0·982	121·	0·985	141·	0·987
	184·	1·923	204·	1·931	244·	1·942	284·	1·950
25	207·56	2·154	230·06	2·163	275·06	2·177	320·06	2·187
5	231·25	2·382	256·25	2·393	306·25	2·410	356·25	2·422
75	255·06	2·609	282·50	2·622	337·56	2·642	392·56	2·656
	279·	2·833	309·	2·848	369·	2·872	429·	2·889
25	303·06	3·055	335·56	3·073	400·56	3·101	465·56	3·121
5	327·25	3·276	362·25	3·296	432·25	3·328	502·25	3·351
75	351·56	3·494	389·06	3·517	464·06	3·553	539·06	3·579
	376·	3·711	416·	3·737	496·	3·777	576·	3·807
25	400·56	3·926	443·06	3·955	528·06	4·	613·06	4·033
5	425·25	4·139	470·25	4·171	560·25	4·221	650·25	4·258
75	450·06	4·351	497·56	4·386	592·56	4·441	687·56	4·481
	475·	4·562	525·	4·600	625·	4·659	725·	4·703
25	500·06	4·769	552·56	4·811	657·56	4·876	762·56	4·924
5	525·25	4·976	580·25	5·021	690·25	5·092	800·25	5·144
75	550·56	5·181	608·06	5·230	723·06	5·306	838·06	5·363
	576·	5·397	636·	5·437	756·	5·519	876·	5·581
25	601·56	5·587	664·06	5·643	789·06	5·731	914·06	5·797
5	627·25	5·788	692·25	5·848	822·25	5·942	952·25	6·013
75	653·06	5·986	720·56	6·050	855·56	6·151	990·56	6·226
	679·	6·184	749·	6·252	889·	6·359	1029·	6·439
25	705·06	6·380	777·56	6·452	922·56	6·566	1067·56	6·651
5	731·25	6·575	806·25	6·652	956·25	6·772	1106·25	6·862
75	757·56	6·769	835·06	6·849	990·06	6·976	1145·06	7·072
	784·	6·961	864·	7·046	1024·	7·179	1184·	7·280
25	810·56	7·152	893·06	7·241	1058·06	7·382	1223·06	7·488
5	837·25	7·342	922·25	7·435	1092·25	7·583	1262·25	7·695
75	864·06	7·530	951·56	7·628	1126·56	7·783	1301·56	7·900
	891·	7·717	981·	7·819	1161·	7·982	1341·	8·105
25	918·06	7·903	1010·56	8·010	1195·56	8·180	1380·56	8·289
5	945·25	8·088	1040·25	8·199	1230·25	8·376	1420·25	8·511
75	972·56	8·271	1070·06	8·387	1265·06	8·572	1460·06	8·713
	1000·	8·454	1100·	8·575	1300·	8·767	1500·	8·912
	1111·	9·173	1221·	9·313	1441·	9·536	1661·	9·707
	1224·	9·876	1344·	10·03	1584·	10·29	1824·	10·49

PART 2 (*cont.*).—*Sectional Areas* (A) *and Hydraulic Radii* (R), *f*

Corresponding to Various Bo

d	$b=160$		$b=180$		$b=200$		$b=$[illegible]
	A	R	A	R	A	R	A
1·0	161·	0·989	181·	0·990	201·	0·991	221·
2·0	324·	1·956	364·	1·961	404·	1·964	444·
2·25	365·06	2·194	410·06	2·200	455·06	2·205	500·06
2·5	406·25	2·432	456·25	2·439	506·25	2·445	556·25
2·75	447·56	2·668	502·56	2·676	557·56	2·683	612·56
3·	489·	2·902	549·	2·913	609·	2·921	669·
3·25	530·56	3·136	595·56	3·148	660·56	3·158	725·56
3·5	572·25	3·368	642·25	3·382	712·25	3·393	782·25
3·75	614·06	3·599	689·06	3·615	764·06	3·628	839·06
4·	656·	3·829	736·	3·847	816·	3·862	896·
4·25	698·06	4·058	783·06	4·078	868·06	4·094	953·06
4·5	740·25	4·286	830·25	4·308	920·25	4·326	1010·25
4·75	782·56	4·512	877·56	4·537	972·56	4·557	1067·56
5·	825·	4·738	925·	4·765	1025·	4·787	1125·
5·25	867·56	4·962	972·56	4·991	1077·56	5·015	1182·56
5·5	910·25	5·185	1020·25	5·217	1130·25	5·243	1240·25
5·75	953·06	5·407	1068·06	5·442	1183·06	5·470	1298·06
6·	996·	5·628	1116·	5·666	1236·	5·697	1356·
6·25	1039·06	5·848	1164·06	5·889	1289·06	5·921	1414·06
6·5	1082·25	6·067	1212·25	6·111	1342·25	6·146	1472·25
6·75	1125·56	6·285	1260·56	6·332	1395·56	6·370	1530·56
7·	1169·	6·498	1309·	6·552	1449·	6·592	1589·
7·25	1212·56	6·717	1357·56	6·770	1502·56	6·814	1647·56
7·5	1256·25	6·927	1406·25	6·973	1556·25	7·035	1706·25
7·75	1300·06	7·146	1455·06	7·206	1610·06	7·255	1765·06
8·	1344·	7·359	1504·	7·422	1664·	7·474	1824·
8·5	1432·25	7·782	1602·25	7·853	1772·25	7·910	1942·25
9·	1521·	8·201	1701·	8·279	1881·	8·343	2061·
9·5	1610·25	8·617	1800·25	8·702	1990·25	8·773	2180·25
10·	1700·	9·029	1900·	9·122	2100·	9·199	2300·
11·	1881·	9·843	2101·	9·952	2321·	10·04	2541·
12·	2064·	10·64	2304·	10·77	2544·	10·87	2784·
13·	2249·	11·43	2509·	11·59	2769·	11·69	3029·
14·	2436·	12·20	2716·	12·37	2996·	12·50	3276·
15·	2625·	12·97	2925·	13·15	3225·	13·30	3525·
16·	2816·	13·72	3136·	13·92	3456·	14·09	3776·

Trapezoidal Sections of Canals with Side Slopes of One to One.

idths (b) *and depths of water* (d).

	b=240		b=260		b=280		b=300	
	A	*R*	*A*	*R*	*A*	*R*	*A*	*R*
	484·	1·970	524·	1·972	564·	1·974	604·	1·976
	606·25	2·454	656·25	2·457	706·25	2·460	756·25	2·463
	729·	2·934	789·	2·939	849·	2·943	909·	2·947
5	790·56	3·173	855·56	3·178	920·56	3·183	985·56	3·188
5	852·25	3·411	922·25	3·417	992·25	3·423	1062·25	3·428
75	914·06	3·647	989·06	3·655	1064·06	3·662	1139·06	3·667
	976·	3·884	1056·	3·892	1136·	3·900	1216·	3·906
25	1038·06	4·119	1123·06	4·129	1208·06	4·136	1293·06	4·144
5	1100·25	4·353	1190·25	4·364	1280·25	4·373	1370·25	4·382
75	1162·56	4·587	1257·56	4·599	1352·56	4·610	1447·56	4·619
	1225·	4·820	1325·	4·833	1425·	4·845	1525·	4·855
25	1287·56	5·053	1392·56	5·067	1497·56	5·079	1602·56	5·090
5	1350·25	5·283	1460·25	5·299	1570·25	5·313	1680·25	5·325
75	1413·06	5·514	1528·06	5·531	1643·06	5·546	1758·06	5·559
	1476·	5·744	1596·	5·762	1716·	5·778	1836·	5·792
25	1539·06	5·973	1664·06	5·993	1789·06	6·010	1914·06	6·025
5	1602·25	6·201	1732·25	6·223	1862·25	6·241	1992·25	6·257
75	1665·56	6·429	1800·56	6·452	1935·56	6·470	2070·56	6·489
	1729·	6·655	1869·	6·680	2009·	6·701	2149·	6·720
25	1792·56	6·881	1937·56	6·908	2082·56	6·930	2227·56	6·950
5	1856·25	7·106	2006·25	7·134	2156·25	7·159	2306·25	7·180
75	1920·06	7·331	2075·06	7·361	2230·06	7·386	2385·06	7·392
	1984·	7·554	2144·	7·586	2304·	7·613	2464·	7·637
5	2112·25	8·000	2282·25	8·035	2452·25	8·066	2622·25	8·092
	2241·	8·442	2421·	8·481	2601·	8·515	2781·	8·545
5	2370·25	8·882	2560·25	8·925	2750·25	8·962	2940·25	8·995
	2500·	9·319	2700·	9·366	2900·	9·407	3100·	9·443
5	2630·25	9·753	2840·25	9·804	3050·25	9·849	3260·25	9·889
	2761·	10·18	2981·	10·24	3201·	10·29	3421·	10·33
5	2892·25	10·61	3122·25	10·67	3352·25	10·73	3582·25	10·77
	3024·	11·04	3264·	11·10	3504·	11·16	3744·	11·21
5	3156·25	11·46	3406·25	11·53	3656·25	11·59	3906·25	11·65
	3289·	11·88	3549·	11·96	3809·	12·02	4069·	12·08
	3556·	12·72	3836·	12·80	4116·	12·88	4[illegible]76·	12·94
	3825·	13·54	4125·	13·64	4425·	13·72	4725·	13·80
	4096·	14·36	4416·	14·47	4736·	14·56	5056·	14·64
	5200·	17·53	5600·	17·69	6000·	17·83	6400·	17·95

REDUCTION MULTIPLIERS FOR *R*.

For obtaining Values of *R'*, the Hydraulic Radius, for any Trapezoidal Section, from those of *R* given for Rectangular Sections in Part I.

$\frac{b}{d}$ is the ratio of the bed-width to the depth of water.

$\frac{b}{d}$	Ratios of Side Slopes.								
	Rectr.	$\frac{1}{16}$ to 1.	$\frac{1}{8}$ to 1.	$\frac{1}{2}$ to 1.	$\frac{3}{4}$ to 1.	1 to 1.	$1\frac{1}{4}$ to 1.	$1\frac{1}{2}$ to 1.	2 to 1.
0·5	1·0	1·179	1·242	1·828	2·083	2·254	2·332	2·435	2·514
0·75		1·105	1·160	1·536	1·692	1·793	1·855	1·894	1·931
1·		1·081	1·119	1·391	1·500	1·567	1·606	1·628	1·645
1·25		1·064	1·095	1·305	1·386	1·434	1·460	1·473	1·477
1·5		1·054	1·078	1·249	1·313	1·348	1·364	1·371	1·368
2·		1·040	1·058	1·180	1·222	1·243	1·249	1·249	1·236
2·5		1·032	1·046	1·140	1·170	1·183	1·184	1·179	1·162
3·0		1·026	1·038	1·114	1·136	1·144	1·142	1·135	1·115
3·5		1·023	1·033	1·096	1·113	1·117	1·114	1·106	1·084
4·0		1·020	1·029	1·082	1·096	1·099	1·093	1·085	1·062
4·5		1·016	1·025	1·072	1·085	1·084	1·078	1·069	1·046
5·		1·016	1·023	1·064	1·073	1·073	1·067	1·057	1·038
6·		1·013	1·018	1·052	1·059	1·057	1·051	1·041	1·019
7·		1·011	1·016	1·044	1·049	1·047	1·039	1·031	1·009
8·		1·010	1·014	1·038	1·042	1·039	1·032	1·023	1·002
9·		1·009	1·012	1·033	1·036	1·033	1·027	1·018	0·998
10·		1·008	1·011	1·030	1·032	1·029	1·023	1·014	0·995
12·		1·006	1·009	1·024	1·026	1·023	1·017	1·009	[illegible]
14·		1·005	1·008	1·021	1·022	1·019	1·013	1·006	0·990
16·		1·004	1·007	1·018	1·018	1·016	1·011	1·004	0·989
18·		1·004	1·006	1·016	1·016	1·014	1·009	1·003	0·989
20·		1·004	1·005	1·014	1·014	1·012	1·007	1·002	0·989
30·		1·003	1·003	1·009	1·009	1·007	1·004	1·000	[illegible]
40·		1·002	1·003	1·007	1·007	1·005	1·002	1·000	[illegible]
50·		1·001	1·002	1·005	1·005	1·004	1·002	0·999	[illegible]
60·		1·001	1·002	1·005	1·005	1·004	1·001	0·999	[illegible]
70·		1·001	1·001	1·004	1·004	1·003	1·001	0·999	0·995
80·		1·001	1·001	1·003	1·003	1·002	1·001	0·999	0·995
90·		1·001	1·001	1·003	1·003	1·002	1·001	0·999	0·995
100·	1·0	1·001	1·001	1·003	1·003	1·002	1·001	0·999	0·996

To obtain values of *A'* the sectional area for any trapezoidal section having *t* to 1 as the ratio of the side slopes, add td^2 to the values of *A* given for rectangular sections in Part I.

Reduction Multipliers for R.

obtaining Values of R', the Hydraulic Radius, for any Trapezoidal Section, from those of R given for Trapezoidal Sections having Side Slopes of One to One in Part 2.

$\frac{b}{d}$ is the ratio of the bed-width to the depth of water.

	Ratios of Side Slopes.								
f	0 to 1.	$\frac{1}{12}$ to 1.	$\frac{1}{4}$ to 1.	$\frac{1}{2}$ to 1.	$\frac{3}{4}$ to 1.	1 to 1.	$1\frac{1}{4}$ to 1.	$1\frac{1}{2}$ to 1.	2 to 1.
5	·4437	0·523	0·551	0·811	0·924	1·0	1·035	1·080	1·116
75	·5577	0·616	0·647	0·857	0·944		1·035	1·056	1·077
	·6382	0·690	0·714	0·888	0·957		1·025	1·039	1·050
25	·6974	0·742	0·764	0·910	0·967		1·018	1·027	1·030
5	·7418	0·782	0·800	0·927	0·974		1·012	1·017	1·015
	·8045	0·837	0·851	0·949	0·983		1·005	1·005	0·994
5	·8453	0·872	0·884	0·964	0·989		1·001	0·997	0·982
	·8741	0·897	0·907	0·974	0·993		0·998	0·992	0·975
5	·8953	0·916	0·919	0·979	0·996		0·997	0·989	0·971
	·9099	0·928	0·933	0·983	0·997		0·994	0·986	0·966
5	·9225	0·937	0·944	0·988	1·000		0·994	0·985	0·965
	·9320	0·947	0·953	0·991	1·000		0·994	0·984	0·964
	·9461	0·958	0·963	0·995	1·002		0·994	0·984	0·963
	·9551	0·966	0·970	0·997	1·002		0·992	0·984	0·963
	·9625	0·972	0·976	0·999	1·003		0·993	0·984	0·964
	·9681	0·977	0·980	1·000	1·003		0·994	0·985	0·966
	·9718	0·980	0·983	1·001	1·003		0·994	0·985	0·967
	·9775	0·983	0·986	1·001	1·003		0·994	0·986	0·970
	·9814	0·986	0·989	1·002	1·003		0·994	0·987	0·972
	·9843	0·988	0·991	1·002	1·002		0·995	0·988	0·974
	·9862	0·990	0·992	1·002	1·002		0·995	0·989	0·976
	·9881	0·992	0·993	1·002	1·002		0·995	0·990	0·978
	·9930	0·996	0·996	1·002	1·002		0·997	0·993	0·983
	·9950	0·997	0·998	1·002	1·002		0·997	0·995	0·987
	·9960	0·997	0·998	1·001	1·001		0·998	0·995	0·988
	·9960	0·997	0·998	1·001	1·001		0·997	0·995	0·990
	·9970	0·998	0·998	1·001	1·001		0·998	0·996	0·992
	·9980	0·999	0·999	1·001	1·001		0·999	0·997	0·993
	·9980	0·999	0·999	1·001	1·001		0·999	0·997	0·993
	·9980	0·999	0·999	1·001	1·001	1·0	0·999	0·997	0·994

To obtain values of A' the sectional area for any trapezoidal section, ng t to 1 as the ratio of the side slopes, add $d^2(t-1)$ to the values of iven for trapezoids of one to one in Part 2.

PART 3.—*Dimensions of equal-discharging*

MEAN WIDTHS				
100	90	80	70	60
	Corresponding depths			
1	1·074	1·164	1·276	1·408
1·5	1·612	1·748	1·919	2·135
2	2·151	2·333	2·564	2·862
2·5	2·689	2·921	3·211	3·591
3	3·230	3·511	3·864	4·327
3·5	3·771	4·102	4·521	5·066
4	4·312	4·695	5·179	5·814
4·5	4·854	5·289	5·838	6·567
5	5·391	5·884	6·503	7·322
5·5	5·935	6·481	7·169	8·087
6	6·483	7·079	7·840	8·854
6·5	7·026	7·678	8·512	9·624
7	7·570	8·278	9·184	10·40
7·5	8·115	8·880	9·861	11·18
8	8·661	9·486	10·54	11·97
9	9·754	10·69	11·91	13·56
10	10·85	11·91	13·29	15·16
11	11·94	13·13	14·67	16·78
12	13·04	14·35	16·07	18·41

MEAN WIDTHS				
60	50	40	30	20
	Corresponding depths			
1	1·135	1·324	1·625	2·198
1·5	1·704	1·998	2·466	3·385
2	2·275	2·674	3·320	4·621
2·5	2·850	3·359	4·196	5·912
3	3·425	4·050	5·088	7·250
3·5	4·003	4·744	5·993	8·635
4	4·581	5·445	6·912	10·07
4·5	5·162	6·154	7·847	11·54
5	5·746	6·868	8·795	13·05
5·5	6·331	7·585	9·753	14·60
6	6·917	8·306	10·73	16·19
6·5	7·504	9·034	11·72	17·81
7	8·092	9·766	12·72	19·46
7·5	8·682	10·50	13·73	21·15
8	9·274	11·24	14·75	22·87
8·5	9·866	11·98	15·78	24·61
9	10·46	12·73	16·82	26·38
9·5	11·06	13·49	17·87	28·18
10	11·66	14·24	18·93	30·00

Sections of Flow in Canals and Channels.

Mean Widths					Mean Widths				
20	18	16	14	12	12	10	8	6	4
Corresponding depths					Corresponding depths				
1	1·079	1·177	1·301	1·465	1	1·149	1·374	1·759	2·610
1·5	1·623	1·776	1·972	2·237	1·25	1·442	1·734	2·244	3·399
2	2·170	2·382	2·657	3·031	1·5	1·737	2·100	2·751	4·230
2·5	2·718	2·993	3·354	3·847	1·75	2·033	2·473	3·266	5·106
3	3·270	3·611	4·061	4·683	2	2·331	2·849	3·787	6·000
3·5	3·822	4·232	4·777	5·536	2·25	2·630	3·230	4·325	6·931
4	4·377	4·860	5·502	6·404	2·5	2·931	3·615	4·875	7·888
4·5	4·933	5·491	6·237	7·286	2·75	3·233	4·004	5·431	8·857
5	5·492	6·126	6·979	8·179	3	3·537	4·397	6·000	9·869
5·5	6·051	6·763	7·724	9·084	3·5	4·147	5·192	7·158	11·93
6	6·612	7·404	8·475	10·	4	4·761	6·000	8·345	14·05
6·5	7·173	8·047	9·234	10·93	4·5	5·379	6·817	9·550	16·22
7	7·737	8·695	9·998	11·86	5	6·000	7·644	10·78	18·44
7·5	8·301	9·345	10·77	12·80	5·5	6·624	8·478	12·03	20·69
8	8·867	9·999	11·54	13·75	6	7·250	9·318	13·29	22·98
8·5	9·433	10·65	12·32	14·70	6·5	7·878	10·17	14·56	25·29
9	9·999	11·31	13·10	15·67	7	8·508	11·02	15·85	27·64
9·5	10·57	11·97	13·88	16·64	7·5	9·139	11·87	17·14	29·95
10	11·13	12·63	14·70	17·62	8	9·773	12·74	18·44	32·37

PART 3 (*cont.*).—*Dimensions of equal-discharg*

Depths of Water					Depths of Water				
1	1·5	2	2·5	3	3	3·5	4	4·5	5
	Corresponding mean-widths					Corresponding mean-widths			
100	55·32	36·85	27·13	21·55	100	80·37	66·77	56·90	49·4[illegible]
90	49·88	33·30	24·59	19·58	90	72·44	60·25	51·42	44·7[illegible]
80	44·44	29·75	22·04	17·61	80	64·48	53·72	45·93	40·06
70	38·99	26·20	19·48	15·63	70	56·52	47·19	40·44	35·[illegible]
60	33·54	22·65	16·92	13·63	60	48·56	40·65	34·92	30·62
50	28·08	19·80	14·34	11·62	50	40·60	34·10	29·39	25·86
40	22·62	15·47	11·73	9·58	40	32·62	27·52	23·86	21·06
30	17·14	11·87	9·10	7·50	30	24·63	20·91	18·30	16·1[illegible]
20	11·64	8·22	6·41	5·35	20	16·62	14·24	12·52	11·21

Depths of Water					Depths of Water				
1	1·25	1·5	1·75	2	2	2·25	2·5	2·75	3
	Corresponding mean-widths					Corresponding mean-widths			
20	14·75	11·64	9·62	8·22	20	17·19	15·01	13·44	12·15
18	13·31	10·53	8·73	7·48	18	15·50	13·56	12·17	11·02
16	11·87	9·42	7·83	6·73	16	13·81	12·11	10·89	9·86
14	10·43	8·31	6·93	5·98	14	12·12	10·66	9·60	8·73
12	8·98	7·19	6·02	5·22	12	10·42	9·20	8·31	7·58
10	7·53	6·07	5·12	4·45	10	8·72	7·73	7·00	6·40
8	6·08	4·93	4·18	3·66	8	7·01	6·24	5·68	5·21
6	4·62	3·79	3·24	2·85	6	5·29	4·74	4·34	4·00
4	3·13	2·61	2·26	2·	4	3·57	3·22	2·96	2·75

...ons of Flow in Canals and Channels.

	Depths of Water			
	6	7	7·5	8
	Corresponding mean-widths			
	77·90	63·57	58·20	53·67
	70·27	57·47	52·68	48·63
	62·63	51·36	41·15	43·58
	54·98	45·23	41·58	38·50
	47·32	39·07	35·99	33·39
	39·63	32·90	30·37	28·23
	31·91	26·66	24·67	23·00
	24·17	20·37	18·94	17·72
	16·36	13·95	13·03	12·25

	Depths of Water			
8	9	10	11	12
	Corresponding mean-widths			
100	85·59	74·78	66·42	59·82
90	77·18	67·56	60·11	54·21
80	68·75	60·28	53·74	48·56
70	60·31	53·00	47·36	42·90
60	51·87	45·71	40·96	37·20
50	43·38	38·40	34·53	31·45
40	34·87	31·01	28·04	25·59
30	26·34	23·57	21·49	19·66
20	17·73	16·00	14·63	13·51

	Depths of Water			
	3·5	4	4·5	5
	Corresponding mean-widths			
	16·62	14·24	12·52	11·21
	15·00	12·89	11·36	10·19
	13·37	11·53	10·19	9·16
	11·75	10·17	9·01	8·13
	10·12	8·79	7·82	7·07
	8·48	7·41	6·61	6·00
	6·83	5·99	5·37	4·89
	5·17	4·57	4·12	3·77
	3·48	3·11	2·82	2·59

	Depths of Water			
5	6	7	7·5	8
	Corresponding mean-widths			
20	16·36	13·95	13·03	12·25
18	14·78	12·65	11·83	11·13
16	13·19	11·33	10·61	10·00
14	11·59	10·00	9·38	8·86
12	9·99	8·65	8·13	7·68
10	8·39	7·29	6·87	6·50
8	6·78	5·90	5·57	5·28
6	5·11	4·50	4·26	4·04
4	3·44	3·05	2·89	2·76

PART 4.—*Sectional Areas* (A) *in square f*

CYLINDRICAL CULVERTS AND PIPES.

Diameter	Full.		Two-thirds full.		One-third ful
	A	*R*	*A*	*R*	*A*
3 inches	0·0491	0·0625	0·0347	0·073	0·0143
4 ,,	0·0872	0·0833	0·0618	0·097	0·0254
6 ,,	0·1963	0·125	0·1390	0·145	0·0573
8 ,,	0·3490	0·1666	0·2472	0·194	0·1018
9 ,,	0·4418	0·1875	0·3128	0·218	0·1289
10 ,,	0·5454	0·2083	0·3807	0·243	0·1592
Feet					
1·	0·7854	0·25	0·5562	0·291	0·2292
1·25	1·2272	0·3125	0·8565	0·364	0·3581
1·5	1·7671	0·375	1·2514	0·436	0·5157
1·75	2·4053	0·4375	1·6409	0·509	0·7019
2·	3·1416	0·5	2·2248	0·582	0·9168
2·25	3·9760	0·5625	2·8157	0·655	1·1609
2·5	4·9087	0·625	3·4262	0·728	1·4325
2·75	5·9395	0·6875	4·2062	0·800	1·7333
3·	7·0686	0·75	5·0058	0·873	2·0628
3·25	8·2957	0·8125	5·8747	0·996	2·4209
3·5	9·6211	0·875	6·5635	1·019	2·8077
3·75	11·045	0·9375	7·8215	1·092	3·2230
4·	12·566	1·	8·8992	1·164	3·6672
4·5	15·904	1·125	11·263	1·310	4·6437
5·	19·635	1·25	13·905	1·455	5·7300
5·5	23·758	1·375	16·825	1·601	6·9333
6·	28·274	1·5	20·023	1·747	8·2512
6·5	33·183	1·625	23·499	1·992	9·6837
7·	38·485	1·75	27·254	2·038	11·231
7·5	44·179	1·875	31·286	2·183	12·892
8·	50·265	2·	35·597	2·329	14·669
8·5	56·745	2·125	40·185	2·475	16·560
9·	63·617	2·25	45·052	2·620	18·565
9·5	70·882	2·375	50·197	2·765	20·685
10·	78·540	2·5	55·620	2·911	22·920

The values of *R* for cylindrical culverts half full are the same a for full cylindrical culverts of the same diameter.

Hydraulic Radii (R) in Feet, for Culverts and Pipes.

HAWKSLEY'S OVOID CULVERT.

Transverse Diameter	Full.		Two-thirds full.		One-third full.	
	A	*R*	*A*	*R*	*A*	*R*
1′ 0″	0·9955	0·2766	0·6714	0·310	0·2569	0·198
1′ 2″	1·3550	0·3227	0·9138	0·362	0·3496	0·231
1′ 4″	1·7697	0·3688	1·1936	0·413	0·4566	0·264
1′ 6″	2·2424	0·4149	1·5106	0·465	0·5780	0·297
1′ 8″	2·7653	0·4610	1·8650	0·517	0·7136	0·330
1′ 10″	3·3457	0·5071	2·2506	0·568	0·8627	0·363
2′ 0″	3·9820	0·5532	2·6856	0·620	1·0276	0·396
2′ 2″	4·6728	0·5993	3·1434	0·672	1·2050	0·429
2′ 4″	5·4199	0·6454	3·6554	0·723	1·3985	0·462
2′ 6″	6·2219	0·6915	4·1962	0·775	1·6054	0·495
2′ 8″	7·0790	0·7376	4·7744	0·826	1·8265	0·528
2′ 10″	7·8908	0·7837	5·3754	0·878	2·0606	0·561
3′ 0″	8·9695	0·8298	6·0426	0·930	2·3121	0·594
3′ 2″	9·9822	0·8759	6·7324	0·981	2·5760	0·627
3′ 4″	11·061	0·9220	7·4600	1·033	2·8544	0·660
3′ 6″	12·195	0·9681	8·2242	1·085	3·1464	0·693
3′ 8″	13·383	1·0142	9·0024	1·136	3·4508	0·726
3′ 10″	14·628	1·0603	9·8657	1·188	3·7749	0·759
4′ 0″	15·928	1·1064	10·742	1·240	4·1104	0·792
4′ 2″	17·282	1·1525	11·656	1·291	4·4600	0·825
4′ 4″	18·691	1·1986	12·574	1·343	4·8200	0·858
4′ 6″	20·182	1·2447	13·595	1·395	5·2020	0·891
4′ 8″	21·680	1·2908	14·622	1·446	5·5942	0·924
4′ 10″	23·253	1·3369	15·683	1·498	6·0006	0·957
5′ 0″	24·887	1·3830	16·785	1·550	6·4225	0·990
5′ 2″	26·567	1·4291	17·918	1·601	6·8560	1·023
5′ 4″	28·316	1·4752	19·098	1·653	7·3062	1·056
5′ 6″	30·111	1·5213	20·255	1·705	7·7643	1·089
5′ 8″	31·563	1·5674	21·502	1·756	8·2424	1·122
5′ 10″	33·871	1·6135	22·844	1·808	8·7407	1·155
6′ 0″	35·838	1·6596	24·170	1·859	9·2484	1·188

The long diameter = 1·2929 × transverse diameter in Hawksley's Ovoid.

PART 4 (cont.)—*Sectional Areas* (A) *in square fe*

PHILLIPS' METROPOLITAN OVOID.

Dimensions.	Full.		Two-thirds full.		One-
	A	*R*	*A*	*R*	*A*
[illegible]	[illegible]	0·290	0·7558	0·316	0·2840
[illegible]	[illegible]	0·338	1·0287	0·368	0·3865
[illegible]	[illegible]	0·386	1·3436	0·421	0·5049
[illegible]	[illegible]	0·434	1·7005	0·474	0·6390
[illegible]	[illegible]	0·483	2·0994	0·526	0·7889
[illegible]	[illegible]	0·531	2·5402	0·579	0·9545
[illegible]	4·5840	0·579	3·0232	0·631	1·1360
[illegible]	5·3806	0·628	3·5480	0·684	1·3332
[illegible]	6·2526	0·676	4·1149	0·737	1·5462
[illegible]	7·1781	0·724	4·7237	0·789	1·7750
[illegible]	8·2172	0·773	5·3746	0·842	2·0195
[illegible]	9·2160	0·821	6·0674	0·894	2·2799
[illegible]	10·336	0·869	6·8022	0·947	2·5560
[illegible]	11·517	0·917	7·5790	1·	2·8479
[illegible]	12·764	0·966	8·3978	1·052	3·1556
[illegible]	14·069	1·014	9·2585	1·105	3·4790
[illegible]	15·410	1·062	10·161	1·158	3·8182
[illegible]	16·877	1·111	11·106	1·210	4·1732
[illegible]	18·376	1·159	12·093	1·263	4·5440
[illegible]	19·939	1·207	13·122	1·315	4·9306
[illegible]	21·566	1·255	14·192	1·368	5·3329
[illegible]	23·257	1·304	15·305	1·421	5·7510
[illegible]	25·012	1·352	16·460	1·473	6·1849
[illegible]	26·830	1·400	17·656	1·526	6·6346
[illegible]	28·713	1·449	18·895	1·579	7·1000
[illegible]	30·665	1·497	20·176	1·631	7·5812
[illegible]	32·668	1·545	21·498	1·684	8·0782
[illegible]	34·742	1·593	22·863	1·736	8·5910
[illegible]	36·880	1·642	24·270	1·789	9·1196
[illegible]	39·081	1·690	25·718	1·842	9·6639
[illegible]	41·346	1·738	27·209	1·894	10·224

and Hydraulic Radii (R) *in feet, for Culverts.*

JACKSON'S PEGTOP SECTION.

Dimensions	Full		Two-thirds full		One-third full	
	A	*R*	*A*	*R*	*A*	*R*
1' 0" × 1' 6"	1·0385	0·268	0·6458	0·280	0·2422	0·190
1' 2" × 1' 9"	1·4136	0·312	0·8790	0·326	0·3296	0·222
1' 4" × 2' 0"	1·8463	0·357	1·1482	0·373	0·4305	0·254
1' 6" × 2' 3"	2·3367	0·402	1·4531	0·420	0·5448	0·286
1' 8" × 2' 6"	2·8848	0·447	1·7929	0·466	0·6504	0·317
1' 10" × 2' 9"	3·4906	0·492	2·1152	0·513	0·8134	0·349
2' 0" × 3' 0"	4·1542	0·536	2·5834	0·560	0·9686	0·381
2' 2" × 3' 3"	4·8735	0·580	3·0317	0·606	1·1355	0·412
2' 4" × 3' 6"	5·6542	0·624	3·5162	0·653	1·3186	0·444
2' 6" × 3' 9"	6·4909	0·669	4·0340	0·699	1·5134	0·476
2' 8" × 4' 0"	7·3851	0·714	4·5928	0·746	1·7220	0·508
2' 10" × 4' 3"	8·3371	0·759	5·1843	0·793	1·9425	0·539
3' 0" × 4' 6"	9·3469	0·803	5·8126	0·839	2·1794	0·571
3' 2" × 4' 9"	10·414	0·848	6·4776	0·886	2·4265	0·603
3' 4" × 5' 0"	11·539	0·893	7·1716	0·933	2·6016	0·634
3' 6" × 5' 3"	12·722	0·937	7·9115	0·979	2·9668	0·666
3' 8" × 5' 6"	13·963	0·982	8·4608	1·026	3·2536	0·698
3' 10" × 5' 9"	15·261	1·027	9·4922	1·072	3·5558	0·730
4' 0" × 6' 0"	16·617	1·071	10·334	1·119	3·8744	0·761
4' 2" × 6' 3"	18·030	1·115	11·215	1·165	4·2011	0·793
4' 4" × 6' 6"	19·501	1·160	12·127	1·212	4·5420	0·825
4' 6" × 6' 9"	21·030	1·205	13·078	1·259	4·9032	0·856
4' 8" × 7' 0"	22·617	1·249	14·065	1·305	5·2744	0·888
4' 10" × 7' 3"	24·261	1·294	15·091	1·352	5·6529	0·920
5' 0" × 7' 6"	25·964	1·339	16·136	1·399	6·0538	0·952
5' 2" × 7' 9"	27·723	1·384	17·244	1·445	6·4595	0·983
5' 4" × 8' 0"	29·540	1·428	18·371	1·492	6·8440	1·015
5' 6" × 8' 3"	31·416	1·472	19·537	1·539	7·3206	1·047
5' 8" × 8' 6"	33·348	1·517	20·737	1·585	7·7700	1·078
5' 10" × 8' 9"	35·339	1·562	21·981	1·632	8·2340	1·110
6' 0" × 9' 0"	37·388	1·607	23·250	1·679	8·7175	1·142

TABLE VI.—HYDRAULIC SLOPES AND GRADIENTS.

Part 1. Reduction of hydraulic slopes and inclinations.
Part 2. Reduction of angular declivities and gradients.
Part 3. Limiting Inclinations, Maximum Gradients, Angles of Repose.

PART I.—*Reduction of hydraulic slopes.*

S per thousand	One in	Feet per mile	*S* per thousand	One in	Feet per mile
0·01	100 000	0·0528	1·	1000	5·28
0·02	50 000	0·1056	1·25	800	6·60
0·03	33 333	0·1584	1·5	666	7·92
0·04	25 000	0·2112	1·75	571	9·24
0·05	20 000	0·2640	2·	500	10·56
0·06	16 666	0·3168	2·25	444	11·88
0·07	14 286	0·3696	2·5	400	13·20
0·08	12 500	0·4224	2·75	364	14·52
0·09	11 111	0·4752	3·	333	15·84
			3·25	308	16·66
0·1	10 000	0·528	3·5	286	18·48
0·15	6 666	0·792	3·75	266	19·80
0·2	5 000	1·056	4·	250	21·12
0·25	4 000	1·320	4·25	235	22·44
0·3	3 333	1·584	4·5	222	23·76
0·35	2 857	1·848	4·75	210	25·08
0·4	2 500	2·112	5·	200	26·40
0·45	2 222	2·376			
0·5	2 000	2·640	6	167	31·68
			7	143	36·96
0·55	1 818	2·904	8	125	42·25
0·6	1 666	3·168	9	111	47·52
0·65	1 538	3·332			
0·7	1 429	3·696	10	100	52·80
0·75	1 333	3·960	20	50	105·6
0·8	1 250	4·224	30	33	158·4
0·85	1 176	4·488	40	25	211·2
0·9	1 111	4·752	50	20	264·0
0·95	1 053	5·016			

PART I (*continued*).

S per thousand	Feet per mile	One in	*S* per thousand	Feet per mile
0·0100	0·0528	1000	1·	5·280
0·0111	0·0587	900	1·111	5·866
0·0125	0·0660	800	1·250	6·6
0·0143	0·0754	700	1·428	7·54
0·0167	0·0880	600	1·666	8·8
0·0200	0·1056	500	2·	10·56
0·0250	0·1320	400	2·5	13·20
0·0333	0·1760	300	3·333	17·60
0·0500	0·2640	200	5·	26·40
0·1000	0·5280	190	5·263	27·78
0·1053	0·5557	180	5·555	29·33
0·1111	0·5866	170	5·882	31·05
0·1177	0·6211	160	6·250	33·
0·1250	0·6600	150	6·667	35·20
0·1333	0·7040	140	7·143	37·71
0·1428	0·7543	130	7·692	40·60
0·1539	0·8123	120	8·333	44·
0·1666	0·8800	110	9·091	48·
		100	10·	52·80
0·1818	0·9600			
0·2	1·0560	90	11·111	58·66
0·2222	1·1733	80	12·5	66·
0·25	1·3200	70	14·286	75·42
0·2856	1·5086	60	16·667	88·
0·3333	1·7600	50	20·	105·6
0·4	2·1120	40	25·	132·
0·5	2·6400	30	33·333	176·
0·6666	3·5200			

PART 2.—*Reduction of gradients.*

Angle in degrees	Ratio to one vertical	Reduction of 100 feet horizontal	Angle in degrees	Ratio to one vertical	Reduction of 100 feet horizontal
1°	57·29	100·02	21°	2·61	107·11
1½	38·19	100·03	22	2·48	107·85
2	28·64	100·06	23	2·36	108·64
2½	22·90	100·10	24	2·25	109·46
3	19·08	100·14	25	2·15	110·34
3½	16·35	100·19	26	2·05	111·26
4	14·30	100·24	27	1·96	112·23
4½	12·71	100·31	28	1·88	113·26
5	11·43	100·38	29	1·80	114·34
5½	10·39	100·46	30	1·73	115·47
6	9·51	100·55	31	1·66	116·66
6½	8·78	100·65	32	1·60	117·92
7	8·14	100·75	33	1·54	119·24
7½	7·60	100·86	34	1·48	120·62
8	7·12	100·98	35	1·43	122·08
8½	6·69	101·11	36	1·38	123·61
9	6·31	101·25	37	1·33	125·21
9½	5·98	101·39	38	1·28	126·90
			39	1·24	128·68
10	5·67	101·54			
11	5·15	101·87	40	1·19	130·54
12	4·71	102·23	41	1·15	132·51
13	4·33	102·63	42	1·11	134·56
14	4·01	103·06	43	1·07	136·73
15	3·73	103·53	44	1·04	139·02
16	3·49	104·03	45	1·	141·4
17	3·27	104·57			
18	3·08	105·15	50	0·84	155·6
19	2·90	105·76	55	0·70	174·3
20	2·75	106·42	60	0·58	200·

PART 2 (*continued*).

Ratio to one vertical	Angle	Reduction of 100 feet horizontal	Ratio to one vertical	Angle	Reduction of 100 feet horizontal
100	0° 34′	100·01	9·5	6° 1′	100·55
60	0 57	100·01	9·	6 20	100·61
55	1 2	100·02	8·5	6 43	100·69
50	1 9	100·02	8·	7 8	100·78
45	1 16	100·02	7·5	7 36	100·88
40	1 26	100·03	7·	8 8	101·01
35	1 36	100·04			
			6·75	8 26	101·09
30	1 55	100·06	6·5	8 45	101·17
29	1 58	100·06	6·25	9 5	101·27
28	2 3	100·06	6·	9 28	101·38
27	2 7	100·07	5·75	9 52	101·50
26	2 12	100·07	5·5	10 18	101·64
25	2 17	100·08	5·25	10 45	101·78
24	2 23	100·09	5·	11 19	101·99
23	2 29	100·09	4·75	11 53	102·19
22	2 36	100·10	4·5	12 32	102·44
21	2 44	100·11	4·25	13 14	102·73
20	2 52	100·12	4·	14 2	103·08
			3·75	14 56	103·50
19	3 1	100·14	3·5	15 57	104·00
18	3 11	100·15	3·25	17 6	104·62
17	3 22	100·17	3·	18 26	105·41
16	3 35	100·20	2·75	19 59	106·41
15	3 49	100·22	2·5	21 48	107·70
14	4 5	100·25	2·25	23 58	109·43
13	4 24	100·30	2·	26 34	111·80
12	4 46	100·34	1·75	29 45	115·18
11	5 12	100·41	1·5	33 41	120·17
10	5 43	100·50	1·25	38 40	128·08
			1·	45 0	141·4

PART 3.—*Various Slopes and Gradients.*

ORDINARY LIMITS OF INCLINATION IN CHANNELS.

Reciprocal of slope	
1 in 500 000	Least canal slope to produce motion.
1 in 16 000 / 1 in 6 000	Limits of tidal navigation for large canals.
1 in 15 000 / 1 in 5 000	Fall of most deltaic or inundation canals.
1 in 6 000 / 1 in 2 000	Fall of most canals.
1 in 3 000 / 1 in 1 000	Fall of smaller canals, channels.
1 in 5 000 / 1 in 500	Fall of most rivers.
1 in 300 / 1 in 80	Fall of torrents.

VARIOUS GRADIENTS.

For sewerage unaided by flushing.

1 in 250	Sewers and mains	minima usual.
1 in 50	Pipes and drains	
1 in 25	House drains	
1 in 600 to 1 in 200	limits for sewers generally.	

MAXIMUM GRADIENTS.

1 in 50	Ordinary railways.
1 in 30	Turnpike road.
1 in 20	Public road.
1 in 16	Private road.
1 in 8	For wheeled vehicles.
1 in 4	Beasts of burden.
1 in 1½	Hill-walking.

ANGLES OF REPOSE.

½ to 1 to 1 to 1	Chalk; dry clay.
1 to 1	Compact earth, dry set, rubble.
1¼ to 1	Gravel, shingle, dry sand.
1½ to 1	Average mixed earth, dry.
1¾ to 1	Vegetable earth, dry.
2 to 1	Sand, dry.
3 to 1 to 4 to 1	Wet clay, peat.

N.B.—Wetted soil requires a less slope than dry soil generally.

VARIOUS SLOPES.

2 to 1	Minimum for slated and tiled roofs.
2½ to 1	Maximum for back slopes of rammed earthen dams.
⅓ to 1	Maximum for breast slopes of rammed earthen dams.

[redacted]

TABLE VII.—CANALS AND CHANNELS.

Approximate velocities of discharge for canals, channels, and straight regular reaches of rivers, for various hydraulic mean radii (R) *and slopes* (S) *according to the formula—*

$$V = c \times 100\,(R\,.\,S)^{\frac{1}{2}} \text{ when } c = 1.$$

Part 1. When the hydraulic slope is represented by a ratio in the d form of a fall of unity in a certain length.

Part 2. When the hydraulic slope is represented by $\dot{S}$, the sine of the ope; and S per 1000 is the fall in 1000 feet.

Part 3. Conditions and dimensions of equal-discharging channels of apezoidal section, with side slopes of 1 to one, under a coefficient of igosity $n = 0{\cdot}025$.

N.B.—For the use of co-efficients (c) and (n), see Table XII.

PART I.—*Values of the expression* 100 $\sqrt{RS}$.

R in feet	For hydraulic slopes of one in									
	1000	2000	3000	4000	5000	6000	7000	8000	9000	10 0
	Approximate velocities of discharge in feet per second									
·05	·707	·5	·409	·353	·316	·289	·267	·25	·236	[illegible]
·1	1·	·707	·577	·5	·447	·408	·378	·353	·333	[illegible]
·15	1·225	·866	·707	·612	·547	·5	·463	·433	·408	[illegible]
·20	1·414	1·	·816	·707	·632	·577	·534	·5	·471	[illegible]
·25	1·581	1·118	·913	·790	·707	·645	·597	·559	·527	[illegible]
·3	1·732	1·225	·999	·866	·775	·706	·655	·612	·577	[illegible]
·35	1·871	1·323	1·801	·935	·837	·764	·707	·661	·624	[illegible]
·4	2·	1·414	1·154	1·	·894	·816	·756	·707	·666	[illegible]
·45	2·121	1·500	1·224	1·060	·949	·865	·802	·750	·707	[illegible]
·5	2·236	1·581	1·290	1·118	1·	·912	·845	·790	·745	[illegible]
·55	2·345	1·658	1·354	1·172	1·049	·957	·886	·829	·782	[illegible]
·6	2·449	1·732	1·414	1·224	1·095	1·	·926	·866	·816	[illegible]
·65	2·550	1·803	1·472	1·275	1·140	1·041	·964	·901	·850	[illegible]
·7	2·646	1·871	1·528	1·323	1·183	1·080	1·	·935	·882	[illegible]
·75	2·739	1·936	1·581	1·369	1·225	1·118	1·035	·968	·913	[illegible]
·8	2·828	2·	1·633	1·414	1·265	1·155	1·069	1·	·943	[illegible]
·85	2·915	2·062	1·683	1·457	1·304	1·190	1·101	1·031	·972	[illegible]
·9	3·	2·121	1·732	1·5	1·342	1·225	1·132	1·060	1·	[illegible]
·95	3·082	2·179	1·779	1·541	1·378	1·257	1·164	1·089	1·027	[illegible]
1·00	3·162	2·236	1·826	1·581	1·414	1·283	1·195	1·118	1·054	1·
1·1	3·317	2·345	1·915	1·658	1·483	1·354	1·254	1·172	1·106	[illegible]
1·2	3·464	2·449	2·	1·732	1·549	1·414	1·310	1·224	1·155	[illegible]
1·3	3·606	2·550	2·082	1·803	1·612	1·472	1·363	1·275	1·202	[illegible]
1·4	3·742	2·646	2·160	1·871	1·673	1·527	1·414	1·323	1·247	[illegible]
1·5	3·873	2·739	2·236	1·936	1·732	1·581	1·464	1·366	1·291	[illegible]
1·6	4·	2·828	2·309	2·	1·789	1·632	1·511	1·414	1·333	[illegible]
1·7	4·123	2·915	2·380	2·061	1·844	1·683	1·558	1·457	1·374	[illegible]
1·8	4·243	3·	2·449	2·121	1·897	1·731	1·604	1·5	1·414	[illegible]
1·9	4·359	3·082	2·517	2·179	1·949	1·779	1·648	1·541	1·453	[illegible]
2·	4·472	3·162	2·582	2·236	2·	1·825	1·691	1·581	1·491	[illegible]
2·1	4·583	3·240	2·646	2·291	2·049	1·871	1·732	1·620	1·528	[illegible]
2·2	4·690	3·317	2·707	2·345	2·098	1·914	1·773	1·658	1·563	[illegible]
2·3	4·796	3·391	2·769	2·398	2·145	1·958	1·812	1·695	1·599	[illegible]
2·4	4·899	3·464	2·828	2·449	2·191	1·999	1·852	1·732	1·633	[illegible]
2·5	5·	3·536	2·886	2·5	2·236	2·040	1·889	1·768	1·666	[illegible]
2·6	5·099	3·606	2·943	2·549	2·280	2·081	1·927	1·803	1·699	[illegible]
2·7	5·196	3·674	3	2·598	2·324	2·121	1·964	1·837	1·732	[illegible]
2·8	5·292	3·742	3·055	2·646	2·366	2·160	2·	1·871	1·764	[illegible]
2·9	5·385	3·808	3·109	2·692	2·408	2·198	2·035	1·904	1·795	[illegible]
3·	5·477	3·873	3·163	2·738	2·449	2·236	2·070	1·936	1·826	[illegible]

PART I (*continued*).

R in feet	For hydraulic slopes of one in									
	1000	2000	3000	4000	5000	6000	7000	8000	9000	10 000
	Approximate velocities of discharge in feet per second									
3·1	5·568	3·937	3·215	2·784	2·490	2·273	2·105	1·968	1·856	1·761
3·2	5·657	4·	3·266	2·828	2·530	2·309	2·138	2·	1·886	1·789
3·3	5·745	4·062	3·317	2·872	2·569	2·345	2·172	2·031	1·915	1·817
3·4	5·831	4·123	3·367	2·915	2·608	2·382	2·204	2·061	1·944	1·844
3·5	5·916	4·183	3·416	2·958	2·646	2·415	2·236	2·092	1·972	1·871
3·6	6·	4·243	3·464	3·	2·683	2·449	2·267	2·121	2·	1·897
3·7	6·083	4·301	3·512	3·041	2·720	2·483	2·299	2·150	2·028	1·924
3·8	6·164	4·359	3·559	3·082	2·757	2·516	2·330	2·179	2·055	1·949
3·9	6·245	4·416	3·606	3·122	2·793	2·548	2·360	2·208	2·082	1·975
4·	6·325	4·472	3·651	3·162	2·828	2·581	2·390	2·236	2·108	2·
4·1	6·403	4·528	3·696	3·202	2·864	2·613	2·421	2·264	2·134	2·025
4·2	6·481	4·563	3·741	3·240	2·898	2·645	2·450	2·291	2·160	2·049
4·3	6·557	4·637	3·786	3·278	2·933	2·680	2·480	2·318	2·186	2·074
4·4	6·633	4·690	3·829	3·316	2·966	2·707	2·507	2·345	2·211	2·098
4·5	6·708	4·743	3·873	3·354	3·	2·738	2·535	2·371	2·236	2·121
4·6	6·782	4·796	3·916	3·391	3·033	2·769	2·564	2·398	2·261	2·145
4·7	6·856	4·848	3·958	3·428	3·066	2·798	2·591	2·424	2·285	2·168
4·8	6·928	4·899	4·	3·464	3·098	2·828	2·619	2·449	2·309	2·191
4·9	7·	4·950	4·041	3·5	3·130	2·857	7·646	2·475	2·333	2·214
5·	7·071	5·	4·082	3·535	3·162	2·886	2·672	2·5	2·357	2·236
5·1	7·141	5·050	4·122	3·570	3·194	2·914	2·699	2·525	2·380	2·258
5·2	7·211	5·099	4·164	3·605	3·225	2·944	2·725	2·549	2·404	2·280
5·3	7·280	5·148	4·204	3·640	3·258	2·972	2·751	2·574	2·427	2·302
5·4	7·348	5·196	4·242	3·674	3·286	2·999	2·777	2·598	2·449	2·324
5·5	7·416	5·244	4·282	3·708	3·317	3·027	2·803	2·622	2·472	2·345
5·6	7·483	5·292	4·320	3·742	3·347	3·054	2·828	2·646	2·494	2·366
5·7	7·550	5·339	4·359	3·775	3·376	3·080	2·854	2·669	2·517	2·387
5·8	7·616	5·385	4·397	3·808	3·406	3·109	2·878	2·692	2·539	2·408
5·9	7·681	5·431	4·434	3·840	3·435	3·135	2·903	2·715	2·560	2·429
6·	7·746	5·477	4·472	3·873	3·464	3·162	2·928	2·738	2·582	2·449
6·1	7·810	5·523	4·508	3·905	3·493	3·187	2·952	2·761	2·603	2·470
6·2	7·874	5·568	4·546	3·937	3·521	3·214	2·977	2·784	2·625	2·490
6·3	7·937	5·612	4·583	3·968	3·550	3·240	3·	2·806	2·646	2·510
6·4	8·	5·657	4·619	4·	3·578	3·264	3·024	2·828	2·666	2·530
6·5	8·062	5·701	4·654	4·031	3·606	3·290	3·048	2·850	2·687	2·550
6·6	8·124	5·745	4·690	4·062	3·633	3·316	3·071	2·872	2·708	2·570
6·7	8·185	5·788	4·725	4·093	3·661	3·340	3·093	2·894	2·728	2·588
6·8	8·246	5·831	4·761	4·123	3·688	3·366	3·117	2·915	2·749	2·608
6·9	8·307	5·874	4·796	4·153	3·715	3·391	3·138	2·937	2·769	2·627
7·	8·367	5·916	4·830	4·184	3·742	3·415	3·162	2·957	2·789	2·646

PART I (*continued*).

R in feet	For hydraulic slopes of one in								
	1000	2000	3000	4000	5000	6000	7000	8000	9000
	Approximate velocities of discharge in feet per second								
7·1	8·426	5·958	4·865	4·213	3·768	3·439	3·185	2·979	2·809
7·2 +	8·485	6·	4·898	4·242	3·795	3·463	3·207	3·	2·828
7·3	8·544	6·042	4·933	4·272	3·821	3·483	3·229	3·021	2·848
7·4	8·602	6·083	4·966	4·301	3·847	3·511	3·252	3·041	2·867
7·5	8·660	6·124	5·	4·330	3·873	3·535	3·273	3·062	2·887
7·6	8·718	6·164	5·033	4·359	3·899	3·558	3·296	3·082	2·906
7·7	8·775	6·205	5·066	4·387	3·924	3·582	3·317	3·102	2·925
7·8	8·832	6·245	5·099	4·416	3·950	3·605	3·339	3·122	2·944
7·9	8·888	6·285	5·132	4·444	3·975	3·628	3·360	3·142	2·963
8·	8·944	6·325	5·163	4·472	4·	3·650	3·380	3·162	2·981
8·1	9·	6·364	5·196	4·5	4·025	3·674	3·400	3·182	3·
8·2	9·055	6·403	5·229	4·527	4·050	3·697	3·423	3·201	3·018
8·3	9·110	6·442	5·261	4·555	4·074	3·719	3·443	3·221	3·037
8·4	9·165	6·481	5·291	4·582	4·099	3·741	3·464	3·240	3·055
8·5	9·220	6·519	5·322	4·610	4·123	3·763	3·485	3·259	3·073
8·6	9·274	6·557	5·354	4·637	4·147	3·785	3·505	3·278	3·091
8·7	9·327	6·595	5·385	4·663	4·171	3·807	3·525	3·297	3·109
8·8	9·381	6·633	5·416	4·690	4·195	3·829	3·545	3·316	3·127
8·9	9·434	6·671	5·447	4·717	4·219	3·851	3·566	3·335	3·145
9·	9·487	6·708	5·477	4·743	4·243	3·872	3·586	3·354	3·162
9·1	9·539	6·745	5·506	4·769	4·266	3·893	3·606	3·372	3·179
9·2	9·592	6·782	5·537	4·796	4·290	3·915	3·625	3·391	3·197
9·3	9·644	6·819	5·568	4·822	4·313	3·636	3·645	3·409	3·215
9·4	9·695	6·856	5·599	4·847	4·336	3·958	3·665	3·428	3·232
9·5	9·747	6·892	5·630	4·873	4·359	3·980	3·685	3·446	3·249
9·6	9·798	6·928	5·658	4·899	4·382	4·	3·704	3·464	3·266
9·7	9·849	6·964	5·686	4·924	4·405	4·020	3·723	3·482	3·283
9·8	9·899	7·	5·714	4·949	4·427	4·039	3·741	3·5	3·299
9·9	9·950	7·036	5·745	4·975	4·450	4·060	3·751	3·518	3·317
10	10·	7·071	5·773	5·	4·472	4·082	3·778	3·535	3·333
15	12·247	8·660	7·070	6·123	5·477	4·998	4·629	4·330	4·082
20	14·142	10·	8·165	7·071	6·325	5·773	5·346	5·	4·714
25	15·811	11·180	9·128	7·905	7·071	6·453	5·975	5·590	5·270
30	17·321	12·247	10·	8·660	7·746	7·070	6·546	6·123	5·773
35	18·708	13·229	10·801	9·354	8·367	7·636	7·071	6·614	6·236
40	20·	14·412	11·545	10·	8·944	8·162	7·559	7·071	6·666
45	21·213	15·	12·247	10·606	9·487	8·659	8·017	7·5	7·071
50	22·361	15·811	12·910	11·180	10·	9·127	8·456	7·905	7·454
60	24·495	17·321	14·142	12·242	10·954	10·	9·258	8·660	8·165
70	26·458	18·708	15·275	13·229	11·832	10·799	10·	9·354	8·819

For true velocities, apply the correct value of *c*. See Table XII.

2.—*Values of the Expression* $100\sqrt{RS}$.

For values of *S* per thousand of					
4·5	4·0	3·5	3·0	2·5	2·0
Approximate velocities of discharge in feet per second					
6·708	6·325	5·916	5·476	5·	4·472
7·5	7·071	6·614	6·123	5·590	5·
8·216	7·746	7·246	6·708	6·123	5·477
8·874	8·367	7·826	7·246	6·614	5·916
9·487	8·944	8·367	7·746	7·071	6·325
10·062	9·487	8·874	8·216	7·5	6·708
10·606	10·	9·354	8·660	7·906	7·071
11·124	10·488	9·810	9·083	8·291	7·416
11·619	10·954	10·247	9·487	8·660	7·746
12·093	11·402	10·665	9·874	9·014	8·062
12·550	11·832	11·068	10·247	9·354	8·367
12·990	12·248	11·456	10·611	9·682	8·660
13·416	12·650	11·832	10·954	10·	8·944
13·829	13·038	12·196	11·292	10·308	9·220
14·230	13·416	12·550	11·619	10·606	9·487
14·620	13·784	12·894	11·937	10·897	9·747
15·	14·142	13·229	12·247	11·180	10·
15·375	14·492	13·555	12·550	11·456	10·246
15·732	14·832	13·874	12·845	11·726	10·488
16·086	15·166	14·186	13·134	11·989	10·724
16·432	15·492	14·491	13·416	12·247	10·954
17·103	16·124	15·083	13·964	12·747	11·402
17·748	16·734	15·652	14·491	13·229	11·832
18·371	17·320	16·202	15·	13·697	12·247
18·974	17·888	16·733	15·492	14·142	12·649
19·558	18·440	17·248	15·969	14·577	13·038
20·125	19·974	17·748	16·432	15·	13·416
21·213	20·	18·708	17·321	15·811	14·142
22·249	20·976	19·621	18·166	16·583	14·832
23·238	21·908	20·494	18·974	17·321	15·492
24·187	22·804	21·331	19·748	18·028	16·124
25·100	23·664	22·136	20·494	18·708	16·734
25·981	24·495	22·913	21·213	19·365	17·320
26·833	25·298	23·664	21·909	20·	17·888
30·	28·284	26·458	24·495	22·361	20·

PART 2 (*contd.*).—*Values of the E*

R in feet	For values of S per thousand of					
	[illegible]	[illegible]	0·95	0·90	0·85	0·80
	Approximate velocities of discharge in feet per second					
[illegible]	[illegible]	[illegible]	[illegible]	3·	2·915	2·828
[illegible]	[illegible]	[illegible]	[illegible]	3·354	3·259	3·162
[illegible]	[illegible]	[illegible]	[illegible]	3·674	3·571	3·464
[illegible]	[illegible]	[illegible]	[illegible]	3·969	3·857	3·742
[illegible]	[illegible]	[illegible]	[illegible]	4·243	4·123	4·
[illegible]	[illegible]	[illegible]	[illegible]	4·5	4·373	4·242
[illegible]	[illegible]	5·	[illegible]	4·743	4·610	4·472
[illegible]	[illegible]	[illegible]	[illegible]	4·975	4·835	4·690
[illegible]	[illegible]	[illegible]	[illegible]	5·196	5·050	4·898
[illegible]	[illegible]	[illegible]	[illegible]	5·408	5·256	5·098
[illegible]	[illegible]	[illegible]	[illegible]	5·612	5·454	5·292
[illegible]	[illegible]	[illegible]	[illegible]	5·809	5·646	5·477
[illegible]	[illegible]	[illegible]	[illegible]	6·	5·831	5·657
[illegible]	[illegible]	[illegible]	[illegible]	6·185	6·010	5·830
[illegible]	[illegible]	[illegible]	[illegible]	6·364	6·185	6·
[illegible]	[illegible]	[illegible]	[illegible]	6·538	6·354	6·164
[illegible]	[illegible]	[illegible]	[illegible]	6·708	6·519	6·325
[illegible]	[illegible]	[illegible]	[illegible]	6·874	6·680	6·482
[illegible]	[illegible]	[illegible]	[illegible]	7·036	6·827	6·633
[illegible]	[illegible]	[illegible]	[illegible]	7·194	6·991	6·782
[illegible]	[illegible]	[illegible]	[illegible]	7·348	7·141	6·928
[illegible]	[illegible]	[illegible]	[illegible]	7·649	7·433	7·211
[illegible]	[illegible]	[illegible]	[illegible]	7·937	7·714	7·484
[illegible]	[illegible]	[illegible]	[illegible]	8·216	7·984	7·746
[illegible]	[illegible]	[illegible]	[illegible]	8·485	8·246	8·
[illegible]	[illegible]	[illegible]	[illegible]	8·746	8·500	8·246
[illegible]	[illegible]	[illegible]	[illegible]	9·	8·740	8·486
[illegible]	[illegible]	[illegible]	[illegible]	9·487	9·220	8·944
[illegible]	[illegible]	[illegible]	[illegible]	9·950	9·670	9·381
[illegible]	[illegible]	[illegible]	[illegible]	10·392	10·100	9·797
[illegible]	[illegible]	[illegible]	[illegible]	10·817	10·512	10·198
[illegible]	[illegible]	[illegible]	[illegible]	11·225	10·909	10·583
[illegible]	[illegible]	[illegible]	[illegible]	11·619	11·292	10·954
[illegible]	[illegible]	[illegible]	[illegible]	12·	11·662	11·314
[illegible]	[illegible]	14·142	13·784	13·416	13·038	12·650

o $\sqrt{RS}$, *suitable to Canals and Channels.*

R in Feet	For values of *S* per thousand of						
	0·70	0·65	0·60	0·55	0·50	0·45	0·40
	Approximate velocities of discharge in feet per second						
1·	2·646	2·550	2·449	2·345	2·236	2·121	2·
1·25	2·958	2·850	2·739	2·622	2·5	2·372	2·236
1·5	3·240	3·122	3·	2·872	2·739	2·598	2·449
1·75	3·500	3·372	3·240	3·102	2·958	2·806	2·646
2·	3·742	3·606	3·464	3·317	3·162	3·	2·828
2·25	3·969	3·824	3·674	3·518	3·354	3·182	3·
2·5	4·183	4·031	3·873	3·708	3·536	3·354	3·162
2·75	4·387	4·228	4·062	3·889	3·708	3·518	3·317
3·	4·583	4·416	4·243	4·062	3·873	3·674	3·464
3·25	4·770	4·596	4·416	4·228	4·031	3·824	3·606
3·5	4·950	4·769	4·583	4·387	4·183	3·969	3·742
3·75	5·123	4·937	4·743	4·541	4·330	4·108	3·873
4·	5·292	5·099	4·899	4·690	4·472	4·243	4·
4·25	5·454	5·256	5·050	4·835	4·610	4·373	4·124
4·5	5·612	5·408	5·196	4·975	4·743	4·5	4·243
4·75	5·766	5·557	5·339	5·111	4·873	4·623	4·358
5·	5·916	5·701	5·477	5·244	5·	4·743	4·472
5·25	6·062	5·842	5·612	5·374	5·123	4·861	4·582
5·5	6·205	5·979	5·744	5·500	5·244	4·975	4·690
5·75	6·344	6·114	5·874	5·624	5·362	5·087	4·796
6·	6·481	6·245	6·	5·745	5·477	5·196	4·898
6·5	6·745	6·5	6·245	5·979	5·701	5·408	5·098
7·	7·	6·745	6·480	6·205	5·916	5·612	5·292
7·5	7·246	6·982	6·708	6·423	6·124	5·809	5·477
8·	7·483	7·211	6·928	6·633	6·325	6·	5·657
8·5	7·714	7·433	7·141	6·837	6·519	6·185	5·830
9·	7·937	7·649	7·348	7·036	6·708	6·364	6·
10·	8·367	8·062	7·746	7·416	7·071	6·708	6·325
11·	8·775	8·456	8·124	7·778	7·416	7·036	6·633
12·	9·165	8·832	8·486	8·124	7·746	7·348	6·928
13·	9·539	9·192	8·832	8·456	8·062	7·649	7·211
14·	9·899	9·539	9·165	8·775	8·367	7·937	7·484
15·	10·247	9·874	9·486	9·083	8·660	8·216	7·746
16·	10·583	10·198	9·798	9·381	8·944	8·485	8·
20·	11·832	11·402	10·954	10·488	10·	9·487	8·944

For true velocities, apply the correct value of *c*. See Table XII.

PART 2 (*continued*).—*Values of the Expression* 100

R in feet	For values of *S* per thousand of 0·35	0·30	0·25	0·20	0·15	0·10
	Approximate velocities of discharge in feet per second					
1·	1·871	1·732	1·581	1·414	1·225	1·
1·25	2·092	1·936	1·767	1·581	1·369	1·118
1·5	2·291	2·121	1·936	1·732	1·5	1·225
1·75	2·475	2·291	2·092	1·871	1·620	1·323
2·	2·646	2·449	2·236	2·	1·732	1·414
2·25	2·806	2·598	2·371	2·121	1·837	1·5
2·5	2·958	2·739	2·5	2·236	1·936	1·581
2·75	3·102	2·872	2·622	2·345	2·031	1·658
3·	3·240	3·	2·739	2·449	2·121	1·732
3·25	3·373	3·122	2·850	2·549	2·208	1·803
3·5	3·5	3·240	2·958	2·646	2·291	1·871
3·75	3·623	3·354	3·062	2·738	2·371	1·937
4·	3·742	3·464	3·102	2·828	2·449	2·
4·25	3·857	3·571	3·259	2·915	2·525	2·062
4·5	3·969	3·674	3·354	3·	2·598	2·121
4·75	4·077	3·775	3·446	3·082	2·669	2·179
5·	4·183	3·873	3·536	3·162	2·739	2·236
5·25	4·287	3·969	3·623	3·241	2·806	2·291
5·5	4·387	4·062	3·708	3·317	2·872	2·345
5·75	4·486	4·153	3·791	3·391	2·937	2·398
6·	4·583	4·243	3·873	3·464	3·	2·449
6·5	4·770	4·416	4·031	3·606	3·122	2·549
7·	4·950	4·583	4·183	3·742	3·240	2·646
7·5	5·123	4·743	4·330	3·874	3·354	2·738
8·	5·292	4·899	4·472	4·	3·464	2·828
8·5	5·454	5·050	4·610	4·124	3·571	2·915
9·	5·612	5·196	4·743	4·243	3·674	3·
10·	5·916	5·477	5·	4·472	3·873	3·162
11·	6·205	5·744	5·244	4·690	4·062	3·317
12·	6·481	6·	5·477	4·898	4·243	3·464
13·	6·745	6·245	5·701	5·098	4·416	3·606
14·	7·	6·480	5·916	5·292	4·583	3·742
15·	7·246	6·708	6·124	5·477	4·743	3·873
16·	7·483	6·928	6·325	5·657	4·899	4·
20·	8·367	7·746	7·071	6·325	5·477	4·472

For true velocities, apply the correct value of *c*. See Table

onditions of equal discharging channels, with low mean velocities to earth, for Trapezoidal Sections having side-slopes of one to one, nnel being in earth, and in good average order, with a co-efficient sity and irregularity, n=0·025.

he quantity discharged; *V*, the mean velocity in feet per second; *S* per 1 000 the fall in 1 000; *b* is the bed-width; *d* is the depth of water in feet.

. .	1·0	1·0	1·5	1·5	1·5	2·	2·	2·	3·	3·
. .	1·0	1·5	0·5	1·0	1·5	0·5	0·75	1·	0·5	0·75
1 000	0·26	0·05	1·90	0·13	0·04	1·04	0·26	0·09	0·48	0·13
. .	0·50	0·27	1·00	0·40	0·22	0·80	0·49	0·33	0·57	0·36
. .	1·5	1·5	2·	2·	2·	2·	3·	3·	3·	4·
. .	1·0	1·5	0·5	0·75	1·	1·25	0·5	0·75	1·	1·
1 000	0·47	0·11	3·74	0·92	0·33	0·15	1·9	0·44	0·17	0·10
. .	0·80	0·44	1·60	0·97	0·67	0·49	1·14	0·71	0·50	0·40
. .	1·5	2·	2·	2·	2·	3·	3·	3·	4·	5·
. .	2·0	0·75	1·	1·25	1·5	0·5	0·75	1·	1·	1·
1 000	0·09	2·06	0·69	0·31	0·16	4·21	0·95	0·35	0·20	0·14
. .	0·43	1·46	1·	0·74	0·57	1·72	1·07	0·75	0·60	0·50
. .	2·	2·	2·	2·	3·	3·	3·	4·	5·	6·
. .	0·75	1·	1·25	1·75	0·75	1·	1·5	1·	1·	1·
1 000	3·73	1·24	0·52	0·15	1·71	0·60	0·15	0·36	0·24	0·17
. .	1·94	1·33	0·99	0·61	1·42	1·	0·59	0·80	0·67	0·57
. .	2·	2·	2·	3·	3·	3·	4·	4·	5·	6·
. .	1·	1·5	2·	0·75	1·	1·5	1·	1·5	1·	1·
1 000	1·91	0·40	0·14	2·70	0·92	0·35	0·54	0·14	0·36	0·26
. .	1·67	0·95	0·63	1·78	1·25	0·74	1·00	0·61	0·83	0·71
. .	2·	2·	2·	3·	3·	3·	4·	4·	5·	6·
. .	1·	1·5	2·	1·	1·5	2·	1·	1·5	1·	1·
1 000	2·72	0·58	0·18	1·35	0·30	0·10	0·77	0·19	0·50	0·36
. .	2·	1·48	0·75	1·50	0·89	0·60	1·20	0·73	1·00	0·86
. .	2·	2·	2·	3·	3·	3·	4·	4·	5·	6·
. .	1·25	1·5	2·	1·	1·5	2·	1·	1·5	1·	1·
1 000	1·51	0·76	0·25	1·80	0·41	0·14	1·04	0·25	0·68	0·48
. .	1·72	1·33	0·88	1·75	1·04	0·70	1·40	0·85	1·17	1·00
. .	2·	2·	3·	3·	3·	4·	4·	4·	5·	6·
. .	1·25	2·	1·	1·5	2·	1·	1·5	2·	1·	1·
1 000	2·04	0·32	2·35	0·52	0·18	1·39	0·33	0·12	0·88	0·62
. .	1·97	1·0	2·	1·18	0·80	1·60	0·97	0·67	1·33	1·14
. .	2·	2·	3·	3·	4·	4·	4·	5·	6·	8·
. .	1·5	2·	1·5	2·	1·	1·5	2·	1·	1·	1·
1 000	1·28	0·39	0·65	0·23	1·74	0·40	0·15	1·12	0·77	0·45
. .	1·72	1·13	1·33	0·90	1·80	1·09	0·75	1·33	1·29	1·00

PART 3 (*continued*).

Q is the quantity discharged ; *V*, the mean velocity in feet per second ; *S* is the fall in 1 000 ; *b* is the bed-width ; *d* is the depth of water in

Q in cubic feet per second										
10	*b* . . .	2·	3·	3·	4·	4·	5·	5·	6·	8·
	d . . .	1·75	2·	2·5	1·5	2·	1·	2·	1·	1·
	S per 1 000	0·83	0·28	0·12	0·49	0·18	1·40	0·12	0·95	0·5
	V . . .	1·52	1·00	0·73	1·21	0·83	1·67	0·71	1·43	1·1
12	*b* . . .	3·	3·	4·	4·	5·	5·	6·	6·	8·
	d . . .	2·	2·5	1·5	2·	1·	2·	1·	2·	1·
	S per 1 000	0·39	0·17	0·70	0·25	1·97	0·17	1·40	0·13	0·7
	V . . .	1·20	0·87	1·45	1·00	2·00	0·86	1·71	0·75	1·3
14	*b* . . .	3·	3·	4·	4·	5·	5·	6·	6·	8·
	d . . .	2·	3·	2·	2·5	2·	2·5	1·	2·	1·
	S per 1 000	0·52	0·11	0·34	0·15	0·23	0·10	1·87	0·17	1·
	V . . .	1·40	0·78	1·17	0·86	1·00	0·75	2·00	0·88	1·5
16	*b* . . .	3·	3·	4·	4·	5·	5·	6·	6·	8·
	d . . .	2·	3·	2·	2·5	2·	2·5	2·	2·5	1·
	S per 1 000	0·67	0·14	0·43	0·19	0·30	0·13	0·21	0·10	1·4
	V . . .	1·60	0·89	1·33	0·98	1·14	0·85	1·00	0·75	1·7
18	*b* . . .	3·	3·	4·	4·	5·	5·	6·	6·	8·
	d . . .	2·	3·	2·	3·	2·	2·5	2·	2·5	1·
	S per 1 000	0·85	0·18	0·54	0·12	0·37	0·17	0·27	0·12	1·7
	V . . .	1·80	1·00	1·50	0·86	1·29	0·96	1·13	0·85	2·0
20	*b* . . .	3·	4·	4·	5·	5·	6·	6·	8·	8·
	d . . .	3·	2·	3·	2·	3·	2·	2·5	1·	2·
	S per 1 000	0·22	0·66	0·15	0·45	0·10	0·33	0·15	2·14	0·1
	V . . .	1·11	1·67	0·95	1·43	0·83	1·25	0·94	2·22	1·0
25	*b* . . .	3·	4·	4·	5·	5·	6·	6·	8·	8·
	d . . .	3·	2·	3·	2·	3·	2·	3·	2·	2·5
	S per 1 000	0·34	1·02	0·22	0·70	0·16	0·50	0·12	0·30	0·1
	V . . .	1·39	2·08	1·19	1·82	1·04	1·56	0·93	1·25	0·9
30	*b* . . .	3·	4·	4·	5·	5·	6·	6·	8·	8·
	d . . .	3·	3·	4·	2·5	3·5	2·	3·	2·	3·
	S per 1 000	0·47	0·32	0·10	0·44	0·13	0·72	0·17	0·42	0·1
	V . . .	1·07	1·43	0·94	1·60	1·01	1·88	1·11	1·50	0·91
35	*b* . . .	4·	4·	5·	5·	6·	6·	8·	8·	10·
	d . . .	3·	4·	2·5	4·	2·5	3·5	2·	3·	2·
	S per 1 000	0·42	0·14	0·59	0·10	0·42	0·13	0·57	0·14	0·3
	V . . .	1·67	1·09	1·87	0·97	1·65	1·05	1·75	1·06	1·4
40	*b* . . .	4·	4·	6·	6·	8·	8·	10·	10·	12·
	d . . .	3·	4·	3·	4·	2·	3·	2·	3·	2·
	S per 1 000	0·55	0·18	0·31	0·10	0·74	0·18	0·49	0·12	0·3
	V . . .	1·90	1·25	1·48	1·00	2·00	1·21	1·67	1·03	1·4

PART 3 (*continued*).

Q is the quantity discharged ; *V*, the mean velocity in feet per second ; *S* per 1 000 is the fall in 1 000 ; *b* is the bed-width ; *d* is the depth of water in feet.

b	4·	6·	6·	8·	8·	10·	10·	12·	12·	14·
d	4·	3·	4·	3·	4·	3·	4·	3·	4·	2·
S per 1 000	0·28	0·48	0·16	0·28	0·09	0·19	0·07	0·17	0·05	0·39
V	1·56	1·85	1·25	1·52	1·04	1·28	0·89	1·11	0·78	1·56
b	4·	6·	6·	8·	8·	10·	10·	12·	12·	14·
d	4·	3·5	5·	3·	4·	3·	4·5	3·	4·	2·
S per 1 000	0·39	0·37	0·09	0·39	0·14	0·29	0·06	0·19	0·07	0·56
V	1·88	1·80	1·09	1·82	1·25	1·54	0·92	1·33	0·94	1·88
b	6·	6·	8·	8·	10·	10·	12·	12·	14·	14·
d	3·5	5·	3·	4·	3·	5·	3·	4·5	3·	4·
S per 1 000	0·49	0·15	0·53	0·19	0·35	0·06	0·25	0·06	0·19	0·07
V	2·11	1·27	2·12	1·46	1·80	0·93	1·56	0·94	1·37	0·97
b	6·	6·	8·	8·	10·	10·	12·	12·	14·	14·
d	4·	5·	3·5	5·	3·5	5·	3·	4·5	3·	4·
S per 1 000	0·39	0·19	0·39	0·10	0·27	0·07	0·33	0·08	0·25	0·09
V	2·00	1·45	1·99	1·23	1·69	1·07	1·78	1·08	1·57	1·11
b	6·	6·	8·	8·	10·	10·	12·	12·	14·	14·
d	4·	5·	4·	5·	3·5	5·	3·	5·	3·	5·
S per 1 000	0·48	0·20	0·31	0·13	0·33	0·09	0·41	0·07	0·31	0·05
V	2·25	1·64	1·88	1·38	1·90	1·20	2·00	1·06	1·76	0·95
b	6·	8·	8·	10·	10·	12·	12·	14·	14·	16·
d	5·	4·	5·	4·	5·	3·5	5·	3·	5·	3·
S per 1 000	0·26	0·38	0·17	0·27	0·11	0·29	0·08	0·38	0·06	0·29
V	1·82	2·08	1·54	1·79	1·33	1·84	1·18	1·96	1·05	1·75
b	8·	10·	12·	12·	14·	14·	16·	16·	18·	18·
d	5·	5·	4·5	5·	4·	6·	4·	6·	4·	5·
S per 1 000	0·37	0·25	0·27	0·19	0·31	0·07	0·24	0·06	0·19	0·09
V	2·31	2·00	2·02	1·76	2·08	1·25	1·88	1·14	1·70	1·30
b	12·	14·	14·	16·	16·	18·	18·	20·	20·	25·
d	5·	5·	7·	5·	7·	5·	6·	4·	6·	4·
S per 1 000	0·33	0·25	0·07	0·19	0·06	0·16	0·08	0·28	0·07	0·18
V	2·35	2·11	1·36	1·90	1·24	1·74	1·39	2·08	1·28	1·72
b	14·	16·	18·	20·	20·	25·	25·	30·	30·	35·
d	7·	7·	7·	6·	7·	5·	7·	5·	6·	4·
S per 1 000	0·16	0·13	0·10	0·15	0·09	0·19	0·06	0·14	0·07	0·21
V	2·04	1·86	1·71	1·92	1·59	2·00	0·89	1·71	1·39	1·92
b	20·	25·	25·	30·	30·	35·	35·	40·	40·	50·
d	7·	6·	8·	6·	7·	5·	7·	4·	6·	4·
S per 1 000	0·16	0·18	0·06	0·12	0·07	0·17	0·05	0·29	0·07	0·18
V	2·12	2·15	1·52	1·85	1·54	2·00	1·36	2·27	1·45	1·82

PART 3 (continued).

Q is the quantity discharged; V, the mean velocity in feet per second; S p[…] is the fall in 1 000; b is the bed-width; d is the depth of water in f[…]

Q										
[illegible]	b	25·	30·	30·	35·	35·	40·	40·	50·	50·
	d	8·	7·	8·	7·	8·	5·	7·	4·5	6·5
	S per 1 000	0·10	0·11	0·07	0·08	0·05	0·20	0·06	0·19	0·05
	V	1·80	1·93	1·64	1·70	1·45	2·22	1·52	2·04	1·36
[illegible]	b	30·	35·	35·	40·	40·	50·	50·	60·	60·
	d	8·	7·	8·	7·	8·	5·	7·	4·5	6·5
	S per 1 000	0·10	0·12	0·08	0·09	0·06	0·19	0·06	0·19	0·05
	V	1·97	2·04	1·70	1·82	1·56	2·18	1·50	2·07	1·39
[illegible]	b	35·	40·	50·	50·	60·	60·	70·	70·	80·
	d	8·	8·	6·	7·5	5·5	7·	5·	6·5	4·5
	S per 1 000	0·10	0·08	0·14	0·06	0·13	0·05	0·13	0·05	0·15
	V	2·04	1·82	2·08	1·62	1·94	1·49	1·87	1·41	1·84
[illegible]	b	40·	50·	50·	60·	60·	70·	70·	80·	80·
	d	8·	6·5	8·	6·5	7·5	5·5	7·	5·	6·5
	S per 1 000	[illegible]	0·14	0·07	0·09	0·06	0·12	0·05	0·13	0·05
	V	2·08	2·18	1·72	1·85	1·58	1·93	1·68	1·88	1·42
[illegible]	b	[illegible]	[illegible]	[illegible]	[illegible]	70·	70·	80·	80·	90·
	d	[illegible]	[illegible]	[illegible]	[illegible]	6·	7·5	5·5	7·	5·
	S per 1 000	[illegible]	[illegible]	[illegible]	[illegible]	0·11	0·05	0·12	0·05	0·13
	V	[illegible]	[illegible]	[illegible]	[illegible]	1·97	1·55	1·91	1·48	1·89
[illegible]	b	[illegible]	[illegible]	[illegible]	[illegible]	70·	80·	80·	90·	90·
	d	[illegible]	[illegible]	[illegible]	[illegible]	7·5	6·	7·	5·5	6·5
	S per 1 000	[illegible]	[illegible]	[illegible]	0·11	0·06	0·11	0·06	0·12	0·06
	V	[illegible]	[illegible]	[illegible]	2·01	1·72	1·94	1·64	1·90	1·59
[illegible]	b	[illegible]	[illegible]	120·	140·	140·	160·	160·	180·	180·
	d	[illegible]	[illegible]	8·	7·5	8·	7·	7·5	6·	7·
	S per 1 000	[illegible]	[illegible]	[illegible]	0·06	0·05	0·07	0·05	0·08	0·05
	V	[illegible]	[illegible]	[illegible]	1·81	1·60	1·71	1·59	1·79	1·53
[illegible]	b	140·	[illegible]	[illegible]	180·	180·	200·	200·	220·	220·
	d	10·	8·	[illegible]	7·	8·	7·	8·	6·5	7·5
	S per 1 000	[illegible]	[illegible]	[illegible]	0·11	0·07	0·09	0·05	0·10	0·06
	V	[illegible]	2·23	[illegible]	2·20	[illegible]	2·07	1·80	2·04	1·76
[illegible]	b	180·	200·	220·	220·	240·	240·	260·	260·	280·
	d	10·	[illegible]	8·	9·	7·5	8·	7·	8·	7·
	S per 1 000	[illegible]	0·07	[illegible]	0·05	0·09	0·07	0·10	0·06	0·0[…]
	V	[illegible]	2·13	2·10	1·94	2·15	2·02	2·14	1·87	1·9[…]
[illegible]	b	240·	260·	280·	300·	6000	280·	300·	7000	
	d	10·	9·	8·	8·		10·	9·		
	S per 1 000	0·05	0·05	0·08	0·07		0·05	0·07		
	V	2·00	2·07	2·17	2·03		2·07	2·16		

These numbers serve for purposes of interpolation, but for accuracy in a[…] more figures should be used in the values of S.

EXPLANATORY EXAMPLES TO TABLE VII.

EXAMPLE I.

An old canal has a hydraulic radius of 5·2 feet, a hydraulic slope of 1 in 5 000 and a cross section of 1 000 square feet, required the discharge, assuming a co-efficient of rugosity of ·03.

By Part 1 of Table VII. the unmodified mean velocity of discharge = 3·225 feet per second, and by Table XII. the value of c the co-efficient suitable to this radius and slope is ·66, hence the true discharge = $c \times A \times V = \cdot 66 \times 1\,000 \times 3{\cdot}225 = 2\,128$ cubic feet per second.

EXAMPLE II.

Suppose the canal mentioned in the last example to have a hydraulic slope of ·0015, the remaining data being as before, required the discharge.

In this case the fall per 1 000 is 1·5, and by interpolating Part 2 of Table VII. to the hydraulic radius, 5·2 feet, an unmodified mean velocity of discharge 8·83 feet per second is obtained. Taking the suitable co-efficient c from Table XII., the true discharge $= c \times A \times V = \cdot 65 \times 1\,000 \times 8{\cdot}83 = 5\,740$ cubic feet per second.

EXAMPLE III.

A canal in earth is of trapezoidal section with side slopes of 1 to one, its bed-width is 40 feet, its depth of water 5 feet; it is to discharge 500 cubic feet per second, when in moderate average order, with a co-efficient of rugosity $n = 0{\cdot}025$. What hydraulic slope must it have?

By Part 3, Table VII., the hydraulic slope is 0·00020, or 0·20 per 1 000.

EXAMPLE IV.

What will be the discharge and the mean velocity in the canal mentioned in the last example, when it has deteriorated to a condition when $n = 0{\cdot}030$?

By sectional data, Part 2, Table V., page 45, $A = 225$, and $R = 4{\cdot}155$; S remains 0·20 per 1 000. Also from Part 2, Table VII., we interpolate to obtain $100\sqrt{RS} = 2{\cdot}88$; from Table XII. we obtain, when $n = 0{\cdot}030$ for given values of R and S, $c = 0{\cdot}63$; hence $V = 0{\cdot}63 \times 2{\cdot}88 = 1{\cdot}814$ feet per second, and $Q = 1{\cdot}814 \times 225 = 408$ cubic feet per second.

For tables of velocity and discharge in canals under various values of n, see 'Canal and Culvert Tables' (London: Allen, 1878).

[redacted]

TABLE VIII.—PIPES AND CULVERTS, JUST FULL.

Part 1. Approximate velocities in feet per second, when $c = 1$, formula—

$$V = c \,.\, 100 \sqrt{RS}.$$

Part 2. Approximate discharges in cubic feet per second, when $c = 1$, formula—

$$Q = A \,.\, c \,.\, 100 \sqrt{RS} = c \,.\, 39{\cdot}27 \sqrt{d^5 S}.$$

Part 3. Approximate diameters in feet, when $c = 1$, formula—

$$d = \frac{1}{c^{\frac{2}{5}}} \times 0{\cdot}23 \left(\frac{Q^2}{S}\right)^{\frac{1}{5}}$$

Part 4. Approximate heads in feet for a length of 1 000 feet, when $c = 1$, formula—

$$h = \frac{1}{c^2} \,.\, 0{\cdot}648 \, \frac{Q^2}{d^5}.$$

Part 5. Conditions of equal-discharging culverts and drain-pipes, running just full, under a co-efficient of rugosity $n = 0{\cdot}013$.

NOTE.—For correct results, apply values of c from Table XII. in Parts 1, 2, 3, and 4.

For the use of co-efficients (c) and (n) see Table XII.

N.B.—For correct velocity, a

feet per second,

$\sqrt{RS}$, *suitable to Culverts and Pipes.*

feet	*S* per thousand						
	12	11	10	9	8	7	6
05	2·449	2·345	2·236	2·121	2·	1·871	1·732
10	3·464	3·317	3·162	3·	2·828	2·648	2·449
15	4·243	4·062	3·873	3·674	3·464	3·240	3·
20	4·899	4·690	4·472	4·243	4·	3·742	3·464
25	5·477	5·244	5·	4·743	4·472	4·183	3·873
30	6·	5·745	5·477	5·196	4·898	4·583	4·243
35	6·480	6·205	5·916	5·612	5·291	4·950	4·583
40	6·928	6·633	6·325	6·	5·656	5·292	4·899
45	7·348	7·035	6·708	6·364	6·	5·612	5·196
50	7·746	7·416	7·071	6·708	6·325	5·916	5·477
6	8·486	8·124	7·746	7·348	6·928	6·481	6·
7	9·165	8·775	8·367	7·937	7·484	7·	6·480
8	9·798	9·381	8·944	8·485	8·	7·483	6 928
9	10·392	9·950	9·487	9·	8·486	7·937	7·348
0	10·954	10·488	10·	9·487	8·944	8·367	7·746
1	11·489	11·	10·488	9·950	9·381	8·775	8·124
2	12·	11·489	10·954	10·392	9·797	9·165	8·486
3	12·490	11·958	11·402	10·817	10·198	9·539	8·832
4	12·961	12·410	11·832	11·225	10·583	9·899	9·165
5	13·416	12·845	12·247	11·619	10·954	10·247	9·487
6	13·856	13·266	12·649	12·	11·314	10·583	9·798
7	14·283	13·675	13·038	12·369	11·662	10·909	10·100
8	14·697	14·071	13·416	12·728	12·	11·225	10·392
9	15·100	14·457	13·784	13·077	12·329	11·533	10·677
0	15·492	14·832	14·142	13·416	12·650	11·832	10·954
1	15·875	15·199	14·491	13·748	12·961	12·124	11·225
2	16·248	15·556	14·832	14·071	13·266	12·410	11·489
3	16·613	15·906	15·166	14·387	13·565	12·689	11·747
4	16·971	16·248	15·492	14·697	13·856	12·961	12·
5	17·321	16·583	15·811	15·	14·142	13·229	12·247
6	17·664	16·912	16·125	15·297	14·422	13·491	12·490
7	18·	17·234	16·432	15·588	14·697	13·748	12·689
8	18·330	17·550	16·733	15·875	14·967	14·	12·961
9	18·655	17·861	17·029	16·155	15·232	14·248	13·191
0	18·974	18·166	17·321	16·432	15·492	14·491	13·416

ble value of *c* from Table XII.

0·05	1·581	
0·10	2·236	
0·15	2·739	
0·20	3·162	
0·25	3·536	
0·30	3·873	3
0·35	4·183	3
0·40	4·472	4
0·45	4·743	4
0·50	5·	4
0·6	5·477	5·
0·7	5·916	5·
0·8	6·325	6·
0·9	6·708	6·3
1·0	7·071	6·7
1·1	7·416	7·0
1·2	7·746	7·34
1·3	8·062	7·64
1·4	8·367	7·93
1·5	8·660	8·21
1·6	8·944	8·485
1·7	9·220	8·746
1·8	9·487	9·
1·9	9·747	9·247
2·0	10·	9·487
2·1	10·247	9·721
2·2	10·488	9·950
2·3	10·724	10·174
2·4	10·954	10·392
2·5	11·180	10·606
2·6	11·402	10·817
2·7		

cities in feet per second,

√RS, suitable to Culverts and Pipes.

R feet	*S* per thousand						
	1·5	1·	0·95	0·90	0·85	0·80	0·75
·05	0·866	0·707	0·689	0·671	0·652	0·632	0·612
·10	1·225	1·	0·975	0·949	0·922	0·894	0·866
·15	1·5	1·225	1·193	1·162	1·129	1·095	1·060
·20	1·732	1·414	1·378	1·342	1·304	1·265	1·225
·25	1·936	1·581	1·541	1·5	1·457	1·414	1·369
·30	2·121	1·732	1·688	1·643	1·592	1·549	1·5
·35	2·291	1·871	1·823	1·775	1·725	1·673	1·620
·40	2·449	2·	1·949	1·897	1·844	1·789	1·732
·45	2·598	2·121	2·007	2·012	1·956	1·897	1·837
·50	2·739	2·236	2·179	2·121	2·061	2·	1·936
·6	3·	2·449	2·387	2·324	2·258	2·191	2·121
·7	3·240	2·646	2·579	2·510	2·439	2·366	2·291
·8	3·464	2·828	2·757	2·683	2·608	2·530	2·449
·9	3·674	3·	2·924	2·846	2·766	2·683	2·598
·0	3·873	3·162	3·082	3·	2·915	2·828	2·739
·1	4·062	3·317	3·233	3·146	3·058	2·966	2·872
·2	4·243	3·464	3·376	3·286	3·194	3·098	3·
·3	4·416	3·606	3·514	3·421	3·324	3·225	3·122
·4	4·583	3·742	3·647	3·550	3·450	3·347	3·240
·5	4·743	3·873	3·775	3·674	3·571	3·464	3·354
·6	4·899	4·	3·899	3·795	3·688	3·578	3·464
·7	5·050	4·123	4·019	3·912	3·801	3·688	3·571
·8	5·196	4·243	4·135	4·025	3·912	3·795	3·674
·9	5·339	4·359	4·249	4·135	4·019	3·899	3·775
·0	5·477	4·472	4·359	4·243	4·123	4·	3·873
·1	5·612	4·583	4·467	4·347	4·225	4·099	3·969
·2	5·744	4·690	4·572	4·450	4·324	4·195	4·062
·3	5·874	4·796	4·674	4·550	4·422	4·313	4·153
·4	6·	4·898	4·775	4·648	4·517	4·382	4·243
·5	6·123	5·	4·873	4·743	4·610	4·472	4·330
·6	6·245	5·098	4·970	4·837	4·701	4·561	4·416
·7	6·364	5·196	5·065	4·930	4·791	4·648	4·500
·8	6·480	5·292	5·158	5·020	4·879	4·733	4·583
·9	6·595	5·385	5·249	5·109	4·965	4·817	4·664
3·0	6·708	5·477	5·339	5·196	5·050	4·898	4·743

able value of *c* from Table XII.

PART 1 (*continued*).—*Approxi*
or, Values of the Expres

R in feet	S per thousand 0·70	0·65	0·60	0·55	0·50	0·45	0·
0·05	0·592	0·570	0·548	0·524	0·5	0·474	0·
0·10	0·837	0·806	0·775	0·742	0·707	0·671	0·
0·15	1·025	0·987	0·949	0·908	0·866	0·822	0·
0·20	1·183	1·140	1·095	1·049	1·	0·949	0·
0·25	1·323	1·275	1·225	1·172	1·118	1·061	1·
0·30	1·449	1·396	1·342	1·284	1·225	1·162	1·
0·35	1·565	1·508	1·449	1·387	1·323	1·255	1·
0·40	1·673	1·612	1·549	1·483	1·414	1·342	1·
0·45	1·775	1·710	1·643	1·573	1·5	1·423	1·
0·50	1·871	1·803	1·732	1·658	1·581	1·5	1·
0·6	2·049	1·975	1·897	1·816	1·732	1·643	1·
0·7	2·214	2·133	2·049	1·962	1·871	1·775	1·
0·8	2·366	2·280	2·191	2·098	2·	1·897	1·
0·9	2·510	2·419	2·324	2·225	2·121	2·012	1·
1·0	2·646	2·550	2·449	2·345	2·236	2·121	2·
1·1	2·775	2·674	2·569	2·460	2·345	2·225	2·
1·2	2·898	2·793	2·683	2·569	2·449	2·324	2·1
1·3	3·017	2·907	2·793	2·674	2·549	2·419	2·
1·4	3·130	3·017	2·898	2·775	2·646	2·510	2·
1·5	3·240	3·122	3·	2·872	2·739	2·598	2·
1·6	3·347	3·225	3·098	2·966	2·828	2·683	2·
1·7	3·450	3·324	3·194	3·058	2·915	2·766	2·
1·8	3·550	3·421	3·286	3·146	3·	2·846	2·
1·9	3·647	3·514	3·376	3·233	3·082	2·924	2·
2·0	3·742	3·606	3·464	3·317	3·162	3·	2·
2·1	3·834	3·695	3·550	3·399	3·240	3·074	2·
2·2	3·924	3·782	3·633	3·479	3·317	3·146	2·9
2·3	4·012	3·867	3·715	3·557	3·391	3·217	3·
2·4	4·099	3·950	3·795	3·633	3·464	3·286	3·
2·5	4·183	4·031	3·873	3·708	3·536	3·354	3·1
2·6	4·266	4·111	3·950	3·782	3·606	3·421	3·2
2·7	4·347	4·189	4·025	3·854	3·674	3·486	3·2
2·8	4·427	4·266	4·099	3·924	3·742	3·550	3·3
2·9	4·506	4·342	4·171	3·994	3·808	3·612	3·4
3·0	4·583	4·416	4·243	4·062	3·873	3·674	3·4

N.B.—For correct velocity, apply

ities in feet per second,

√RS, *suitable to Culverts and Pipes.*

feet	*S* per thousand						
	0·35	0·30	0·25	0·20	0·15	0·10	0·05
05	0·418	0·387	0·354	0·316	0·274	0·224	0·158
10	0·592	0·548	0·500	0·447	0·387	0·316	0·224
15	0·725	0·671	0·612	0·548	0·474	0·387	0·274
20	0·837	0·775	0·707	0·632	0·548	0·447	0·316
25	0·935	0·866	0·790	0·707	0·612	0·500	0·354
30	1·025	0·949	0·866	0·775	0·671	0·548	0·387
·35	1·107	1·025	0·935	0·837	0·725	0·592	0·418
·40	1·183	1·095	1·	0·894	0·775	0·632	0·447
·45	1·255	1·162	1·061	0·949	0·822	0·671	0·474
·50	1·323	1·225	1·118	1·	0·866	0·707	0·500
·6	1·449	1·342	1·225	1·095	0·949	0·775	0·548
·7	1·565	1·449	1·323	1·183	1·025	0·837	0·592
·8	1·673	1·549	1·414	1·265	1·095	0·894	0·632
·9	1·775	1·643	1·5	1·342	1·162	0·949	0·671
·0	1·871	1·732	1·581	1·414	1·225	1·	0·707
·1	1·962	1·817	1·658	1·483	1·285	1·049	0·742
·2	2·049	1·897	1·732	1·549	1·342	1·095	0·775
·3	2·133	1·975	1·803	1·612	1·396	1·140	0·806
·4	2·214	2·049	1·871	1·673	1·449	1·183	0·837
·5	2·291	2·121	1·936	1·732	1·500	1·225	0·866
·6	2·366	2·191	2·	1·789	1·549	1·265	0·894
·7	2·439	2·258	2·062	1·844	1·597	1·304	0·922
·8	2·510	2·324	2·121	1·897	1·643	1·342	0·949
·9	2·579	2·387	2·179	1·949	1·688	1·378	0·975
·0	2·646	2·449	2·236	2·	1·732	1·414	1·
·1	2·711	2·510	2·291	2·049	1·775	1·449	1·025
·2	2·775	2·569	2·345	2·098	1·817	1·483	1·049
·3	2·837	2·627	2·398	2·145	1·857	1·517	1·072
·4	2·898	2·683	2·449	2·191	1·897	1·549	1·095
·5	1·958	2·739	2·500	2·236	1·936	1·581	1·118
·6	3·017	2·793	2·549	2·280	1·975	1·612	1·140
·7	3·074	2·847	2·598	2·324	2·012	1·643	1·162
·8	3·130	2·898	2·646	2·366	2·049	1·673	1·183
·9	3·186	2·950	2·693	2·408	2·086	1·703	1·204
·0	3·240	3·	2·739	2·449	2·121	1·732	1·225

able value of *c* from Table XII.

PART 2.—*Approximate Discharges through full cylindric tubes, Pipes, Culverts, &c.*

For diameters in feet	For slopes of one in						
	100	150	200	300	400	500	1000
	Approximate discharges in cubic feet per second						
(1″) ·083	·008	·006	·006	·005	·004	·004	·003
(2″) ·166	·04	·04	·03	·03	·02	·02	·01
(3″) ·25	·12	·10	·09	·07	·06	·05	·04
(4″) ·33	·25	·21	·18	·15	·13	·11	·08
(5″) ·416	·44	·36	·31	·25	·22	·20	·14
(6″) ·5	·69	·57	·49	·40	·35	·31	·22
(7″) ·583	1·02	·83	·72	·59	·51	·46	·32
(8″) ·66	1·43	1·16	1·01	·82	·71	·64	·45
(9″) ·75	1·91	1·56	1·35	1·10	·97	·86	·61
(10″) ·83	2·49	2·03	1·76	1·44	1·25	1·11	·79
(11″) ·916	3·16	2·58	2·23	1·82	1·58	1·41	1·00
(12″) 1·00	3·93	3·28	2·78	2·27	1·96	1·76	1·24
1·25	6·86	5·60	4·85	3·96	3·43	3·07	2·16
1·5	10·82	8·82	7·55	6·25	5·41	4·84	3·42
1·75	15·91	12·99	11·25	9·18	7·95	7·11	5·03
2·	22·21	18·14	15·71	12·83	11·11	9·93	7·02
2·25	29·82	24·35	21·08	17·22	14·91	13·34	9·43
2·5	38·81	31·69	27·44	22·41	19·40	17·35	12·27
2·75	49·25	40·22	34·82	28·43	24·62	22·02	15·57
3·	61·21	49·99	43·28	35·34	30·61	27·37	19·35
3·25	74·77	61·04	52·87	43·18	37·38	33·44	23·64
3·5	88·99	73·49	63·63	51·96	44·99	40·25	28·46
3·75	106·94	87·33	75·61	61·74	53·46	47·82	33·81
4·	125·66	102·63	88·84	72·55	62·83	56·20	39·73
4·25	146·23	119·42	103·38	84·32	73·11	65·39	46·24
4·5	168·69	137·76	119·26	97·39	84·34	75·44	53·34
4·75	193·10	157·70	136·52	111·48	96·55	86·36	61·06
5·	219·54	179·26	155·24	126·75	109·77	99·18	69·43
5·5	278·61	227·48	197·00	160·85	139·30	124·60	88·10
6·	346·31	282·76	244·88	199·94	173·16	154·88	109·51
6·5	423·03	345·40	299·13	244·23	211·51	189·18	133·77
7·	509·13	415·70	360·01	293·65	254·57	227·69	161·00

N.B.—For correct discharge, apply the suitable value of *c* from Table

PART 2 (*continued*).

For diameters in feet	For hydraulic slopes of one in						
	1250	1500	2000	2500	3000	4000	5000
	Approximate discharges in cubic feet per second						
1"	0·002	0·002	0·002	0·002	0·001	0·001	0·001
2"	0·013	0·011	0·010	0·009	0·008	0·007	0·006
3"	0·035	0·032	0·028	0·025	0·022	0·019	0·017
4"	0·071	0·065	0·056	0·050	0·046	0·040	0·036
5"	0·124	0·114	0·099	0·088	0·080	0·070	0·062
6"	0·196	0·179	0·155	0·139	0·127	0·110	0·098
7"	0·289	0·264	0·228	0·204	0·186	0·161	0·144
8"	0·403	0·368	0·319	0·285	0·260	0·225	0·202
9"	0·541	0·494	0·428	0·383	0·349	0·302	0·271
10"	0·704	0·643	0·557	0·498	0·455	0·394	0·352
11"	0·894	0·816	0·706	0·632	0·577	0·500	0·447
12"	1·111	1·014	0·878	0·785	0·717	0·621	0·555
1·25	1·940	1·771	1·534	1·372	1·252	1·085	0·970
1·5	3·060	2·794	2·420	2·164	1·976	1·711	1·530
1·75	4·500	4·108	3·558	3·182	2·905	2·516	2·250
2·	6·284	5·736	4·968	4·442	4·056	3·513	3·142
2·25	8·444	7·708	6·675	5·964	5·450	4·720	4·222
2·5	10·98	10·02	8·678	7·762	7·086	6·136	5·489
2·75	13·93	12·72	11·01	9·850	8·991	7·786	6·965
3·	17·31	15·80	13·69	12·24	11·18	9·679	8·657
3·25	21·16	19·31	16·72	15·95	13·65	11·82	10·58
3·5	25·46	23·24	20·13	18·00	16·43	14·23	12·73
3·75	30·24	27·61	23·91	21·38	19·52	16·91	15·12
4·	35·54	32·45	28·10	25·14	22·94	19·87	17·77
4·25	41·36	37·76	32·70	29·24	26·70	23·12	20·68
4·5	47·72	43·55	37·73	33·74	30·80	26·67	23·86
4·75	55·88	49·86	43·18	38·62	35·25	30·53	27·94
5·	62·10	56·69	49·10	43·90	40·08	34·71	31·05
5·5	78·80	71·94	62·30	55·72	50·87	44·05	39·40
6·	97·96	89·42	77·44	69·26	63·23	54·76	48·98
6·5	119·8	109·2	94·59	84·60	77·24	66·89	59·83
7·	144·0	131·5	113·9	101·8	92·96	80·50	72·01

N.B.—For correct discharge, apply the suitable value of *c* from Table XII.

1″	0·011	0
2″	0·063	0·
3″	0·174	0·
4″	0·356	0·
5″	0·622	0·
6″	0·981	0·
7″	1·443	1·2
8″	2·015	1·7
9″	2·705	2·3
10″	3·521	3·0
11″	4·468	3·8
12″	5·554	4·8
1·25	9·702	8·40
1·5	15·30	13·25
1·75	22·50	19·49
2·	31·42	27·21
2·25	42·22	36·56
2·5	54·89	47·53
2·75	69·65	60·31
3·	86·57	74·97
3·25	105·8	91·58
3·5	127·3	110·2
3·75	151·2	131·0
4·	177·7	153·9
4·25	206·8	171·0
4·5	238·6	201·9
4·75	279·4	236·5
5·	310·5	268·9

PART 2 (*continued*).

For hydraulic slopes S per thousand						
5·	4·	3·	2·5	2·	1·75	1·5
Approximate discharges in cubic feet per second						
0·006	0·005	0·004	0·004	0·004	0·003	0·003
0·032	0·028	0·024	0·022	0·020	0·019	0·017
0·087	0·078	0·067	0·061	0·055	0·052	0·048
0·178	0·159	0·138	0·126	0·113	0·106	0·098
0·311	0·278	0·241	0·220	0·197	0·184	0·171
0·491	0·439	0·380	0·347	0·311	0·291	0·269
0·722	0·646	0·559	0·510	0·457	0·427	0·395
1·008	0·901	0·781	0·713	0·638	0·596	0·552
1·353	1·210	1·148	0·956	0·856	0·800	0·741
1·761	1·575	1·364	1·250	1·113	1·042	0·964
2·234	1·998	1·731	1·580	1·413	1·322	1·224
2·777	2·484	2·151	1·964	1·756	1·643	1·521
4·851	4·339	3·758	3·430	3·068	2·870	2·657
7·650	6·844	5·928	5·411	4·840	4·527	4·191
11·250	10·06	8·714	7·955	7·115	6·655	6·160
15·71	14·05	12·17	11·11	9·935	9·295	8·600
21·11	18·88	16·39	14·91	13·35	12·49	11·56
27·44	24·55	21·26	19·40	17·36	16·24	15·03
34·82	31·15	26·98	24·62	22·03	20·60	19·07
43·28	38·72	33·53	30·61	27·37	25·61	23·70
52·87	47·30	40·96	37·38	33·44	31·28	28·95
63·63	56·92	49·30	44·99	40·25	37·65	34·85
75·61	67·64	58·58	53·46	47·82	44·74	41·41
88·84	79·48	68·84	62·83	56·20	52·55	48·66
103·38	92·49	80·10	73·11	65·40	61·15	56·60
119·26	106·7	92·39	84·34	75·45	70·55	65·30
136·52	122·1	105·8	96·55	86·35	80·75	74·75
155·24	138·9	120·3	109·77	98·20	91·85	85·00
197·00	176·2	152·6	139·30	124·60	116·6	107·9
244·88	219·0	189·7	173·16	154·88	144·9	134·1
299·13	267·5	231·7	211·51	189·18	177·0	163·8
360·01	322·0	278·9	254·57	227·69	213·0	197·2

table value of c from Table XII.

PART 2 (*continued*).

Diam of Pipe	For hydraulic slopes S per thousand						
	1·25	1·	0·9	0·8	0·7	0·6	0·5
	Approximate discharges in cubic feet per second						
1″	0·003	0·002	0·002	0·002	0·002	0·002	0·002
2″	0·016	0·014	0·014	0·013	0·012	0·011	0·010
3″	0·044	0·039	0·037	0·035	0·032	0·030	[illegible]
4″	0·089	0·080	0·076	0·071	0·067	0·062	[illegible]
5″	0·156	0·139	0·132	0·124	0·116	0·108	0·099
6″	0·246	0·219	0·208	0·196	0·184	0·170	0·155
7″	0·361	0·323	0·306	0·289	0·270	0·250	0·228
8″	0·504	0·451	0·428	0·403	0·377	0·349	0·319
9″	0·677	0·605	0·574	0·541	0·506	0·469	0·428
10″	0·881	0·787	0·747	0·704	0·659	0·610	0·557
11″	1·117	0·999	0·948	0·894	0·836	0·774	0·706
12″	1·389	1·242	1·178	1·111	1·039	0·962	0·878
1·25	2·426	2·170	2·058	1·940	1·815	1·680	1·534
1·5	3·825	3·422	3·247	3·060	2·863	2·650	2·420
1·75	5·625	5·031	4·773	4·500	4·209	3·898	3·558
2·	7·855	7·025	6·665	6·284	5·877	5·442	4·968
2·25	10·55	9·440	8·956	8·444	7·898	7·312	6·675
2·5	13·72	12·27	11·64	10·98	10·27	9·506	8·678
2·75	17·41	15·57	14·77	13·93	13·03	12·06	11·01
3·	21·64	19·36	18·37	17·3	16·20	14·99	13·69
3·25	26·44	23·65	22·43	21·16	19·78	18·32	16·72
3·5	31·82	28·46	27·00	25·46	23·81	22·04	20·13
3·75	37·81	33·82	32·08	30·24	28·29	26·20	23·91
4·	44·42	39·74	37·70	35·54	33·25	30·78	28·10
4·25	51·69	46·24	43·87	41·36	38·69	34·20	32·70
4·5	59·63	53·34	50·61	47·72	44·63	40·38	37·73
4·75	68·26	61·06	57·93	55·88	51·09	47·30	43·18
5·	77·62	69·43	65·87	62·10	58·09	53·78	49·10
5·5	98·50	88·10	83·58	78·80	73·71	68·24	62·30
6·	122·4	109·51	103·9	97·96	91·62	84·82	77·44
6·5	149·6	133·77	126·9	119·8	111·9	103·6	94·39
7·	180·0	161·00	152·8	144·0	134·7	124·7	113·9

N.B.—For correct discharge, apply the

PART 2 (*continued*).

For hydraulic slopes *S* per thousand of					
0·3	0·25	0·2	0·15	0·1	0·05
Approximate discharges in cubic feet per second.					
0·001	0·001	0·001	0·001	0·001	0·001
0·008	0·007	0·006	0·006	0·004	0·003
0·021	0·019	0·017	0·015	0·012	0·009
0·044	0·040	0·036	0·031	0·025	0·018
0·076	0·070	0·062	0·054	0·044	0·031
0·120	0·110	0·098	0·085	0·069	0·049
0·177	0·161	0·144	0·125	0·102	0·072
0·247	0·225	0·202	0·175	0·143	0·101
0·331	0·302	0·271	0·234	0·191	0·135
0·431	0·394	0·352	0·305	0·249	0·176
0·547	0·500	0·447	0·387	0·316	0·223
0·608	0·621	0·555	0·481	0·393	0·278
1·188	1·085	0·970	0·840	0·686	0·485
1·874	1·711	1·530	1·325	1·082	0·765
2·756	2·516	2·250	1·949	1·591	1·125
3·848	3·513	3·142	2·721	2·221	1·571
5·182	4·720	4·222	3·656	2·982	2·108
6·722	6·136	5·489	4·753	3·881	2·744
8·531	7·786	6·965	6·031	4·925	3·482
10·60	9·679	8·657	7·497	6·121	4·328
12·95	11·82	10·58	9·158	7·477	5·287
15·59	14·23	12·73	11·02	8·999	6·363
18·52	16·91	15·12	13·10	10·69	7·561
21·77	19·87	17·77	15·39	12·57	8·884
25·33	23·12	20·68	17·10	14·62	10·34
29·22	26·67	23·86	20·19	16·87	11·93
33·45	30·53	27·94	23·65	19·31	13·65
38·03	34·71	31·05	26·89	21·95	15·52
48·26	44·05	39·40	34·12	27·86	19·70
59·98	54·76	48·98	42·41	34·63	24·49
73·27	66·89	59·83	51·81	42·30	29·91
88·19	80·50	72·01	62·36	50·91	30·00

c from Table XII.

PART 3.—*Approximate diameters of full P*

Discharges in cubic feet per second	For slopes of one in							Tabl No. t multip by $\left(\frac{1}{s}\right)$ other sl
	100	150	200	300	400	500	1000	
	Approximate diameters in feet							
·1	·23	·25	·26	·29	·30	·32	·36	·091
·2	·30	·33	·35	·38	·40	·42	·48	·120
·3	·36	·39	·41	·44	·47	·49	·57	·142
·4	·40	·43	·46	·50	·53	·55	·63	·159
·5	·44	·47	·50	·55	·58	·60	·69	·174
·6	·47	·51	·54	·59	·62	·65	·75	·187
·7	·50	·54	·58	·62	·66	·69	·79	·199
·8	·53	·57	·61	·66	·70	·73	·84	·210
·9	·56	·60	·64	·69	·73	·77	·88	·221
1·	·58	·63	·66	·72	·76	·80	·92	·232
1·1	·60	·65	·69	·75	·79	·83	·95	·238
1·2	·62	·67	·71	·77	·82	·86	·99	·247
1·3	·64	·70	·74	·80	·85	·89	1·02	·255
1·4	·66	·72	·76	·82	·87	·91	1·05	·263
1·5	·68	·74	·78	·85	·90	·94	1·08	·270
1·6	·70	·76	·80	·87	·92	·96	1·11	·277
1·7	·71	·77	·82	·89	·94	·99	1·13	·284
1·8	·73	·79	·84	·91	·96	1·01	1·16	·291
1·9	·75	·81	·86	·93	·99	1·03	1·18	·297
2·0	·76	·83	·88	·95	1·01	1·05	1·21	·303
2·1	·78	·84	·89	·97	1·03	1·07	1·23	·309
2·2	·79	·86	·91	·99	1·04	1·09	1·26	·315
2·3	·81	·87	·93	1·01	1·06	1·11	1·28	·320
2·4	·82	·89	·94	1·02	1·08	1·13	1·30	·326
2·5	·83	·90	·96	1·04	1·10	1·15	1·32	·331
2·6	·85	·92	·97	1·05	1·12	1·17	1·34	·336
2·7	·86	·93	·99	1·07	1·13	1·19	1·36	·342
2·8	·87	·95	1·00	1·09	1·15	1·20	1·38	·347
2·9	·88	·96	1·02	1·10	1·17	1·22	1·40	·352
3·0	·90	·97	1·03	1·12	1·18	1·24	1·42	·356

Modify the discharge by a co-efficient (c) before applying it to the ta to find the correct diameter. See Table XII.

small discharge and high inclination.

ischarges n cubic feet per second	For slopes of one in							Tabular No. to be multiplied by $\left(\frac{1}{S}\right)^{\frac{1}{5}}$ for other slopes
	500	1000	1500	2000	2500	3000	4000	
	Approximate diameters in feet							
1	·80	·92	·99	1·05	1·10	1·14	1·21	·23
2	1·05	1·21	1·31	1·39	1·45	1·51	1·59	·30348
3	1·24	1·42	1·54	1·63	1·71	1·77	1·88	·35692
4	1·39	1·59	1·73	1·83	1·91	1·99	2·10	·40045
5	1·52	1·74	1·89	2·00	2·09	2·17	2·30	·43780
6	1·63	1·87	2·03	2·15	2·25	2·34	2·47	·47096
7	1·74	1·99	2·16	2·29	2·40	2·48	2·63	·50092
8	1·83	2·10	2·28	2·42	2·53	2·62	2·78	·52840
9	1·92	2·21	2·39	2·53	2·65	2·75	2·91	·55389
10	2·00	2·30	2·49	2·64	2·76	2·87	3·04	·57773
11	2·08	2·39	2·59	2·74	2·87	2·98	3·15	·60018
12	2·15	2·47	2·68	2·84	2·97	3·08	3·27	·62144
13	2·22	2·55	2·76	2·93	3·07	3·18	3·37	·64166
14	2·29	2·63	2·85	3·02	3·16	3·28	3·47	·66096
15	2·36	2·71	2·93	3·11	3·25	3·37	3·57	·67946
16	2·42	2·78	3·01	3·19	3·32	3·46	2·66	·69723
17	2·48	2·84	3·08	3·27	3·42	3·54	3·75	·71434
18	2·53	2·91	3·16	3·34	3·50	3·63	3·84	·73086
19	2·59	2·97	3·22	3·42	3·57	3·70	3·92	·74684
20	2·64	3·03	3·29	3·49	3·65	3·78	4·00	·76232
30	3·11	3·57	3·87	4·10	4·29	4·45	4·71	·89655
40	3·49	4·00	4·34	4·60	4·81	4·99	5·28	1·0059
50	3·81	4·38	4·75	5·03	5·26	5·45	5·78	1·0998
60	4·10	4·71	5·11	5·41	5·66	5·87	6·21	1·1830
70	4·36	5·01	5·43	5·75	6·02	6·24	6·61	1·2582
80	4·60	5·28	5·73	6·07	6·35	6·58	6·97	1·3273
90	4·82	5·54	6·00	6·36	6·65	6·90	7·31	1·3913
100	5·03	5·78	6·26	6·64	6·94	7·20	7·62	1·4512
200	6·64	7·62	8·27	8·76	9·16	9·50	10·06	1·9149
300	7·81	8·97	9·72	10·30	10·77	11·16	11·83	2·2520

Modify the discharge by a co-efficient (e) before applying it to the table, o find the correct diameter. See Table XII.

PART 4.—*Pipes. Appr*

For discharges in cubic feet per second	For diameters in feet				
	·083 (1″)	·166 (2″)	·25 (3″)	·333 (4″)	·416 (5″)
	Approximate head of water in feet				
0·01	16·1	0·504	0·066	0·016	0·005
0·02	64·5	2·016	0·265	0·063	0·021
0·03	145·1	4·535	0·597	0·142	0·046
0·04	258·0	8·062	1·062	0·253	0·083
0·05	403·1	12·597	1·659	0·394	0·129
0·06	580·4	18·056	2·389	0·567	0·186
0·07	790·0	24·690	3·251	0·772	0·253
0·08	1031·8	32·248	4·247	1·008	0·330
0·09	1306·1	40·815	5·375	1·275	0·418
·1	1612·	50·4	6·64	1·57	0·516
·2	6450·	201·6	26·54	6·30	2·064
·3	14512·	453·5	59·72	14·17	4·644
·4		806·2	106·17	25·25	8·256
·5		1259·7	165·89	39·37	12·899
·6		1805·6	238·88	56·69	18·575
·7		2469·0	325·14	77·16	25·283
·8		3224·8	424·67	100·78	33·023
·9		4081·5	537·48	127·54	41·794
1·0		5038·9	663·55	157·46	51·598
1·1			802·90	190·53	62·433
1·2			955·51	226·75	74·301
1·3			1121·40	266·11	87·200
1·4			1300·56	308·63	101·132
1·5			1492·99	354·29	116·095
1·6			1698·69	403·11	132·090
1·7			1917·67	455·07	149·118
1·8			2149·92	510·18	167·177
1·9			2395·42	568·44	186·268
2·0			2054·21	629·86	206·391

For special cases modify the discharge by a co-efficient (c) before it, to find the correct head.

Head for a length of 1 000 *feet.*

For discharges in cubic feet per second	For diameters in feet 0·5 (6″)	0·583 (7″)	0·666 (8″)	0·75 (9″)	0·833 (10″)	Tabular number to be divided by d^5 for other diameters
	Approximate head of water in feet					
0·1	0·207	0·096	0·049	0·027	0·016	0·00648
0·2	0·829	0·384	0·197	0·107	0·064	0·02592
0·3	1·866	0·863	0·443	0·246	0·145	0·05832
0·4	3·318	1·535	0·787	0·437	0·258	0·10368
0·5	5·184	2·398	1·230	0·683	0·403	0·162
0·6	7·465	3·454	1·772	0·989	0·580	0·23328
0·7	10·163	4·701	2·411	1·338	0·790	0·31752
0·8	13·271	6·140	3·149	1·748	1·032	0·41472
0·9	16·796	7·753	3·995	2·212	1·306	0·52488
1·0	20·736	9·594	4·921	2·731	1·612	0·648
1·1	25·091	11·608	5·954	3·304	1·951	0·78408
1·2	29·860	13·815	7·086	3·932	2·322	0·93312
1·3	35·044	16·213	8·316	4·615	2·725	1·09512
1·4	40·643	18·804	9·645	5·352	3·160	1·27008
1·5	46·656	21·586	11·072	6·144	3·628	1·458
1·6	53·084	24·560	12·597	6·991	4·128	1·65888
1·7	59·927	27·726	14·221	7·892	4·660	1·87272
1·8	67·185	31·084	15·943	8·847	5·224	2·09952
1·9	74·857	34·633	17·764	9·858	5·821	2·33928
2·0	82·944	38·375	19·683	10·674	6·450	2·592
2·1	91·446	42·309	21·701	12·042	7·111	2·85768
2·2	100·362	45·377	23·816	13·216	7·804	3·13632
2·3	109·693	50·751	26·031	14·445	8·530	3·42792
2·4	119·439	55·260	28·343	15·729	9·288	3·73248
2·5	129·600	59·961	30·755	17·067	10·078	4·050
2·6	140·175	64·854	33·264	18·459	10·900	4·38048
2·7	151·165	69·939	35·872	19·906	11·755	4·72392
2·8	162·570	75·215	38·579	21·408	12·642	5·08032
2·9	174·390	80·683	41·383	22·965	13·561	5·44968
3·0	186·624	86·344	44·287	24·576	14·512	5·832

Modify the discharge by a co-efficient (*c*) before applying it, to find the correct head.

	1	
1	0·648	
2	2·592	
3	5·832	
4	10·368	
5	16·2	
6	23·328	
7	31·752	
8	41·472	
9	52·488	[illegible]
10	64·8	[illegible]
11	78·408	1c
12	93·312	12
13	109·512	14
14	127·008	16·
15	145·8	19·
16	165·888	21·
17	187·272	24·
18	209·952	27·6
19	233·928	30·8
20	259·2	34·1
21		37·63
22		41·30
23		45·14
24		49·15
25		53·333
26		57·685
27		

pproximate Head for a length of 1 000 *feet.*

For discharges in cubic feet per second	For diameters in feet					Tabular numbers to be divided by d^5 for other diameters
	3	4	5	6	7	
	Approximate head of water in feet					
1	0·003	0·0006	0·0002	0·00008	0·00004	0·6
2	0·011	0·0025	0·0008	0·00033	0·00015	2·6
3	0·024	0·0057	0·0018	0·00075	0·00035	5·8
4	0·043	0·0101	0·0033	0·00133	0·00062	10·4
5	0·067	0·0158	0·0052	0·00208	0·00096	16·2
6	0·096	0·0228	0·0074	0·00300	0·00139	23·3
7	0·131	0·0310	0·0102	0·00408	0·00189	31·8
8	0·167	0·0405	0·0133	0·00533	0·00247	41·5
9	0·216	0·0513	0·0168	0·00675	0·00312	52·5
10	0·267	0·0633	0·0207	0·00833	0·00386	64·8
15	0·600	0·1424	0·0466	0·01875	0·00868	145·8
20	1·067	0·2531	0·0829	0·03333	0·0154[illegible]	259·2
25	1·667	0·3955	0·1296	0·05208	0·02410	405·0
30	2·400	0·5695	0·1866	0·07500	0·03470	583·2
35	3·267	0·7752	0·2540	0·10208	0·04723	793·8
40	4·267	1·0132	0·3318	0·13333	0·06169	1036·8
45	5·400	1·2815	0·4199	0·16875	0·07875	1312·2
50	6·667	1·5823	0·5184	0·20833	0·09639	1620·0
55	8·067	1·9143	0·6273	0·25208	0·11663	1960·2
60	9·600	2·2781	0·7465	0·30000	0·13880	2332·8
65	11·267	2·6736	0·8761	0·35208	0·16289	2737·8
70	13·067	3·1008	1·0161	0·40833	0·18892	3175·2
75	15·000	3·5596	1·1664	0·46875	0·21687	3645·0
80	16·678	4·0500	1·3271	0·53333	0·24675	41[illegible]7·2
85	19·267	4·5721	1·4982	0·60208	0·27856	4681·8
90	21·600	5·1258	1·6796	0·67500	0·31230	5248·8
95	24·067	5·7112	1·8714	0·75208	0·34796	5848·2
100		6·3281	2·0736	0·83333	0·38555	6480·
200		25·3120	18·2944	3·33333	1·54222	25920·
300		56·9530	18·6624	7·50000	3·46998	58320·

Modify the discharge by a co-efficient (c) before applying it, to find the orrect head.

	. . . .	2·87	2·26	
2	d	0·83	1·	
	S per 1 000	9·83	3·58	
	e	0·81	0·85	
	V	3·67	2·55	
4	d	1·	1·25	
	S per 1 000	14·3	4·17	
	e	0·85	0·90	
	V	5·09	3·26	
6	d	1·25	1·50	
	S per 1 000	9·37	3·43	
	e	0·90	0·95	[illegible]
	V	4·89	3·39	[illegible]
8	d	1·25	1·50	1
	S per 1 000	16·7	6·11	2
	e	0·90	0·95	0
	V	6·52	4·52	3
10	d	1·5	1·75	2·
	S per 1 000	9·57	4·10	1·
	e	0·95	0·98	1·
	V	5·65	4·16	3·
15	d	2·	2·25	2·5
	S per 1 000	4·46	2·35	1·3
	e	1·01	1·04	1·0
	V	4·77	3·77	3·0
20	d	2·25	2·5	2·7
	S per 1 000	4·18	2·36	1·41
	e	1·04	1·06	1·08
	V	5·03	4·07	3·37
25	d	2·5	2·75	3·
	S per 1 000	3 68	2·20	1·39
	e	1·06	[illegible]	

; d *being the transverse diameter in feet,* S *per* 1 000 *the fall*
er second.

HAWKSLEY'S OVOID CULVERT, with a co-efficient of rugosity, n = 0·013.

. . . .	1' 0"	1' 2"	1' 4"	1' 6"
per 1 000	7·59	3·26	1·60	0·77
. . . .	0·88	0·91	0·94	0·97
. . . .	4·02	2·95	2·26	1·78
. . . .	1' 0"	1' 2"	1' 4"	1' 6"
per 1 000	17·07	7·31	3·52	1·86
. . . .	0·88	0·91	0·94	0·97
. . . .	6·03	4·43	3·39	2·68
. . . .	1' 2"	1' 4"	1' 6"	1' 8"
per 1 000	13·00	6·24	3·29	1·86
. . . .	0·91	0·94	0·97	0·99
V . . .	5·90	4·52	3·57	2·89
. . . .	1' 4"	1' 6"	1' 8"	1' 10"
S per 1 000	9·75	5·11	2·89	1·76
. . . .	0·94	0·97	0·99	1·01
V . . .	5·65	4·46	3·62	2·99
d . . .	1' 8"	1' 10"	2' 0"	2' 2"
S per 1 000	6·48	3·86	2·43	1·60
e . . .	0·99	1·01	1·03	1·05
V . . .	5·42	4·48	3·76	3·21
d . . .	1' 10"	2' 0"	2' 4"	2' 8"
S per 1 000	6·86	4·28	1·87	0·90
e . . .	1·01	1·03	1·07	1·10
V . . .	5·97	5·02	3·69	2·83
d . . .	2' 0"	2' 4"	2' 8"	3' 0"
S per 1 000	6·67	2·90	1·41	0·75
e . . .	1·03	1·07	1·10	1·12
V . . .	6·28	4·61	3·53	2·78
d . . .	2' 4"	2' 8"	3' 0"	3' 4"
S per 1 000	4·16	2·01	1·07	0·61
e . . .	1·07	1·10	1·13	1·14
V . . .	5·54	4·24	3·34	2·71
d . . .	2' 8"	3' 0"	3' 4"	3' 8"
S per 1 000	3·58	1·90	1·09	0·65
e . . .	1·10	1·13	1·15	1·16
V . . .	5·65	4·46	3·62	2·99
d . . .	3' 0"	3' 4"	3' 8"	4' 0"
S per 1 000	3·06	1·69	1·01	0·64
e . . .	1·13	1·15	1·17	1·18
V . . .	5·57	4·52	3·74	3·14

Q in cubic feet per second					
60	d . . .	3' 6"	4' 0"	4' 4"	4' 8"
	S per 1 000	1·87	0·90	0·60	0·41
	e . . .	1·16	1·19	1·20	1·21
	V . . .	4·92	3·77	3·21	2·77
70	d . . .	4' 0"	4' 4"	4' 8"	5' 0"
	S per 1 000	1·24	0·81	0·55	0·38
	e . . .	1·20	1·20	1·21	1·22
	V . . .	4·39	3·75	3·23	2·81
80	d . . .	4' 4"	4' 8"	5' 0"	5' 4"
	S per 1 000	1·05	0·72	0·50	0·36
	e . . .	1·20	1·22	1·23	1·23
	V . . .	4·28	3·69	3·21	2·83
90	d . . .	4' 8"	5' 0"	5' 4"	5' 8"
	S per 1 000	0·90	0·53	0·45	c·3
	e . . .	1·22	1·23	1·24	1·25
	V . . .	4·15	3·62	3·18	2·85
100	d . . .	5' 0"	5' 4"	5' 6"	5' 8"
	S per 1 000	0·77	0·55	0·46	0·41
	e . . .	1·23	1·24	1·24	1·25
	V . . .	4·02	3·53	3·32	3·17
120	d . . .	5' 4"	5' 6"	5' 8"	6' 0"
	S per 1 000	0·79	0·66	0·59	0·43
	e . . .	1·24	1·25	1·25	1·26
	V . . .	4·24	3·99	3·80	3·35
140	d . . .	5' 4"	5' 6"	5' 8"	6' 0"
	S per 1 000	1·06	0·90	0·80	0·58
	e . . .	1·25	1·25	1·26	1·27
	V . . .	4·94	4·65	4·44	3·91
160	d . . .	5' 6"	5' 0"	6' 0"	
	S per 1 000	1·17	1·03	0·75	
	e . . .	1·25	1·26	1·27	
	V . . .	5·31	3·04	4·46	
180	d . . .	5' 8"	6' 0"		
	S per 1 000	1·28	0·91		
	e . . .	1·26	1·27		
	V . . .	5·70	5·02		
200	d . . .	6' 0"			
	S per 1 000	1·15			
	e . . .	1·27			
	V . . .	5·58			

deposition of sediment. For long diameter and sectional data, see Table V. Part 4.

PART 5 (*cont.*).—*Conditions of drain pipes and culverts of equal di*
per 1000,

METROPOLITAN OVOID CULVERT, with a co-efficient of rugosity, n = 0

Q in cubic feet per second					
4	*d*	1′ 0	1′ 2″	1′ 4″	1′ 6″
	S per 1 000	5·31	2·30	1·12	0·94
	e	0·89	0·92	0·95	0·98
	V	3·48	2·56	1·96	1·55
6	*d*	1′ 0″	1′ 2″	1′ 4″	1′ 6″
	S per 1 000	11·92	5·12	2·49	1·33
	e	0·89	0·92	0·95	0·98
	V	5·22	3·84	2·94	2·32
8	*d*	1′ 2″	1′ 4″	1′ 6″	1′ 8″
	S per 1 000	9·10	4·39	2·32	1·33
	e	0·92	0·95	0·98	1·00
	V	5·12	3·92	3·10	2·51
10	*d*	1′ 4″	1′ 6″	1′ 8″	1′ 10″
	S per 1 000	6·85	3·61	2·02	1·23
	e	0·95	0·98	1·00	1·03
	V	4·90	3·87	3·13	2·59
15	*d*	1′ 8″	1′ 10″	2′ 0″	2′ 2″
	S per 1 000	4·56	2·71	1·73	1·11
	e	1·00	1·03	1·05	1·06
	V	4·70	3·89	3·27	2·78
20	*d*	1′ 10″	2′ 0″	2′ 4″	2′ 8″
	S per 1 000	4·82	3·00	1·34	0·64
	e	1·03	1·05	1·08	1·10
	V	5·18	4·35	3·20	2·45
25	*d*	2′ 0″	2′ 4″	2′ 8″	3′ 0″
	S per 1 000	4·70	2·03	0·99	0·53
	e	1·05	1·08	1·11	1·13
	V	5·44	3·99	3·06	2·42
30	*d*	2′ 4″	2′ 8″	3′ 0″	3′ 4″
	S per 1 000	2·90	1·43	0·76	0·43
	e	1·08	1·11	1·13	1·15
	V	4·80	3·67	2·90	2·35
40	*d*	2′ 8″	3′ 0″	3′ 4″	3′ 8″
	S per 1 000	2·53	1·35	0·76	0·46
	e	1·10	1·14	1·16	1·17
	V	4·90	3·87	3·13	2·60
50	*d*	3′ 0″	3′ 4″	3′ 8″	4′ 0″
	S per 1 000	2·09	1·40	0·72	0·45
	e	1·14	1·16	1·17	1·19
	V	4·84	3·92	3·24	2·72

Q in cubic feet per second			
60	*d*	3′ 6″	4′ 0″
	S per 1 000	1·33	0·65
	e	1·17	1·19
	V	4·26	3·27
70	*d*	4′ 0″	4′ 4″
	S per 1 000	0·86	0·58
	e	1·19	1·21
	V	3·81	3·25
80	*d*	4′ 4″	4′ 8″
	S per 1 000	0·75	0·51
	e	1·21	1·22
	V	3·71	3·20
90	*d*	4′ 8″	5′ 0″
	S per 1 000	0·64	0·45
	e	1·22	1·23
	V	3·60	3·03
100	*d*	5′ 0″	5′ 4″
	S per 1 000	0·55	0·39
	e	1·24	1·25
	V	3·37	3·06
120	*d*	5′ 4″	5′ 6″
	S per 1 000	0·56	0·48
	e	1·25	1·25
	V	3·67	3·45
140	*d*	5′ 4″	5′ 6″
	S per 1 000	0·76	0·68
	e	1·25	1·26
	V	4·29	4·03
160	*d*	5′ 4″	5′ 6″
	S per 1 000	0·99	0·84
	e	1·26	1·26
	V	4·00	4·60
180	*d*	5′ 6″	5′ 8″
	S per 1 000	1·06	0·90
	e	1·26	1·27
	V	5·18	4·88
200	*d*	5′ 8″	6′ 0″
	S per 1 000	1·11	0·83
	e	1·27	1·28
	V	5·42	4·84

For long diameter and sectional data see Table V. Part 4.

just full; d *being the transverse diameter in feet,* S *per* 1000 *the fall* *n feet per second.*

s OVOID (PEG-TOP SECTION) CULVERT, with a co-efficient of rugosity, $n = 0{\cdot}013$.

. . .	1′ 0″	1′ 2″	1′ 4″	1′ 6″
per 1 000	7·33	3·15	1·55	0·73
. . .	0·87	0·90	0·93	0·96
. . .	3·85	2·83	2·17	1·71
. . .	1′ 0″	1′ 2″	1′ 4″	1′ 6″
per 1 000	16·50	7·06	3·41	1·81
. . .	0·87	0·90	0·93	0·96
. . .	5·78	4·24	3·25	2·57
. . .	1′ 2″	1′ 4″	1′ 6′	1′ 8″
per 1 000	12·56	6·04	3·04	1·80
. . .	0·90	0·93	0·96	0·99
. . .	5·66	4·33	3·42	2·77
. . .	1′ 4″	1′ 6″	1′ 8″	1′ 10″
per 1 000	9·43	4·93	2·78	1·68
. . .	0·93	0·96	0·99	1·01
. . .	5·42	4·28	3·47	2·86
. . .	1′ 8″	1′ 10″	2′ 0″	2′ 2″
S per 1 000	6·23	3·70	2·33	1·54
. . .	0·99	1·01	1·03	1·05
. . .	5·20	4·30	3·61	3·08
. . .	1′ 10″	2′ 0″	2′ 4″	2′ 8″
S per 1 000	6·56	4·11	1·81	0·87
. . .	1·01	1·03	1·06	1·09
V . . .	5·73	4·81	3·54	2·71
d . . .	2′ 0″	2′ 4″	2′ 8″	3′ 0″
S per 1 000	6·42	2·79	1·36	0·72
e . . .	1·03	1·06	1·09	1·11
V . . .	6·02	4·42	3·36	2·67
d . . .	2′ 4″	2′ 8″	3′ 0″	3′ 4″
S per 1 000	4·00	1·94	1·03	0·59
e . . .	1·06	1·09	1·12	1·13
V . . .	5·31	4·06	3·21	2·60
d . . .	2′ 8″	3′ 0″	3′ 4″	3′ 8″
S per 1 000	3·45	1·84	1·04	0·63
e . . .	1·09	1·12	1·14	1·16
V . . .	5·42	4·28	3·47	2·86
d . . .	3′ 0″	3′ 4″	3′ 8″	4′ 0″
S per 1 000	2·86	1·62	0·97	0·61
e . . .	1·12	1·14	1·16	1·17
V . . .	5·35	4·33	3·58	3·01

Q in cubic feet per second					
60	d . . .	3′ 6″	4′ 0″	4′ 4″	4′ 8′
	S per 1 000	1·78	0·88	0·58	0·39
	e . . .	1·15	1·18	1·19	1·20
	V . . .	4·72	3·61	3·08	2·65
70	d . . .	4′ 0″	4′ 4″	4′ 8″	5′ 0″
	S per 1 000	1·17	0·78	0·53	0·37
	e . . .	1·18	1·19	1·21	1·21
	V . . .	4·21	3·59	3·09	2·70
80	d . . .	4′ 4′	4′ 8″	5′ 0″	5′ 4″
	S per 1 000	1·13	0·69	0·46	0·34
	e . . .	1·20	1·21	1·22	1·23
	V . . .	4·10	3·54	3·08	2·71
90	d . . .	4′ 8″	5′ 0″	5′ 4″	5′ 8″
	S per 1 000	0·87	0·60	0·43	0·31
	e . . .	1·21	1·22	1·23	1·24
	V . . .	3·98	3·47	3·05	2·70
100	d . . .	5′ 0″	5′ 4″	5′ 6″	5′ 8″
	S per 1 000	0·74	0·53	0·45	0·39
	e . . .	1·22	1·23	1·24	1·24
	V . . .	3·85	3·39	3·18	3·00
120	d . . .	5′ 4″	5′ 6″	5′ 8″	6′ 0″
	S per 1 000	0·76	0·64	0·55	0·41
	e . . .	1·24	1·24	1·25	1·25
	V . . .	4·06	3·82	3·60	3·21
140	d . . .	5′ 4″	5′ 6″	5′ 8″	6′ 0″
	S per 1 000	1·02	0·87	0·75	0·55
	e . . .	1·24	1·24	1·25	1·26
	V . . .	4·74	4·46	4·20	3·75
160	d . . .	5′ 6″	5′ 8″	6′ 0″	
	S per 1 000	1·13	0·97	0·72	
	e . . .	1·25	1·25	1·26	
	V . . .	5·09	4·80	4·28	
180	d . . .	5′ 8″	6′ 0″		
	S per 1 000	1·20	0·91		
	e . . .	1·25	1·26		
	V . . .	5·40	4·82		
200	d . . .	6′ 0″			
	S per 1 000	1·11			
	e . . .	1·26			
	V . . .	5·35			

The values of *V* in sewers should exceed 2·5 feet per second to prevent deposit.

EXPLANATORY EXAMPLES TO TABLE VIII.

Example I.

What is the discharge of a new glazed 3-inch pipe having a hydraulic slope of 1 in 400; and what would be its least full discharge when old, irrespectively of sectional obstruction?

By Table VIII., Part 2, the approximate discharge is ·06 cubic feet per second; and by the Table of Co-efficients (Table XII., Part 3), for very smooth surfaces, including smooth plaster, and enamelled or glazed pipes, the co-efficient c for a pipe having this slope and a hydraulic radius, which for cylindrical pipes running full is one-fourth of the diameter, is ·84; hence the discharge when new is $= \cdot 84 \times \cdot 06 = \cdot 05$ cubic feet per second.

If preferred in any other unit, refer to Table II., Part 4, p. 12, by inspecting which we find this to be 18 gallons per minute.

When the pipe is rather old its surface will be as rough as that of ordinary metal, and taking the co-efficient for metal with this slope and radius to be ·61, the discharge is then $= \cdot 61 \times \cdot 06 = \cdot 037$ cubic feet per second or 14 gallons per minute.

Note.—In this example, the co-efficient adopted for roughness (n) of glazed surfaces is 0·010, and that for unglazed metal surfaces is 0·013; the corresponding co-efficients of velocity will be found under them in Table XII.

Example II.

A cylindrical masonry culvert has a diameter of 42 inches, and a fall of 5 in 1 000, what is its discharge when just running full?

By Part 2, Table VIII., the approximate discharge is 63·63 cubic feet per second, and the co-efficient for this slope and a hydraulic radius of ·875 feet will according to Table XII. be 1·10; hence the actual discharge will be $1 \cdot 10 \times 63 \cdot 63 = 70$ cubic feet per second.

Note.—The co-efficient of roughness (n) for new ashlar masonry is 0·013, the required velocity co-efficients (c) will be found under it in Table XII.

Example III.

What must be the diameter of a cylindrical cast-iron pipe to discharge 20 cubic feet per second with a slope of one in 500?

By Part 3, Table VIII., the approximate diameter will be 2·64 feet; and hence the hydraulic radius is 0·66 feet; from the table of co-efficients (Table XII., Part 3), take $c = 1 \cdot 03$; and assuming a modified discharge $\frac{Q}{c} = 19 \cdot 4$, refer again to Part 3, Table VIII., and obtain a true diameter $= 2 \cdot 62$ feet.

EXAMPLE 4.

A series of glazed pipes has a total head of 30 feet, and consists of 600 feet of 8-inch pipe, 2 100 feet of 6-inch, and 600 feet of 5-inch; required the discharge and head necessary for each pipe.

Assume any discharge as 1 cubic foot per second, and obtaining the separate tabular heads due to it in Part 4, Table VIII., divide the total head in the same proportion.

$4{\cdot}921 \times 3{\cdot}6 = 17{\cdot}72$	$17{\cdot}72 \times 30 \div 92 = 5{\cdot}77$ feet
$20{\cdot}736 \times 2{\cdot}1 = 43{\cdot}55$	$43{\cdot}55 \times 30 \div 92 = 14{\cdot}15$,,
$51{\cdot}598 \times 0{\cdot}6 = 30{\cdot}95$	$30{\cdot}95 \times 30 \div 92 = 10{\cdot}08$,,
Total $= 92{\cdot}22$	Total $= 30{\cdot}$ feet.

Modifying these by the squares of the suitable co-efficients, obtain actual heads for a first approximation, and reduce them by proportion.

$5{\cdot}77 \div (\cdot 95)^2 = 6{\cdot}41$	$6{\cdot}41 \times 30 \div 39{\cdot}22 = 4{\cdot}90$ feet in 3 600
$14{\cdot}15 \div (\cdot 87)^2 = 18{\cdot}92$	$18{\cdot}62 \times 30 \div 39{\cdot}22 = 14{\cdot}24$,, in 2 100
$10{\cdot}08 \div (\cdot 84)^2 = 14{\cdot}19$	$14{\cdot}19 \times 30 \div 39{\cdot}22 = 10{\cdot}86$,, in 600
Total $= 39{\cdot}22$	Total $= 30{\cdot}$ feet.

The discharge $= \dfrac{1 \times \sqrt{30}}{\sqrt{92}} = 0{\cdot}57$ cubic feet per second: and this by Table II., Part 4, is 213 gallons per minute.

EXAMPLE 5.

A discharge of 300 gallons per minute is required through a series of ordinary iron pipes composed of 800 yards of 7-inch, 300 yards of 6-inch, and 100 yards of 5-inch; what is the head required for each pipe?

By Tables of Equivalents (Part 4, Table II.), 300 gallons per minute = ·8 cubic feet per second. Taking the corresponding tabular heads in Part 4, Table VIII., as first approximations, and modifying these by the squares of the suitable co-efficients given in Table XII., we get the true heads thus:—

	Length. Heads.	True Heads.
7 inch	$6{\cdot}140 \times 2{\cdot}4 = 14{\cdot}74$	$14{\cdot}74 \div (\cdot 66)^2 = 33{\cdot}50$ feet
6 inch	$13{\cdot}271 \times 0{\cdot}9 = 11{\cdot}94$	$11{\cdot}94 \div (\cdot 63)^2 = 29{\cdot}85$,,
5 inch	$33{\cdot}023 \times 0{\cdot}3 = 9{\cdot}91$	$9{\cdot}91 \div (\cdot 61)^2 = 26{\cdot}78$,,
	36·59 feet.	Total 90·13 feet.

NOTE.—The squares and the reciprocals required with co-efficients can be obtained through the Table of Powers and Roots in the Miscellaneous Tables.

EXAMPLE 6.

Required the dimensions and conditions of a brickwork sewer, the section Metropolitan Ovoid, to discharge 50 cubic feet per second; with a hydraulic slope, or fall per 1 000 of 1·40 feet, when running just full.

By inspecting page 102, Part 5, Table VIII.; the mean velocity will be 3·92 feet per second, and the transverse diameter will be 3 feet 4 inches; referring to Table V., Part 4, page 58, its long diameter is 5 feet, and its sectional area 12·76 square feet.

EXAMPLE 7.

What will be the mean velocity in the sewer last mentioned, when its supply is reduced so that it runs one-third full, that is, the depth of liquid is one-third the depth of the sewer?

By Table V., Part 4, page 58, the section of flow will be 3·156 square feet, and the hydraulic radius 0·689 feet, and the fall per 1 000 is still 1·40 feet. By interpolating Part 1 of Table VIII. at page 85, the approximate velocity is 3·098 feet per second; and obtaining from Table XII. the co-efficient suitable to these values of R and S, which is 1·08; we obtain the true velocity $=3·098 \times 1·08 = 3·35$ feet per second; also $Q = AV = 3·16 \times 3·35 = 10·59$ cubic feet per second.

EXAMPLE 8.

What will be the discharge in the same sewer when it is running two-thirds full, or filled to two-thirds its depth? the remaining conditions being as before.

By Table V., part 4, page 58, the section of flow will be 8·4 square feet and the hydraulic radius 1·052 feet; the fall per 1 000 is still 1·40 feet. By Table XII. the co-efficient of velocity under $n = 0·013$ will be 1·18. By interpolating Part 1, Table VIII., page 85, the approximate velocity is 3·822; hence $Q = A\,.\,c\,.\,100\sqrt{RS} = 8·4 \times 1·18 \times 3·822 = 37·88$ cubic feet per second.

NOTE.—Many of these calculations may be abbreviated by using accented four-figure logarithms. For tables of velocity and discharge in culverts and pipes of various sections under different values of n, see 'Canal and Culvert Tables' (London: Allen, 1878).

[redacted]

Table IX.—BENDS AND OBSTRUCTIONS.

Part 1. Giving loss of head in feet due to bends of 90° in pipes corresponding to certain discharges.—(Weisbach formula.)

$$h' = \frac{v^2}{2g} \cdot \frac{d}{2R}; \quad R = \text{radius of bend.}$$

Part 2. Giving loss of head due to bends in channels corresponding to certain velocities.—(Mississippi formula.)

$$h' = N \cdot V^2 \times 0{\cdot}001865.$$

Part 3. Giving approximate rise of water in feet due to obstructions, bridges, weirs, &c. :—(the whole section of water being = 1), and corresponding to certain velocities.—(Dubuat formula.)

$$h' = \frac{v^2}{2g \cdot o^2}\left(\frac{A^2}{a^2} - 1\right), \text{ when } o = 0{\cdot}96.$$

Note.—This table does not allow for variable co-efficients, and hence is merely generally correct for ordinary purposes.

PART I.—*Table giving loss of head due to one bend*

Diameter of pipe		Radius of bend	Loss of head of water in feet				
			0·01	0·05	0·1	0·2	
	Feet	Feet	Corresponding to discharges in cubic feet per se				
(1")	·083	·5	·02	·04	·05	·06	
(2")	·166	·5	·07	·15	·22	·30	
(3")	·25	1·	·15	·34	·49	·69	
(4")	·33	1·	·26	·59	·84	1·18	
(5")	·416	1·5	·43	·96	1·33	1·93	
(6")	·5	1·5	·61	1·35	1·92	2·71	
(7")	·583	1·5	·81	1·81	2·56	3·62	
(8")	·66	1·5	1·06	2·38	3·34	4·76	
(9")	·75	1·5	1·32	2·94	4·16	5·89	
(10")	·83	1·5	1·57	3·52	4·98	7·04	
(11")	·916	1·5	1·89	4·22	5·96	8·43	1
(12")	1·0	1·75	2·27	5·08	7·18	10·16	1
	1·25	2·	3·4	7·7	10·9	15·4	1
	1·5	2·5	5·0	11·3	15·9	22·6	2
	1·75	3·	6·9	15·5	21·9	30·9	3
	2·	4·	9·4	20·9	29·6	41·9	5
	2·25	4·5	11·8	26·5	38·5	53·0	6
	2·5	5·0	14·6	32·7	46·2	65·4	8
	2·75	5·5	17·7	39·6	56·0	79·2	9
	3·	6·	21·1	47·1	66·6	94·2	11
	3·25	6·5	21·7	55·3	78·2	110·6	13
	3·5	7·	28·7	64·1	90·7	128·2	15
	3·75	7·5	32·9	73·6	104·1	147·2	18
	4·	8·	37·3	83·9	118·7	167·9	20
	4·5	9·	47·4	106·0	149·9	212·0	25
	5·	10·	58·5	130·9	185·1	261·7	32
	5·5	11·	71·	158·	224·	317·	38
	6·	12·	84·	188·	266·	377·	46
	6·5	13·	99·	221·	313·	442·	54
	7·	14·	115·	336·	363·	513·	62

NOTE.—Interpolate the given discharge in the horizontal line correspond line. See example following the table.

drical pipes with different discharges.

	Loss of head of water in feet						
	0·5	0·6	0·7	0·8	0·9	1	2
	Corresponding to discharges in cubic feet per second of						
o	·12	·13	·14	·15	·16	·17	·23
3	·48	·53	·57	·61	·64	·68	·96
7	1·08	1·19	1·28	1·37	1 46	1·53	2·17
6	1·87	2·05	2·21	2·36	2·51	2·64	3·74
6	3·05	3·34	3·61	3·86	4·00	4·31	6·09
3	4·29	4·69	5·07	5·42	5·75	6·06	8·55
2	5·73	6·28	6·78	7·25	7·69	8·10	11·46
9	7·52	8·24	8·90	9·52	10·03	10·64	15·05
33	9·31	10·20	11·02	11·78	12·49	13·17	18·58
6	11·13	12·20	13·18	14·09	14·94	15·75	22·27
2	13·34	14·61	15·78	16·87	17·89	18·86	26·67
6	16·06	17·60	19·01	20·32	21·55	22·71	32·12
8	24·4	26·7	28·9	30·9	32·7	34·5	48·1
9	35·7	39·1	42·2	45·1	47·9	50·4	71·4
7	48·9	53·5	57·8	61·8	65·6	69·1	97·7
2	66·2	72·5	78·3	83·7	88·8	93·6	132·4
9	83·8	91·8	99·2	106·0	112·4	118·5	167·6
4	103·4	113·3	122·4	130·9	138·8	146·3	206·9
0	125·2	137·1	148·1	158·3	167·9	177·0	250·3
2	148·9	163·2	176·3	188·4	199·9	210·7	297·9
4	174·8	191·5	206·9	221·1	234·6	247·2	349·7
3	202·8	222·1	239·9	256·4	272·0	286·7	405·5
2	232·8	255·0	275·4	294·4	311·1	329·2	465·5
4	265·4	290·8	314·1	335·8	356·1	375·4	530·9
8	335·2	367·2	396·6	424·0	449·7	474·0	670·4
1	413·8	453·3	489·6	523·4	555·2	585·2	827·6
·	501·	548·	502·	633·	672·	708·	1001·
·	596·	653·	705·	754·	800·	843·	1192·
·	699·	766·	827·	885·	938·	989·	1399·
·	811·	888·	960·	1026·	1088·	1147·	1622·

en diameter of pipe, and obtain the loss of head by interpolation in the head-

PART 2.—*Loss of head due to Bends of Channels.*

Velocity in feet per second	Arc of bend				
	10°	15°	30°	60°	90°
	Loss of head in feet				
0·25	·0000	·0001	·0001	·0002	·0003
0·5	·0002	·0002	·0005	·0009	·0014
0·75	·0003	·0005	·0011	·0021	·0031
1·	·0006	·0009	·0019	·0037	·0056
1·25	·0009	·0015	·0029	·0058	·0087
1·5	·0014	·0021	·0042	·0084	·0126
1·75	·0019	·0029	·0057	·0113	·0171
2·	·0025	·0050	·0075	·0149	·0224
2·25	·0031	·0047	·0094	·0189	·0284
2·5	·0039	·0058	·0117	·0233	·0349
2·75	·0047	·0071	·0141	·0282	·0423
3·	·0056	·0084	·0168	·0336	·0504
3·25	·0066	·0099	·0197	·0394	·0591
3·5	·0076	·0114	·0227	·0457	·0685
3·75	·0087	·0131	·0262	·0524	·0786
4·	[illegible]	·0149	·0298	·0597	·0895
4·25	·0103	·0164	·0327	·0674	·1011
4·5	·0126	·0189	·0378	·0755	·1133
4·75	·0140	·0210	·0421	·0842	·1262
5·	·0155	·0233	·0466	·0933	·1399
5·5	·0188	·0282	·0564	·1128	·1692
6·	·0224	·0336	·0671	·1343	·2014
6·5	·0263	·0394	[illegible]	·1576	·2364
7·	·0305	·0457	·0914	·1828	·2742
7·5	·0350	·0525	·1049	·2098	·3147
8·	·0398	·0597	·1194	·2387	·3581
8·5	·0449	·0674	·1347	·2695	·4042
9·	·0503	·0756	·1511	·3021	·4532
9·5	·0561	·0842	·1683	·3366	·5049
10·	·0622	·0933	·1865	·3730	·5595

PART 3.—*Rise from Obstructions in Channels.*

Antecedent velocity in feet per second	Proportion of Section Obstructed					
	0·1	0·2	0·3	0·4	0·5	0·6
	Rise in feet					
0·25	0·000	0·001	0·001	0·002	0·003	0·006
0·5	0·001	0·002	0·004	0·008	0·013	0·022
0·75	0·002	0·005	0·010	0·017	0·028	0·050
1·	0·004	0·009	0·018	0·031	0·051	0·089
1·25	0·006	0·015	0·028	0·047	0·079	0·136
1·5	0·009	0·022	0·040	0·068	0·114	0·199
1·75	0·012	0·029	0·054	0·092	0·155	0·272
2·	0·015	0·038	0·070	0·120	0·203	0·355
2·25	0·020	0·048	0·059	0·152	0·257	0·499
2·5	0·024	0·060	0·110	0·188	0·317	0·555
2·75	0·029	0·072	0·133	0·227	0·383	0·671
3·	0·035	0·086	0·158	0·271	0·456	0·798
3·25	0·041	0·101	0·192	0·318	0·536	0·937
3·5	0·048	0·117	0·215	0·369	0·621	1·087
3·75	0·055	0·134	0·247	0·423	0·713	1·248
4·	0·062	0·153	0·281	0·481	0·811	1·420
4·25	0·070	0·173	0·318	0·543	0·916	1·603
4·5	0·079	0·194	0·356	0·609	1·027	1·797
4·75	0·088	0·216	0·394	0·679	1·144	2·002
5·	0·097	0·239	0·439	0·752	1·268	2·218
5·5	0·118	0·289	0·532	0·910	1·534	2·684
6·	0·140	0·344	0·633	1·083	1·825	3·194
6·5	0·164	0·404	0·768	1·271	2·142	3·748
7·	0·191	0·468	0·861	1·474	2·484	4·347
7·5	0·219	0·538	0·989	1·692	2·852	4·991
8·	0·249	0·011	1·125	1·925	3·245	5·678
8·5	0·281	0·691	1·270	2·173	3·663	6·410
9·	0·315	0·774	1·424	2·436	4·107	7·186
9·5	0·351	0·863	1·587	2·715	4·576	8·007
10·	0·389	0·956	1·758	3·008	5·070	8·872

EXPLANATORY EXAMPLES TO TABLE IX.

EXAMPLE 1.

A series of pipes have to discharge 5 gallons per second; there ar bends in the portion that consists of 5-inch pipe, 4 in that of 6-inch p and 8 in that of 7-inch pipe; what is the total loss of head on account these bends?

From Table II. Part 4, page 13, 5 gallons per second = 0·8 cubic per second. Taking the heads separately from Table IX. Part 1,

7 bends in 5-inch give	$7 \times 0·045 = 0·315$ feet.	
4 ,, ,, 6 ,, ,,	$4 \times 0·030 = 0·120$,,	
8 ,, ,, 7 ,, ,,	$8 \times 0·010 = 0·080$,,	
	Total loss of head = 0·515 feet.	

The head on the pipes must therefore not only be sufficient to force cubic feet per second through the pipes under ordinary conditions, must also be increased by 0·515 feet on account of bends.

EXAMPLE 2.

A channel has one bend of 15°, two of 30°, and one of 90°, what i total loss of head expended in overcoming these bends, when the vel is 5 feet per second?

From Part 2, Table IX.

1 bend of 15° gives	$1 \times 0·0233 = 0·0233$ feet.
2 ,, ,, 30° ,,	$2 \times 0·0466 = 0·0932$,,
1 ,, ,, 90° ,,	$1 \times 0·1399 = 0·1399$,,
	Total head expended = 0·2564 feet.

EXAMPLE 3.

A channel having a hydraulic slope less than 0·001 has its sectio structed by the piers and abutments of a bridge to the extent of one the normal velocity being 3·5 per second, what is the rise caused by bridge?

By Part 3, Table IX., the rise will be 0·117 feet.

NOTE.—For channels having steeper hydraulic slopes, that is, fal more than 1 foot in 1 000, apply a correction according to the formula in the text, page 106.

Table X.—ORIFICES AND OVERFALLS.

Velocities of discharge in feet per second for sluices, and orifices, due to various heads for certain co-efficients, also theoretical velocities to which any co-efficient may be applied; being an application of the formula

$$V = o \times 8{\cdot}025 \sqrt{H},$$

where for orifices H = depth of centre of motion of orifice.

The same table also applies to overfalls, weirs, and notches, but in this case using the same general formula, H is the depth from still water to sill-level; but the velocity given in the table must be reduced by one-third to obtain velocity of discharge for any overfall, as by formula

$$V = \tfrac{2}{3} \,.\, 0 \times 8{\cdot}025 \sqrt{H}.$$

For values of (o) the co-efficient, see Parts 5 and 6, Table XII.

This table can also be used for the converse purpose.

To obtain the discharge (Q) in either case

$$Q = A\,V,$$

where A is the hydraulic section, see text, page 115.

Table X.—*Orifices and Overfalls.*

Effective head in feet	Co-efficients: For natural velocity 1·	For narrow bridge-openings 9·	For velocity of approach 8·	For special weirs 7·	For special orifices 6·	For lo[illegible] 5·
	Velocities of discharge					
·01	·803	·722	·642	·562	·482	·401
·02	1·135	1·021	·908	·794	·681	·567
·03	1·390	1·251	1·112	·973	·834	·695
·04	1·605	1·445	1·284	1·123	·963	·803
·05	1·794	1·615	1·435	1·256	1·076	·897
·06	1·966	1·769	1·573	1·376	1·180	·983
·07	2·123	1·911	1·698	1·486	1·274	1·062
·08	2·270	2·043	1·816	1·589	1·362	1·135
·09	2·408	2·167	1·926	1·686	1·445	1·204
·1	2·538	2·284	2·030	1·777	1·523	1·269
·2	3·589	3·230	2·871	2·512	2·153	1·794
·3	4·395	3·956	3·516	3·078	2·637	2·198
·4	5·075	4·568	4·060	3·553	3·045	2·538
·5	5·675	5·108	4·540	3·973	3·405	2·837
·6	6·216	5·594	4·973	4·351	3·730	3·108
·7	6·714	6·043	5·371	4·700	4·028	3·352
·8	7·178	6·460	5·742	5·025	4·307	3·589
·9	7·613	6·852	6·090	5·329	4·568	3·807
1·	8·025	7·223	6·420	5·618	4·815	4·013

N.B.—For overfalls, reduce the tabular velocity by one-third.

TABLE X.—*continued.*

Co-efficients					
For wide bridge-openings	For lock sluices	For special weirs	For weirs generally	For orifices generally	For special orifices
·96	·84	·727	·666	·62	·55
Velocities of discharge					
·770	·674	·584	·535	·498	·441
1·089	·953	·825	·756	·704	·624
1·334	1·168	1·011	·926	·862	·765
1·541	1·348	1·167	1·069	·995	·883
1·722	1·507	1·304	1·185	1·112	·987
1·887	1·651	1·429	1·309	1·219	1·081
2·038	1·783	1·543	1·414	1·316	1·169
2·179	1·907	1·650	1·512	1·407	1·249
2·311	2·023	1·751	1·604	1·493	1·324
2·436	2·132	1·845	1·690	1·574	1·396
3·445	3·014	2·609	2·390	2·225	1·973
4·219	3·694	3·195	2·927	2·725	2·418
4·872	4·264	3·689	3·380	3·147	2·792
5·448	4·768	4·126	3·780	3·519	3·121
5·968	5·221	4·519	4·140	3·854	3·419
6·445	5·640	4·881	4·471	4·163	3·687
6·890	6·030	5·218	4·781	4·450	3·948
7·308	6·395	5·535	5·070	4·720	4·187
7·704	6·742	5·834	5·345	4·976	4·414

N.B.—For overfalls, reduce the tabular velocity by one-third.

TABLE X.—*continued.*

Effective head in feet	Co-efficients					
	For natural velocity ·1	For narrow bridge-openings ·9	For velocity of approach ·8	For special weirs ·7	For special orifices ·6	For broad-crested dams ·5
	Velocities of discharge					
1·	8·0250	7·223	6·420	5·618	4·815	4·013
1·25	8·9722	8·075	7·178	6·281	5·383	4·486
1·5	9·8286	8·846	7·863	6·880	5·897	4·915
1·75	19·6161	9·554	8·943	7·431	6·370	5·308
2·	11·3491	10·214	9·079	7·944	6·809	5·675
2·25	12·0375	10·834	9·630	8·426	7·223	6·019
2·5	12·6886	11·420	10·151	8·882	7·613	6·345
2·75	13·3079	11·977	10·646	9·316	7·985	6·654
3·	13·8997	12·510	11·120	9·730	8·340	6·950
3·25	14·4673	13·020	11·574	10·127	8·680	7·234
3·5	15·0134	13·512	12·010	10·509	9·008	7·507
3·75	15·5403	13·986	12·432	10·878	9·324	7·770
4·	16·0500	14·445	12·840	11·235	9·630	8·025
4·25	16·5439	14·890	13·235	11·581	9·926	8·272
4·5	17·0235	15·322	13·619	11·916	10·214	8·512
4·75	17·4901	15·741	13·992	12·243	10·494	8·743
5·	17·9444	16·150	14·355	12·561	10·767	8·972
5·25	18·3876	16·549	14·710	12·871	11·033	9·191
5·5	18·8203	18·938	15·056	13·174	11·292	9·410
5·75	19·2433	17·319	15·395	13·470	11·546	9·622
6·	19·6572	17·691	15·726	13·760	11·794	9·829
6·25	20·0625	18·057	16·050	14·044	12·038	10·032
6·5	20·4598	18·414	16·368	14·322	12·276	10·230
6·75	20·8496	18·765	16·680	14·595	12·510	10·425
7·	21·2322	19·109	16·986	14·863	12·739	10·616
7·25	21·6079	19·447	17·286	15·126	12·965	10·804
7·5	21·9774	16·779	17·582	15·384	13·186	10·989
7·75	22·3406	20·107	17·873	15·638	13·404	11·171
8·	22·6981	20·428	18·158	15·889	13·619	11·349

N.B.—For overfalls, reduce the tabular velocity by one-third.

TABLE X.—*continued.*

...ctive ...d in ...et	Co-efficients					
	For wide bridge-openings ·96	For lock sluices ·84	For special weirs ·727	For weirs generally ·666	For orifices generally ·62	For special orifices ·55
	Velocities of discharge					
	7·704	6·741	5·836	5·345	4·975	4·413
25	8·614	7·537	6·525	5·976	5·562	4·934
50	9·436	8·256	7·147	6·546	6·109	5·420
75	10·192	8·918	7·720	7·071	6·582	5·839
	10·895	9·533	8·253	7·558	6·936	6·241
·25	11·556	10·112	8·754	8·017	7·461	6·621
·50	12·181	10·659	9·227	8·451	7·867	6·978
·75	12·776	11·179	9·678	8·863	8·251	7·319
	13·344	11·676	10·108	9·257	8·618	7·645
·25	13·879	12·153	10·521	9·635	8·825	7·957
·50	14·413	12·612	10·918	9·999	9·308	8·258
·75	14·919	13·054	11·301	10·350	9·635	8·547
	15·408	13·482	11·672	10·689	9·951	8·827
·25	15·882	13·897	12·027	11·018	10·257	9·099
·50	16·343	14·300	12·380	11·338	10·554	9·363
·75	16·800	14·695	12·718	11·651	10·846	9·622
	17·227	15·074	13·049	11·952	10·121	9·865
·25	17·652	15·446	13·372	12·247	11·400	10·113
·50	18·068	15·809	13·686	12·534	11·669	10·351
·75	18·474	16·165	13·994	12·817	11·931	10·584
	18·871	16·512	14·295	13·092	12·188	10·812
·25	19·260	16·853	14·590	13·362	12·439	11·034
·50	19·642	17·187	14·879	13·627	12·685	11·253
·75	20·016	17·514	15·162	13·886	12·927	11·467
	20·383	17·835	15·440	14·141	13·164	11·688
·25	20·744	18·181	15·714	14·391	13·402	11·889
·50	21·099	18·481	15·982	14·637	13·626	12·082
·75	21·447	18·767	16·246	14·879	13·851	12·287
	21·791	19·067	16·506	15·117	14·073	12·484

N.B.—For overfalls, reduce the tabular velocity by one-third.

TABLE X.—*continued.*

Effective head in feet	Co-efficients					
	For natural velocity	For narrow bridge-openings	For velocity of approach	For special weirs	For special orifices	For broad-crested dams
	1·	·9	·8	·7	·6	·5
	Velocities of discharge					
8·25	23·051	20·746	18·441	16·135	13·831	11·525
8·50	23·397	21·057	18·717	16·377	14·032	11·698
8·75	23·739	21·365	18·992	16·617	14·243	11·869
9·	24·076	21·668	19·261	16·853	14·445	12·038
9·25	24·408	21·996	19·526	17·085	14·645	12·204
9·50	24·735	22·261	19·788	17·316	14·821	12·367
9·75	2 ·059	22·553	20·047	17·541	15·035	12·529
10·	25·378	22·840	20·302	17·764	15·227	12·689
10·5	26·005	23·404	20·804	18·203	15·603	13·002
11·	26·617	23·955	21·293	18·631	15·970	13·308
11·5	27·215	24·493	21·772	19·050	16·329	13·607
12·	27·800	25·020	22·240	19·460	16·6·0	13·900
12·5	28·373	25·535	22·698	19·861	17·024	14·186
13·	28·935	26·041	23·148	20·254	17·361	14·467
13·5	29·486	26·545	23·596	20·646	17·697	14·747
14·	30·027	27·024	24·021	21·019	18·016	15·013
14·5	30·559	27·503	24·447	21·391	18·335	15·279
15·	31·081	27·973	24·864	21·756	18·648	15·540
15·	31·594	28·434	25·275	22·115	18·956	15·797
16·5	32·101	28·891	25·681	22·470	19·261	16·090
16·5	32·598	29·338	26·078	22·818	19·555	16·299
17·	33·089	29·780	26·471	23·162	19·853	16·544
17·5	33·572	30·214	26·857	23·500	20·143	16·786
18·	34·048	30·643	27·238	23·833	20·429	17·024
18·5	34·518	31·066	27·614	24·162	20·711	17·259
19·	34·981	31·483	27·985	24·486	20·988	17·490
19·5	35·438	31·894	28·350	24·806	21·283	17·719
20·	35·889	32·300	29·711	25·122	21·533	17·944

N.B.—For overfalls, reduce the tabular velocity by one-third.

TABLE X.—*continued.*

Effective head in feet	Co-efficients					
	For wide bridge-openings 96	For lock sluices ·84	For special weirs ·727	For weirs generally ·666	For orifices generally ·62	For special orifices ·55
	Velocities of discharge					
8·25	22·129	19·362	16·762	15·352	14·292	12·677
8·50	22·461	19·654	17·014	15·582	14·506	12·867
8·75	22·789	19·941	17·263	15·810	14·718	13·056
9·	23·112	20·223	17·508	16·034	14·927	13·242
9·25	23·431	20·502	17·749	16·256	15·133	13·424
9·50	23·746	20·778	17·987	16·473	15·336	13·604
9·75	24·056	28·049	18·223	16·689	15·536	13·782
10·	24·363	21·317	18·455	16·902	15·734	13·958
10·5	24·964	21·844	18·910	17·112	16·123	14·302
11·	25·552	22·358	19·355	17·727	16·502	14·639
11·5	26·126	22·860	19·791	18·125	16·873	14·968
12·	26·688	23·352	20·216	18·515	17·236	15·290
12·5	27·238	23·834	20·613	18·897	17·591	15·605
13·	27 778	24·306	21·042	19·271	17·940	15·914
13·5	28·307	24·769	21·442	19·637	18·287	16·222
14·	28·826	25·223	21·836	19·998	18·617	16·514
14· 5	29·337	25·670	22·222	20·352	18·946	16·807
15·	29·838	26·108	22·602	20·700	19·270	17·094
15·5	30·331	26·540	22·976	21·042	19·588	17·377
16·	30·817	26·965	23·344	21·379	19·903	17·655
16·5	31·294	27·383	23·706	21·711	20·207	17·929
17·	31·765	27·794	24·062	22·037	20·515	18·198
17·5	32·229	28·200	24·413	22·358	20·815	18·465
18·	32·686	28·600	24·760	22·676	21·110	18·726
18·5	33·137	28·995	25·101	22·988	21·391	18·985
19·	33·582	29·384	25·438	23·298	21·688	19·239
19·5	34·021	29·768	25·771	23·602	21·991	19·491
20·	34·454	30·147	26·091	23·902	22·251	19·739

N.B.—For overfalls, reduce the tabular velocity by one-third.

TABLE X.—*continued.*

Effective head in feet	Co-efficients					
	For natural velocity 1	For narrow bridge-openings ·9	For velocity of approach ·8	For special weirs ·7	For special orifices ·6	For broad-crested dams ·5
	Velocities of discharge					
20·5	36·336	32·702	29·068	25·435	21·801	18·168
21·	36·776	33·098	29·420	25·743	22·066	18·388
21·5	37·211	33·490	29·768	26·047	22·327	18·605
22·	37·641	33·877	30·112	26·348	22·585	18·820
22·5	38·067	34·260	30·453	26·646	22·840	19·033
23·	38·487	34·647	30·797	26·948	23·098	19·298
23·5	38·903	35·012	31·122	27·232	23·342	19·451
24·	39·315	35·383	31·452	27·520	23·589	19·657
24·5	39·723	35·750	31·778	27·806	23·834	19·861
25·	40·126	36·113	32·100	28·088	24·075	20·063
25·5	40·525	36·472	32·420	28·367	24·315	20·262
26·	40·921	36·379	32·737	28·644	24·553	20·460
26·5	41·312	37·180	33·049	28·918	24·787	20·656
27·	41·700	37·530	33·360	29·190	25·020	20·850
27·5	42·084	37·875	33·667	29·458	25·250	21·042
28·	42·465	38·218	33·972	29·725	25·479	21·232
28·5	42·843	38·558	34·275	29·990	25·706	21·421
29·	43·216	38·890	34·569	30·248	25·927	21·606
29·5	43·588	39·229	34·870	30·511	26·153	21·794
30·	43·956	39·560	35·164	30·779	26·374	21·975
30·5	44·320	39·888	35·456	31·024	26·592	22·160
31·	44·682	40·213	35·745	31·277	26·809	22·340
31·5	45·041	40·537	36·032	31·528	27·025	22·520
32·	45·397	40·857	36·317	31·778	27·238	22·698
32·5	45·751	41·176	36·601	32·025	27·451	22·875
33·	46·101	41·491	36·880	32·270	27·660	23·050
33·5	46·449	41·804	37·159	32·514	27·869	23·224
34·	46·794	42·114	37·435	32·755	28·076	23·397
34·5	47·137	42·423	37·709	32·996	28·282	23·568
35·	47·478	42·730	37·982	33·234	28·487	23·739

N.B.—For overfalls, reduce the tabular velocity by one-third.

TABLE X.—*continued.*

Effective head in feet	Co-efficients: For wide bridge-openings ·96	For lock sluices ·84	For special weirs ·727	For weirs generally ·666	For orifices generally ·62	For special orifices ·55
	Velocities of discharge					
20·5	34·882	30·522	26·423	24·199	22·528	19·985
21·	35·305	30·892	26·737	24·493	22·701	20·227
21·5	35·723	31·257	27·060	24·783	22·971	20·465
22·	36·136	31·619	27·373	25·069	23·337	20·702
22·5	36·544	31·976	27·682	25·353	23·601	20·936
23·	36·948	32·329	27·998	25·633	23·868	21·228
23·5	37·347	32·679	28·291	25·910	24·120	21·396
24·	37·743	33·025	28·590	26·184	24·375	21·623
24·5	38·134	33·367	28·886	26·455	24·628	21·847
25·	38·521	33·706	29·180	26·724	24·878	22·069
25·5	38·904	34·041	29·470	26·990	25·125	22·288
26·	39·284	34·373	29·757	27·253	25·371	22·506
26·5	39·660	34·702	30·042	27·514	25·613	22·722
27·	40·032	35·028	30·324	27·761	25·854	22·935
27·5	40·401	35·351	39·604	28·028	26·092	23·146
28·	40·767	35·671	30·881	28·282	26·328	23·355
28·5	41·129	35·988	31·155	28·533	26·563	23·563
29·	41·488	36·302	31·427	28·782	26·891	23·766
29·5	41·844	36·614	31·697	29·029	27·024	23·973
30·	42·197	36·923	31·956	29·274	27·253	24·176
30·5	42·548	37·229	32·230	29·517	27·478	24·376
31·	42·895	37·533	32·493	29·758	27·703	24·574
31·5	43·240	37·835	32·754	29·997	27·925	24·772
32·	43·581	38·134	33·013	30·234	28·146	24·968
32·5	43·920	38·430	33·270	30·470	28·365	25·162
33·	44·257	38·725	33·525	30·703	28·582	25·355
33·5	44·591	39·017	33·778	30·935	28·798	25·546
34·	44·923	39·307	34·029	31·165	29·012	25·737
34·5	45·252	39·595	34·278	31·393	29·225	25·925
35·	45·578	39·881	34·526	31·620	29·436	26·113

N. B.—For overfalls, reduce the tabular velocity by one-third.

EXPLANATORY EXAMPLES TO TABLE X.

EXAMPLE 1.

An orifice 6 inches in diameter, has its centre under a head of 5 feet of water; required its discharge.

For a circular orifice using ·62 for a co-efficient, the velocity of discharge is 11·121 feet per second, and the sectional area, according to Part 7, Table XII., being ·1963, the discharge = ·1963 × 11·121 = 2·1836 cubic feet per second.

EXAMPLE 2.

A rectangular orifice is 8 inches broad and 4 inches deep, and is under an effective head of 4 feet 3 inches; required its discharge.

Since the breadth is greater than the depth, a special co-efficient is required. (*See* Co-efficients in Table XII.)

$$\text{Here } \frac{H}{L} = \frac{4 \cdot 25}{\cdot 66} = 7 \text{ approximately, and } \frac{D}{L} = \frac{\cdot 33}{\cdot 66} = 0 \cdot 5.$$

These require a co-efficient ·612, which must hence be applied to the tabular discharge for natural velocity due to the co-efficient 1·00 ∴ the discharge = 16·544 × ·22 × ·612 = 2·227 cubic feet per second.

EXAMPLE 3.

The fall of water through a bridge, having a sectional area of 500 square feet, is 0·05 feet; required the discharge.

Take ·96 as a co-efficient for a wide opening, and we get the discharge = 1·758 × 500 = 879 cubic feet per second.

EXAMPLE 4.

The difference of level between the upper and lower ponds of a canal is 6 feet, and the communicating sluice is 2 feet square; required its discharge.

Using the co-efficient ·84 and height 6, for a constant head of 6 feet, the discharge is 16·512 × 4 = 66·048 cubic feet per second.

The effective head gradually decreasing, the mean discharge due to the height is 33·024 cubic feet per second.

If the lock is 60 long and 20 broad, it will hold 7 200 cubic feet of nd at the above rate will be filled in 218 seconds, or about three and a half.

EXAMPLE 5.

ired the diameter of a vertical pipe to discharge 2 cubic feet per rom a reservoir under a head of 30 feet.

g the co-efficient ·84, we obtain from the Table 36·923 as velocity rge.

section will then $= \frac{2\cdot}{36\cdot923} = 0\cdot05417$ square feet $= 5\cdot42$ square which will require a diameter of 3 tithes, or 4 inches, for the pipe.

EXAMPLE 6.

ired the length of a weir to discharge 5 696 cubic feet per second, h or head from still water to sill of 4 feet.

a co-efficient ·666, the tabular velocity of discharge is 10·689, ch one-third has to be deducted to obtain the mean velocity of over a weir.

e $V = 10\cdot689 - 3\cdot563 = 7\cdot126$ feet per second,

section $= \frac{5696}{7\cdot126} =$ nearly 800 feet;

length $= \frac{\text{section}}{\text{depth}} =$ nearly 200 feet.

EXAMPLE 7.

er passes over a drowned weir: the upper level of water is 3 feet e lower level, and is 4 feet above the sill of the weir, which is 100 ; required the discharge.

upper portion may be considered as a simple overfall with a head d with a co-efficient ·666; the lower portion as an orifice, with the d, but a co-efficient ·62.

rding to the Table the velocity of discharge for the one is ·086 = 6·171 feet per second; and that for the other is 8·618 feet d. Hence the discharge:

$$= 50\ (6\cdot171 \times 3 + 8\cdot618 \times 1) = 50 \times 27\cdot131$$
$$= 1356 \text{ cubic feet per second.}$$

EXAMPLE 8.

required to raise the upper portion of a river 1·5 feet by means of d weir across it. The river has a discharge of 812 cubic feet per second, and a width of 70 feet; what must be the height of the dam—1st, neglecting velocity of approach; 2nd, taking it at 2·5 feet per second?

1st. Let d = depth of sill of dam below the lower water.

Then V = velocity of upper portion, or true overfall;
= $\frac{2}{3}$ velocity for head 1·5 to a co-efficient ·666;
= 4·364 feet per second (from Table);

and V^1 = velocity of lower portion of orifice;
= velocity for a head 1·5 to a co-efficient ·62;
= 6·109 feet per second (from Table).

Then the total discharge 812, is as in the last Example

$$=70\left\{V\times 1{\cdot}5+V^1\times d\right\}=70\,(6{\cdot}546+d\times 6{\cdot}109)$$

hence $d=\dfrac{5{\cdot}054}{6{\cdot}109}=0{\cdot}827$ feet.

2nd. Taking into consideration the velocity of approach and modifying the co-efficients (*vide* Table XII.) accordingly.

The head due to velocity of approach 2·5 feet per second, for a co-efficient ·8, is from Table IX. about ·15 feet.

Hence the modified co-efficient for overfall will be

$$o\left[\left\{1+\frac{h^{\frac{3}{2}}}{H}\right\}-\left\{\frac{h^{\frac{3}{2}}}{H}\right\}\right]=\cdot 666\left\{\left\{1+\frac{\cdot 15^{\frac{3}{2}}}{1{\cdot}5}\right\}-\left\{\frac{\cdot 15^{\frac{3}{2}}}{1{\cdot}5}\right\}\right\}$$

$$=\cdot 666\left\{(1\cdot)^{\frac{3}{2}}-(\cdot 1)^{\frac{3}{2}}\right\}=\cdot 745$$

and the modified co-efficient for orifice will be

$$o\,\sqrt{\left\{1+\frac{\cdot 15}{1{\cdot}5}\right\}}=o\sqrt{1{\cdot}1}=\cdot 62\times 1{\cdot}049=\cdot 648.$$

Making use of these two co-efficients instead of ·666 and ·62 as in the first portion of the Example, we obtain other values.

$$V=4{\cdot}894\,;\ \text{and}\ V^1=6{\cdot}385\,;$$

hence $\dfrac{812}{70}=11{\cdot}6=1{\cdot}5\ V+d\,V^1=7{\cdot}341+d\times 6{\cdot}385$

and $d=\dfrac{4{\cdot}259}{6{\cdot}385}=0{\cdot}667$ feet.

Table XI.

**Mean velocities of discharge in feet per second,
in small channels of rectangular section
corresponding to observed maximum velocities (V_x) and to co-efficients
(c), of mean velocity;
calculated according to the Bazin formula—**

$$V_m = \frac{c \,.\, V_x}{c + 0{\cdot}2535},$$

Also a table of Limiting Velocities for Culverts and Canals.

Mean Velocities of Discharge corresponding to

a —	Maximum Velocities 0·5	1·	1·5	2·	2·5	3·	3·5	4·
0·25	0·248	0·497	0·745	0·994	1·241	1·490	1·738	1·986
0·30	0·271	0·542	0·813	1·084	1·355	1·626	1·897	2·168
0·35	0·290	0·580	0·870	1·160	1·450	1·740	2·030	2·320
0·40	0·306	0·612	0·918	1·224	1·530	1·836	2·142	2·448
0·45	0·320	0·640	0·959	1·279	1·599	1·919	2·239	2·568
0·50	0·332	0·664	0·995	1·327	1·659	1·991	2·323	2·654
0·55	0·342	0·685	1·027	1·370	1·711	2·054	2·396	2·738
0·60	0·352	0·703	1·055	1·406	1·758	2·109	2·461	2·812
0·65	0·360	0·719	1·079	1·439	1·799	2·158	2·518	2·878
0·70	0·367	0·734	1·102	1·469	1·836	2·203	2·570	2·937
0·75	0·374	0·747	1·121	1·495	1·869	2·242	2·616	2·990
0·80	0·380	0·759	1·139	1·519	1·899	2·278	2·658	3·038
0·85	0·385	0·770	1·156	1·541	1·926	2·311	2·696	3·081
0·90	0·390	0·780	1·171	1·561	1·951	2·341	2·731	3·121
0·95	0·395	0·789	1·184	1·579	1·974	2·368	2·763	3·158
1·00	0·399	0·798	1·197	1·596	1·995	2·393	2·792	3·192
1·05	0·403	0·806	1·208	1·611	2·014	2·416	2·819	3·222
1·10	0·406	0·813	1·219	1·626	2·032	2·438	2·845	3·251
1·15	0·410	0·819	1·229	1·639	2·049	2·459	2·869	3·278
1·20	0·413	0·826	1·238	1·651	2·064	2·477	2·890	3·302
1·25	0·416	0·831	1·247	1·663	2·079	2·495	2·911	3·326
1·30	0·418	0·837	1·255	1·674	2·092	2·510	2·929	3·347
1·35	0·421	0·842	1·263	1·684	2·105	2·526	2·947	3·368
1·40	0·423	0·847	1·270	1·694	2·117	2·540	2·964	3·387
1·45	0·426	0·851	1·277	1·702	2·128	2·554	2·979	3·405
1·50	0·428	0·855	1·283	1·711	2·139	2·567	2·995	3·422
1·55	0·430	0·860	1·289	1·719	2·149	2·579	3·009	3·438
1·60	0·432	0·863	1·295	1·726	2·158	2·590	3·021	3·453
1·65	0·433	0·867	1·300	1·734	2·167	2·600	3·034	3·467
1·70	0·435	0·870	1·306	1·741	2·176	2·611	3·046	3·482
1·75	0·437	0·873	1·310	1·747	2·184	2·621	3·058	3·494
1·80	0·438	0·877	1·315	1·754	2·191	2·630	3·069	3·507
1·85	0·440	0·880	1·319	1·759	2·199	2·639	3·079	3·518
1·90	0·441	0·882	1·324	1·765	2·206	2·647	3·088	3·530
1·95	0·442	0·885	1·327	1·770	2·212	2·654	3·097	3·539
2·00	0·444	0·888	1·331	1·775	2·219	2·663	3·107	3·550
2·10	0·446	0·892	1·339	1·785	2·231	2·677	3·123	3·570
2·20	0·448	0·897	1·345	1·794	2·242	2·690	3·139	3·587

observed Maximum Velocities and Co-efficients (c).

c	Maximum Velocities 4·5	5·	5·5	6·	0·5	7·	7·5	8·
0·25	2·235	2·483	2·732	2·980	3·228	3·476	3·724	3·972
0·30	2·439	2·710	2·982	3·252	3·524	3·794	4·066	4·336
0·35	2·610	2·900	3·190	3·480	3·770	4·060	4·350	4·640
0·40	2·754	3·060	3·366	3·672	3·978	4·284	4·590	4·896
0·45	2·878	3·198	3·518	3·838	4·158	4·478	4·798	5·118
0·50	2·986	3·318	3·650	3·982	4·314	4·646	4·978	5·308
0·55	3·081	3·423	3·766	4·108	4·450	4·792	5·134	5·476
0·60	3·164	3·515	3·866	4·218	4·570	4·922	5·272	5·624
0·65	3·217	3·597	3·957	4·316	4·676	5·036	5·396	5·756
0·70	3·304	3·671	4·038	4·406	4·772	5·140	5·506	5·874
0·75	3·363	3·737	4·110	4·484	4·858	5·232	5·606	5·980
0·80	3·417	3·797	4·176	4·556	4·936	5·316	5·696	6·076
0·85	3·466	3·851	4·236	4·622	5·006	5·392	5·776	6·162
0·90	3·511	3·901	4·292	4·682	5·072	5·462	5·852	6·242
0·95	3·552	3·947	4·342	4·736	5·132	5·526	5·920	6·316
1·00	3·590	3·989	4·388	4·786	5·186	5·584	5·984	6·384
1·05	3·624	4·027	4·430	4·832	5·236	5·638	6·040	6·444
1·10	3·658	4·064	4·470	4·876	5·283	5·690	6·096	6·502
1·15	3·688	4·097	4·508	4·918	5·327	5·737	6·147	6·557
1·20	3·715	4·128	4·541	4·954	5·366	5·779	6·192	6·605
1·25	3·742	4·157	4·574	4·990	5·405	5·821	6·237	6·653
1·30	3·766	4·184	4·602	5·021	5·439	5·858	6·276	6·694
1·35	3·789	4·210	4·631	5·052	5·473	5·894	6·315	6·736
1·40	3·811	4·234	4·657	5·081	5·504	5·928	6·351	6·774
1·45	3·830	4·256	4·682	5·107	5·533	5·958	6·384	6·810
1·50	3·850	4·277	4·706	5·134	5·561	5·989	6·407	6·845
1·55	3·868	4·297	4·728	5·158	5·587	6·017	6·447	6·877
1·60	3·884	4·316	4·748	5·179	5·611	6·042	6·474	6·906
1·65	3·904	4·334	4·767	5·201	5·634	6·068	6·501	6·934
1·70	3·917	4·351	4·787	5·222	5·658	6·093	6·528	6·963
1·75	3·931	4·367	4·805	5·242	5·678	6·115	6·552	6·989
1·80	3·944	4·383	4·820	5·258	5·697	6·135	6·573	7·011
1·85	3·958	4·397	4·838	5·278	5·717	6·157	6·597	7·037
1·90	3·971	4·412	4·853	5·294	5·736	6·177	6·618	7·059
1·95	3·982	4·425	4·866	5·309	5·751	6·194	6·636	7·078
2·00	3·994	4·438	4·882	5·326	5·769	6·213	6·657	7·101
2·10	4·016	4·462	4·908	5·354	5·801	6·247	6·693	7·139
2·20	4·036	4·484	4·932	5·381	5·829	6·278	6·726	7·174

Mean Velocities of Discharge corresponding to

c	Maximum Velocities							
	8·5	9·	9·5	10·	10·5	11·	11·5	12·
0·25	4·222	4·470	4·718	4·965	5·22	5·46	5·71	5·96
0·30	4·608	4·878	5·150	5·420	5·70	5·97	6·24	[illegible]
0·35	4·930	5·220	5·510	5·800	6·09	6·38	6·67	6·96
0·40	5·202	5·508	5·814	6·120	6·43	6·73	7·04	7·34
0·45	5·436	5·756	6·076	6·395	6·72	7·04	7·36	7·68
0·50	5·640	5·972	6·304	6·636	6·97	7·30	7·64	7·97
0·55	5·820	6·162	6·504	6·845	7·19	7·53	7·88	8·22
0·60	5·976	6·328	6·678	7·030	7·38	7·73	8·09	8·44
0·65	6·114	6·474	6·834	7·194	7·56	7·97	8·28	8·64
0·70	6·240	6·608	6·976	7·342	7·71	8·08	8·45	8·81
0·75	6·352	6·726	7·100	7·474	7·85	8·23	8·60	8·98
0·80	6·454	6·834	7·214	7·594	7·98	8·36	8·74	9·12
0·85	6·546	6·932	7·318	7·703	8·09	8·47	8·86	9·25
0·90	6·632	7·022	7·412	7·802	8·19	8·58	8·97	9·36
0·95	6·710	7·104	7·498	7·894	8·29	8·69	9·08	9·48
1·00	6·782	7·180	7·580	7·978	8·38	8·78	9·18	9·58
1·05	6·846	7·248	7·652	8·055	8·46	8·86	9·26	9·67
1·10	6·908	7·316	7·722	8·128	8·53	8·94	9·35	9·75
1·15	6·967	7·376	7·786	8·194	8·61	9·02	9·43	9·84
1·20	7·018	7·430	7·843	8·256	8·67	9·08	9·49	9·90
1·25	7·069	7·484	7·900	8·314	8·74	9·15	9·57	9·98
1·30	7·113	7·531	7·950	8·368	8·79	9·24	9·62	10·06
1·35	7·157	7·578	7·999	8·419	8·85	9·27	9·69	10·11
1·40	7·198	7·621	8·045	8·467	8·89	9·32	9·74	10·17
1·45	7·235	7·661	8·086	8·512	8·94	9·36	9·80	10·21
1·50	7·273	7·700	8·128	8·554	8·99	9·42	9·84	10·27
1·55	7·307	7·736	8·166	8·595	9·03	9·46	9·89	10·32
1·60	7·337	7·769	8·200	8·633	9·06	9·50	9·93	10·36
1·65	7·368	7·801	8·235	8·668	9·11	9·54	9·97	10·41
1·70	7·398	7·834	8·269	8·702	9·14	9·57	10·02	10·45
1·75	7·426	7·862	8·299	8·734	9·17	9·61	10·05	10·4[illegible]
1·80	7·449	7·888	8·326	8·765	9·21	9·65	10·08	10·52
1·85	7·477	7·916	8·356	8·795	9·24	9·68	10·12	10·56
1·90	7·500	7·942	8·383	8·823	9·27	9·71	10·15	10·59
1·95	7·521	7·963	8·406	8·849	9·29	9·73	10·18	10·62
2·00	7·545	7·988	8·432	8·875	9·32	9·77	10·21	10·66
2·10	7·585	8·032	8·478	8·923	9·37	9·82	10·27	10·71
2·20	7·623	8·071	8·520	8·967	9·42	9·87	10·31	10·76

observed Maximum Velocities and Co-efficients (c).

c	Maximum Velocities 13·	14·	15·	16·	17·	18·	19·	20·
0·25	6·46	6·95	7·45	7·94	8·43	8·94	9·43	9·93
0·30	7·05	7·59	8·13	8·67	9·21	9·76	10·30	10·84
0·35	7·54	8·12	8·70	9·28	9·86	10·44	11·02	11·60
0·40	7·96	8·57	9·18	9·79	10·40	11·02	11·63	12·24
0·45	8·31	8·95	9·59	10·23	10·87	11·51	12·15	12·79
0·50	8·63	9·29	9·95	10·62	11·28	11·94	12·61	13·27
0·55	8·90	9·58	10·27	10 95	11·63	12·32	13·01	13·69
0·60	9·14	9·84	10·55	11·25	11·95	12·65	13·36	14·06
0·65	9·35	10·07	10·79	11·51	12·23	12·95	13·67	14·39
0·70	9·54	10·28	11·02	11·73	12·48	13·21	13·95	14·68
0·75	9·65	10·40	11·21	11·88	12·62	13·37	14·11	14·95
0·80	9·87	10·63	11·39	12·15	12·91	13·67	14·43	
0·85	10·02	10·79	11·56	12·33	13·10	13·87	14·64	
0·90	10·14	10·92	11·71	12·48	13·26	14·04	14·82	
0·95	10·26	11·05	11·84	12·63	13·42	14·21	15·00	
1·00	10·44	11·24	11·97	12·85	13·65	14·45		
1·05	10·47	11·27	12·08	12·89	13·69	14·50		
1·10	10·57	11·38	12·19	13·01	13·82	14·63		
1·15	10·65	11·47	12 29	13·11	13·93	14·75		
1·20	10·73	11·56	12·38	13·21	14·03	14·86		
1·25	10·81	11·64	12·47	13·30	14·13	14·97		
1·30	10·88	11·72	12·55	13·39	14·23			
1·35	10·95	11·79	12·63	13·47	14·31			
1·40	11·01	11·85	12·70	13·54	14·39			
1·45	11·06	11·91	12·77	13·62	14·47			
1·50	11·12	11·98	12·83	13·69	14·54			
1·55	11·17	12·03	12·89	13·75	14·61			
1·60	11·23	12·09	12·95	1 ·82	14·68			
1·65	11·27	12·14	13·00	13·87	14·74			
1·70	11·31	12·18	13·06	13·92	14·79			
1·75	11·36	12·23	13·10	13·98	14·85			
1·80	11·40	12·27	13·15	14·02	14·90			
1·85	11·43	12·31	13·19	14·07	14·95			
1·90	11·47	12·36	13·24	14·12	15·00			
1·95	11·51	12·39	13·28	14·16				
2·00	11·54	12·43	13·31	14·20				
2·10	11·62	12·51	13·40	14·30				
2·20	11 66	12·55	13·48	14·34				

Various limiting velocities.

MAXIMA IN OPEN CANALS.

	Feet per second.
For the worst or most sandy soil	2·5
For sandy soil generally	2·75
For ordinary loam	3·
For firm gravel and hard soil	4·
For brickwork, ashlar or rubble in cement	5·5 to 7·5
For hard sound stratified rock	10·
For very hard homogeneous rock	14 or 15

MINIMA FOR DRAINAGE IN CYLINDRICAL PIPES AND CULVERTS.[1]

Small drain-pipes under 6″ in diameter	3·5
Drain-pipes, 6″ to 18″ in diameter	3·
Culverts from 1·5 to 4 feet in diameter	2·5
Larger cylindrical culverts	2·

For ovoidal culverts, &c., compare with cylindrical culverts of equal hydraulic radius.

LIMITING VELOCITIES.

Limits usual for canals	1 to 4
Limits for rivers and canals just navigable	3 to 4½
Limits for irrigating channels	1 to 3
Limits for sewers and brick conduits	1 to 4½
Limits for self-cleansing sewers and drainage pipes	2·5 to 4½
Limiting velocities for water-pipes, so as to get a maximum discharge under pressure	25 to 35

NATURAL CHANNELS.

Slow rivers, from	0·25 to 1·5
Ordinary rivers, from	1·5 to 3·0
Rapid rivers and torrents from	3·0 to 12·0
Maximum tidal current measured	15

[1] Working minima are 0·5 higher than these, which are extreme minima.

[redacted]

Table XII.—HYDRAULIC CO-EFFICIENTS.

1. Co-efficients of flood-discharge (*k*) from catchment areas.
2. Formulæ connecting the co-efficients of velocity (*c*) with those of rugosity (*n*).
3. General values of co-efficients (*n*) of roughness in channels and culverts.
   Local values of *n* for various canals and rivers.
4. Velocity co-efficients (*c*) for channels, culverts, and pipes.
   Under grouped values of (*n*) for two fixed extreme values of *S*.
   Under separate values of *n*, in separate tables.
5. Co-efficients of discharge (*c*) for orifices and outlets.
6. Co-efficients of discharge (*c*) for overfalls.

PART I.—*General and Local Co-efficients of flood-discharge from catchment areas.*

For the formula in Table IV., Part I, also given in the text.

$$Q = k \times 100 (K)^{\frac{3}{4}}$$

The value of this co-efficient (k) can be determined and made use of within local limits only, as it depends on the average maximum local downpour, the evaporation, the quality, inclination, and disposition of the surface of the area under consideration; it has hitherto been determined for very few districts, and not sufficiently satisfactory for some of those. In some cases, unfortunately, doubtful flood-marks have been used to obtain the flood gradient, and the velocities calculated according to very varied formulæ: in others, the obstructions caused by bridges and embankments have vitiated all the bases of calculation of discharge.

	Values of k
For very large Indian rivers near their mouths . .	0·3 to 2
For catchment areas in Oudh generally . . .	1 to 2
The Madras Presidency, the whole Kaveri The Godavery, Kistna, Tumbaddra, Pennair, Vigay } .	about 2·
The Chittaur, Palaur, Manjilanthi, Varhazanthi below	5·
For the Kanhan River, Central Provinces, according to the highest flood yet known, less than . .	5·
For Bengal and Bahar, rainfall 2 to 4 feet—Col. Dickens gives a co-efficient of	8·25
The Upper Kaveri, Tambrapurni, Gadanamatti . }	12, 16, and 22·
For some rivers in Berar and the Central Provinces, according to calculated velocities only . . .	16· to 24·

Some further data for Indian rivers will be found in the 'Hydraulic Statistics' of the Author.

PART 2.—*Formulæ connecting the Co-efficients of Velocity* (c) *with those of Rugosity* (n).

$$Q=\left\{\frac{\frac{1\cdot811}{n}+41\cdot6+\frac{0\cdot00281}{S}}{1+\left(41\cdot6+\frac{0\cdot00281}{S}\right)\frac{n}{\sqrt{R}}}\right\}A\sqrt{RS}$$

where Q is the mean discharge in cubic feet per second,
A is the sectional area of water-way in square feet,
R is the hydraulic radius of the section in feet,
S is the sine of the hydraulic slope of the water surface,
n is the co-efficient of roughness.

This may be reduced into the more convenient form,

$$Q=\frac{\sqrt{R}}{n}\left(\frac{m+1\cdot811}{m+\sqrt{R}}\right).A\sqrt{RS},$$

where m is a variable dependent on S and n alone,

$$\text{and } m=n\left(41\cdot6+\frac{0\cdot00281}{S}\right);$$

or may be further modified into the form,

$$Q=cA.100\sqrt{RS},$$

where c is the co-efficient of mean velocity,

$$\text{and } c=\frac{\sqrt{R}}{100n}\left(\frac{m+1\cdot811}{m+\sqrt{R}}\right);$$

or, into its most simple form, $Q=AV$,

where V is the mean velocity of discharge in feet per second,

and $V=c.100\sqrt{RS}$; c being a variable quantity.

NOTE.

The values of S, the sine of the hydraulic slope, are more generally expressed for conciseness in the form of S per thousand in the Tables, thus, S per thousand $=0\cdot4$ instead of $S=0\cdot0004$; and S per thousand $=20$, instead of $S=0\cdot02$.

PART 3.—*General or Average Values of Co-efficients* (n) *as applied by the*

AQUEDUCTS, CANALS,

n	
0·010	Pure cement in England and Europe generally; also Glazed materials of every sort; glazed, coated, or
0·013	Brickwork and ashlar, in aqueducts, canals, and culverts } Ordinary cast and wrought iron. Unglazed stoneware } Materials mentioned under 0·010 when in bad order and
0·017	Rubble in cement, in good order. Also, earth in highly Materials mentioned under 0·013 when in bad order and
0·020	Coarse rubble, set dry. Rubble in cement in bad condi-
0·0225	Dry coarse rubble in bad order. Rubble in cement,

CANALS IN NATURAL

0·020	Class I.—Very firm, regular gravel, carefully trimmed and
0·0225	Class II.—Earth. Canals and channels. (Based on
0·0250	Class III.—Earth. Canals and channels. (Based on
0·0275	Class IV.—Earth. Canals and channels. (Based on
0·030	Class V.—Earth. Canals in bad order, rather damaged,

General values of n *for Temporary*

0·009	Well-planed timber, in perfect order and alignment, and
0·012	Unplaned timber, when perfectly continuous on the inside.
0·015	{ Wooden frames covered with canvas. Rectangular wooden troughs, with battens on the inside,
0·020	Rectangular wooden troughs, with battens on the inside,

NOTE.

The local values of n, suitable to rivers and natural channels perimentally determined for other rivers, or may be deduced nexion with other data and conditions. They vary between

of Roughness, for various Materials, and Conditions of Surface;
Author in the Tables.

CULVERTS, AND PIPES.

Indian cement-plaster, with worked surface.
enamelled stoneware and iron.

in good order.

condition.

regular cases.
condition.

tion. Ruined brickwork and masonry.

in a ruinous condition.

UNWORKED MATERIAL.

punned in defective places. Trimmed earth in perfect order.

various data by the Author); above the average.

various data by the Author); in good average order.

various data by the Author); below the average.

slightly overgrown with weeds, or obstructed by detritus.

Constructions, determined by Kutter.

perfectly straight; otherwise perhaps 0·010 would be suitable.

Flumes.

0·5 inch apart.

2 inches apart.

NOTE.

generally, may be obtained by comparison with those already ex-
from a consideration of the observed maximum velocities in con-
the limits of 0·020 and 0·035. See Kutter's local values, p. 136.

[redacted]

PART 3 (*cont.*).—*Local Values of the Co-efficient* n *of Rough and Irregularity, according to Kutter.*

NATURAL CHANNELS.

n		
0·0200	Bayou Lafourche.	Generally free from obstruct
0·0210	Ohio, Point Pleasant.	
0·0220	Lech.[1]	
0·0227	Rhine at Germersheim.[1]	
0·0228	Tiber at Rome.	
0·0232	Weser.	
0·0237	Hübengraben.	
0·0243	Hockenbach.	
0·0243	Rhine in Holland.	
0·0250	Seine at Paris.	
0·0252	Newka.	
0·0260	Speyerbach.	
0·0260	Seine at Poissy.	
0·0260	Haine.	
0·0260	Rhine at Speyer.[1]	
0·0262	Newa.	
0·0270	Mississippi.	
0·0270	Saalach.[1]	
0·0270	Plessur.[1]	
0·0280	Saône at Raconnay.	
0·0280	Salzach.[1]	
0·0285	Elbe.	
0·0294	Bayou Plaquemine.	
0·0300	Rhine at Basle.[1]	Obstructed by detritus.
0·0305	Isaar.[1]	
0·0310	Meuse at Misox.[1]	
0·0310	Rhine at Rheinwald.[1]	
0·0345	Simme at Lenk.[1]	
0·0350	Rhine at Domleschgerthal.[1]	

[1] Obstructed by detritus.

PART 3 (*cont.*)—*Local Values of the Co-efficient* n *of Roughness and Irregularity, selected from Bazin and Kutter.*

ARTIFICIAL CHANNELS.

In Cement.

n	
0·0100	Series No. 24 of D'Arcy and Bazin, semicircular.
0·0104	Series No. 2 of D'Arcy and Bazin, rectangular.
0·0111	Series No. 25, D. & B., with one-third sand, semicircular.

In Ashlar and Brickwork.

0·0129	Series No. 3, D'Arcy and Bazin, brickwork, rectangular.
0·0129	Series No. 39, D'Arcy and Bazin, ashlar, rectangular.
0·0133	Series Nos. 1 & 2, D'Arcy and Bazin, ashlar, rectangular.

In Rubble.

0·0145	Gontenbachschale, new, dry, semicircular.
0·0167	Series No. 32, D'Arcy and Bazin, rather damaged, rectangular.
0·0170	Series No. 33, D'Arcy and Bazin, rather damaged, rectangular.
0·0175	Grunnbachschale, damaged, dry, semicircular.
0·0185	Gerbebachschale, damaged, dry, semicircular.
0·0180	Series No. 1·4, D'Arcy and Bazin, rough.
0·0182	Series No. 1·3, D'Arcy and Bazin, rough.
0·0184	Series No. 1·6, D'Arcy and Bazin, rough.
0·0192	Series No. 1·5, D'Arcy and Bazin, rough.
0·0204	Series No. 44, D'Arcy and Bazin, with deposits, rectangular.
0·0210	Series No. 46, D'Arcy and Bazin, with deposits, rectangular.
0·0220	Series No. 35, D'Arcy and Bazin, damaged, trapezoidal.
0·0230	Alpbachschale, much damaged, semicircular.

In Rammed Gravel.

0·0163	Series No. 27, D'Arcy and Bazin, $\frac{3}{4}$-inch thick, semicircular.
0·0170	Series No. 4, D'Arcy and Bazin, $\frac{3}{4}$-inch thick, rectangular.
0·0190	Series No. 5, D'Arcy and Bazin, $1\frac{1}{2}$-inch thick, rectangular.

In Earth.

0·0184	A Canal in England.
0·0222	Linth Canal, trapezoidal.
0·0244	Marseilles Canal, rounded.
0·0254	Pannerden Canal, Holland.
0·0255	Jard Canal.
0·0262	Lauter Canal, Neuberg.
0·0300	Escher Canal (detritus).
0·0301	Marmels Canal.
0·0330	Chesapeake-Ohio Canal, rounded.

PART 4.—*Co-efficients of mean velocity suited to various material*
calculated for a fixed value of S=0·001.

R in feet	Values of *n* ·010	·013	·017	·020	·0225	·0250	·0275	·030…
	(1)	(2	(3)	(I.)	(II.)	(III.)	(IV.)	(V.)
0·5	1·385	1·011	0·730	0·598	0·518	0·455	0·404	0·36…
1·	1·562	1·615	0·860	0·715	0·625	0·554	0·496	0·44…
1·25	1·614	1·212	0·901	0·752	0·660	0·586	0·527	0·47…
1·5	1·655	1·249	0·933	0·782	0·688	0·613	0·552	0·50…
1·75	1·688	1·279	0·961	0·808	0·712	0·635	0·573	0·52…
2·	1·716	1·305	0·984	0·829	0·732	0·655	0·592	0·45…
2·25	1·740	1·327	1·004	0·848	0·750	0·672	0·608	0·55…
2·5	1·761	1·346	1·021	0·864	0·765	0·687	0·622	0·56…
2·75	1·779	1·363	1·037	0·879	0·779	0·700	0·635	0·581
3·	1·795	1·378	1·051	0·892	0·792	0·712	0·647	0·59…
3·25	1·809	1·392	1·063	0·904	0·804	0·723	0·657	0·60…
3·5	1·823	1·404	1·075	0·915	0·814	0·733	0·667	0·61…
4·	1·845	1·426	1·095	0·935	0·833	0·751	0·685	[illegible]
4·5	1·865	1·444	1·113	0·951	0·849	0·767	0·700	0·64…
5·	1·881	1·460	1·128	0·966	0·863	0·781	0·713	0·65…
5·5	1·896	1·474	1·141	0·979	0·876	0·793	0·725	0·66…
6·	1·909	1·487	1·153	0·991	0·887	0·804	0·736	[illegible]
6·5	1·921	1·498	1·164	1·001	0·897	0·814	0·746	0·68…
7·	1·931	1·508	1·174	1·010	0·907	0·823	0·754	[illegible]
7·5	1·940	1·517	1·183	1·019	0·915	0·831	0·763	0·70…
8·	1·949	1·526	1·191	1·027	0·923	0·839	0·770	0·71…
8·5	1·957	1·534	1·198	1·034	0·930	0·846	0·777	0·71…
9	1·964	1·541	1·205	1·041	0·937	0·853	0·784	0·72…
10	1·977	1·554	1·218	1·054	0·949	0·865	0·795	0·73…
15	2·023	1·599	1·263	1·098	0·993	0·908	0·838	0·78…
20	2·051	1·627	1·291	1·126	1·021	0·936	0·866	0·80…

PART 4 (*cont.*).—*Co-efficients of mean velocity suited to various materials, calculated for a fixed value of* S=0·0001.

R in feet	Values of *n* ·010	·013	·017	·020	·0225	·0250	·0275	·0300
	(1)	(2)	(3)	(I.)	(II.)	(III.)	(IV.)	(V.)
0·5	1·263	0·916	0·658	0·539	0·467	0·410	0·365	0·329
1·	1·478	1·097	0·806	0·669	0·585	0·518	0·465	0·421
1·25	1·545	1·155	0·855	0·713?	0·625	0·556	0·499	0·453
1·5	1·598	1·201	0·895	0·750?	0·659	0·587	0·529	0·480
1·75	1·643	1·240	0·929	0·780	0·687	0·613	0·554	0·504
2·	1·680	1·274	0·959	0·807	0·712	0·637	0·576	0·525
2·25	1·712	1·303	0·984	0·831	0·734	0·658	0·595	0·543
2·5	1·741	1·329	1·007	0·852	0·754	0·676	0·613	0·560
2·75	1·766	1·352	1·028	0·871	0·772	0·693	0·629	0·575
3·	1·788	1·372	1·046	0·888	0·788	0·709	0·643	0·589
3·25	1·809	1·391	1·063	0·904	0·803	0·723	0·657	0·602
3·5	1·827	1·408	1·079	0·918	0·817	0·736	0·670	0·614
4·	1·860	1·438	1·106	0·944	0·842	0·760	0·692	0·636
4·5	1·888	1·465	1·130	0·967	0·864	0·780	0·712	0·655
5·	1·912	1·487	1·152	0·987	0·883	0·799	0·730	0·672
5·5	1·933	1·508	1·170	1·005	0·900	0·816	0·746	0·688
6	1·952	1·526	1·187	1·021	0·916	0·831	0·760	0·702
7	1·985	1·557	1·217	0·050	0·943	0·857	0·786	0·727
8	2·012	1·583	1·242	1·073	0·966	0·880	0·808	0·748
9	2·035	1·605	1·263	1·094	0·986	0·899	0·827	0·767
10	2·055	1·625	1·282	1·112	1·004	0·916	0·844	0·783
11	2·073	1·642	1·298	1·128	1·020	0·932	0·859	0·798
12	2·088	1·657	1·313	1·143	1·034	0·946	0·873	0·811
13	2·102	1·670	1·326	1·156	1·047	0·958	0·885	0·823
14	2·114	1·683	1·338	1·168	1·058	0·970	0·896	0·834
15	2·126	1·694	1·349	1·178	1·069	0·980	0·907	0·845
20	2·170	1·738	1·393	1·222	1·112	1·023	0·949	0·886

PART 4 (*cont.*).—*Co-efficient* (c) *of Mean Velocit*
Corresponding to Values of R, *the Hydrauli*

$n = 0{\cdot}010$

R in feet	*S* per thousand				
	1·0	0·8	0·6	0·5	0·4
0·1	0·938	0·932	0·923	0·916	0·905
0·2	1·132	1·126	1·117	1·111	1·101
0·3	1·245	1·241	1·233	1·226	1·217
0·4	1·325	1·320	1·313	1·307	1·299
0·5	1·385	1·381	1·374	1·369	1·361
0·6	1·433	1·430	1·423	1·419	1·411
0·7	1·473	1·470	1·464	1·460	1·453
0·8	1·507	1·504	1·499	1·494	1·488
0·9	1·536	1·533	1·528	1·524	1·519
1·	1·562	1·559	1·554	1·551	1·546
1·5	1·655	1·653	1·650	1·648	1·644
2·	1·716	1·715	1·713	1·712	1·710
2·5	1·761	1·760	1·759	1·758	1·757
3·	1·795	1·795	1·794	1·794	1·794
3·5	1·823	1·823	1·823	1·823	1·823
4·	1·845	1·846	1·847	1·847	1·848
4·5	1·865	1·865	1·867	1·867	1·869
5·	1·881	1·882	1·884	1·885	1·887
5·5	1·896	1·897	1·899	1·900	1·903
6·	1·909	1·910	1·913	1·914	1·917
7·	1·931	1·933	1·935	1·937	1·941
8·	1·949	1·951	1·954	1·957	1·960
9·	1·964	1·966	1·970	1·973	1·977
10·	1·977	1·980	1·984	1·987	1·991
11·	1·989	1·991	1·995	1·999	2·004
12·	1·999	2·002	2·006	2·009	2·015
13·	2·008	2·011	2·015	2·019	2·024
14·	2·016	2·019	2·024	2·027	2·033
15·	2·023	2·026	2·031	2·035	2·041
16·	2·030	2·033	2·038	2·042	2·048
20·	2·051	2·055	2·061	2·065	2·072

or Cement and Glazed Material (New),
Radius in feet, and of 8 *per thousand.*

$n = 0{\cdot}010$

R in feet	*S* per thousand				
	0·3	0·2	0·15	0·1	0·05
0·1	0·889	0·858	0·830	0·783	0·682
0·2	1·085	1·055	1·028	0·980	0·875
0·3	1·202	1·174	1·149	1·104	1·001
0·4	1·285	1·259	1·236	1·193	1·095
0·5	1·349	1·325	1·303	1·263	1·170
0·6	1·400	1·378	1·357	1·320	1·233
0·7	1·442	1·422	1·403	1·368	1·286
0·8	1·478	1·460	1·442	1·410	1·332
0·9	1·510	1·492	1·476	1·446	1·373
1·	1·537	1·521	1·506	1·478	1·410
1·5	1·639	1·628	1·618	1·598	1·551
2·	1·706	1·699	1·692	1·680	1·649
2·5	1·755	1·751	1·748	1·741	1·723
3·	1·793	1·792	1·791	1·788	1·783
3·5	1·824	1·825	1·826	1·827	1·832
4·	1·849	1·852	1·855	1·860	1·873
4·5	1·871	1·875	1·880	1·888	1·909
5·	1·890	1·896	1·901	1·912	1·940
5·5	1·906	1·914	1·920	1·933	1·968
6·	1·921	1·929	1·937	1·952	1·993
7·	1·946	1·956	1·966	1·985	2·036
8·	1·966	1·978	1·990	2·012	2·072
9·	1·984	1·997	2·010	2·035	2·103
10·	1·999	2·013	2·028	2·055	2·130
11·	2·012	2·027	2·043	2·073	2·154
12·	2·023	2·040	2·056	2·088	2·175
13·	2·033	2·051	2·068	2·102	2·194
14·	2·042	2·061	2·079	2·114	2·211
15·	2·051	2·070	2·089	2·126	2·227
16·	2·058	2·078	2·098	2·136	2·241
20·	2·083	2·106	2·127	2·170	2·229

PART 4 (*cont.*).—*Co-efficients* (c) *of Mean Velocity for Brickwork, Corresponding to values of* R

$n = 0{\cdot}013$

R in feet	*S* per thousand				
	1·0	0·8	0·6	0·5	0·4
0·1	0·650	0·646	0·639	0·634	0·627
0·2	0·802	0·798	0·791	0·786	0·779
0·3	0·895	0·891	0·885	0·880	0·873
0·4	0·961	0·957	0·951	0·947	0·940
0·5	1·011	1·008	1·003	0·999	0·992
0·6	1·053	1·050	1·045	1·041	1·035
0·7	1·087	1·084	1·080	1·076	1·071
0·8	1·117	1·114	1·110	1·106	1·101
0·9	1·142	1·140	1·136	1·133	1·128
1·0	1·165	1·163	1·159	1·156	1·152
1·5	1·249	1·247	1·247	1·243	1·240
2·	1·305	1·304	1·302	1·301	1·299
2·5	1·346	1·345	1·344	1·344	1·343
3·	1·378	1·378	1·378	1·377	1·377
3·5	1·404	1·404	1·404	1·404	1·405
4·	1·426	1·426	1·427	1·427	1·428
4·5	1·444	1·445	1·446	1·447	1·448
5·	1·460	1·461	1·463	1·464	1·465
5·5	1·474	1·475	1·477	1·478	1·480
6·	1·487	1·488	1·490	1·492	1·494
7·	1·508	1·510	1·512	1·514	1·517
8·	1·526	1·528	1·530	1·533	1·536
9·	1·541	1·543	1·546	1·548	1·552
10·	1·554	1·556	1·559	1·562	1·566
11·	1·565	1·567	1·571	1·574	1·579
12·	1·575	1·577	1·581	1·585	1·589
13·	1·584	1·586	1·591	1·594	1·599
14·	1·592	1·594	1·599	1·602	1·608
15·	1·599	1·602	1·606	1·610	1·616
16·	1·606	1·608	1·613	1·617	1·623
20·	1·627	1·630	1·636	1·640	1·647

Ashlar, New Cast and Wrought Iron, and Unglazed Stoneware in feet and S per thousand.

$n = 0{\cdot}013$

R in feet	*S* per thousand				
	0·3	0·2	0·15	0·1	0·05
0·1	0·615	0·593	0·574	0·541	0·472
0·2	0·767	0·745	0·725	0·691	0·617
0·3	0·861	0·840	0·821	0·788	0·714
0·4	0·929	0·910	0·891	0·859	0·788
0·5	0·982	0·964	0·947	0·916	0·847
0·6	1·026	1·008	0·992	0·963	0·898
0·7	1·062	1·046	1·031	1·003	0·941
0·8	1·093	1·078	1·064	1·038	0·979
0·9	1·120	1·106	1·093	1·069	1·013
1·	1·145	1·131	1·119	1·097	1·044
1·5	1·235	1·226	1·217	1·201	1·163
2·	1·296	1·290	1·284	1·274	1·249
2·5	1·341	1·338	1·335	1·329	1·314
3·	1·376	1·375	1·374	1·372	1·367
3·5	1·405	1·406	1·407	1·408	1·412
4·	1·429	1·432	1·434	1·438	1·450
4·5	1·450	1·454	1·458	1·465	1·483
5·	1·468	1·473	1·478	1·487	1·512
5·5	1·484	1·490	1·496	1·508	1·538
6·	1·498	1·505	1·512	1·526	1·561
7·	1·522	1·531	1·540	1·557	1·602
8·	1·542	1·553	1·563	1·583	1·636
9·	1·559	1·571	1·583	1·605	1·665
10·	1·573	1·587	1·600	1·625	1·691
11·	1·586	1·601	1·615	1·642	1·714
12·	1·597	1·613	1·628	1·657	1·735
13·	1·607	1·624	1·640	1·670	1·753
14·	1·617	1·634	1·650	1·683	1·770
15·	1·625	1·643	1·660	1·694	1·785
16·	1·632	1·651	1·669	1·704	1·799
20·	1·657	1·678	1·699	1·738	1·846

PART 3 (*cont.*).—*Co-efficients* (c) *of Mean Velocity for New Rubble, Corresponding to values of* R

$n = 0{\cdot}017$

R in feet	*S* per thousand				
	1·0	0·8	0·6	0·5	0·4
0·1	0·445	0·443	0·438	0·434	0·429
0·2	0·561	0·558	0·554	0·550	0·545
0·3	0·634	0·632	0·627	0·623	0·618
0·4	0·688	0·685	0·681	0·677	0·672
0·7	0·730	0·727	0·723	0·720	0·715
0·6	0·764	0·762	0·758	0·755	0·750
0·7	0·793	0·791	0·787	0·784	0·780
0·8	0·818	0·816	0·813	0·810	0·806
0·9	0·840	0·838	0·835	0·833	0·829
1·	0·860	0·858	0·855	0·853	0·849
1·6	0·933	0·932	0·930	0·928	0·926
2·	0·984	0·983	0·982	0·980	0·979
2·5	1·021	1·021	1·020	1·019	1·019
3·	1·051	1·051	1·050	1·050	1·050
3·5	1·075	1·075	1·075	1·076	1·076
4·	1·095	1·096	1·096	1·097	1·097
4·5	1·113	1·113	1·114	1·115	1·116
5·	1·128	1·129	1·130	1·131	1·132
5·5	1·141	1·142	1·144	1·145	1·147
6·	1·153	1·154	1·156	1·158	1·160
7·	1·174	1·175	1·177	1·179	1·182
8·	1·191	1·193	1·195	1·197	1·200
9·	1·205	1·207	1·210	1·212	1·210
10·	1·218	1·220	1·223	1·226	1·230
11·	1·229	1·231	1·235	1·237	1·242
12·	1·239	1·241	1·245	1·248	1·252
13·	1·248	1·250	1·254	1·257	1·262
14·	1·256	1·258	1·262	1·265	1·270
15·	1·263	1·265	1·270	1·273	1·278
16·	1·269	1·272	1·276	1·280	1·285
20·	1·291	1·294	1·299	1·303	1·309

Old Brickwork or Ashlar, and Old Iron and Unglazed Stoneware.
in feet and S per thousand.

$n = 0{\cdot}017$

R in feet	*S* per thousand				
	0·3	0·2	0·15	0·1	0·05
0·1	0·421	0·406	0·393	0·371	0·326
0·2	0·536	0·520	0·507	0·483	0·433
0·3	0·610	0·594	0·581	0·557	0·506
0·4	0·664	0·650	0·636	0·613	0·563
0·5	0·708	0·693	0·681	0·658	0·610
0·6	0·743	0·730	0·718	0·696	0·649
0·7	0·773	0·761	0·749	0·729	0·684
0·8	0·800	0·788	0·777	0·758	0·715
0·9	0·823	0·812	0·802	0·783	0·742
1·	0·844	0·833	0·824	0·806	0·767
1·5	0·922	0·915	0·908	0·895	0·867
2·	0·976	0·971	0·967	0·959	0·939
2·5	1·017	1·014	1·012	1·007	0·996
3·	1·049	1·049	1·048	1·046	1·042
3·5	1·076	1·077	1·077	1·079	1·082
4·	1·099	1·101	1·103	1·106	1·115
4·5	1·118	1·121	1·124	1·130	1·145
5·	1·135	1·139	1·144	1·152	1·172
5·5	1·150	1·155	1·161	1·170	1·195
6·	1·163	1·170	1·176	1·187	1·217
7·	1·186	1·194	1·202	1·217	1·254
8·	1·205	1·215	1·224	1·242	1·287
9·	1·222	1·233	1·243	1·263	1·314
10·	1·236	1·248	1·260	1·282	1·339
11·	1·248	1·261	1·274	1·298	1·361
12·	1·259	1·273	1·287	1·313	1·380
13·	1·269	1·284	1·299	1·326	1·398
14·	1·278	1·294	1·309	1·338	1·414
15·	1·287	1·303	1·319	1·349	1·429
16·	1·294	1·311	1·328	1·359	1·443
20·	1·319	1·338	1·357	1·393	1·489

PART 4 (*cont.*).—*Coefficients* (c) *of Mean Velocity for damaged Rubble, or for Earthwork in Class I. of the best order corresponding to values of* R *in feet, and of* S *per thousand, when* n=0·020.

R in feet	*S* per thousand				
	1·0	0·8	0·6	0·5	0·4
0·4	0·561	0·559	0·555	0·553	0·549
0·6	0·629	0·627	0·623	0·621	0·617
0·8	0·677	0·675	0·672	0·670	0·667
1·	0·715	0·713	0·711	0·709	0·706
1·5	0·782	0·781	0·779	0·778	0·776
2·	0·829	0·828	0·827	0·826	0·825
2·5	0·864	0·864	0·863	0·863	0·862
3·	0·892	0·892	0·892	0·892	0·891
4·	0·935	0·935	0·935	0·936	0·936
5·	0·966	0·967	0·968	0·969	0·970
6·	0·991	0·991	0·993	0·994	0·996
7·	1·010	1·012	1·014	1·015	1·018
8·	1·027	1·029	1·031	1·033	1·036
9·	1·041	1·043	1·046	1·048	1·051
10·	1·054	1·056	1·059	1·061	1·064
11·	1·065	1·067	1·070	1·072	1·076
12·	1·074	1·076	1·080	1·083	1·087
13·	1·083	1·085	1·089	1·092	1·096
14·	1·091	1·093	1·097	1·100	1·105
16·	1·104	1·107	1·111	1·115	1·120
20·	1·126	1·129	1·134	1·138	1·143

R in feet	*S* per thousand				
	0·3	0·2	0·15	0·1	0·05
0·4	0·542	0·530	0·519	0·500	0·460
0·6	0·611	0·600	0·590	0·572	0·534
0·8	0·661	0·651	0·642	0·626	0·591
1·	0·701	0·692	0·684	0·669	0·637
1·5	0·772	0·766	0·760	0·750	0·725
2·	0·822	0·818	0·814	0·807	0·790
2·5	0·861	0·858	0·856	0·852	0·842
3·	0·891	0·890	0·889	0·888	0·885
4·	0·937	0·939	0·941	0·944	0·952
5·	0·972	0·976	0·980	0·987	1·005
6·	0·999	1·005	1·011	1·021	1·047
7·	1·022	1·029	1·036	1·050	1·083
8·	1·040	1·049	1·058	1·074	1·114
9·	1·056	1·066	1·076	1·094	1·140
10·	1·070	1·081	1·092	1·112	1·164
11·	1·083	1·095	1·106	1·128	1·185
12·	1·093	1·107	1·119	1·143	1·204
13·	1·103	1·117	1·131	1·156	1·221
14·	1·112	1·127	1·141	1·168	1·237
16·	1·128	1·144	1·159	1·188	1·265
20·	1·153	1·171	1·188	1·222	1·312

PART 4 (*cont.*).—*Coefficients* (c) *of Mean Velocity for Earthwork in Class II. in above-average order, corresponding to values of* R *in feet, and of* S *per thousand, when* n=0·0225.

R in feet	S per thousand				
	1·0	0·8	0·6	0·5	0·4
0·4	0·484	0·482	0·479	0·477	0·473
0·6	0·545	0·544	0·541	0·539	0·535
0·8	0·590	0·588	0·586	0·584	0·581
1·	0·625	0·623	0·621	0·619	0·617
1·5	0·688	0·687	0·685	0·684	0·682
2·	0·732	0·731	0·730	0·729	0·728
2·5	0·765	0·765	0·764	0·764	0·763
3·	0·792	0·792	0·792	0·792	0·791
4·	0·833	0·833	0·834	0·834	0·835
5·	0·863	0·864	0·865	0·866	0·867
6·	0·887	0·888	0·890	0·891	0·893
7·	0·907	0·908	0·910	0·911	0·913
8·	0·923	0·924	0·926	0·928	0·931
9·	0·937	0·939	0·941	0·943	0·946
10·	0·949	0·951	0·954	0·956	0·959
11·	0·960	0·962	0·965	0·967	0·971
12·	0·969	0·971	0·975	0·977	0·981
13·	0·978	0·980	0·984	0·987	0·991
14·	0·986	0·988	0·992	0·995	0·999
16·	0·999	1·002	1·006	1·009	1·014
20·	1·021	1·024	1·028	1·032	1·037

R in feet	S per thousand				
	0·3	0·2	0·15	0·1	0·05
0·4	0·467	0·457	0·448	0·432	0·398
0·6	0·530	0·520	0·512	0·497	0·464
0·8	0·576	0·567	0·559	0·546	0·515
1·	0·612	0·605	0·597	0·585	0·557
1·5	0·679	0·673	0·668	0·659	0·638
2·	0·726	0·722	0·719	0·712	0·698
2·5	0·762	0·760	0·758	0·754	0·746
3·	0·791	0·790	0·790	0·788	0·785
4·	0·836	0·837	0·839	0·842	0·849
5·	0·869	0·873	0·876	0·883	0·899
6·	0·895	0·901	0·906	0·916	0·939
7·	0·917	0·924	0·931	0·943	0·973
8·	0·935	0·944	0·952	0·966	1·003
9·	0·951	0·961	0·970	0·986	1·029
10·	0·965	0·975	0·985	1·004	1·051
11·	0·977	0·988	0·999	1·020	1·072
12·	0·988	1·000	1·012	1·034	1·090
13·	0·997	1·011	1·023	1·047	1·107
14·	1·006	1·020	1·033	1·058	1·123
16·	1·022	1·037	1·051	1·079	1·150
20·	1·046	1·064	1·080	1·112	1·195

PART 4 (*cont.*).—*Co-efficients* (c) *of Mean Velocity, for Earthwork in Class III., in good average order, corresponding to values of* R *in feet, and of* S *per thousand, when* n = 0·025.

R in feet	*S* per thousand				
	1·0	0·8	0·6	0·5	0·4
0·4	0·424	0·422	0·420	0·418	0·414
0·6	0·480	0·479	0·476	0·474	0·471
0·8	0·521	0·520	0·518	0·516	0·513
1·	0·554	0·553	0·550	0·549	0·546
1·5	0·613	0·612	0·611	0·609	0·608
2·	0·655	0·654	0·653	0·652	0·651
2·5	0·687	0·686	0·686	0·685	0·684
3·	0·712	0·712	0·712	0·712	0·711
4·	0·751	0·752	0·752	0·753	0·753
5·	0·781	0·781	0·782	0·783	0·784
6.	0·804	0·805	0·806	0·808	0·809
6·	0·823	0·824	0·826	0·827	0·830
8·	0·839	0·840	0·843	0·844	0·847
9·	0·853	0·854	0·857	0·859	0·862
10·	0·865	0·867	0·869	0·871	0·875
11·	0·876	0·877	0·880	0·883	0·886
12·	0·885	0·887	0·890	0·893	0·896
13·	0·893	0·895	0·899	0·902	0·905
14·	0·901	0·903	0·907	0·910	0·914
16·	0·915	0·917	0·921	0·924	0·929
20·	0·936	0·939	0·943	0·947	0·952

R in feet	*S* per thousand				
	0·3	0·2	0·15	0·1	0·05
0·4	0·409	0·400	0·392	0·379	0·350
0·6	0·467	0·458	0·451	0·437	0·410
0·8	0·509	0·501	0·494	0·482	0·456
1·	0·543	0·536	0·529	0·518	0·494
1·5	0·605	0·600	0·595	0·587	0·568
2·	0·649	0·646	0·643	0·637	0·624
2·5	0·633	0·681	0·680	0·676	0·669
3·	0·711	0·710	0·710	0·709	0·706
4·	0·754	0·755	0·757	0·760	0·766
5·	0·786	0·790	0·793	0·799	0·813
6·	0·812	0·817	0·822	0·831	0·852
7·	0·833	0·840	0·846	0·857	0·885
8·	0·851	0·859	0·866	0·880	0·913
9·	0·866	0·875	0·884	0·899	0·938
10·	0·880	0·890	0·899	0·916	0·960
11·	0·892	0·902	0·913	0·932	0·980
12·	0·902	0·914	0·925	0·946	0·998
13·	0·912	0·924	0·936	0·958	1·015
14·	0·921	0·934	0·946	0·970	1·030
16·	0·936	0·950	0·964	0·990	1·057
20·	0·961	0·977	0·993	1·023	1·101

ART 4 (*cont.*).—*Co-efficients* (c) *of Mean Velocity, for Earthwork in Class IV. in below-average order, corresponding to values of* R *in feet, and of* S *per thousand, when* n=0·0275.

R in feet	*S* per thousand				
	1·0	0·8	0·6	0·5	0·4
0·4	0·376	0·375	0·372	0·370	0·368
0·6	0·428	0·427	0·424	0·423	0·420
0·8	0·466	0·465	0·463	0·461	0·459
1·	0·496	0·495	0·493	0·492	0·490
1·5	0·552	0·551	0·550	0·549	0·547
2·	0·592	0·591	0·590	0·589	0·588
2·5	0·622	0·622	0·621	0·621	0·620
3·	0·647	0·647	0·646	0·646	0·646
4·	0·685	0·685	0·685	0·686	0·686
5·	0·713	0·714	0·715	0·715	0·716
6·	0·736	0·737	0·738	0·739	0·741
7·	0·754	0·755	0·757	0·758	0·760
8·	0·770	0·771	0·773	0·775	0·777
9·	0·784	0·785	0·787	0·789	0·792
10·	0·795	0·797	0·800	0·802	0·805
11·	0·806	0·808	0·810	0·813	0·816
12·	0·815	0·817	0·820	0·822	0·826
13·	0·824	0·826	0·829	0·831	0·835
14·	0·831	0·833	0·837	0·839	0·843
16·	0·845	0·847	0·851	0·854	0·858
20·	0·866	0·869	0·873	0·876	0·881

R in feet	*S* per thousand				
	0·3	0·2	0·15	0·1	0·05
0·4	0·363	0·355	0·348	0·336	0·312
0·6	0·416	0·408	0·402	0·390	0·366
0·8	0·455	0·448	0·442	0·431	0·408
1·	0·486	0·480	0·475	0·465	0·444
1·5	0·545	0·540	0·536	0·529	0·512
2·	0·587	0·584	0·581	0·576	0·564
2·5	0·619	0·617	0·616	0·613	0·606
3·	0·646	0·645	0·645	0·643	0·641
4·	0·687	0·688	0·690	0·692	0·698
5·	0·718	0·721	0·724	0·730	0·743
6·	0·743	0·748	0·752	0·760	0·780
7·	0·764	0·770	0·776	0·786	0·812
8·	0·781	0·788	0·795	0·808	0·839
9·	0·796	0·805	0·813	0·827	0·863
10·	0·809	0·819	0·828	0·844	0·884
11·	0·821	0·831	0·841	0·859	0·904
12·	0·832	0·843	0·853	0·873	0·921
13·	0·841	0·853	0·864	0·885	0·937
14·	0·850	0·862	0·874	0·896	0·952
16·	0·865	0·879	0·892	0·916	0·979
20·	0·889	0·905	0·920	0·949	1·022

PART 4 (*cont.*).—*Co-efficients* (c) *of Mean Velocity, for Earthwork in Class V., in bad order, partly overgrown, or partly impeded by detritus, when* n=0·030.

R in feet	*S* per thousand				
	1·0	0·8	0·6	0·5	0·4
0·4	0·337	0·336	0·334	0·332	0·330
0·6	0·385	0·384	0·382	0·380	0·378
0·8	0·421	0·420	0·418	0·416	0·414
1·	0·449	0·448	0·447	0·445	0·443
1·5	0·502	0·501	0·500	0·499	0·498
2·	0·540	0·539	0·538	0·538	0·537
2·5	0·569	0·568	0·568	0·568	0·567
3·	0·592	0·592	0·592	0·592	0·592
4·	0·629	0·629	0·630	0·630	0·630
5·	0·657	0·657	0·658	0·659	0·660
6·	0·679	0·679	0·681	0·682	0·683
7·	0·697	0·698	0·699	0·701	0·703
8·	0·712	0·713	0·715	0·717	0·719
9·	0·726	0·727	0·729	0·731	0·733
10·	0·737	0·739	0·741	0·743	0·746
11·	0·748	0·749	0·752	0·754	0·757
12·	0·757	0·759	0·761	0·764	0·767
13·	0·765	0·767	0·770	0·772	0·776
14·	0·773	0·775	0·778	0·780	0·784
15·	0·786	0·788	0·782	0·795	0·799
20·	0·807	0·810	0·814	0·817	0·822

R in feet	*S* per thousand				
	0·3	0·2	0·15	0·1	0·05
0·4	0·326	0·319	0·313	0·302	0·281
0·6	0·374	0·368	0·362	0·352	0·330
0·8	0·411	0·405	0·399	0·390	0·370
1·	0·440	0·435	0·430	0·421	0·402
1·5	0·495	0·491	0·487	0·480	0·466
2·	0·535	0·532	0·529	0·525	0·514
2·5	0·566	0·564	0·563	0·560	0·554
3·	0·591	0·591	0·590	0·589	0·587
4·	0·631	0·632	0·634	0·636	0·641
5·	0·661	0·664	0·667	0·672	0·684
6·	0·686	0·690	0·694	0·702	0·720
7·	0·706	0·711	0·717	0·727	0·750
8·	0·723	0·730	0·736	0·748	0·776
9·	0·738	0·745	0·753	0·767	0·800
10·	0·751	0·759	0·768	0·783	0·821
11·	0·762	0·772	0·781	0·798	0·839
12·	0·772	0·783	0·793	0·811	0·856
13·	0·782	0·793	0·804	0·823	0·872
14·	0·790	0·802	0·814	0·834	0·887
16·	0·806	0·818	0·831	0·854	0·912
20·	0·830	0·845	0·859	0·886	0·955

[redacted]

PART 5.—*Co-efficients of Discharge for Orifices, being values of o for the formula in Table X., and given in the Text.*

$$V = o \times 8{\cdot}025\sqrt{H}$$

Applied in the Table.	According to Experiment.	
·55	·572	Rectangular, width 7 depth, ($W\ 7\ D$); see next page.
·6	·709	
·62	·62	Orifices generally.
66	·66	Sluices without side walls.
·7	·7	Canal lock gates and dock gates.
·727	·62	Undershot wheel gates.
·84	·83	Sluices in lock gates.
·84	·84	Large vertical pipes.
·9	·9	Narrow bridge openings.
·96	·94	Large sluices.
·96	·96	Wide openings from reservoirs.
·96	·96	Wide bridge openings.
·96	·96	Orifices with converging mouth-pieces.
1·	1·	Large orifices with diverging mouth-pieces.
	1·3	Attached diverging mill channels.

Modification of the co-efficient so as to include the effect due to velocity of approach;

Let h = head due to this velocity only,

then $o_1 = o\sqrt{1 + \frac{h}{H}}$

and o_1 is the new co-efficient to be used.

[redacted]

PART 5 (*cont.*).—*Co-efficients of Discharge for Orifices.*

Table of Co-efficients of Velocity or Discharge for Rectangular Orifices, when the depth (*D*) is less than the width (*W*) for a head (*H*).

$\frac{H}{W}$	$\frac{D}{W}$ 1·0	$\frac{D}{W}$ 0·5	$\frac{D}{W}$ 0·25	$\frac{D}{W}$ 0·15	$\frac{D}{W}$ 0·1	$\frac{D}{W}$ 0·05
	Values of *c*					
·05						·709
·10					·660	·698
·15				·638	·660	·691
·20			·612	·640	·659	·685
·25			·617	·640	·659	·682
·30			·622	·640	·658	·678
·40		·600	·626	·639	·657	·671
·50		·605	·628	·638	·655	·667
·60	·572	·609	·630	·637	·654	·664
·75	·585	·611	·631	·635	·653	·660
1·00	·592	·613	·634	·634	·650	·655
1·50	·598	·616	·632	·632	·645	·650
2·00	·400	·617	·631	·631	·642	·647
2·50	·602	·617	·631	·630	·640	·643
3·50	·604	·616	·629	·629	·637	·638
4·00	·605	·615	·627	·627	·632	·627
6·00	·604	·613	·623	·623	·625	·621
8·00	·602	·611	·619	·619	·618	·616
10·00	·601	·607	·613	·613	·613	·613

The above was deduced by Rankine from results of experiments by Poncelet and Lesbros.

N.B.—When $H > 3D$, the centre of figure may be considered the centre of motion.

PART 6.—*Co-efficients of Discharge for Overfalls, being values of* o *for the formula applied in Table X., and given in the Text.*[1]

$$V = \tfrac{2}{3}o \times 8{\cdot}025\sqrt{H}$$

Here l = length of weir sill: L = length of dam, or breadth of channel: H = head on sill: D = depth of notch.

In Table.	By Experimentalists.	
·5	·5	Broad-crested or flat-topped dams; Dams with a channel attached
·55	·595 ·662	Weirs with 1-inch crests when l = or $7\frac{L}{4}$; the exact value of o being $= {\cdot}57 \times \frac{l}{10L}$
·6	·6	Overfalls when $l \, 7 \frac{L}{4}$ and $< \frac{L}{3}$; V-shaped notch, when $l = \frac{D}{2}$
62	·62	V-shaped notch, when $l = \frac{D}{4}$
·666	·552	Weirs when $l = L$, and $H \, 7 \frac{1}{3}$ height of the barrier; in this case the velocity of approach must be considered in addition.
·7 ·727	·666	Weirs generally when $l = L$ and $H < \frac{1}{3}$ the height of the barrier.

To modify the co-efficient o so as to include the effect due to velocity of approach,

Let h = head due to velocity of approach only :—

$$\text{then} \quad o_1 = o\left\{\left(1 + \frac{h}{H}\right)^{\frac{3}{2}} - \left(\frac{h}{H}\right)^{\frac{3}{2}}\right\}$$

and o_1 is the new co-efficient to be used.

[1] In using Table X. for overfalls, always diminish the velocity of discharge there given by one-third; this alone admits of the use of the same table for discharges both of orifices and overfalls.

[redacted]

APPENDIX

OF

MISCELLANEOUS TABLES AND DATA.

- Masonry Dams.
- Retaining Walls.
- Weight of Materials.
- Thickness and Weight of Water-pipes.
- Absorption and Strength of Stoneware Pipes.
- Ovoid Culvert-sections.
- Table of Arcs and Sectors.
- Tables of Powers, Roots, and Reciprocals.
- Duty of Hydraulic Machines and Contrivances.
- Constants of Labour and Cartage.

Masonry Dams.

(By the Author.)

Dimensions of Trapezoidal Masonry Dams, having both faces battering, for heights up to 40 feet.

	Good rubble.	Inferior rubble.	Brickwork.
Height of dam . . .	H	H	H
Thickness at top . . .	$\frac{1}{3}H$	$\cdot 2H$	$\cdot 3H$
Thickness at bottom . . .	$\cdot 5H$	$\cdot 6H$	$\cdot 7H$
Front batter . . .	1 in 24	1 in 15	1 in 15
Back batter . . .	1 in 3	1 in 3	1 in 3
Sectional area . . .	$\cdot 3H^2$	$\cdot 4H^2$	$\cdot 5H^2$

[illegible] Trapezoidal Masonry Dams, having the water face vertical, for heights up to 40 feet.

	[illegible]	Inferior rubble.	Brickwork.
[illegible] per [illegible]	[illegible] lbs.	120 lbs.	100 lbs.
[illegible]	H	H	H
[illegible]	$\cdot 24H$	$\cdot 25H$	$\cdot 28H$
[illegible]	[illegible]	$\cdot 51H$	$\cdot 56H$
[illegible]	Vertical	Vertical	Vertical
[illegible]	[illegible]	1 in 4	1 in 3·57
[illegible]	[illegible]	$\cdot 375H^2$	$\cdot 42H^2$
[illegible]	[illegible]	$45H^2$	$42H^2$
[illegible]	[illegible]	$90H$	$75H$
[illegible]	[illegible]	$360H$	$300H$

[illegible] value of q, the ratio to the breadth [illegible] from the foot at which the direction of [illegible] is taken at one-third. A slight modifi- [illegible] may be used for heights up to 50 feet. For [illegible] profiles, the mode of Delocre, or its modifications, [illegible] to the individual case and conditions in order to obtain [illegible] dimensions.

Lofty Dams.

he Delocre polygonal section (No. 25) applies to masonry having the density of water, or weighing 2 footweight per cubic foot, and le of resisting a pressure of nearly 200 footweight per square foot. latter is also assumed to be the limiting pressure allowed on the foun-n. The co-efficient of friction for the sliding of the courses on each is taken at 0·73; the effect of cohesion of the mortar being neglected. he trace is polygonal on both faces, thus consisting of four rectilinear ons; and is thus a practical approximation to the theoretical double-l dam without any top-thickness; the flatter curvature being on the -face, the greater curvature on the rear or outer face. The following e dimensions in feet.

	Height.	Breadth.	Front offset.	Rear offset.
t the top . .	0	16·40	0	5·
	39·36	21·38	0	33·27
	65·60	54·65	10·73	35·01
	124·64	100·39	18·83	39·76
xtreme . .	164·	158·95		

Iolesworth corresponding curved section is obtained by ordinates; very nearly thus :—

If P = limiting pressure in footweight per square foot
b = top width of dam
a = width of dam at any depth x from the top
x = depth from water surface
y = offset from vertical line to outer face at any depth x
z = offset from vertical line to inner face at any depth x

hen $y = 0{\cdot}95\left(\frac{x^2}{P}\right)^{\frac{1}{2}}$; $z = \frac{1}{10}y$; also $b = 0{\cdot}55\,y$; and

$a = 1{\cdot}1\,y$ when $x = \frac{1}{4}H$, the total height of the dam; but no value of y less than $0{\cdot}6\,x$ is admissible.

lso in very lofty dams the value of P should be diminished by substi- for it the term $P(1 - 0{\cdot}0013\,x)$.

Formulæ and Data for Retaining Walls.

Extracted from various articles by J. H. E. Hart, C.E.

(1) General equation for breadth of base, $x = \sqrt{\left\{\frac{nH}{3w(q \pm q^1)}\right\}}$

Where H = total horizontal pressure against the back of the wall.

n = the ratio of its sectional area to that of a rectangle of eq[ual] height and breadth.

w = the weight of a cubic foot of the wall.

qx = the horizontal deviation of the centre of resistance of the b[ase] from the middle of the base.

q^1x = the horizontal deviation of the centre of gravity of the pro[file] from the middle of the base.

With vertical rectangular sections, $n = 1$, $q^1 = 0$, $x = \sqrt{\left(\frac{H}{3wq}\right)}$

With plumb-faced trapezoidal sections of a top thickness (t)

$$n = \frac{x+t}{2x} \text{ and } q^1 = \left(\frac{t-x}{6}\right) \quad \left(\frac{x+2t}{x(x+t)}\right)$$

$$x = \sqrt{\left\{\frac{2H - wt}{3w(q - \frac{1}{6})} + \left(\frac{t}{2}\right)^2\right\}} - \frac{t}{2}$$

With plumb-backed trapezoidal sections of a top thickness (t)

$$n = \frac{x-t}{2x} \text{ and } q^1 = \left(\frac{x-t}{6}\right) \quad \left(\frac{x+2t}{x(x+t)}\right)$$

$$x = \sqrt{\left\{\frac{2H + wt^2}{3w(q + \frac{1}{6})} + \left(\frac{t}{2}\right)^2\right\}} - \frac{t}{2}.$$

(2) Modulus. The limiting value of q to avoid tension in the mas[onry] is $\frac{1}{6}$, but its limiting value in actual practice is $\frac{1}{4}$. In special cases, it must not be so great as to cause the maximum pressure (P) to e[xceed] the safe resistance (C) to crushing of the material, its values correspon[d as] follows to the values of $\frac{P}{p}$, where p = the mean pressure per unit of su[rface] of base, = sum of the vertical forces ÷ area of the base; and P is less [than] C.

$$q = \frac{1}{12}, \frac{1}{11}, \frac{1}{10}, \frac{1}{9}, \frac{1}{8}, \frac{1}{7}, \frac{1}{6}; \frac{2}{11}, \frac{1}{5}, \frac{2}{9}, \frac{1}{4}$$

$$\text{when } \frac{P}{p} = \frac{3}{2}, \frac{17}{11}, \frac{8}{5}, \frac{5}{3}, \frac{7}{4}, \frac{13}{7}, 2; \frac{15}{7}, \frac{20}{9}, \frac{12}{5}, \frac{8}{3}.$$

(3) Surcharge. If x = thickness of a vertical rectangular wall to su[stain] a horizontal-topped bank,

x_1 = do. for an indefinite surcharge,

x_2 = do. for a surcharge of a height c,

$$x_2 = \frac{hx + 2cx_1}{h + 2c} \text{ where } h = \text{height of the wall.}$$

Additional formulæ for Retaining Walls.

(1) Horizontal thrust (H) for a section whose breadth is unity.

r walls having vertical backs, and for earth with various angles of
.

ontal pressure H = co-efficient × weight of 1 cubic foot of earth × h^2.

s of repose of	27°	30°	33°	36°	39°	42°	45°	48°
	Co-efficients of earth pressure.							
horizontal at the level he top . . .	·188	·167	·147	·130	·114	·099	·085	·073
nite Surcharge to le of repose . .	·397	·375	·351	·327	·302	·276	·250	·224

r walls with sloping backs, having determined the position of the of maximum pressure, and hence also the values of ϵ the inclination plane with the angle of repose, and A the sectional area of effective e, then $H = A \tan \epsilon \times$ weight of 1 cubic foot of the earth.

r water pressure, $H = \frac{1}{2} w_1 h^2 = 31{\cdot}25 \times h^2$, when $w_1 = 62{\cdot}5$.

(2) Allowance for limiting resistance to crushing.

ving calculated x, the bottom thickness, in the ordinary way, obtain ditional bottom thickness necessary, as follows.

- resistance, which is roughly 8 tons per square foot for brickwork and 40 tons per square foot for the heaviest masonry.

= weight of wall per unit of length, also in tons.

or a brickwork wall of height h, and mean thickness t in feet,

$$= \frac{W}{2C} = \frac{ht}{20 \times 2 \times 8} = \frac{ht}{320} \text{ in feet.}$$

case the whole thickness $x = x_1 + x_2 = x_1 \left(1 + \frac{h}{320}\right)$.

mits of weight of wall are from 80 to 160 lbs. per cubic foot; the 100; granite rubble 140; basalt rubble 150; ashlar from 120 to s.

(3) Allowance for the effect of batter in a wall.

ate as for a rectangular wall the suitable bottom thickness; but as rhanging walls the horizontal thrust would be greater, and in re- walls it would be less, the altered thickness may be obtained by acting a diagram to scale, and allowing the plumb-face to revolve a point at one-third of the height. Under that condition the h may be scaled; for the horizontal movement of the centre of of the wall is not affected, nor its stability.

Weight of Materials for Dams and Walls.

(By Rymer, in Spon's 'Dictionary of Engineering.')

	Specific gravity.		Specific gravity.
Clay, dry	1·93	Brickwork in new mortar	1·87
,, wet	2·17	,, in old mortar	1·52
Earth, common dry	1·44	Cement new	1·61
Earthy clay and sand	1·6 to 1·7	Flint masonry	2·34
Gravel	1·5 to 1·9	Granites	3·05 to 2·25
Mould, garden	1·4	Granite masonry	2·75
Sand, dry fine	1·4 to 1·6	Limestones	2·54 to 1·86
,, damp	1·9	Mortars, new	1·9
Shingle, loose	2·2	,, old	1·42
Basalts and traps	3 to 2·4	Sandstones	2·67 to 1·38
Bricks, red	2·16	Slates	2·9 to 2·5
,, common	1·78		
,, stock (London)	1·84		
Brickwork in cement	1·92		

NOTE.—Ashlar, weight = $\frac{7}{8}$ that of stone + $\frac{1}{8}$ that of mortar.
Rubble, weight = $\frac{2}{3}$ to $\frac{3}{4}$ that of stone + $\frac{1}{4}$ to $\frac{1}{3}$ that of mortar.

Working Loads per square unit of pressure adopted in existing structures.

(By Rymer, in Spon's 'Dictionary of Engineering.')

	Tons on the square foot.
Soft rock foundations	9
Concrete in lime mortar	3
Earth	$1\frac{1}{4}$
Ashlar masonry, limestone, Britannia Bridge	16
,, ,, granite, Saltash Bridge	10
,, backed with rubble, Penistone Viaduct	6
Rubble masonry, sandstone in Aberthaw lime, Pont y Pridd	$20\frac{3}{4}$
,, ,, limestone in chalk lime, Barentine Viaduct	$3\frac{1}{4}$
,, ,, in hydraulic lime, Almanza Dam	12·8
,, ,, ,, ,, Ban	7·3
,, ,, ,, ,, Furens	6·[illegible]
,, ,, ,, ,, Tulsi	8·9 to 6·3
Brickwork, London paviors' in cement, Charing Cross Bridge	12
,, Staffordshire blue brick in cement, Clifton Suspension Bridge	10
,, red Birmingham in lias lime, Railway Viaduct	7
Cement mortar	20 to 32
Lime mortar	$2\frac{1}{2}$ to $5\frac{1}{4}$

NOTE. The safe working load for masonry and brickwork is that for the mortar used; but in ordinary calculation, 5 tons per square foot for brickwork and rubble in lime, and 30 for ashlar in cement, is generally allowed.

Proportions of Sections of Ovoid Culverts.

(By the Author.)

	Phillips	Hawksley	Pegtop
Transverse diameter or extreme inside width	2	2	2
Radius of top circle .	1	1	1
Total vertical depth .	3	2·5858	3
Radius of curved side .	3	2	x
Radius of invert . .	0·5	0·5858	0·375
Length of side, or arc .	36° 52′ 14″	45°	1·5
Arc of top circle . .	180°	180°	220°
Arc of invert . . .	106° 16′	90°	140°
Area of Full Section .	4·594	3·9820	4·1542
Area, filled to ⅔ depth .	3·023	2·6858	2·5834
Area, filled to ⅓ depth .	1·136	1·0278	0·9687
Perimeter of Full Section	7·930	7·2034	7·7560
,, filled to ⅔ depth	4·788	4·3375	4·6144
,, filled to ⅓ depth	2·750	2·5957	2·5413
Hyd. Rad. for Full Section	0·579	0·553	0·536
,, filled to ⅔ depth	0·631	0·620	0·560
,, filled to ⅓ depth	0·413	0·396	0·381

The above comparison is based on an equal transverse diameter for each form of culvert.

If the culverts are assumed to be of equal section when completely filled, the relative diameters for the different forms of culvert are thus—

Cylindrical Section	1·1286
Phillips's Metropolitan	1·0002 and 1·2930
Hawksley's Ovoid	0·9331 and 1·3996
Jackson's Pegtop	0·9813 and 1·4720

The Pegtop section flushes highest with the same quantity of liquid; but its sides must be of slightly increased thickness, when subject to much lateral pressure.

Cast Iron Water-pipes; adopted in the Rio de Janeiro Waterworks.

Diameter of pipe m.	inches	Thickness in.	Length without socket feet	Socket inches	Weight without ring or socket cwts.	qrs.	lbs.	Total weight with ring and socket cwts.	qrs.	lbs.
0·80 or	$31\frac{1}{2}$	$1\frac{3}{16}$	12	$5\frac{14}{16}$	40	2	4	43	3	23
0·80 or	$31\frac{1}{2}$	$1\frac{3}{16}$	9	$5\frac{14}{16}$	30	1	17	33	3	8
0·50 or	$19\frac{11}{16}$	1	12	$5\frac{2}{16}$	21	1	13	22	3	27
0·50 or	$19\frac{11}{16}$	1	9	$5\frac{2}{16}$	16	0	3	17	2	17
0·40 or	$15\frac{12}{16}$	$\frac{14}{16}$	12	$5\frac{2}{16}$	15	0	13	16	1	14
0·40 or	$15\frac{12}{16}$	$\frac{14}{16}$	9	$5\frac{2}{16}$	11	1	10	12	2	11
0·30 or	$11\frac{13}{16}$	$\frac{13}{16}$	9	$4\frac{15}{16}$	7	3	7	8	2	15
0·30 or	$11\frac{13}{16}$	$\frac{11}{16}$	9	$4\frac{15}{16}$	6	3	27	7	2	27
0·25 or	$9\frac{13}{16}$	$\frac{10}{16}$	9	$4\frac{15}{16}$	5	0	23	5	3	5
0·20 or	$7\frac{14}{16}$	$\frac{9}{16}$	9	$4\frac{5}{16}$	3	2	18	4	0	6
0·15 or	$5\frac{14}{16}$	$\frac{8}{16}$	9	$4\frac{5}{16}$	2	2	10	2	3	14
0·10 or	$3\frac{14}{16}$	$\frac{8}{16}$	9	$4\frac{5}{16}$	1	2	16	1	3	10

Testing pressure 15 atmospheres; for $31\frac{1}{2}''$ pipes 20 atmospheres; specific gravity of iron taken at 7·20.

Cast Iron Water-pipes adopted at Glasgow.

Length	Thickness	Weight incl. Socket cwts.	qrs.	lbs.	Working head feet	Length	Thickness	Weight incl. Socket cwts.	qrs.	lbs.	Working head feet
33"	1"	39	1	25	210	14	$\frac{11}{16}$	8	3	25	290
30	$1\frac{1}{4}$	44	0	3	300	14	$\frac{10}{16}$	8	0	25	250
30	1	35	3	5	230	14	$\frac{9}{16}$	7	2	0	200
24	1	28	1	23	300	12	$\frac{5}{8}$	6	3	13	290
20	$\frac{7}{8}$	16	0	4	270	12	$\frac{9}{16}$	6	0	26	240
20	$\frac{3}{4}$	13	3	25	240	10	$\frac{9}{16}$	5	0	16	300
18	$\frac{13}{16}$	13	1	12	300	9	$\frac{9}{16}$	4	2	24	"
18	$\frac{3}{4}$	12	1	19	260	8	$\frac{1}{2}$	3	2	23	"
18	$\frac{11}{16}$	11	1	27	230	7	$\frac{1}{2}$	3	1	1	"
16	$\frac{3}{4}$	10	3	27	300	6	$\frac{7}{16}$	2	1	27	"
16	$\frac{11}{16}$	10	0	18	250	5	$\frac{13}{32}$	1	3	24	"
16	$\frac{5}{8}$	9	1	9	200	4	$\frac{3}{8}$	1	1	20	"
15	$\frac{11}{16}$	9	2	3	270	3	$\frac{3}{8}$	1	0	10	"
15	$\frac{9}{16}$	7	3	25	180	2	$\frac{3}{8}$	0	2	4	300

Testing strain double the working pressure.

The lengths are 9 feet excluding socket; but for 24" pipes and upwards the length is 12 feet; and for 2" pipe 6 feet.

bsorption and Strength of Cylindrical Stoneware Pipes.

(By Baldwin Latham, C.E.)

er and place	Diam.	Thick-ness	Length	Weight when dry	Weight after 24 hours' immersion	Percentage of absorption
		″		lbs.	lbs.	
n . .	6″	0·75	1′ 11″	31	31·25	0·806
n, London .		0·72	1 11	29·5	29·75	0·85
. . .		0·63	2 0	28	28·75	2·68
y . .		0·74	1 11	30·5	31·75	4·10
n, London .	9″	0·87	2 0	57·75	58·75	1·73
rsfield .		0·92	2 4	73	73·75	1·03
Wortley .		0·81	2 4	60·5	63·25	4·54
ord . .		1·00	2 0	58	62	6·89
n, Stafford .	12″	1·05	2 0	96·0	97·5	1·56
. . .		1	1 11	84	88	4·76
. . .		1·02	1 10	66·25	67·5	1·88
, Wortley .		1·03	1 11	79·5	82·5	3·77
n, London .	15″	1·06	1 11	116·5	117·0	0·43
n, Stafford .		1·26	2 6	132	139	5·30
t . .		1·72	1 10	130	137	5·38
n . .		·31	2 6	165	174·5	5·75
n . .	18″	1·43	2 4	221	226	2·26
. .		1·38	2 5	210	217	3·33

	Diam.	Thick-ness	Length	Bursting pressure	Tensile strength	Resistance to crushing
		″	′ ″	B.	T.	C.
n, Stafford .	6″	0·65	1 11	50	230·7	1742 to 2956
London .		0·72	1 11	10	41·6	
, Wortley .		0·48	1 11	4	25	
” . .		0·69	1 11	70	304·3	
n, London .	9″	0·84	2 0	40	214·2	2470 to 3561
Stafford .		0·79	1 11	20	113·9	
rd . .		1·00	2 0	45	202·5	
Vortley .		0·84	2 4	60	321·4	
n, Stafford .	12″	1·07	2 0	7	39·2	2834 to 2956
, Wortley .		0·94	1 11	7	44·6	
n, London .	15″	1·19	2 5	33	207·9	Not tested
Stafford .		1·10	1 10	20	136·3	
, Wortley .		1·15	2 5	20	130·4	
be, Ruabon		1·10	1 10	63	429·5	

B, T, and C are all in lbs. per sq. inch.

Arcs of Circles, having a Diameter=1; or Areas of Sectors of Circles, having a Radius=1.

Deg.	Arc or Sector	Deg.	Arc or Sector	Deg.	Arc or Sector	Deg.	Arc or Sector	Deg.	Arc or Sector
1	·00873	31	·27053	61	·53233	91	·79412	121	1·05592
2	·01745	32	·27925	62	·54105	92	·80206	122	1·06465
3	·02618	33	·28798	63	·54978	93	·81158	123	1·07338
4	·03491	34	·29671	64	·55851	94	·82030	124	1·08210
5	·04363	35	·30543	65	·56723	95	·82903	125	1·09083
6	·05236	36	·31416	66	·57596	96	·83776	126	1·09956
7	·06109	37	·32289	67	·58469	97	·84648	127	1·10828
8	·06981	38	·33161	68	·59341	98	·85521	128	1·11701
9	·07854	39	·34034	69	·60214	99	·86394	129	1·12574
10	·08727	40	·34907	70	·61087	100	·87266	130	1·13446
11	·09599	41	·35779	71	·61959	101	·88139	131	1·14319
12	·10472	42	·36652	72	·62832	102	·89012	132	1·15192
13	·11345	43	·37525	73	·63705	103	·89884	133	1·16064
14	·12217	44	·38397	74	·64577	104	·90757	134	1·16937
15	·13090	45	·39270	75	·65450	105	·91630	135	1·17810
16	·13963	46	·40143	76	·66323	106	·92502	136	1·18682
17	·14835	47	·41015	77	·67195	107	·93375	137	1·19555
18	·15708	48	·41888	78	·68068	108	·94248	138	1·20428
19	·16581	49	·42761	79	·68941	109	·95120	139	1·21300
20	·17453	50	·43633	80	·69813	110	·95993	140	1·22173
21	·18326	51	·44506	81	·70686	111	·96866	141	1·23046
22	·19199	52	·45379	82	·71559	112	·97738	142	1·23918
23	·20071	53	·46251	83	·72431	113	·98611	143	1·24791
24	·20944	54	·47124	84	·73304	114	·99484	144	1·25664
25	·21817	55	·47997	85	·74176	115	1·00356	145	1·26536
26	·22689	56	·48869	86	·75049	116	1·01229	146	1·27409
27	·23562	57	·49742	87	·75922	117	1·02102	147	1·28282
28	·24435	58	·50615	88	·76794	118	1·02974	148	1·29154
29	·25307	59	·51487	89	·77667	119	1·03847	149	1·30027
30	·26180	60	·52360	90	·78540	120	1·04720	150	1·30900

Arcs of Circles, having a Diameter=1;
or Areas of Sectors of Circles, having a Radius=1.

Deg.	Arc or Sector	Min.	Arc or Sector	Min.	Arc or Sector	Sec.	Arc or Sector	Sec.	Arc or Sector
151	1·31772	1	·00015	31	·00451	1	·000 002	31	·000 075
152	1·32645	2	·00029	32	·00465	2	·000 005	32	·000 078
153	1·33518	3	·00044	33	·00480	3	·000 007	33	·000 080
154	1·34390	4	·00058	34	·00494	4	·000 010	34	·000 082
155	1·35263	5	·00078	35	·00509	5	·000 012	35	·000 085
156	1·36136	6	·00087	36	·00524	6	·000 015	36	·000 087
157	1·37008	7	·00102	37	·00538	7	·000 017	37	·000 090
158	1·37881	8	·00116	38	·00553	8	·000 019	38	·000 092
159	1·38754	9	·00131	39	·00567	9	·000 022	39	·000 095
160	1·39626	10	·00145	40	·00582	10	·000 024	40	·000 097
161	1·40499	11	·00160	41	·00596	11	·000 026	41	·000 099
162	1·41372	12	·00175	42	·00611	12	·000 029	42	·000 102
163	1·42244	13	·00189	43	·00625	13	·000 031	43	·000 104
164	1·43117	14	·00204	44	·00640	14	·000 034	44	·000 107
165	1·43990	15	·00218	45	·00655	15	·000 036	45	·000 109
166	1·44862	16	·00233	46	·00669	16	·000 039	46	·000 112
167	1·45735	17	·00247	47	·00684	17	·000 041	47	·000 114
168	1·46608	18	·00262	48	·00698	18	·000 044	48	·000 116
169	1·47380	19	·00276	49	·00713	19	·000 046	49	·000 119
170	1·48353	20	·00291	50	·00727	20	·000 049	50	·000 121
171	1·49226	21	·00305	51	·00742	21	·000 051	51	·000 124
172	1·50098	22	·00320	52	·00756	22	·000 053	52	·000 126
173	1·50971	23	·00335	53	·00771	23	·000 056	53	·000 129
174	1·51844	24	·00349	54	·00785	24	·000 058	54	·000 131
175	1·52716	25	·00364	55	·00800	25	·000 061	55	·000 133
176	1·53589	26	·00378	56	·00814	26	·000 063	56	·000 136
177	1·54962	27	·00393	57	·00829	27	·000 065	57	·000 138
178	1·55334	28	·00407	58	·00844	28	·000 068	58	·000 141
179	1·56207	29	·00422	59	·00858	29	·000 070	59	·000 143
180	1·57080	30	·00436	60	·00873	30	·000 073	60	·000 145

Powers, Roots, and Reciprocals

Number	Square	Square Root	Cube Root	Fifth Root	Power of $\frac{5}{2}$	Power of $\frac{2}{5}$	Reci proca
0·01	·0001	·1	·2154	·3981	·00001	·1584	100·
0·015	·0002	·1225	·2466	·4317	·00003	·1864	66·66
0·02	·0004	·1414	·2714	·4573	·00006	·2140	50·
0·025	·0006	·1581	·2924	·4782	·00010	·2287	40·
0·03	·0009	·1732	·3107	·4959	·00017	·2460	33·33
0·035	·0012	·1871	·3271	·5115	·00023	·2616	28·57
0·04	·0016	·2	·3420	·5253	·00032	·2759	25·
0·045	·0020	·2121	·3557	·5378	·00043	·2893	22·22
0·05	·0025	·2236	·3684	·5493	·00056	·3017	20·
0·055	·0030	·2345	·3803	·5599	·00071	·3134	18·18
0·06	·0036	·2449	·3915	·5697	·00088	·3245	16·66
0·065	·0042	·2550	·4021	·5789	·00108	·3351	15·38
0·07	·0049	·2646	·4121	·5875	·00130	·3452	14·28
0·075	·0056	·2739	·4217	·5957	·00154	·3548	13·33
0·08	·0064	·2828	·4309	·6034	·00181	·3641	12·5
0·085	·0072	·2915	·4397	·6108	·00211	·3731	11·76
0·09	·0081	·3	·4481	·6178	·00243	·3817	11·11
0·095	·0090	·3082	·4563	·6245	·00278	·3900	10·52
0·1	·01	·3162	·4642	·6310	·0032	·3981	10·
0·15	·0225	·3873	·5313	·6843	·0087	·4682	6·66
0·2	·04	·4472	·5848	·7248	·0179	·5253	5·
0·25	·0625	·5	·6300	·7579	·0313	·5743	4·
0·3	·09	·5477	·6694	·7860	·0493	·6178	3·33
0·35	·1225	·5916	·7047	·8106	·0769	·6571	2·85
0·4	·1600	·6324	·7368	·8326	·1012	·6931	2·5
0·45	·2025	·6708	·7663	·8524	·1358	·7266	2·22
0·5	·25	·7071	·7937	·8706	·1768	·7579	2·
0·52	·2704	·7211	·8041	·8774	·1950	·7698	1·92
0·54	·2916	·7348	·8143	·8841	·2143	·7816	1·85
0·56	·3136	·7483	·8243	·8905	·2347	·7930	1·78
0·58	·3364	·7616	·8340	·8968	·2562	·8042	1·72
0·6	·36	·7746	·8434	·9029	·2788	·8152	1·66
0·62	·3844	·7874	·8527	·9088	·3027	·8260	1·61
0·64	·4096	·8	·8618	·9146	·3277	·8365	1·56
0·66	·4356	·8124	·8707	·9203	·3539	·8469	1·51
0·68	·4624	·8246	·8794	·9258	·3813	·8570	1·47
0·7	·49	·8366	·8879	·9312	·4100	·8670	1·42
0·72	·5184	·8485	·8963	·9364	·4399	·8769	1·38
0·74	·5476	·8602	·9045	·9416	·4711	·8865	1·35
0·76	·5776	·8718	·9126	·9466	·5036	·8961	1·31
0·78	·6084	·8832	·9205	·9515	·5373	·9054	1·28
0·8	·64	·8944	·9283	·9564	·5724	·9146	1·25

Powers, Roots, and Reciprocals.

Number	Square	Square Root	Cube Root	Fifth Root	Power of $\frac{4}{3}$	Power of $\frac{2}{3}$	Reciprocal
0·82	·6724	·9055	·9360	·9611	·6089	·9237	1·2195
0·84	·7056	·9165	·9435	·9657	·6467	·9327	1·1905
0·86	·7396	·9274	·9510	·9702	·6859	·9415	1·1628
0·88	·7744	·9381	·9583	·9748	·7265	·9502	1·1364
0·9	·81	·9487	·9655	·9791	·7684	·9587	1·1111
0·92	·8464	·9592	·9726	·9834	·8118	·9672	1·0870
0·94	·8836	·9695	·9796	·9877	·8567	·9756	1·0638
0·96	·9216	·9798	·9865	·9918	·9030	·9838	1·0427
0·98	·9604	·9899	·9933	·9960	·9507	·9920	1·0204
1·	1·	1·	1·	1·	1·	1·	1·
1·02	1·0404	1·0099	1·0066	1·0040	1·0508	1·0080	0·98039
1·04	1·0816	1·0198	1·0132	1·0079	1·1030	1·0158	0·96154
1·06	1·1236	1·0296	1·0196	1·0117	1·1569	1·0236	0·94340
1·08	1·1664	1·0392	1·0260	1·0155	1·2122	1·0313	0·92593
1·1	1·2100	1·0488	1·0323	1·0192	1·2691	1·0389	0·90909
1·12	1·2544	1·0583	1·0385	1·0229	1·3275	1·0464	0·89286
1·14	1·2996	1·0677	1·0446	1·0266	1·3876	1·0538	0·87719
1·16	1·3456	1·0770	1·0507	1·0301	1·4492	1·0612	0·86207
1·18	1·3924	1·0863	1·0567	1·0337	1·5126	1·0685	0·84746
1·2	1·4400	1·0954	1·0627	1·0371	1·5775	1·0757	0·83333
1·22	1·4884	1·1045	1·0685	1·0405	1·6440	1·0827	0·81967
1·24	1·5376	1·1136	1·0743	1·0440	1·7122	1·0899	0·80645
1·26	1·5876	1·1225	1·0801	1·0473	1·7821	1·0969	0·79365
1·28	1·6384	1·1314	1·0858	1·0506	1·8536	1·1038	0·78125
1·3	1·6900	1·1402	1·0914	1·0539	1·9269	1·1107	0·76923
1·32	1·7424	1·1489	1·0970	1·0571	2·0018	1·1175	0·75758
1·34	1·7956	1·1576	1·1025	1·0603	2·0786	1·1242	0·74627
1·36	1·8496	1·1619	1·1079	1·0634	2·1570	1·1309	0·73529
1·38	1·9044	1·1747	1·1133	1·0665	2·2372	1·1375	0·72464
1·4	1·96	1·1832	1·1187	1·0696	2·3196	1·1442	0·71429
1·42	2·0164	1·1916	1·1243	1·0734	2·4028	1·1522	0·70423
1·44	2·0736	1·2	1·1292	1·0757	2·4883	1·1570	0·69444
1·46	2·1316	1·2083	1·1344	1·0786	2·5756	1·1634	0·68493
1·48	2·1904	1·2166	1·1396	1·0816	2·6648	1·1698	0·67568
1·5	2·25	1·2247	1·1447	1·0845	2·7556	1·1761	0·66667
1·55	2·4025	1·2450	1·1573	1·0916	2·9911	1·1916	0·64516
1·6	2·56	1·2649	1·1696	1·0986	3·2382	1·2068	0·625
1·65	2·7225	1·2845	1·1817	1·1053	3·4971	2·2218	0·60606
1·7	2·89	1·3038	1·1935	1·1120	3·7681	1·2365	0·58824
1·75	3·0625	1·3229	1·2051	1·1184	4·0513	1·2509	0·57143
1·8	3·24	1·3416	1·2164	1·1247	4·3469	1·2651	0·55556
1·85	3·4225	1·3601	1·2276	1·1309	4·6551	1·2790	0·54054
1·9	3·61	1·3784	1·2386	1·1370	4·9760	1·2927	0·52632

Powers, Roots, and Reciprocals.

Number	Square	Square Root	Cube Root	Fifth Root	Power of $\frac{5}{2}$	Power of $\frac{2}{5}$	Reciprocal
1·95	3·8025	1·3964	1·2493	1·1429	5·3098	1·3062	0·51282
2·	4·	1·4142	1·2599	1·1487	5·6569	1·3195	0.5
2·1	4·41	1·4491	1·2806	1·1600	6·3834	1·3455	0·47619
2·2	4·84	1·4832	1·3006	1·1708	7·1790	1·3708	0·45455
2·3	5·29	1·5166	1·3200	1·1813	8·0227	1·3954	0·43478
2·4	5·76	1·5492	1·3389	1·1914	8·9214	1·4194	0·41667
2·5	6·25	1·5811	1·3572	1·2011	9·8823	1·4427	0·4
2·75	7·5625	1·6583	1·4010	1·2242	12·541	1·4988	0·36364
3·	9·	1·7321	1·4423	1·2457	15·589	1·5518	0·33333
3·25	10·5625	1·8028	1·4812	1·2658	19·041	1·6023	0·30769
3·5	12·25	1·8708	1·5183	1·2846	22·918	1·6505	0·28571
3·75	14·0625	1·9365	1·5536	1·3026	27·232	1·6967	0·26667
4·	16·	2·	1·5874	1·3195	32·	1·7411	0·25
4·25	18·0625	2·0616	1·6198	1·3356	37·2361	1·7838	0·23529
4·5	20·25	2·1213	1·6510	1·3510	42·9561	1·8251	0·22222
4·75	22·5625	2·1794	1·6810	1·3656	49·1731	1·8650	0·21053
5·	25·	2·2361	1·7099	1·3804	55·9010	1·9054	0·2
5·25	27·563	2·2913	1·7380	1·3933	63·154	1·9414	0·19048
5·5	30·25	2·3452	1·7652	1·4063	70·943	1·9776	0·18182
5·75	33·063	2·3979	1·7915	1·4189	79·283	2·0133	0·17391
6·	36·	2·4495	1·8171	1·4310	88·176	2·0477	0·16667
6·25	39·063	2·5	1·8420	1·4427	97·657	2·0814	0·16
6·5	42·25	2·5495	1·8663	1·4541	107·71	2·1143	0·15385
6·75	45·563	2·5981	1·8899	1·4651	118·38	2·1465	0·14815
7·	49·	2·6458	1·9129	1·4758	129·64	2·1779	0·1428[illegible]
7·25	52·563	2·6926	1·9354	1·4862	141·53	2·2087	0·13793
7·5	56·25	2·7386	1·9574	1·4963	154·04	2·2388	0·13333
7·75	60·063	2·7839	1·9789	1·5061	167·21	2·2684	0·12903
8·	64·	2·8284	2·	1·5157	181·01	2·2974	0·125
8·25	68·063	2·8723	2·0206	1·5251	195·49	2·3258	0·1212[illegible]
8·5	72·25	2·9155	2·0408	1·5342	214·64	2·3538	0·1176[illegible]
8·75	76·563	2·9580	2·0606	1·5431	226·48	2·3812	0·1142[illegible]
9·	81·	3·	2·0801	1·5518	243·	2·4082	0·1111[illegible]
9·5	90·25	3·0822	2·1179	1·5687	278·16	2·4609	0·1052[illegible]
10·	100·	3·1623	2·1544	1·5849	316·23	2·5119	0·1
11	121	3·3166	2·2239	1·6154	401·31	2·6095	0·0909[illegible]
12	144	3·4641	2·2894	1·6437	498·83	2·7019	0·0833[illegible]
13	169	3·6056	2·3513	1·6702	609·34	2·7896	0·0769[illegible]
14	196	3·7417	2·4101	1·6952	733·36	2·8738	0·0714[illegible]
15	225	3·8729	2·4662	1·7188	871·42	2·9543	0·0666[illegible]
16	256	4·	2·5198	1·7411	1024·	3·0314	0·0625
17	289	4·1231	2·5713	1·7623	1191·8	3·1058	0·0588[illegible]
18	324	4·2426	2·6207	1·7826	1374·6	3·1777	0·0555[illegible]

Powers, Roots, and Reciprocals.

Square	Square Root	Cube Root	Fifth Root	Power of 5/2	Power of 2/5	Reciprocal
361	4.3589	2.6684	1.8020	1573.5	3.2472	0.052 632
400	4.4721	2.7144	1.8206	1788.8	3.3145	0.05
441	5.5826	2.7589	1.8384	2020.9	3.3798	0.047 619
484	4.6904	2.8020	1.8556	2270.11	3.4433	0.045 455
529	4.7958	2.8439	1.8722	2537.00	3.5050	0.043 478
576	4.8989	2.8845	1.8882	2821.8	3.5652	0.041 667
625	5.	2.9240	1.9037	3125.0	3.6239	0.04
676	5.0990	2.9625	1.9186	3446.9	3.6812	0.038 462
729	5.1962	3.	1.9332	3788.0	3.7372	0.037 037
784	5.2915	3.0366	1.9473	4148.5	3.7920	0.035 714
841	5.3852	3.0723	1.9610	4528.9	3.8455	0.034 483
900	5.4772	3.1072	1.9744	4929.5	3.8981	0.033 333
961	5.5678	3.1414	1.9873	5350.6	3.9493	0.032 258
1024	5.6569	3.1748	2.	5792.6	4.	0.031 250
1089	5.7746	3.2075	2.0124	6255.8	4.0495	0.030 303
1156	5.8309	3.2396	2.0244	6740.5	4.0982	0.029 412
1225	5.9161	3.2711	2.0362	7247.2	4.1460	0.028 571
1296	6.	3.3019	2.0477	7776.0	4.1930	0.027 778
1369	6.0828	3.3322	2.0589	8327.3	4.2392	0.027 027
1444	6.1644	3.3620	2.0699	8901.4	4.2846	0.026 316
1521	6.2449	3.3912	2.0807	9498.6	4.3294	0.025 641
1600	6.3245	3.4200	2.0913	10120	4.3735	0.025
1681	6.4031	3.4482	2.1017	10763	4.4169	0.024 390
1764	6.4807	3.4760	2.1118	11432	4.4596	0.023 809
1849	6.5574	3.5034	2.1217	12124	4.5018	0.023 256
1936	6.6332	3.5303	2.1315	12842	4.5434	0.022 727
2025	6.7082	3.5569	2.1411	13584	4.5844	0.022 222
2116	6.7823	3.5830	2.1506	14351	4.6249	0.021 739
2209	6.8557	3.6088	2.1598	15144	4.6649	0.021 277
2304	6.9282	3.6342	2.1689	15962	4.7043	0.020 833
2401	7.	3.6593	2.1779	16807	4.7433	0.020 408
2500	7.0711	3.6840	2.1867	17677	4.7818	0.02
2601	7.1414	3.7084	2.1954	18574	4.8198	0.019 608
2704	7.2111	3.7325	2.2039	19499	4.8574	0.019 231
2809	7.2801	3.7563	2.2124	20449	4.8945	0.018 868
2916	7.3484	3.7798	2.2206	21428	4.9313	0.018 519
3025	7.4162	3.8030	2.2288	22435	4.9676	0.018 182
3136	7.4833	3.8259	2.2369	23468	5.0035	0.017 857
3249	7.5498	3.8485	2.2448	24529	5.0391	0.017 544
3364	7.6158	3.8709	2.2526	25619	5.0742	0.017 241

[redacted]

59	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
61	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
62	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
63	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
64	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
65	4225	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
66	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
67	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
68	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
69	4761	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
70	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
71	5041	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
72	[illegible]	8·4853	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
73	5329	8·5440	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
74	5476	8·6023	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
75	5625	[illegible]	4·2172	[illegible]	[illegible]	[illegible]	[illegible]
76	5776	8·7178	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
77	5929	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
78	6084	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
79	6241	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
80	6400	8·9443	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
81	6561	9·	4·3267	[illegible]	[illegible]	[illegible]	[illegible]
82	6724	9·0554	4·3445	2·4141	[illegible]	[illegible]	[illegible]
83	6889	9·1104	4·3621	2·4200	[illegible]	[illegible]	[illegible]
84	7056	9·1652	4·3795	[illegible]	[illegible]	[illegible]	0·011
85	7225	9·2195	4·3968	2·4315	[illegible]	[illegible]	0·011
86	7396	9·2736	4·4140	2·4372	[illegible]	[illegible]	0·011
87	7569	9·3273	4·4310	2·4429	70559	[illegible]	0·011
88	7744	9·3808	4·4480	2·4485	[illegible]	5·9951	0·011
89	7921	9·4340	4·4647	2·4540	[illegible]	6·0222	0·011
90	8100	9·4868	4·4814	2·4595	76843	6·0492	0·011
91	8281	9·5394	4·4979	2·4650	78995	6·0760	0·010
92	8464	9·5917	4·5144	2·4703	81183	6·1026	0·010
93	8649	9·6437	4·5307	2·4757	83408	6·1291	0·010
94	8836	9·6954	4·5468	2·4810	85668	6·1553	0·010
95	9025	9·7468	4·5629	2·4863	87964	6·1814	0·010
96	9216	9·7980	4·5789	2·4915	90298	6·2074	0·010
97	9409	9·8489	4·5947	2·4966	92668	6·2332	0·010
98	9604	9·8995	4·6104	2·5018	95075	6·2588	0·010
99	9801	9·9499	4·6261	2·5068	97519	6·2843	0·010
100	10000	1·0	4·6416	2·5119	100000	6·3096	0·01

Note. This table admits of finding the fourth and fifth powers of num

Hydraulic Machines:—Return of Motive Power.

Deduced from Morin's experiments.

	Proportion of Motive Power yielded
Lift pump	·316
Force pump	·516
Fire engine	·233
Chinese wheel	·36 ·59
Flash wheel	·75
Wirtz pump	·181 ·640
Rotary.	
Stotz pump	·43
Leclerc	·307
Centrifugal.	
Piatti	·20
Appold	·70
Gwynne	·190 ·300
Girard	·300
Vertical helix	·19
Water Rams.	
Montgolfier	·47 ·80
Caligny	·43
Foex	·55
Dartige's balance	·72
Belidor	not used
Huelgoat	·45
Pfetsch	·771

	Proportion of Motive Power yielded	Proportion of Water raised
Fire Engines.		
Merryweather	·572	·920
Tylor	·625	·887
Letestu	·452	·910
Perry	·300	·910
Flaud	·194	·920
Perrin	·210	·900
Drainage Pumps.		
Denizot	·690	·930
Delpech	·600	·926
Letestu	·513	·940
Millus	·502	
Supply Pumps.		
At Ivry (feeder alone)	·230	
At Ivry (three pumps)	·530	
At St. Ouen	·696	
At Lisbon (Farcot)	·652	
Solid piston pumps	·900	
Oscillating Pumps.		
Vascile's fire-engine	·50	
Gray's oscillating	·45	

Hydraulic Contrivances.

(By the Author.)

	Coefficient of reduction for power		Coefficient of reduction for power
Baling	0·75	Single chain of pots	0·55
Windlass	0·50	Double chain of pots	0·60
Dāl (Indian)	0·70	Single Môt (Indian)	0·70
Dāl (South India)	0·70	Double Môt (Indian)	0·60
Beam and bucket	0·80	Common pump	0·50
Picotah (S. Indian)	0·80	Lift and force-pump	0·60

Memoranda for Conversion of Quantities.

Expressed in commercial measure.

MEASURES.

Feet	× 0·015	= Gunter's chains.	See also pages 14 and 15 of the text for scientific system at 32° and 39° Fahr.
Feet	× 0·00019	= Miles.	
Square feet	× 0·111	= Square yards.	
Square feet	× 0·000023	= Acres.	
Cubic feet	× 6·23	= Gallons.	
Cubic feet	× 0·779	= Bushels.	
Cubic feet	× 0·037	= Cubic yards.	

RAINFALL.

Feet of downpour × 193600· = cubic feet per square mile.
Feet of downpour × 302·5 = cubic feet per acre.

DRAINAGE AREAS.

The drainage from 1 square mile collecting 1 foot in depth yearly will irrigate 176 acres at a duty of 200 acres per cubic foot per second. will supply 47,580 inhabitants at a duty of 10 gallons daily. will yield ·8833 cubic feet per second throughout the year.

VELOCITIES.

Feet per second	× ·68	give miles per hour.
Feet per second	× 60	give feet per minute.
Feet per second	× 20	give yards per minute.
Feet per second	× 1200	give yards per hour.

DISCHARGES.

Cub. feet per sec.	× 2·2	give cubic yards per minute.
Cub. feet per sec.	× 133	give cubic yards per hour.
Cub. feet per sec.	× 3200	give cubic yards per day.
Cub. feet per sec.	× $6\frac{1}{4}$	give gallons per second.
Cub. feet per sec.	× 375	give gallons per minute.
Cub. feet per sec.	× 22	give thousands of gallons per hour.
Cub. feet per sec.	× 500	give thousands of gallons per day.
Cub. feet per sec.	× 2400	give tons per day.

WEIGHT.

Cubic feet.		Gallons.	
1·	=	6·232	and weighs 62·32 lbs.
·1605	=	1	and weighs 10 lbs.
1·8	=	11·2	and weighs 1 cwt.
35·943	=	224	and weighs 1 ton.
1 cubic inch	=	·0036	and weighs ·0361 lbs.

luid ounce weighs 437·5 grains.
Troy ounce measures 8 fluid drams, 46 minims.
Avoirdupois ounce measures 8 fluid drams.
b. Troy = 5760 grains = 6319·54 minims of water.
allon = 76800 minims = 70000 grs. of water.
b. Avoir. = 7000 grains = 7680 minims of water.

All comparisons between measures of capacity and those of weight are de with distilled water at a maximum density, at a specific gravity of 1; , in commercial measure, the vessel is at a temperature of 62° Fahr.

PRESSURE OF WATER.

H = head of water in feet	$H = P \times 0{\cdot}016$
P = pressure in lbs. per square foot	$P = H \times 62{\cdot}32$

HORSE-POWER.

IP = 33000 lbs. of water raised 1 foot in 1 minute.
= 884 tons of water raised 1 foot in 1 hour.
eoretical HP = ·113 Q × fall in feet.

The drainage of 10 square miles collecting 12″ yearly gives 1 HP for h foot of fall.

For pumping engines of the best class, allow HP = ·142 Q H where = quantity raised in cubic feet per second, H = height in feet.

TOWAGE.

The general formula referred to in the text is

$$R = b\,T\,.\,V^2,$$

where R = the pull on the rope in pounds,
T = the displacement of the barge in tons,
V = the velocity through the water,
b = a coefficient varying with the form of the barge, from ·109 to ·369.

Constants of Labour.

(Hurst.)

EARTHWORK.

Expressed in terms of a day's labour of 10 *hours.*

Days of a Labourer.

		Soil		
		Soft	Moderate	Hard
Excavating only	per cub. yard	·050	·100	·200
,, in rock requiring blasting	,, ,,			·450
		Light	Heavy	Wet mud
Throwing 5 feet high, or filling trucks	,, ,,	·048	·055	·065
Filling barrows	,, ,,	·045	·052	·061
Removing with wheelbarrow to 25 yards' distance . . .	,, ,,	·026	·030	·039
Filling at back of walls . . .	,, ,,	·048	·055	·058
Ramming earth in 6-inch layers .	,, ,,	·040		
,, ,, 12-inch . .	,, ,,	·025		
Levelling earth from barrow-heaps without throwing . . .	,, ,,	·012	·019	

Levelling and trimming slopes .	per sq. yard	·020 to ·030
Turf 4 inches thick, cutting and stacking only . . .	,, ,,	·045
,, ,, resodding only . .	,, ,,	·065

Days of driver, horse, and cart. (See also Cartage Table.)

Removing 220 yards' distance, per c. yard . .	·035 to ·040
Each additional 220 yards ,, ,, . . .	·020 to ·025

N.B.—The vertical transport of earth is equal to 15 times the same horizontal distance when barrows are used, and 12 times when horses and carts are employed.

Days of an Indian Coolie.

	Sand	Gravel	[illegible] soil
Excavating down to 9 feet, carrying to 25 yds. in a basket and depositing up to 6 ft., per cub. yard	1·25	2·00	3·75
Excavating down to 15 feet . . ,, ,,	2·00	2·75	4·50
Add for each 3 feet more of depth or height of delivery, or for each 15 yards' additional distance . . . . . . per cub. yard	·25	·25	·25

Constants of Labour.

(Hurst.)

BRICKLAYERS' WORK.

Expressed in terms of a day's labour of 10 *hours.*

One Bricklayer's Labourer.

		Days
Mixing concrete, wheeling and throwing from a stage,	per cub. yard	·300
Mixing mortar with a shovel	,, ,,	·720
A two-horse pug-mill mixes 25 cubic yards of mortar in		1·
Picking up and stacking bricks without moving	per 1,000	·150
,, ,, if handed to him	,,	·100
Selecting bricks for facings	,,	·300
Taking down old brickwork in mortar, cleaning and stacking	per cub. yard	·410

One Bricklayer and Labourer.

		Days
Brickwork in mortar to walls, exclusive of face work,	per cub. yard	·320
,, in cement	,,	·373
,, in mortar to covering arches	,,	·410
Pointing flat joint in mortar and raking out mortar joints	per sq. yard	·110
Pointing flat joint in cement and raking out cement joints	,,	·170
Pointing tuck in cement and raking out cement joints	,,	·258
Paving with stock bricks on edge in mortar	,,	·086
,, ,, ,, in cement	,,	·100
Laying and jointing in cement 3-inch drain pipes	per lin. yard	·024
,, ,, ,, 6 ,,	,,	·048
,, ,, ,, 9 ,,	,,	·069
,, ,, ,, 12 ,,	,,	·093
,, ,, ,, 18 ,,	,,	·150

One Bricklayer only.

		Days
Working each fair face to brickwork and pointing	per s. yd.	·080
Working each fair face in malms or facing of superior bricks	per s. yd.	·117
Working each fair face in malms, circular to template	,,	·189
Rough cutting to brickwork	,,	·135
Fair ,, ,,	,,	·360

Constants of Labour—(continued).

(Hurst.)

MASONS' WORK.

Days of a Labourer.

		Days
Rubble stone.—Filling barrows	per cubic yard	·060
,, Removing 25 yards and returning	,, ,,	·040
,, Unloading barrows	,, ,,	·030
,, Taking down old masonry in mortar, cleaning and stacking	,, ,,	·600
Breaking stone to $1\frac{1}{2}''$ ordinary limestone	,, ,,	·700
,, granite or very hard stone	,, ,,	·930
Spreading the same for metalling 3″ deep	per square yard	·022

Days of a Mason and Labourer.

		Days
Rubble masonry, dry in foundations	per cubic yard	·240
,, ,, in mortar above foundations	,, ,,	·310
,, ,, all beds being horizontal	,, ,,	·480
,, ,, in cement ,,	,, ,,	·570
Ashlar masonry, 12″ thick and in 12″ courses, rubble with chisel-drafted margins	,, ,,	2·160
Cubed stone hoisted and set in mortar	,, ,,	·756
,, ,, ,, in cement	,, ,,	·945

Days of a Mason only.

		Days
Add to rubble masonry for each fair face	per square yard	·090
,, ,, if hammer dressed	,, ,,	·360
,, ,, if curved	,, ,,	·414
Squaring 2″ flags for paving	,, ,,	·072
,, 4″ ,,	,, ,,	·135

Days of a Mason on stone of various sorts.

		Caen Days	Portland Days	Granite Days
Whole sawing, or axing, per square yard		·270	·540	1·270
Plain work	,, ,,	·540	·765	1·800
,, circular	,, ,,	·900	1·395	2·160
Sunk work	,, ,,	·675	1·080	2·135
,, circular	,, ,,	1·035	1·575	2·925
Moulded work	,, ,,	1·395	1·800	3·825
,, circular	,, ,,	1·800	2·700	4·905

Constants of Labour—(continued).

(Hurst.)

PAVIORS', PLASTERERS', SLATERS', AND PAINTERS' WORK.

Days of a Pavior and Labourer.

			Days
Coursed pilcher paving, 6″, in gravel, 6″ deep	.	per square yard	0·076
,, ,, ,, 9 ,,	.	,, ,,	0·087
Add for grouting and setting in mortar	. .	,, ,,	0·035

Days of a Slate-mason.

		Days
Planing slate slabs	per square yard	0·144
Polishing slabs with very fine sand . . .	,, ,,	0·270
Plastering on under side of slating . . .	,, ,,	0·050

Days of a Slater and Labourer.

			Days
Preparing and laying.	Doubles . . .	per square	1·000
,, ,,	Duchesses . . .	,,	0·500

Days of a Labourer.

		Days
Mixing lime and hair . . .	per cubic yard	0·032
,, ,, fine stuff . . .	,, ,,	1·080

Days of a Plasterer and Labourer.

		Days
Rendering and setting or floating . . .	per square yard	0·030
Rendering two coats and setting . . .	,, ,,	0·042
Lathing with double fir laths	,, ,,	0·021
Stucco trowelled	,, ,,	0·082
Rendering with cement and sand . . .	,, ,,	0·083
Rough casting in lime and fine gravel . .	,, ,,	0·015
Lime whiting	,, ,,	0·004
Whiting and size, two coats, exc. scouring .	,, ,,	0·009
Colouring, stone or buff, two coats . . .	,, ,,	0·012

Days of a Painter or Glazier.

		Days
Knotting, stopping, and painting, 1st coat . .	per square yard	0·025
Second or following coats, each . . .	,, ,,	0·012
Tarring with Stockholm tar, 1st coat . .	,, ,,	0·040
Sash squares, each side, 2 coats . . .	per square	0·009
Stopping, crown glass into new sashes . .	per square foot	0·019
,, ,, old ,, . . .	,, ,,	0·060

Constants of Labour—(continued).

(Hurst.)

CARPENTERS' WORK.

Days of a pair of Sawyers.

			Days
Sawing.	Pine or Fir	per square foot	0·0024
,,	Ash, beech, elm, birch	,, ,,	0·0034
,,	English oak, teak	,, ,,	0·0050

For arris-wise sawing add two-thirds.

Days of a Carpenter.

		Days
Working fir into rafters, purlins, joists, when under 16 sq. inches in section	per cubic foot	0·080
Under 36 sq. in. 0·069; under 81, 0·061, over 81	,, ,,	0·054
Working fir into rough frames as naked floors over 16" sq. in.	,, ,,	0·100
Working fir into trusses, section 16" and over	,, ,,	0·135
Framing and fixing fir, rough under 16"	,, ,,	0·160
,, ,, ,, over 81"	,, ,,	0·108
,, wrought two sides under 16"	,, ,,	0·232
,, ,, ,, over 81"	,, ,,	0·138
,, wrought all round under 16"	,, ,,	0·280
,, ,, ,, over 81"	,, ,,	0·158
Planing fir and squaring	per square foot	0·017
Sawing off end of sheeting piles	,, ,,	0·110
Single tenon and mortice in fir under 16"	each	0·040
,, ,, ,, ,, 81"	,,	0·080
,, ,, ,, ,, 144"	,,	0·10

For double tenon and mortice add one-third.

Cartage Table.

(By J. H. E. Hart.)

Constants of Labour per ton and per 100 cubic feet in terms of a day's work of a cart.

Distance of 'lead' in miles	No. of trips	Cost of one trip	Constants for one ton			
			For a weight of load of			
			8 cwt.	8½ cwt.	9 cwt.	10 cwt.
3/16 to ¼	16	·0625	·156	·149	·139	·125
¼ ,, ⅜	12	·083	·208	·196	·185	·167
⅜ ,, ½	10	·1	·25	·235	·222	·2
½ ,, ¾	8	·125	·313	·294	·278	·25
¾ ,, 1	6	·167	·417	·392	·370	·333
1 ,, 1¼	5	·2	·5	·471	·445	·4
1¼ ,, 1¾	4	·25	·625	·588	·556	·5
1¾ ,, 2½	3	·333	·833	·784	·741	·667
2½ ,, 3½	2	·5	1·25	1·176	1·111	1·0
3½ ,, 4½	1½	·667	1·67	1·57	1·48	1·33
4½ ,, 5½	1¼	·8	2·0	1·88	1·78	1·6
5½ ,, 8	1	1·0	2·5	2·35	2·22	2·0

Distance of 'lead' in miles	No. of trips	Cost of one trip	Constants for 100 cubic feet						
			For a capacity of load in cubic feet of						
			6	8	9	10	12	15	16
3/16 to ¼	16	·0625	1·042	·781	·694	·625	·521	·417	·391
¼ ,, ⅜	12	·083	1·389	1·042	·926	·833	·694	·556	·521
⅜ ,, ½	10	·1	1·667	1·25	1·111	1·	·833	·667	·625
½ ,, ¾	8	·125	2·083	1·563	1·389	1·25	1·042	·833	·781
¾ ,, 1	6	·167	2·778	2·083	1·852	1·667	1·389	1·111	1·042
1 ,, 1¼	5	·2	3·333	2·5	2·222	2·	1·667	1·333	1·25
1¼ ,, 1¾	4	·25	4·167	3·125	2·778	2·5	2·083	1·667	1·563
1¾ ,, 2½	3	·333	5·556	4·167	3·704	3·333	2·778	2·222	2·083
2½ ,, 3½	2	·5	8·333	6·250	5·556	5·	4·167	3·333	3·125
3½ ,, 4½	1½	·667	11·111	8·333	7·407	6·667	5·556	4·444	4·167
4½ ,, 5½	1¼	·3	13·333	10·	8·889	8·	6·667	5·333	5·
5½ ,, 8	1	·1	16·667	12·5	11·111	10·	8·333	6·667	6·25

INDEX.

LONDON : PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
AND PARLIAMENT STREET

LONDON, *November*, 1882.

A Catalogue of Books

INCLUDING MANY NEW AND STANDARD WORKS IN

ENGINEERING, ARCHITECTURE, AGRICULTURE, MATHEMATICS, MECHANICS, SCIENCE, ETC.

PUBLISHED BY

CROSBY LOCKWOOD & CO.,

7, STATIONERS'-HALL COURT, LUDGATE HILL, E.C.

ENGINEERING, SURVEYING, ETC.

Humber's New Work on Water-Supply.

A COMPREHENSIVE TREATISE on the WATER-SUPPLY of CITIES and TOWNS. By WILLIAM HUMBER, A.-M. Inst. C.E., and M. Inst. M.E. Illustrated with 50 Double Plates, 1 Single Plate, Coloured Frontispiece, and upwards of 250 Woodcuts, and containing 400 pages of Text. Imp. 4to, 6*l*. 6*s*. elegantly and substantially half-bound in morocco.

List of Contents:—

I. Historical Sketch of some of the means that have been adopted for the Supply of Water to Cities and Towns.—II. Water and the Foreign Matter usually associated with it.—III. Rainfall and Evaporation.—IV. Springs and the water-bearing formations of various districts.—V. Measurement and Estimation of the Flow of Water.—VI. On the Selection of the Source of Supply.—VII. Wells.—VIII. Reservoirs.—IX. The Purification of Water.—X. Pumps.—XI. Pumping Machinery.—XII. Conduits.—XIII. Distribution of Water.—XIV. Meters, Service Pipes, and House Fittings.—XV. The Law and Economy of Water Works.—XVI. Constant and Intermittent Supply.—XVII. Description of Plates.—Appendices, giving Tables of Rates of Supply, Velocities, &c. &c., together with Specifications of several Works illustrated, among which will be found:—Aberdeen, Bideford, Canterbury, Dundee, Halifax, Lambeth, Rotherham, Dublin, and others

"The most systematic and valuable work upon water supply hitherto produced in English, or in any other language . . . . Mr. Humber's work is characterised almost throughout by an exhaustiveness much more distinctive of French and German than of English technical treatises."—*Engineer.*

Humber's Great Work on Bridge Construction.

A COMPLETE and PRACTICAL TREATISE on CAST and WROUGHT-IRON BRIDGE CONSTRUCTION, including Iron Foundations. In Three Parts—Theoretical, Practical, and Descriptive. By WILLIAM HUMBER, A.-M. Inst. C.E., and M. Inst. M.E. Third Edition, with 115 Double Plates. In 2 vols. imp. 4to, 6*l*. 16*s*. 6*d*. half-bound in morocco.

"A book—and particularly a large and costly treatise like Mr. Humber's—which has reached its third edition may certainly be said to have established its own reputation."—*Engineering.*

Humber's Modern Engineering.

A RECORD of the PROGRESS of MODERN ENGINEERING. First Series. Comprising Civil, Mechanical, Marine, Hydraulic, Railway, Bridge, and other Engineering Works, &c. By WILLIAM HUMBER, A.-M. Inst. C.E., &c. Imp. 4to, with 36 Double Plates, drawn to a large scale, and Portrait of John Hawkshaw, C.E., F.R.S., &c., and descriptive Letter-press, Specifications, &c. 3*l*. 3*s*. half morocco.

List of the Plates and Diagrams.

Victoria Station and Roof, L. B. & S. C. R. (8 plates); Southport Pier (2 plates); Victoria Station and Roof, L. C. & D. and G. W. R. (6 plates); Roof of Cremorne Music Hall; Bridge over G. N. Railway; Roof of Station, Dutch Rhenish Rail (2 plates); Bridge over the Thames, West London Extension Railway (5 plates); Armour Plates; Suspension Bridge, Thames (4 plates); The Allen Engine; Suspension Bridge, Avon (3 plates); Underground Railway (3 plates).

"Handsomely lithographed and printed. It will find favour with many who desire to preserve in a permanent form copies of the plans and specifications prepared for the guidance of the contractors for many important engineering works."—*Engineer.*

HUMBER'S RECORD OF MODERN ENGINEERING. Second Series. Imp. 4to, with 36 Double Plates, Portrait of Robert Stephenson, C.E., &c., and descriptive Letterpress, Specifications, &c. 3*l*. 3*s*. half morocco.

List of the Plates and Diagrams.

Birkenhead Docks, Low Water Basin (15 plates); Charing Cross Station Roof, C. C. Railway (3 plates); Digswell Viaduct, G. N. Railway; Robbery Wood Viaduct, G. N. Railway; Iron Permanent Way; Clydach Viaduct, Merthyr, Tredegar, and Abergavenny Railway; Ebbw Viaduct, Merthyr, Tredegar, and Abergavenny Railway; College Wood Viaduct, Cornwall Railway; Dublin Winter Palace Roof (3 plates); Bridge over the Thames, L. C. and D. Railway (6 plates); Albert Harbour, Greenock (4 plates).

HUMBER'S RECORD OF MODERN ENGINEERING. Third Series. Imp. 4to, with 40 Double Plates, Portrait of J. R. M'Clean, Esq., late Pres. Inst. C.E., and descriptive Letterpress, Specifications, &c. 3*l*. 3*s*. half morocco.

List of the Plates and Diagrams.

MAIN DRAINAGE, METROPOLIS.—*North Side.*—Map showing Interception of Sewers; Middle Level Sewer (2 plates); Outfall Sewer, Bridge over River Lea (3 plates); Outfall Sewer, Bridge over Marsh Lane, North Woolwich Railway, and Bow and Barking Railway Junction; Outfall Sewer, Bridge over Bow and Barking Railway (3 plates); Outfall Sewer, Bridge over East London Waterworks' Feeder (2 plates); Outfall Sewer, Reservoir (2 plates); Outfall Sewer, Tumbling Bay and Outlet; Outfall Sewer, Penstocks. *South Side.*—Outfall Sewer, Bermondsey Branch (2 plates); Outfall Sewer, Reservoir and Outlet (4 plates); Outfall Sewer, Filth Hoist; Sections of Sewers (North and South Sides).

THAMES EMBANKMENT.—Section of River Wall; Steamboat Pier, Westminster (2 plates); Landing Stairs between Charing Cross and Waterloo Bridges; York Gate (2 plates); Overflow and Outlet at Savoy Street Sewer (3 plates); Steamboat Pier, Waterloo Bridge (3 plates); Junction of Sewers, Plans and Sections; Gullies, Plans and Sections; Rolling Stock; Granite and Iron Forts.

HUMBER'S RECORD OF MODERN ENGINEERING. Fourth Series. Imp. 4to, with 36 Double Plates, Portrait of John Fowler, Esq., late Pres. Inst. C.E., and descriptive Letterpress, Specifications, &c. 3*l*. 3*s*. half morocco.

List of the Plates and Diagrams.

Abbey Mills Pumping Station, Main Drainage, Metropolis (4 plates); Barrow Docks (5 plates); Manquis Viaduct, Santiago and Valparaiso Railway (2 plates); Adam's Locomotive, St. Helen's Canal Railway (2 plates); Cannon Street Station Roof, Charing Cross Railway (3 plates); Road Bridge over the River Moka (2 plates). Telegraphic Apparatus for Mesopotamia; Viaduct over the River Wye, Midland Railway (3 plates); St. German's Viaduct, Cornwall Railway (2 plates); Wrought-Iron Cylinder for Diving Bell; Millwall Docks (6 plates); Milroy's Patent Excavator, Metropolitan District Railway (6 plates); Harbours, Ports, and Breakwaters (3 plates).

Strains, Formulæ & Diagrams for Calculation of.

A HANDY BOOK for the CALCULATION of STRAINS in GIRDERS and SIMILAR STRUCTURES, and their STRENGTH; consisting of Formulæ and Corresponding Diagrams, with numerous Details for Practical Application, &c. By WILLIAM HUMBER, A.-M. Inst. C.E., &c. Third Edition. With nearly 100 Woodcuts and 3 Plates, Crown 8vo, 7*s.* 6*d.* cloth.

"The system of employing diagrams as a substitute for complex computations is one justly coming into great favour, and in that respect Mr. Humber's volume is fully up to the times."—*Engineering.*

Strains.

THE STRAINS ON STRUCTURES OF IRONWORK; with Practical Remarks on Iron Construction. By F. W. SHEILDS, M. Inst. C.E. Second Edition, with 5 Plates. Royal 8vo, 5*s.* cloth.

"The student cannot find a better book on this subject than Mr. Sheilds'."—*Engineer.*

Barlow on the Strength of Materials, enlarged.

A TREATISE ON THE STRENGTH OF MATERIALS, with Rules for application in Architecture, the Construction of Suspension Bridges, Railways, &c.; and an Appendix on the Power of Locomotive Engines, and the effect of Inclined Planes and Gradients. By PETER BARLOW, F.R.S. A New Edition, revised by his Sons, P. W. BARLOW, F.R.S., and W. H. BARLOW, F.R.S. The whole arranged and edited by W. HUMBER, A-M. Inst. C.E. 8vo, 400 pp., with 19 large Plates, 18*s.* cloth.

"The standard treatise upon this particular subject."—*Engineer.*

Strength of Cast Iron, &c.

A PRACTICAL ESSAY on the STRENGTH of CAST IRON and OTHER METALS. By T. TREDGOLD, C.E. 5th Edition. To which are added, Experimental Researches on the Strength, &c., of Cast Iron, by E. HODGKINSON, F.R.S. 8vo, 12*s.* cloth.

*** HODGKINSON'S RESEARCHES, separate, price 6*s.*

Hydraulics.

HYDRAULIC TABLES, CO-EFFICIENTS, and FORMULÆ for finding the Discharge of Water from Orifices, Notches, Weirs, Pipes, and Rivers. With New Formulæ, Tables, and General Information on Rain-fall, Catchment-Basins, Drainage, Sewerage, Water Supply for Towns and Mill Power. By JOHN NEVILLE, Civil Engineer, M.R.I.A. Third Edition, carefully revised, with considerable Additions. Numerous Illustrations. Cr. 8vo, 14*s.* cloth.

"Undoubtedly an exceedingly useful and elaborate compilation."—*Iron.*

"Alike valuable to students and engineers in practice."—*Mining Journal.*

River Engineering.

RIVER BARS: Notes on the Causes of their Formation, and on their Treatment by 'Induced Tidal Scour,' with a Description of the Successful Reduction by this Method of the Bar at Dublin. By I. J. MANN, Assistant Engineer to the Dublin Port and Docks Board. With Illustrations. Royal 8vo. 7*s.* 6*d.* cloth.

Hydraulics.

HYDRAULIC MANUAL. Consisting of Working Tables and Explanatory Text. Intended as a Guide in Hydraulic Calculations and Field Operations. By LOWIS D'A. JACKSON. Fourth Edition. Rewritten and Enlarged. Large Crown 8vo. [*In the press.*

B 2

Levelling.

A TREATISE on the PRINCIPLES and PRACTICE of LEVELLING; showing its Application to Purposes of Railway and Civil Engineering, in the Construction of Roads; with Mr. TELFORD'S Rules for the same. By FREDERICK W. SIMMS, F.G.S., M. Inst. C.E. Sixth Edition, very carefully revised, with the addition of Mr. LAW'S Practical Examples for Setting out Railway Curves, and Mr. TRAUTWINE'S Field Practice of Laying out Circular Curves. With 7 Plates and numerous Woodcuts. 8vo, 8*s.* 6*d.* cloth. *** TRAUTWINE on Curves, separate, 5*s.*

"The text-book on levelling in most of our engineering schools and colleges."—*Engineer.*

Practical Tunnelling.

PRACTICAL TUNNELLING: Explaining in detail the Setting out of the Works, Shaft-sinking and Heading-Driving, Ranging the Lines and Levelling under Ground, Sub-Excavating, Timbering, and the Construction of the Brickwork of Tunnels with the amount of labour required for, and the Cost of, the various portions of the work. By F. W. SIMMS, M. Inst. C.E. Third Edition, Revised and Extended. By D. KINNEAR CLARK, M.I.C.E. Imp. 8vo, with 21 Folding Plates and numerous Wood Engravings, 30*s.* cloth.

"It has been regarded from the first as a text-book of the subject. . . . Mr. Clark has added immensely to the value of the book."—*Engineer.*

Steam.

STEAM AND THE STEAM ENGINE, Stationary and Portable. Being an Extension of Sewell's Treatise on Steam. By D. KINNEAR CLARK, M.I.C.E. Second Edition. 12mo, 4*s.* cloth.

Civil and Hydraulic Engineering.

CIVIL ENGINEERING. By HENRY LAW, M. Inst. C.E. Including a Treatise on Hydraulic Engineering, by GEORGE R. BURNELL, M.I.C.E. Sixth Edition, Revised, with large additions on Recent Practice in Civil Engineering, by D. KINNEAR CLARK, M. Inst. C.E. 12mo, 7*s.* 6*d.*, cloth boards.

Gas-Lighting.

COMMON SENSE FOR GAS-USERS: a Catechism of Gas-Lighting for Householders, Gasfitters, Millowners, Architects, Engineers, &c. By R. WILSON, C.E. 2nd Edition. Cr. 8vo, 2*s.* 6*d.*

Bridge Construction in Masonry, Timber, & Iron.

EXAMPLES OF BRIDGE AND VIADUCT CONSTRUCTION IN MASONRY, TIMBER, AND IRON; consisting of 46 Plates from the Contract Drawings or Admeasurement of select Works. By W. DAVIS HASKOLL, C.E. Second Edition, with the addition of 554 Estimates, and the Practice of Setting out Works, with 6 pages of Diagrams. Imp. 4to, 2*l.* 12*s.* 6*d.* half-morocco.

"A work of the present nature by a man of Mr. Haskoll's experience, must prove invaluable. The tables of estimates considerably enhance its value."—*Engineering.*

Earthwork.

EARTHWORK TABLES, showing the Contents in Cubic Yards of Embankments, Cuttings, &c., of Heights or Depths up to an average of 80 feet. By JOSEPH BROADBENT, C.E., and FRANCIS CAMPIN, C.E. Cr. 8vo, oblong, 5*s.* cloth.

Tramways and their Working.

TRAMWAYS: their CONSTRUCTION and WORKING. With Special Reference to the Tramways of the United Kingdom. By D. KINNEAR CLARK, M.I.C.E. SUPPLEMENTARY VOLUME; recording the Progress recently made in the Design and Construction of Tramways, and in the Means of Locomotion by Mechanical Power. With Wood Engravings. 8vo, 12*s.* cloth.

Tramways and their Working.

TRAMWAYS: their CONSTRUCTION and WORKING. By D. KINNEAR CLARK, M. Inst. C. E. With Wood Engravings, and thirteen folding Plates. THE COMPLETE WORK, in 2 vols., Large Crown 8vo, 30*s.* cloth.

"All interested in tramways must refer to it, as all railway engineers have turned to the author's work 'Railway Machinery.'"—*The Engineer.*

Pioneer Engineering.

PIONEER ENGINEERING. A Treatise on the Engineering Operations connected with the Settlement of Waste Lands in New Countries. By EDWARD DOBSON, A.I.C.E. With Plates and Wood Engravings. Revised Edition. 12mo, 5*s.* cloth.

"A workmanlike production, and one without possession of which no man should start to encounter the duties of a pioneer engineer."—*Athenæum.*

Steam Engine.

TEXT-BOOK ON THE STEAM ENGINE. By T. M. GOODEVE, M.A., Barrister-at-Law, Author of "The Principles of Mechanics," "The Elements of Mechanism," &c. Fourth Edition. With numerous Illustrations. Crown 8vo, 6*s.* cloth.

"Mr. Goodeve's text-book is a work of which every young engineer should possess himself."—*Mining Journal.*

Steam.

THE SAFE USE OF STEAM: containing Rules for Unprofessional Steam Users. By an ENGINEER. 4th Edition. Sewed, 6*d.*

"If steam-users would but learn this little book by heart, boiler explosions would become sensations by their rarity."—*English Mechanic.*

Mechanical Engineering.

DETAILS OF MACHINERY: Comprising Instructions for the Execution of various Works in Iron, in the Fitting-Shop, Foundry, and Boiler-Yard. Arranged expressly for the use of Draughtsmen, Students, and Foremen Engineers. By FRANCIS CAMPIN, C.E. 12mo. 3*s.* 6*d.* cloth. [*Just published.*

Mechanical Engineering.

MECHANICAL ENGINEERING: Comprising Metallurgy, Moulding, Casting, Forging, Tools, Workshop Machinery, Manufacture of the Steam Engine, &c. By F. CAMPIN, C.E. 3*s.* cloth.

Works of Construction.

MATERIALS AND CONSTRUCTION: a Theoretical and Practical Treatise on the Strains, Designing, and Erection of Works of Construction. By F. CAMPIN, C.E. 12mo. 3*s.* 6*d.* cl. brds.

Iron Bridges, Girders, Roofs, &c.

A TREATISE ON THE APPLICATION OF IRON TO THE CONSTRUCTION OF BRIDGES, GIRDERS, ROOFS, AND OTHER WORKS. By F. CAMPIN, C.E. 12mo, 3*s.*

[redacted]

Boiler Construction.

THE MECHANICAL ENGINEER'S OFFICE BOOK: Boiler Construction. By NELSON FOLEY, Cardiff, late Assistant Manager Palmer's Engine Works, Jarrow. With 29 full-page Lithographic Diagrams. Folio 21*s.* half-bound.

Oblique Arches.

A PRACTICAL TREATISE ON THE CONSTRUCTION of OBLIQUE ARCHES. By JOHN HART. 3rd Ed. Imp. 8vo, 8*s.* cloth.

Oblique Bridges.

A PRACTICAL and THEORETICAL ESSAY on OBLIQUE BRIDGES, with 13 large Plates. By the late GEO. WATSON BUCK, M.I.C.E. Third Edition, revised by his Son, J. H. WATSON BUCK, M.I.C.E.; and with the addition of Description to Diagrams for Facilitating the Construction of Oblique Bridges, by W. H. BARLOW, M.I.C.E. Royal 8vo, 12*s.* cloth.

"The standard text book for all engineers regarding skew arches."—*Engineer.*

Gas and Gasworks.

THE CONSTRUCTION OF GASWORKS AND THE MANUFACTURE AND DISTRIBUTION OF COAL-GAS. Originally written by S. HUGHES, C.E. Sixth Edition. Re-written and enlarged, by W. RICHARDS, C.E. 12mo, 5*s.* cloth.

Waterworks for Cities and Towns.

WATERWORKS for the SUPPLY of CITIES and TOWNS, with a Description of the Principal Geological Formations of England as influencing Supplies of Water. By S. HUGHES. 4*s.* 6*d.* cloth.

Locomotive-Engine Driving.

LOCOMOTIVE-ENGINE DRIVING: a Practical Manual for Engineers in charge of Locomotive Engines. By MICHAEL REYNOLDS, M.S.E. Fifth Edition. Comprising A KEY TO THE LOCOMOTIVE ENGINE. With Illustrations. Cr. 8vo, 4*s.* 6*d.* cl.

"Mr. Reynolds has supplied a want, and has supplied it well."—*Engineer.*

The Engineer, Fireman, and Engine-Boy.

THE MODEL LOCOMOTIVE ENGINEER, FIREMAN, AND ENGINE-BOY. By M. REYNOLDS. Crown 8vo, 4*s.* 6*d.*

Stationary Engine Driving.

STATIONARY ENGINE DRIVING. A Practical Manual for Engineers in Charge of Stationary Engines. By MICHAEL REYNOLDS. Second Edition, Revised and Enlarged. With Plates and Woodcuts. Crown 8vo, 4*s.* 6*d.* cloth. [*Just published.*

Engine-Driving Life.

ENGINE-DRIVING LIFE; or Stirring Adventures and Incidents in the Lives of Locomotive Engine-Drivers. By MICHAEL REYNOLDS. Crown 8vo, 2*s.* cloth.

Continuous Railway Brakes.

CONTINUOUS RAILWAY BRAKES. A Practical Treatise on the several Systems in Use in the United Kingdom; their Construction and Performance. With copious Illustrations and numerous Tables. By MICHAEL REYNOLDS. Large Crown 8vo, 9*s.* cloth. [*Just published.*

Construction of Iron Beams, Pillars, &c.

IRON AND HEAT; exhibiting the Principles concerned in the construction of Iron Beams, Pillars, and Bridge Girders, and the Action of Heat in the Smelting Furnace. By J. ARMOUR, C.E. 3s.

Fire Engineering.

FIRES, FIRE-ENGINES, AND FIRE BRIGADES. With a History of Fire-Engines, their Construction, Use, and Management; Remarks on Fire-Proof Buildings, and the Preservation of Life from Fire; Statistics of the Fire Appliances in English Towns; Foreign Fire Systems; Hints on Fire Brigades, &c., &c. By CHARLES F. T. YOUNG, C.E. With numerous Illustrations, handsomely printed, 544 pp., demy 8vo, 1*l.* 4*s.* cloth.

"We can most heartily commend this book."—*Engineering.*

"Mr. Young's book on 'Fire Engines and Fire Brigades' contains a mass of information, which has been collected from a variety of sources. The subject is so intensely interesting and useful that it demands consideration."—*Building News.*

Trigonometrical Surveying.

AN OUTLINE OF THE METHOD OF CONDUCTING A TRIGONOMETRICAL SURVEY, for the Formation of Geographical and Topographical Maps and Plans, Military Reconnaissance, Levelling, &c., with the most useful Problems in Geodesy and Practical Astronomy. By LIEUT.-GEN. FROME, R.E., late Inspector-General of Fortifications. Fourth Edition, Enlarged, and partly Re-written. By CAPTAIN CHARLES WARREN, R.E. With 19 Plates and 115 Woodcuts, royal 8vo, 16*s.* cloth.

Tables of Curves.

TABLES OF TANGENTIAL ANGLES and MULTIPLES for setting out Curves from 5 to 200 Radius. By ALEXANDER BEAZELEY, M. Inst. C.E. Second Edition. Printed on 48 Cards, and sold in a cloth box, waistcoat-pocket size, 3*s.* 6*d.*

"Each table is printed on a small card, which, being placed on the theodolite, leaves the hands free to manipulate the instrument."—*Engineer.*

"Very handy: a man may know that all his day's work must fall on two of these cards, which he puts into his own card-case, and leaves the rest behind."—[*Athenæum.*

Engineering Fieldwork.

THE PRACTICE OF ENGINEERING FIELDWORK, applied to Land and Hydraulic, Hydrographic, and Submarine Surveying and Levelling. Second Edition, revised, with considerable additions, and a Supplement on WATERWORKS, SEWERS, SEWAGE, and IRRIGATION. By W. DAVIS HASKOLL, C.E. Numerous folding Plates. In 1 Vol., demy 8vo, 1*l.* 5*s.*, cl. boards.

Large Tunnel Shafts.

THE CONSTRUCTION OF LARGE TUNNEL SHAFTS. A Practical and Theoretical Essay. By J. H. WATSON BUCK, M. Inst. C.E., Resident Engineer, London and North-Western Railway. Illustrated with Folding Plates. Royal 8vo, 12*s.* cloth.

"Many of the methods given are of extreme practical value to the mason, and the observations on the form of arch, the rules for ordering the stone, and the construction of the templates, will be found of considerable use. We commend the book to the engineering profession, and to all who have to build similar shafts."—*Building News.*

"Will be regarded by civil engineers as of the utmost value, and calculated to save much time and obviate many mistakes."—*Colliery Guardian.*

Survey Practice.

AID TO SURVEY PRACTICE: for Reference in Surveying, Levelling, Setting-out and in Route Surveys of Travellers by Land and Sea. With Tables, Illustrations, and Records. By LOWIS D'A. JACKSON, A.-M.I.C.E. Author of "Hydraulic Manual and Statistics," &c. Large crown 8vo, 12*s.* 6*d.*, cloth.

"Mr. Jackson has produced a valuable *vade-mecum* for the surveyor. We can recommend this book as containing an admirable supplement to the teaching of the accomplished surveyor."—*Athenæum.*

"A general text book was wanted, and we are able to speak with confidence of Mr. Jackson's treatise. . . . We cannot recommend to the student who knows something of the mathematical principles of the subject a better course than to fortify his practice in the field under a competent surveyor with a study of Mr. Jackson's useful manual. The field records illustrate every kind of survey, and will be found an essential aid to the student."—*Building News.*

"The author brings to his work a fortunate union of theory and practical experience which, aided by a clear and lucid style of writing, renders the book both a very useful one and very agreeable to read."—*Builder.*

Sanitary Work.

SANITARY WORK IN THE SMALLER TOWNS AND IN VILLAGES. Comprising:—1. Some of the more Common Forms of Nuisance and their Remedies; 2. Drainage; 3. Water Supply. By CHAS. SLAGG, Assoc. Inst. C.E. Crown 8vo, 3*s.* cloth.

"A very useful book, and may be safely recommended. The author has had practical experience in the works of which he treats."—*Builder.*

Locomotives.

LOCOMOTIVE ENGINES, A Rudimentary Treatise on. Comprising an Historical Sketch and Description of the Locomotive Engine. By G. D. DEMPSEY, C.E. With large additions treating of the MODERN LOCOMOTIVE, by D. KINNEAR CLARK, C.E., M.I.C.E., Author of "Tramways, their Construction and Working," &c., &c. With numerous Illustrations. 12mo. 3*s.* 6*d.* cloth boards.

"The student cannot fail to profit largely by adopting this as his preliminary textbook."—*Iron and Coal Trades Review.*

"Seems a model of what an elementary technical book should be."—*Academy.*

Fuels and their Economy.

FUEL, its Combustion and Economy; consisting of an Abridgment of "A Treatise on the Combustion of Coal and the Prevention of Smoke." By C. W. WILLIAMS, A.I.C.E. With extensive additions on Recent Practice in the Combustion and Economy of Fuel—Coal, Coke, Wood, Peat, Petroleum, &c.; by D. KINNEAR CLARK, C.E., M.I.C.E. Second Edition, revised. With numerous Illustrations. 12mo. 4*s.* cloth boards.

"Students should buy the book and read it, as one of the most complete and satisfactory treatises on the combustion and economy of fuel to be had."—*Engineer.*

Roads and Streets.

THE CONSTRUCTION OF ROADS AND STREETS. In Two Parts. I. The Art of Constructing Common Roads. By HENRY LAW, C.E. Revised and Condensed. II. Recent Practice in the Construction of Roads and Streets: including Pavements of Stone, Wood, and Asphalte. By D. KINNEAR CLARK, C.E., M.I.C.E. Second Edit., revised. 12mo, 5*s.* cloth.

"A book which every borough surveyor and engineer must possess, and which will be of considerable service to architects, builders, and property owners generally."—*Building News.*

Sewing Machine (The).

SEWING MACHINERY; being a Practical Manual of the Sewing Machine, comprising its History and Details of its Construction, with full Technical Directions for the Adjusting of Sewing Machines. By J. W. URQUHART, Author of "Electro Plating: a Practical Manual;" "Electric Light: its Production and Use." With Numerous Illustrations. 12mo, *2s. 6d.* cloth.

Field-Book for Engineers.

THE ENGINEER'S, MINING SURVEYOR'S, and CONTRACTOR'S FIELD-BOOK. By W. DAVIS HASKOLL, C.E. Consisting of a Series of Tables, with Rules, Explanations of Systems, and Use of Theodolite for Traverse Surveying and Plotting the Work with minute accuracy by means of Straight Edge and Set Square only; Levelling with the Theodolite, Casting out and Reducing Levels to Datum, and Plotting Sections in the ordinary manner; Setting out Curves with the Theodolite by Tangential Angles and Multiples with Right and Left-hand Readings of the Instrument; Setting out Curves without Theodolite on the System of Tangential Angles by Sets of Tangents and Offsets; and Earthwork Tables to 80 feet deep, calculated for every 6 inches in depth. With numerous Woodcuts. 4th Edition, enlarged. Cr. 8vo. *12s.* cloth.

"The book is very handy, and the author might have added that the separate tables of sines and tangents to every minute will make it useful for many other purposes, the genuine traverse tables existing all the same."—*Athenæum.*

"Cannot fail, from its portability and utility, to be extensively patronised by the engineering profession."—*Mining Journal.*

Earthwork, Measurement and Calculation of.

A MANUAL on EARTHWORK. By ALEX. J. S. GRAHAM, C.E., Resident Engineer, Forest of Dean Central Railway. With numerous Diagrams. 18mo, *2s. 6d.* cloth.

"As a really handy book for reference, we know of no work equal to it; and the railway engineers and others employed in the measurement and calculation of earthwork will find a great amount of practical information very admirably arranged, and available for general or rough estimates, as well as for the more exact calculations required in the engineers' contractor's offices."—*Artizan.*

Drawing for Engineers, &c.

THE WORKMAN'S MANUAL OF ENGINEERING DRAWING. By JOHN MAXTON, Instructor in Engineering Drawing, Royal Naval College, Greenwich, formerly of R. S. N. A., South Kensington. Fourth Edition, carefully revised. With upwards of 300 Plates and Diagrams. 12mo, cloth, strongly bound, *4s.*

"A copy of it should be kept for reference in every drawing office."—*Engineering.*

"Indispensable for teachers of engineering drawing."—*Mechanics' Magazine.*

Weale's Dictionary of Terms.

A DICTIONARY of TERMS used in ARCHITECTURE, BUILDING, ENGINEERING, MINING, METALLURGY, ARCHÆOLOGY, the FINE ARTS, &c. By JOHN WEALE. Fifth Edition, revised by ROBERT HUNT, F.R.S., Keeper of Mining Records, Editor of "Ure's Dictionary of Arts." 12mo, *6s.* cl. bds.

"The best small technological dictionary in the language."—*Architect.*

"The absolute accuracy of a work of this character can only be judged of after extensive consultation, and from our examination it appears very correct and very complete."—*Mining Journal.*

MINING, METALLURGY, ETC.

Coal and Iron.

THE COAL AND IRON INDUSTRIES OF THE UNITED KINGDOM: comprising a Description of the Coal Fields, and of the Principal Seams of Coal, with returns of their Produce and its Distribution, and Analyses of Special Varieties. Also, an Account of the occurrence of Iron Ores in Veins or Seams; Analyses of each Variety; and a History of the Rise and Progress of Pig Iron Manufacture since the year 1740, exhibiting the economies introduced in the Blast Furnaces for its Production and Improvement. By RICHARD MEADE, Assistant Keeper of Mining Records. With Maps of the Coal Fields and Ironstone Deposits of the United Kingdom. 8vo., £1 8s. cloth. [*Just published.*

Metalliferous Minerals and Mining.

A TREATISE ON METALLIFEROUS MINERALS AND MINING. By D.C. DAVIES, F.G.S., author of "A Treatise on Slate and Slate Quarrying." With numerous wood engravings. Second Edition, revised. Cr. 8vo. 12s. 6d. cloth.

"Without question, the most exhaustive and the most practically useful work we have seen; the amount of information given is enormous, and it is given concisely and intelligibly."—*Mining Journal.*

Slate and Slate Quarrying.

A TREATISE ON SLATE AND SLATE QUARRYING, Scientific, Practical, and Commercial. By D. C. DAVIES, F.G.S., Mining Engineer, &c. With numerous Illustrations and Folding Plates. Second Edition, carefully revised. 12mo, 3s. 6d. cloth boards.

"Mr. Davies has written a useful and practical hand-book on an important industry, with all the conditions and details of which he appears familiar."—*Engineering.*

Metallurgy of Iron.

A TREATISE ON THE METALLURGY OF IRON: containing Outlines of the History of Iron Manufacture, Methods of Assay, and Analyses of Iron Ores, Processes of Manufacture of Iron and Steel, &c. By H. BAUERMAN, F.G.S. Fifth Edition, Revised and greatly Enlarged. With Numerous Illustrations. 12mo. 5s. 6d., cloth boards. [*Just published.*

Manual of Mining Tools.

MINING TOOLS. For the use of Mine Managers, Agents, Mining Students, &c. By WILLIAM MORGANS. Volume of Text. 12mo, 3s. With an Atlas of Plates, containing 235 Illustrations. 4to, 6s. Together, 9s. cloth boards.

Mining, Surveying and Valuing.

THE MINERAL SURVEYOR AND VALUER'S COMPLETE GUIDE, comprising a Treatise on Improved Mining Surveying, with new Traverse Tables; and Descriptions of Improved Instruments; also an Exposition of the Correct Principles of Laying out and Valuing Home and Foreign Iron and Coal Mineral Properties. By WILLIAM LINTERN, Mining and Civil Engineer. With four Plates of Diagrams, Plans, &c., 12mo, 4s. cloth.

*** The above, bound with THOMAN'S TABLES. (See page 20.) Price 7s. 6d. cloth.

Coal and Coal Mining.

COAL AND COAL MINING: a Rudimentary Treatise on. By WARINGTON W. SMYTH, M.A., F.R.S., &c., Chief Inspector of the Mines of the Crown. Fifth edition, revised and corrected. 12mo, with numerous Illustrations, 4*s.* cloth boards.

"Every portion of the volume appears to have been prepared with much care, and as an outline is given of every known coal-field in this and other countries, as well as of the two principal methods of working, the book will doubtless interest a very large number of readers."—*Mining Journal.*

Underground Pumping Machinery.

MINE DRAINAGE; being a Complete and Practical Treatise on Direct-Acting Underground Steam Pumping Machinery, with a Description of a large number of the best known Engines, their General Utility and the Special Sphere of their Action, the Mode of their Application, and their merits compared with other forms of Pumping Machinery. By STEPHEN MICHELL, Joint-Author of "The Cornish System of Mine Drainage." 8vo, 15*s.* cloth.

NAVAL ARCHITECTURE, NAVIGATION, ETC.

Pocket Book for Naval Architects & Shipbuilders.

THE NAVAL ARCHITECT'S AND SHIPBUILDER'S POCKET BOOK OF FORMULÆ, RULES, AND TABLES AND MARINE ENGINEER'S AND SURVEYOR'S HANDY BOOK OF REFERENCE. By CLEMENT MACKROW, M. Inst. N. A., Naval Draughtsman. Second Edition, revised. With numerous Diagrams. Fcap., 12*s.* 6*d.*, strongly bound in leather.

"Should be used by all who are engaged in the construction or design of vessels."—*Engineer.*

"There is scarcely a subject on which a naval architect or shipbuilder can require to refresh his memory which will not be found within the covers of Mr. Mackrow's book."—*English Mechanic.*

"Mr. Mackrow has compressed an extraordinary amount of information into this useful volume."—*Athenæum.*

Grantham's Iron Ship-Building.

ON IRON SHIP-BUILDING; with Practical Examples and Details. Fifth Edition. Imp. 4to, boards, enlarged from 24 to 40 Plates (21 quite new), including the latest Examples. Together with separate Text, also considerably enlarged, 12mo, cloth limp. By JOHN GRANTHAM, M. Inst. C.E., &c. 2*l.* 2*s.* complete.

"Mr. Grantham's work is of great interest. It will, we are confident, command an extensive circulation among shipbuilders in general. By order of the Board of Admiralty, the work will form the text-book on which the examination in iron ship-building of candidates for promotion in the dockyards will be mainly based."—*Engineering.*

Pocket-Book for Marine Engineers.

A POCKET-BOOK OF USEFUL TABLES AND FORMULÆ FOR MARINE ENGINEERS. By FRANK PROCTOR, A.I.N.A. Third Edition. Royal 32mo, leather, gilt edges, 4*s.*

"A most useful companion to all marine engineers."—*United Service Gazette.*

"Scarcely anything required by a naval engineer appears to have been forgotten."—*Iron.*

Light-Houses.

EUROPEAN LIGHT-HOUSE SYSTEMS; being a Report of a Tour of Inspection made in 1873. By Major GEORGE H. ELLIOT, Corps of Engineers, U.S.A. Illustrated by 51 Engravings and 31 Woodcuts in the Text. 8vo, 21*s.* cloth.

Surveying (Land and Marine).

LAND AND MARINE SURVEYING, in Reference to the Preparation of Plans for Roads and Railways, Canals, Rivers, Towns' Water Supplies, Docks and Harbours; with Description and Use of Surveying Instruments. By W. DAVIS HASKOLL, C.E. With 14 folding Plates, and numerous Woodcuts. 8vo, 12*s.* 6*d.* cloth.

"A most useful and well arranged book for the aid of a student."—*Builder.*

"Of the utmost practical utility, and may be safely recommended to all students who aspire to become clean and expert surveyors."—*Mining Journal.*

Storms.

STORMS: their Nature, Classification, and Laws, with the Means of Predicting them by their Embodiments, the Clouds. By WILLIAM BLASIUS. Crown 8vo, 10*s.* 6*d.* cloth boards.

Rudimentary Navigation.

THE SAILOR'S SEA-BOOK: a Rudimentary Treatise on Navigation. By JAMES GREENWOOD, B.A. New and enlarged edition. By W. H. ROSSER. 12mo, 3*s.* cloth boards.

Mathematical and Nautical Tables.

MATHEMATICAL TABLES, for Trigonometrical, Astronomical, and Nautical Calculations; to which is prefixed a Treatise on Logarithms. By HENRY LAW, C.E. Together with a Series of Tables for Navigation and Nautical Astronomy. By J. R. YOUNG, formerly Professor of Mathematics in Belfast College. New Edition. 12mo, 4*s.* cloth boards.

Navigation (Practical), with Tables.

PRACTICAL NAVIGATION: consisting of the Sailor's Sea-Book, by JAMES GREENWOOD and W. H. ROSSER; together with the requisite Mathematical and Nautical Tables for the Working of the Problems. By HENRY LAW, C.E., and Professor J. R. YOUNG. Illustrated with numerous Wood Engravings and Coloured Plates. 12mo, 7*s.* strongly half bound in leather.

WEALE'S RUDIMENTARY SERIES.

The following books in Naval Architecture, etc., are published in the above series.

MASTING, MAST-MAKING, AND RIGGING OF SHIPS. By ROBERT KIPPING, N.A. Fourteenth Edition. 12mo, 2*s.* 6*d.* cloth.

SAILS AND SAIL-MAKING. Tenth Edition, enlarged. By ROBERT KIPPING, N.A. Illustrated. 12mo, 3*s.* cloth boards.

NAVAL ARCHITECTURE. By JAMES PEAKE. Fourth Edition, with Plates and Diagrams. 12mo, 4*s.* cloth boards.

MARINE ENGINES, AND STEAM VESSELS. By ROBERT MURRAY, C.E. Seventh Edition. 12mo, 3*s.* 6*d.* cloth boards.

ARCHITECTURE, BUILDING, ETC.

Construction.

THE SCIENCE of BUILDING: An Elementary Treatise on the Principles of Construction. By E. WYNDHAM TARN, M.A., Architect. With 58 Wood Engravings. Second Edition, revised and enlarged, including an entirely new chapter on the Nature of Lightning, and the Means of Protecting Buildings from its Violence. Crown 8vo, 7*s.* 6*d.* cloth.

"A very valuable book, which we strongly recommend to all students."—*Builder.*
"No architectural student should be without this hand-book."—*Architect.*

Civil and Ecclesiastical Building.

A BOOK ON BUILDING, CIVIL AND ECCLESIASTICAL, Including CHURCH RESTORATION. By Sir EDMUND BECKETT, Bart., LL.D., Q.C., F.R.A.S. Author of "Clocks and Watches and Bells," &c. 12mo, 5*s.* cloth boards.

"A book which is always amusing and nearly always instructive. We are able very cordially to recommend all persons to read it for themselves."—*Times.*
"We commend the book to the thoughtful consideration of all who are interested in the building art."—*Builder.*

Villa Architecture.

A HANDY BOOK of VILLA ARCHITECTURE; being a Series of Designs for Villa Residences in various Styles. With Detailed Specifications and Estimates. By C. WICKES, Architect, Author of "The Spires and Towers of the Mediæval Churches of England," &c. 30 Plates, 4to, half morocco, gilt edges, 1*l.* 1*s.*

*** Also an Enlarged edition of the above. 61 Plates, with Detailed Specifications, Estimates, &c. 2*l.* 2*s.* half morocco.

Useful Text-Book for Architects.

THE ARCHITECT'S GUIDE: Being a Text-book of Useful Information for Architects, Engineers, Surveyors, Contractors, Clerks of Works, &c. By F. ROGERS. Cr. 8vo, 6*s.* cloth.

"As a text-book of useful information for architects, engineers, surveyors, &c., it would be hard to find a handier or more complete little volume."—*Standard.*

The Young Architect's Book.

HINTS TO YOUNG ARCHITECTS. By G. WIGHTWICK. New Edition. By G. H. GUILLAUME. 12mo, cloth, 4*s.*

"Will be found an acquisition to pupils, and a copy ought to be considered as necessary a purchase as a box of instruments."—*Architect.*

Drawing for Builders and Students.

PRACTICAL RULES ON DRAWING for the OPERATIVE BUILDER and YOUNG STUDENT in ARCHITECTURE. By GEORGE PYNE. With 14 Plates, 4to, 7*s.* 6*d.* boards.

Boiler and Factory Chimneys.

BOILER AND FACTORY CHIMNEYS; their Draught-power and Stability, with a chapter on Lightning Conductors. By ROBERT WILSON, C.E. Crown 8vo, 3*s.* 6*d.* cloth.

Taylor and Cresy's Rome.

THE ARCHITECTURAL ANTIQUITIES OF ROME. By the late G. L. TAYLOR, Esq., F.S.A., and EDWARD CRESY, Esq. New Edition, Edited by the Rev. ALEXANDER TAYLOR, M.A. (son of the late G. L. Taylor, Esq.) This is the only book which gives on a large scale, and with the precision of architectural measurement, the principal Monuments of Ancient Rome in plan, elevation, and detail. Large folio, with 130 Plates, half-bound, 3*l.* 3*s.*

*** Originally published in two volumes, folio, at 18*l.* 18*s.*

Vitruvius' Architecture.

THE ARCHITECTURE OF MARCUS VITRUVIUS POLLIO. Translated by JOSEPH GWILT, F.S.A., F.R.A.S. Numerous Plates. 12mo, cloth limp, 5*s.*

Ancient Architecture.

RUDIMENTARY ARCHITECTURE (ANCIENT); comprising VITRUVIUS, translated by JOSEPH GWILT, F.S.A., &c., with 23 fine plates; and GRECIAN ARCHITECTURE. By the EARL of ABERDEEN; 12mo, 6*s.*, half-bound.

*** *The only edition of VITRUVIUS procurable at a moderate price.*

Modern Architecture.

RUDIMENTARY ARCHITECTURE (MODERN); comprising THE ORDERS OF ARCHITECTURE. By W. H. LEEDS, Esq.; The STYLES of ARCHITECTURE of VARIOUS COUNTRIES. By T. TALBOT BURY; and The PRINCIPLES of DESIGN in ARCHITECTURE. By E. L. GARBETT. Numerous illustrations, 12mo, 6*s.* half-bound.

Civil Architecture.

A TREATISE on THE DECORATIVE PART of CIVIL ARCHITECTURE. By Sir WILLIAM CHAMBERS, F.R.S. With Illustrations, Notes, and an Examination of Grecian Architecture. By JOSEPH GWILT, F.S.A. Revised and edited by W. H. LEEDS. 66 Plates, 4to, 21*s.* cloth.

House Painting.

HOUSE PAINTING, GRAINING, MARBLING, AND SIGN WRITING: a Practical Manual of. With 9 Coloured Plates of Woods and Marbles, and nearly 150 Wood Engravings. By ELLIS A. DAVIDSON. Third Edition, Revised. 12mo, 6*s.* cloth.

Plumbing.

PLUMBING; a Text-book to the Practice of the Art or Craft of the Plumber. With chapters upon House-drainage, embodying the latest Improvements. By W. P. BUCHAN, Sanitary Engineer. Fourth Edition, Revised and much enlarged, with 300 illustrations. 12mo. 4*s.* cloth. [*Just published.*

Joints used in Building, Engineering, &c.

THE JOINTS MADE AND USED BY BUILDERS in the construction of various kinds of Engineering and Architectural works, with especial reference to those wrought by artificers in erecting and finishing Habitable Structures. By W. J. CHRISTY, Architect. With 160 Illustrations. 12mo, 3*s.* 6*d.* cloth boards. [*Just published.*

Handbook of Specifications.

THE HANDBOOK OF SPECIFICATIONS; or, Practical Guide to the Architect, Engineer, Surveyor, and Builder, in drawing up Specifications and Contracts for Works and Constructions. Illustrated by Precedents of Buildings actually executed by eminent Architects and Engineers. By Professor THOMAS L. DONALDSON, M.I.B.A. New Edition, in One large volume, 8vo, with upwards of 1000 pages of text, and 33 Plates, cloth, 1*l.* 11*s.* 6*d.*

"In this work forty-four specifications of executed works are given. . . . Donaldson's Handbook of Specifications must be bought by all architects."—*Builder.*

Specifications for Practical Architecture.

SPECIFICATIONS FOR PRACTICAL ARCHITECTURE: A Guide to the Architect, Engineer, Surveyor, and Builder; with an Essay on the Structure and Science of Modern Buildings. By FREDERICK ROGERS, Architect. 8vo, 15*s.* cloth.

*** A volume of specifications of a practical character being greatly required, and the old standard work of Alfred Bartholomew being out of print, the author, on the basis of that work, has produced the above.—*Extract from Preface.*

Designing, Measuring, and Valuing.

THE STUDENT'S GUIDE to the PRACTICE of MEASURING and VALUING ARTIFICERS' WORKS; containing Directions for taking Dimensions, Abstracting the same, and bringing the Quantities into Bill, with Tables of Constants, and copious Memoranda for the Valuation of Labour and Materials in the respective Trades of Bricklayer and Slater, Carpenter and Joiner, Painter and Glazier, Paperhanger, &c. With 43 Plates and Woodcuts. Originally edited by EDWARD DOBSON, Architect. New Edition, re-written, with Additions on Mensuration and Construction, and useful Tables for facilitating Calculations and Measurements. By E. WYNDHAM TARN, M.A., 8vo, 10*s.* 6*d.* cloth.

"Well fulfils the promise of its title-page. Mr. Tarn's additions and revisions have much increased the usefulness of the work."—*Engineering.*

Beaton's Pocket Estimator.

THE POCKET ESTIMATOR FOR THE BUILDING TRADES, being an easy method of estimating the various parts of a Building collectively, more especially applied to Carpenters' and Joiners' work. By A. C. BEATON. Second Edition. Waistcoat-pocket size. 1*s.* 6*d.*

Beaton's Builders' and Surveyors' Technical Guide.

THE POCKET TECHNICAL GUIDE AND MEASURER FOR BUILDERS AND SURVEYORS: containing a Complete Explanation of the Terms used in Building Construction, Memoranda for Reference, Technical Directions for Measuring Work in all the Building Trades, &c. By A. C. BEATON. 1*s.* 6*d.*

The House-Owner's Estimator.

THE HOUSE-OWNER'S ESTIMATOR; or, What will it Cost to Build, Alter, or Repair? A Price-Book for Unprofessional People, Architectural Surveyors, Builders, &c. By the late JAMES D. SIMON. Edited by F. T. W. MILLER, A.R.I.B.A. Third Edition, Revised. Crown 8vo, 3*s.* 6*d.*, cloth.

"In two years it will repay its cost a hundred times over."—*Field*

Cement.

PORTLAND CEMENT FOR USERS. By HENRY FAIJA, A.M. Inst. C.E., with Illustrations. Crown 8vo. 3s. 6d. cloth.

"A useful compendium of results for the builder and architect."—*Building News.*

Builder's and Contractor's Price Book.

LOCKWOOD & CO.'S BUILDER'S AND CONTRACTOR'S PRICE BOOK, containing the latest prices of all kinds of Builders' Materials and Labour, and of all Trades connected with Building, &c. Revised by F. T. W. MILLER, A.R.I.B.A. Half-bound, 4s.

CARPENTRY, TIMBER, ETC.

Tredgold's Carpentry, new and cheaper Edition.

THE ELEMENTARY PRINCIPLES OF CARPENTRY: a Treatise on the Pressure and Equilibrium of Timber Framing, the Resistance of Timber, and the Construction of Floors, Arches, Bridges, Roofs, Uniting Iron and Stone with Timber, &c. To which is added an Essay on the Nature and Properties of Timber, &c., with Descriptions of the Kinds of Wood used in Building; also numerous Tables of the Scantlings of Timber for different purposes, the Specific Gravities of Materials, &c. By THOMAS TREDGOLD, C.E. Edited by PETER BARLOW, F.R.S. Fifth Edition, corrected and enlarged. With 64 Plates, Portrait of the Author, and Woodcuts. 4to, published at 2l. 2s., reduced to 1l. 5s. cloth.

"Ought to be in every architect's and every builder's library, and those who do not already possess it ought to avail themselves of the new issue."—*Builder.*

"A work whose monumental excellence must commend it wherever skilful carpentry is concerned. The Author's principles are rather confirmed than impaired by time. The additional plates are of great intrinsic value."—*Building News.*

Grandy's Timber Tables.

THE TIMBER IMPORTER'S, TIMBER MERCHANT'S, & BUILDER'S STANDARD GUIDE. By R. E. GRANDY. 2nd Edition. Carefully revised and corrected. 12mo, 3s. 6d. cloth.

"Everything it pretends to be: built up gradually, it leads one from a forest to a treenail, and throws in, as a makeweight, a host of material concerning bricks, columns, cisterns, &c.—all that the class to whom it appeals requires."—*English Mechanic.*

Timber Freight Book.

THE TIMBER IMPORTERS' AND SHIPOWNERS' FREIGHT BOOK: Being a Comprehensive Series of Tables for the Use of Timber Importers, Captains of Ships, Shipbrokers, Builders, and Others. By W. RICHARDSON. Crown 8vo, 6s.

Tables for Packing-Case Makers.

PACKING-CASE TABLES; showing the number of Superficial Feet in Boxes or Packing-Cases, from six inches square and upwards. By W. RICHARDSON. Oblong 4to, 3s. 6d. cloth.

"Invaluable labour-saving tables."—*Ironmonger.*

Carriage Building, &c.

COACH BUILDING: A Practical Treatise, Historical and Descriptive, containing full information of the various Trades and Processes involved, with Hints on the proper keeping of Carriages, &c. 57 Illustrations. By JAMES W. BURGESS. 12mo, 3s. cloth.

Horton's Measurer.

THE COMPLETE MEASURER; setting forth the Measurement of Boards, Glass, &c.; Unequal-sided, Square-sided, Octagonal-sided, Round Timber and Stone, and Standing Timber. With just allowances for the bark in the respective species of trees, and proper deductions for the waste in hewing the trees, &c.; also a Table showing the solidity of hewn or eight-sided timber, or of any octagonal-sided column. By RICHARD HORTON. Fourth Edition, with considerable and valuable additions, 12mo, strongly bound in leather, 5*s.*

Horton's Underwood and Woodland Tables.

TABLES FOR PLANTING AND VALUING UNDERWOOD AND WOODLAND; also Lineal, Superficial, Cubical, and Decimal Tables, &c. By R. HORTON. 12mo, 2*s.* leather.

Nicholson's Carpenter's Guide.

THE CARPENTER'S NEW GUIDE; or, BOOK of LINES for CARPENTERS: comprising all the Elementary Principles essential for acquiring a knowledge of Carpentry. Founded on the late PETER NICHOLSON'S standard work. A new Edition, revised by ARTHUR ASHPITEL, F.S.A., together with Practical Rules on Drawing, by GEORGE PYNE. With 74 Plates, 4to, 1*l.* 1*s.* cloth.

Dowsing's Timber Merchant's Companion.

THE TIMBER MERCHANT'S AND BUILDER'S COMPANION; containing New and Copious Tables of the Reduced Weight and Measurement of Deals and Battens, of all sizes, from One to a Thousand Pieces, also the relative Price that each size bears per Lineal Foot to any given Price per Petersburgh Standard Hundred, &c., &c. Also a variety of other valuable information. By WILLIAM DOWSING, Timber Merchant. Third Edition, Revised. Crown 8vo, 3*s.* cloth.

"Everything is as concise and clear as it can possibly be made. There can be no doubt that every timber merchant and builder ought to possess it."—*Hull Advertiser.*

Practical Timber Merchant.

THE PRACTICAL TIMBER MERCHANT, being a Guide for the use of Building Contractors, Surveyors, Builders, &c., comprising useful Tables for all purposes connected with the Timber Trade, Essay on the Strength of Timber, Remarks on the Growth of Timber, &c. By W. RICHARDSON. Fcap. 8vo, 3*s.* 6*d.* cl.

Woodworking Machinery.

WOODWORKING MACHINERY; its Rise, Progress, and Construction. With Hints on the Management of Saw Mills and the Economical Conversion of Timber. Illustrated with Examples of Recent Designs by leading English, French, and American Engineers. By M. POWIS BALE, M.I.M.E. Large crown 8vo, 12*s.* 6*d.* cloth.

"Mr. Bale is evidently an expert on the subject, and he has collected so much information that his book is all-sufficient for builders and others engaged in the conversion of timber."—*Architect.*

"The most comprehensive compendium of wood-working machinery we have seen. The author is a thorough master of his subject."—*Building News.*

"It should be in the office of every wood-working factory."—*English Mechanic.*

MECHANICS, ETC.

Turning.

LATHE-WORK: a Practical Treatise on the Tools, Appliances, and Processes employed in the Art of Turning. By PAUL N. HASLUCK. With Illustrations drawn by the Author. Crown 8vo, 5*s*.

"Evidently written from personal experience, and gives a large amount of just that sort of information which beginners at the lathe require."—*Builder*.

Mechanic's Workshop Companion.

THE OPERATIVE MECHANIC'S WORKSHOP COMPANION, and THE SCIENTIFIC GENTLEMAN'S PRACTICAL ASSISTANT. By W. TEMPLETON. 13th Edit., with Mechanical Tables for Operative Smiths, Millwrights, Engineers, &c.; and an Extensive Table of Powers and Roots, 12mo, 5*s*. bound.

"Admirably adapted to the wants of a very large class. It has met with great success in the engineering workshop, as we can testify; and there are a great many men who, in a great measure, owe their rise in life to this little work."—*Building News*.

Engineer's and Machinist's Assistant.

THE ENGINEER'S, MILLWRIGHT'S, and MACHINIST'S PRACTICAL ASSISTANT; comprising a Collection of Useful Tables, Rules, and Data. By WM. TEMPLETON. 18mo, 2*s*. 6*d*.

Smith's Tables for Mechanics, &c.

TABLES, MEMORANDA, and CALCULATED RESULTS, FOR MECHANICS, ENGINEERS, ARCHITECTS, BUILDERS, &c. Selected and Arranged by FRANCIS SMITH. Waistcoat-pocket size, 1*s*. 6*d*., limp leather. [*Just published*.

Boiler Making.

THE BOILER-MAKER'S READY RECKONER. With Examples of Practical Geometry and Templating, for the use of Platers, Smiths, and Riveters. By JOHN COURTNEY, Edited by D. K. CLARK, M. I. C.E. 12mo, 9*s*. half-bd. [*Just published*.

Superficial Measurement.

THE TRADESMAN'S GUIDE TO SUPERFICIAL MEASUREMENT. Tables calculated from 1 to 200 inches in length, by 1 to 108 inches in breadth. By J. HAWKINGS. Fcp. 3*s*. 6*d*. cl.

The High-Pressure Steam Engine.

THE HIGH-PRESSURE STEAM ENGINE. By Dr. ERNST ALBAN. Translated from the German, with Notes, by Dr. POLE, F.R.S. Plates, 8vo, 16*s*. 6*d*. cloth.

Steam Boilers.

A TREATISE ON STEAM BOILERS: their Strength, Construction, and Economical Working. By R. WILSON, C.E. Fifth Edition. 12mo, 6*s*. cloth.

"The best work on boilers which has come under our notice."—*Engineering*.

"The best treatise that has ever been published on steam boilers."—*Engineer*.

Mechanics.

THE HANDBOOK OF MECHANICS. By DIONYSIUS LARDNER, D.C.L. New Edition, Edited and considerably Enlarged, by BENJAMIN LOEWY, F.R.A.S., &c., post 8vo, 6*s*. cloth.

MATHEMATICS, TABLES, ETC.

Metrical Units and Systems, &c.

MODERN METROLOGY: A Manual of the Metrical Units and Systems of the present Century. With an Appendix containing a proposed English System. By LOWIS D'A. JACKSON, A.-M. Inst. C.E., Author of "Aid to Survey Practice," &c. Large Crown 8vo, 12*s.* 6*d.* cloth. [*Just published.*

Gregory's Practical Mathematics.

MATHEMATICS for PRACTICAL MEN; being a Common-place Book of Pure and Mixed Mathematics. Designed chiefly for the Use of Civil Engineers, Architects, and Surveyors. Part I. PURE MATHEMATICS—comprising Arithmetic, Algebra, Geometry, Mensuration, Trigonometry, Conic Sections, Properties of Curves. Part II. MIXED MATHEMATICS—comprising Mechanics in general, Statics, Dynamics, Hydrostatics, Hydrodynamics, Pneumatics, Mechanical Agents, Strength of Materials, &c. By OLINTHUS GREGORY, LL.D., F.R.A.S. Enlarged by H. LAW, C.E. 4th Edition, revised by Prof. J. R. YOUNG. With 13 Plates. 8vo, 1*l.* 1*s.* cloth.

Mathematics as applied to the Constructive Arts.

A TREATISE ON MATHEMATICS AS APPLIED TO THE CONSTRUCTIVE ARTS. Illustrating the various processes of Mathematical Investigation by means of Arithmetical and simple Algebraical Equations and Practical Examples, &c. By FRANCIS CAMPIN, C.E. 12mo, 3*s.* 6*d.* cloth. [*Just published.*

Geometry for the Architect, Engineer, &c.

PRACTICAL GEOMETRY, for the Architect, Engineer, and Mechanic. By E. W. TARN, M.A. With Appendices on Diagrams of Strains and Isometrical projection. Demy 8vo, 9*s.* cloth.

The Metric System.

A SERIES OF METRIC TABLES, in which the British Standard Measures and Weights are compared with those of the Metric System at present in use on the Continent. By C. H. DOWLING, C.E. 2nd Edit., revised and enlarged. 8vo, 10*s.* 6*d.* cl.

Inwood's Tables, greatly enlarged and improved.

TABLES FOR THE PURCHASING of ESTATES, Freehold, Copyhold, or Leasehold; Annuities, Advowsons, &c., and for the Renewing of Leases; also for Valuing Reversionary Estates, Deferred Annuities, &c. By WILLIAM INWOOD. 21st edition, with Tables of Logarithms for the more Difficult Computations of the Interest of Money, &c. By M. FÉDOR THOMAN. 12mo. 8*s.* cloth.

"Those interested in the purchase and sale of estates, and in the adjustment of compensation cases, as well as in transactions in annuities, life insurances, &c., will find the present edition of eminent service."—*Engineering.*

Weights, Measures, Moneys, &c.

MEASURES, WEIGHTS, and MONEYS of all NATIONS, and an Analysis of the Christian, Hebrew, and Mahometan Calendars. Entirely New Edition, Revised and Enlarged. By W. S. B. WOOLHOUSE, F.R.A.S. 12mo, 2*s.* 6*d.* cloth boards.

Compound Interest and Annuities.

THEORY of COMPOUND INTEREST and ANNUITIES; with Tables of Logarithms for the more Difficult Computations of Interest, Discount, Annuities, &c., in all their Applications and Uses for Mercantile and State Purposes. By FÉDOR THOMAN, of the Société Crédit Mobilier, Paris. 3rd Edit., 12mo, 4s. 6d. cl.

Iron and Metal Trades' Calculator.

THE IRON AND METAL TRADES' COMPANION: Being a Calculator containing a Series of Tables upon a new and comprehensive plan for expeditiously ascertaining the value of any goods bought or sold by weight, from 1s. per cwt. to 112s. per cwt., and from one farthing per lb. to 1s. per lb. Each Table extends from one lb. to 100 tons. By T. DOWNIE. 396 pp., 9s., leather.

"Will supply a want, for nothing like it before existed."—*Building News.*

Iron and Steel.

IRON AND STEEL: a Work for the Forge, Foundry, Factory, and Office. Containing Information for Ironmasters and their Stocktakers; Managers of Bar, Rail, Plate, and Sheet Rolling Mills; Iron and Metal Founders; Iron Ship and Bridge Builders; Mechanical, Mining, and Consulting Engineers; Architects, Builders, &c. By CHARLES HOARE, Author of 'The Slide Rule,' &c. Eighth Edition. Oblong 32mo, 6s., leather.

"For comprehensiveness the book has not its equal."—*Iron.*

Comprehensive Weight Calculator.

THE WEIGHT CALCULATOR, being a Series of Tables upon a New and Comprehensive Plan, exhibiting at one Reference the exact Value of any Weight from 1 lb. to 15 tons, at 300 Progressive Rates, from 1 Penny to 168 Shillings per cwt., and containing 186,000 Direct Answers, which, with their Combinations, consisting of a single addition (mostly to be performed at sight), will afford an aggregate of 10,266,000 Answers; the whole being calculated and designed to ensure Correctness and promote Despatch. By HENRY HARBEN, Accountant, Sheffield. New Edition. Royal 8vo, 1*l*. 5*s*., strongly half-bound.

Comprehensive Discount Guide.

THE DISCOUNT GUIDE: comprising several Series of Tables for the use of Merchants, Manufacturers, Ironmongers, and others, by which may be ascertained the exact profit arising from any mode of using Discounts, either in the Purchase or Sale of Goods, and the method of either Altering a Rate of Discount, or Advancing a Price, so as to produce, by one operation, a sum that will realise any required profit after allowing one or more Discounts: to which are added Tables of Profit or Advance from 1¼ to 90 per cent., Tables of Discount from 1¼ to 98¾ per cent., and Tables of Commission, &c., from ⅛ to 10 per cent. By HENRY HARBEN, Accountant. New Edition. Demy 8vo, 1*l*. 5*s*., half-bound.

Mathematical Instruments.

MATHEMATICAL INSTRUMENTS: Their Construction, Adjustment, Testing, and Use; comprising Drawing, Measuring, Optical, Surveying, and Astronomical Instruments. By J. F. HEATHER, M.A. Enlarged Edition. 12mo, 5s. cloth.

SCIENCE AND ART.

Gold and Gold-Working.

THE GOLDSMITH'S HANDBOOK: containing full instructions for the Alloying and Working of Gold. Including the Art of Alloying, Melting, Reducing, Colouring, Collecting and Refining. Chemical and Physical Properties of Gold, with a new System of Mixing its Alloys; Solders, Enamels, &c. By GEORGE E. GEE. Second Edition, enlarged. 12mo, 3*s*. 6*d*. cloth.

"The best work yet printed on its subject for a reasonable price."—*Jeweller.*

"Essentially a practical manual, well adapted to the wants of amateurs and apprentices, containing trustworthy information that only a practical man can supply."—*English Mechanic.*

Silver and Silver Working.

THE SILVERSMITH'S HANDBOOK, containing full Instructions for the Alloying and Working of Silver. Including the different Modes of Refining and Melting the Metal, its Solders, the Preparation of Imitation Alloys, &c. By G. E. GEE. 12mo, 3*s*. 6*d*.

"The chief merit of the work is its practical character. The workers in the trade will speedily discover its merits when they sit down to study it."—*English Mechanic.*

Hall-Marking of Jewellery.

THE HALL-MARKING OF JEWELLERY PRACTICALLY CONSIDERED, comprising an account of all the different Assay Towns of the United Kingdom; with the Stamps at present employed; also the Laws relating to the Standards and Hall-Marks at the various Assay Offices; and a variety of Practical Suggestions concerning the Mixing of Standard Alloys, &c. By GEORGE E. GEE. Crown 8vo, 5*s*. cloth. [*Just published.*

Electro-Plating, &c.

ELECTROPLATING: A Practical Handbook. By J. W. URQUHART, C.E. Crown 8vo, 5*s*. cloth.

"Any ordinarily intelligent person may become an adept in electro-deposition with a very little science indeed, and this is the book to show the way."—*Builder.*

Electrotyping, &c.

ELECTROTYPING: A Practical Manual on the Reproduction and Multiplication of Printing Surfaces and Works of Art by the Electro-deposition of Metals. By J. W. URQUHART, C.E. Crown 8vo, 5*s*. cloth.

"A guide to beginners and those who practise the old and imperfect methods."—*Iron.*

Electro-Plating.

ELECTRO-METALLURGY PRACTICALLY TREATED. By ALEXANDER WATT, F.R.S.S.A. Including the Electro-Deposition of Copper, Silver, Gold, Brass and Bronze, Platinum, Lead, Nickel, Tin, Zinc, Alloys of Metals, Practical Notes, &c., &c. Seventh Edition, Revised and Enlarged, including the most recent Processes. 12mo, 3*s*. 6*d*. cloth.

"From this book both amateur and artisan may learn everything necessary for the successful prosecution of electroplating."—*Iron.*

"A practical treatise for the use of those who desire to work in the art of electro-deposition as a business."—*English Mechanic.*

Dentistry.

MECHANICAL DENTISTRY. A Practical Treatise on the Construction of the various kinds of Artificial Dentures. Comprising also Useful Formulæ, Tables, and Receipts for Gold Plate, Clasps, Solders, etc., etc. By CHARLES HUNTER. Second Edition, Revised; including a new chapter on the use of Celluloid. With over 100 Engravings. Cr. 8vo, *7s. 6d.* cl. [*Just published.*

"An authoritative treatise, which we can strongly recommend to all students."—*Dublin Journal of Medical Science.*

"The best book on the subject with which we are acquainted."—*Medical Press.*

Electricity.

A MANUAL of ELECTRICITY; including Galvanism, Magnetism, Diamagnetism, Electro-Dynamics, Magneto-Electricity, and the Electric Telegraph. By HENRY M. NOAD, Ph.D., F.C.S. Fourth Edition, with 500 Woodcuts. 8vo, *1l. 4s.* cloth.

"The accounts given of electricity and galvanism are not only complete in a scientific sense, but, which is a rarer thing, are popular and interesting."—*Lancet.*

Text-Book of Electricity.

THE STUDENT'S TEXT-BOOK OF ELECTRICITY. By HENRY M. NOAD, Ph.D., F.R.S., &c. New Edition, Revised. With an Introduction and Additional Chapters by W. H. PREECE, M.I.C.E., Vice-President of the Society of Telegraph Engineers, &c. With 470 Illustrations. Crown 8vo, *12s. 6d.* cloth.

"A reflex of the existing state of Electrical Science adapted for students."—W. H. Preece, Esq., vide "Introduction."

"We can recommend Dr. Noad's book for clear style, great range of subject, a good index, and a plethora of woodcuts. Such collections as the present are indispensable."—*Athenæum.*

"An admirable text-book for every student—beginner or advanced—of electricity."—*Engineering.*

"Recommended to students as one of the best text-books on the subject that they can have. Mr. Preece appears to have introduced all the newest inventions in the shape of telegraphic, telephonic, and electric-lighting apparatus."—*English Mechanic.*

"Under the editorial hand of Mr. Preece the late Dr. Noad's text-book of electricity has grown into an admirable handbook."—*Westminster Review.*

Electric Lighting.

ELECTRIC LIGHT: Its Production and Use, embodying plain Directions for the Working of Galvanic Batteries, Electric Lamps, and Dynamo-Electric Machines. By J. W. URQUHART, C.E., Author of "Electroplating." Edited by F. C. WEBB, M.I.C.E., M.S.T.E. With 94 Illustrations. Crown 8vo, *7s. 6d.* cloth.

"The book is by far the best that we have yet met with on the subject."—*Athenæum.*

"An important addition to the literature of the electric light. Students of the subject should not fail to read it."—*Colliery Guardian.*

Lightning, &c.

THE ACTION of LIGHTNING, and the MEANS of DEFENDING LIFE AND PROPERTY FROM ITS EFFECTS. By ARTHUR PARNELL, Major in the Corps of Royal Engineers. 12mo, *7s. 6d.* cloth. [*Just published.*

"Major Parnell has written an original work on a scientific subject of unusual interest; and he has prefaced his arguments by a patient and almost exhaustive citation of the best writers on the subject in the English language."—*Athenæum.*

"The work comprises all that is actually known on the subject."—*Land.*

"Major Parnell's measures are based on the results of experience. A valuable *repertoire* of facts and principles arranged in a scientific form."—*Building News.*

The Alkali Trade—Sulphuric Acid, &c.

A MANUAL OF THE ALKALI TRADE, including the Manufacture of Sulphuric Acid, Sulphate of Soda, and Bleaching Powder. By JOHN LOMAS, Alkali Manufacturer, Newcastle-upon-Tyne and London. With 232 Illustrations and Working Drawings, and containing 386 pages of text. Super-royal 8vo, 2*l*. 12*s*. 6*d*. cloth.

This work provides (1) *a Complete Handbook for intending Alkali and Sulphuric Acid Manufacturers, and for those already in the field who desire to improve their plant, or to become practically acquainted with the latest processes and developments of the trade;* (2) *a Handy Volume which Manufacturers can put into the hands of their Managers and Foremen as a useful guide in their daily rounds of duty.*

SYNOPSIS OF CONTENTS.

Chap. I. Choice of Site and General Plan of Works—II. Sulphuric Acid—III. Recovery of the Nitrogen Compounds, and Treatment of Small Pyrites—IV. The Salt Cake Process—V. Legislation upon the Noxious Vapours Question—VI. The Hargreaves' and Jones' Processes—VII. The Balling Process—VIII. Lixiviation and Salting Down—IX. Carbonating or Finishing—X. Soda Crystals—XI. Refined Alkali—XII. Caustic Soda—XIII. Bi-carbonate of Soda—XIV. Bleaching Powder—XV. Utilisation of Tank Waste—XVI. General Remarks—Four Appendices, treating of Yields, Sulphuric Acid Calculations, Anemometers, and Foreign Legislation upon the Noxious Vapours Question.

"The author has given the fullest, most practical, and, to all concerned in the alkali trade, most valuable mass of information that, to our knowledge, has been published in any language."—*Engineer*.

"This book is written by a manufacturer for manufacturers. The working details of the most approved forms of apparatus are given, and these are accompanied by no less than 232 wood engravings, all of which may be used for the purposes of construction. Every step in the manufacture is very fully described in this manual, and each improvement explained. Everything which tends to introduce economy into the technical details of this trade receives the fullest attention. The book has been produced with great completeness."—*Athenæum*.

"The author is not one of those clever compilers who, on short notice, will 'read up' any conceivable subject, but a practical man in the best sense of the word. We find here not merely a sound and luminous explanation of the chemical principles of the trade, but a notice of numerous matters which have a most important bearing on the successful conduct of alkali works, but which are generally overlooked by even the most experienced technological authors. This most valuable book, which we trust will be generally appreciated, we must pronounce a credit alike to its author and to the enterprising firm who have undertaken its publication."—*Chemical Review*.

Chemical Analysis.

THE COMMERCIAL HANDBOOK of CHEMICAL ANALYSIS; or Practical Instructions for the determination of the Intrinsic or Commercial Value of Substances used in Manufactures, in Trades, and in the Arts. By A. NORMANDY, Author of "Practical Introduction to Rose's Chemistry," and Editor of Rose's "Treatise on Chemical Analysis." *New Edition*. Enlarged, and to a great extent re-written, by HENRY M. NOAD, Ph. D., F.R.S. With numerous Illustrations. Cr. 8vo, 12*s*. 6*d*. cloth.

"We recommend this book to the careful perusal of every one; it may be truly affirmed to be of universal interest, and we strongly recommend it to our readers as a guide, alike indispensable to the housewife as to the pharmaceutical practitioner."—*Medical Times*.

"Essential to the analysts appointed under the new Act. The most recent results are given, and the work is well edited and carefully written."—*Nature*.

Dr. Lardner's Museum of Science and Art.

THE MUSEUM OF SCIENCE AND ART. Edited by DIONYSIUS LARDNER, D.C.L., formerly Professor of Natural Philosophy and Astronomy in University College, London. With upwards of 1200 Engravings on Wood. In 6 Double Volumes. Price £1 1*s*., in a new and elegant cloth binding, or handsomely bound in half morocco, 31*s*. 6*d*.

OPINIONS OF THE PRESS.

"This series, besides affording popular but sound instruction on scientific subjects, with which the humblest man in the country ought to be acquainted, also undertakes that teaching of 'common things' which every well-wisher of his kind is anxious to promote. Many thousand copies of this serviceable publication have been printed, in the belief and hope that the desire for instruction and improvement widely prevails; and we have no fear that such enlightened faith will meet with disappointment."—*Times.*

"A cheap and interesting publication, alike informing and attractive. The papers combine subjects of importance and great scientific knowledge, considerable inductive powers, and a popular style of treatment."—*Spectator.*

"The 'Museum of Science and Art' is the most valuable contribution that has ever been made to the Scientific Instruction of every class of society."—*Sir David Brewster in the North British Review.*

"Whether we consider the liberality and beauty of the illustrations, the charm of the writing, or the durable interest of the matter, we must express our belief that there is hardly to be found among the new books, one that would be welcomed by people of so many ages and classes as a valuable present."—*Examiner.*

⁂ *Separate books formed from the above, suitable for Workmen's Libraries, Science Classes, &c.*

COMMON THINGS EXPLAINED. Containing Air, Earth, Fire, Water, Time, Man, the Eye, Locomotion, Colour, Clocks and Watches, &c. 233 Illustrations, cloth gilt, 5*s*.

THE MICROSCOPE. Containing Optical Images, Magnifying Glasses, Origin and Description of the Microscope, Microscopic Objects, the Solar Microscope, Microscopic Drawing and Engraving, &c. 147 Illustrations, cloth gilt, 2*s*.

POPULAR GEOLOGY. Containing Earthquakes and Volcanoes, the Crust of the Earth, etc. 201 Illustrations, cloth gilt, 2*s*. 6*d*.

POPULAR PHYSICS. Containing Magnitude and Minuteness, the Atmosphere, Meteoric Stones, Popular Fallacies, Weather Prognostics, the Thermometer, the Barometer, Sound, &c. 85 Illustrations, cloth gilt, 2*s*. 6*d*.

STEAM AND ITS USES. Including the Steam Engine, the Locomotive, and Steam Navigation. 89 Illustrations, cloth gilt, 2*s*.

POPULAR ASTRONOMY. Containing How to Observe the Heavens. The Earth, Sun, Moon, Planets. Light, Comets, Eclipses, Astronomical Influences, &c. 182 Illustrations, 4*s*. 6*d*.

THE BEE AND WHITE ANTS: Their Manners and Habits. With Illustrations of Animal Instinct and Intelligence. 135 Illustrations, cloth gilt, 2*s*.

THE ELECTRIC TELEGRAPH POPULARISED. To render intelligible to all who can Read, irrespective of any previous Scientific Acquirements, the various forms of Telegraphy in Actual Operation. 100 Illustrations, cloth gilt, 1*s*. 6*d*.

Dr. Lardner's Handbooks of Natural Philosophy.

⁂ The following five volumes, though each is Complete in itself, and to be purchased separately, form A COMPLETE COURSE OF NATURAL PHILOSOPHY, *and are intended for the general reader who desires to attain accurate knowledge of the various departments of Physical Science, without pursuing them according to the more profound methods of mathematical investigation. The style is studiously popular. It has been the author's aim to supply Manuals such as are required by the Student, the Engineer, the Artisan, and the superior classes in Schools.*

THE HANDBOOK OF MECHANICS. Enlarged and almost rewritten by BENJAMIN LOEWY, F.R.A.S. With 378 Illustrations. Post 8vo, 6*s*. cloth.

"The perspicuity of the original has been retained, and chapters which had become obsolete, have been replaced by others of more modern character. The explanations throughout are studiously popular, and care has been taken to show the application of the various branches of physics to the industrial arts, and to the practical business of life."—*Mining Journal.*

THE HANDBOOK of HYDROSTATICS and PNEUMATICS. New Edition, Revised and Enlarged by BENJAMIN LOEWY, F.R.A.S. With 236 Illustrations. Post 8vo, 5*s*. cloth.

"For those 'who desire to attain an accurate knowledge of physical science without the profound methods of mathematical investigation,' this work is not merely intended, but well adapted."—*Chemical News.*

THE HANDBOOK OF HEAT. Edited and almost entirely Rewritten by BENJAMIN LOEWY, F.R.A.S., etc. 117 Illustrations. Post 8vo, 6*s*. cloth.

"The style is always clear and precise, and conveys instruction without leaving any cloudiness or lurking doubts behind."—*Engineering.*

THE HANDBOOK OF OPTICS. New Edition. Edited by T. OLVER HARDING, B.A. 298 Illustrations. Post 8vo, 5*s*. cloth.

"Written by one of the ablest English scientific writers, beautifully and elaborately illustrated."—*Mechanics' Magazine.*

THE HANDBOOK OF ELECTRICITY, MAGNETISM, and ACOUSTICS. New Edition. Edited by GEO. CAREY FOSTER, B.A., F.C.S. With 400 Illustrations. Post 8vo, 5*s*. cloth.

"The book could not have been entrusted to any one better calculated to preserve the terse and lucid style of Lardner, while correcting his errors and bringing up his work to the present state of scientific knowledge."—*Popular Science Review.*

Dr. Lardner's Handbook of Astronomy.

THE HANDBOOK OF ASTRONOMY. Forming a Companion to the "Handbooks of Natural Philosophy." By DIONYSIUS LARDNER, D.C.L. Fourth Edition. Revised and Edited by EDWIN DUNKIN, F.R.S., Royal Observatory, Greenwich. With 38 Plates and upwards of 100 Woodcuts. In 1 vol., small 8vo, 550 pages, 9*s*. 6*d*., cloth.

"Probably no other book contains the same amount of information in so compendious and well-arranged a form—certainly none at the price at which this is offered to the public."—*Athenæum.*

"We can do no other than pronounce this work a most valuable manual of astronomy, and we strongly recommend it to all who wish to acquire a general—but at the same time correct—acquaintance with this sublime science."—*Quarterly Journal of Science.*

Dr. Lardner's Handbook of Animal Physics.

THE HANDBOOK OF ANIMAL PHYSICS. By DR. LARDNER. With 520 Illustrations. New edition, small 8vo, cloth, 732 pages, 7*s*. 6*d*.

"We have no hesitation in cordially recommending it."—*Educational Times.*

Dr. Lardner's School Handbooks.

NATURAL PHILOSOPHY FOR SCHOOLS. By DR. LARDNER. 328 Illustrations. Sixth Edition. 1 vol. 3s. 6d. cloth.

"Conveys, in clear and precise terms, general notions of all the principal divisions of Physical Science."—*British Quarterly Review.*

ANIMAL PHYSIOLOGY FOR SCHOOLS. By DR. LARDNER. With 190 Illustrations. Second Edition. 1 vol. 3s. 6d. cloth.

"Clearly written, well arranged, and excellently illustrated."—*Gardeners' Chronicle.*

Dr. Lardner's Electric Telegraph.

THE ELECTRIC TELEGRAPH. By DR. LARDNER. New Edition. Revised and Re-written, by E. B. BRIGHT, F.R.A.S. 140 Illustrations. Small 8vo, 2s. 6d. cloth.

"One of the most readable books extant on the Electric Telegraph."—*Eng. Mechanic.*

Mollusca.

A MANUAL OF THE MOLLUSCA; being a Treatise on Recent and Fossil Shells. By Dr. S. P. WOODWARD, A.L.S. With Appendix by RALPH TATE, A.L.S., F.G.S. With numerous Plates and 300 Woodcuts. 3rd Edition. Cr. 8vo, 7s. 6d. cloth.

Geology and Genesis.

THE TWIN RECORDS OF CREATION; or, Geology and Genesis, their Perfect Harmony and Wonderful Concord. By GEORGE W. VICTOR LE VAUX. Fcap. 8vo, 5s. cloth.

"A valuable contribution to the evidences of revelation, and disposes very conclusively of the arguments of those who would set God's Works against God's Word. No real difficulty is shirked, and no sophistry is left unexposed."—*The Rock.*

Science and Scripture.

SCIENCE ELUCIDATIVE OF SCRIPTURE, AND NOT ANTAGONISTIC TO IT; being a Series of Essays on—1. Alleged Discrepancies; 2. The Theory of the Geologists and Figure of the Earth; 3. The Mosaic Cosmogony; 4. Miracles in general—Views of Hume and Powell; 5. The Miracle of Joshua—Views of Dr. Colenso, &c. By Prof. J. R. YOUNG. Fcap. 5s. cloth.

Geology.

A CLASS-BOOK OF GEOLOGY: Consisting of "Physical Geology," which sets forth the Leading Principles of the Science; and "Historical Geology," which treats of the Mineral and Organic Conditions of the Earth at each successive epoch, especial reference being made to the British Series of Rocks. By RALPH TATE. With more than 250 Illustrations. Fcap. 8vo, 5s. cloth.

Practical Philosophy.

A SYNOPSIS OF PRACTICAL PHILOSOPHY. By Rev. JOHN CARR, M.A., late Fellow of Trin. Coll., Camb. 18mo, 5s. cl.

Pictures and Painters.

THE PICTURE AMATEUR'S HANDBOOK AND DICTIONARY OF PAINTERS: A Guide for Visitors to Picture Galleries, and for Art-Students, including methods of Painting, Cleaning, Re-Lining, and Restoring, Principal Schools of Painting, Copyists and Imitators. By PHILIPPE DARYL, B.A. Cr. 8vo, 3s. 6d. cl.

Clocks, Watches, and Bells.

RUDIMENTARY TREATISE on CLOCKS, and WATCHES, and BELLS. By Sir EDMUND BECKETT, Bart. (late E. B. Denison), LL.D., Q.C., F.R.A.S. Sixth Edition, revised and enlarged. Limp cloth (No. 67, Weale's Series), 4*s.* 6*d.*; cloth bds. 5*s.* 6*d.*

"The best work on the subject probably extant. The treatise on bells is undoubtedly the best in the language."—*Engineering.*

"The only modern treatise on clock-making."—*Horological Journal.*

The Construction of the Organ.

PRACTICAL ORGAN-BUILDING. By W. E. DICKSON, M.A., Precentor of Ely Cathedral. Second Edition, revised, with Additions. 12mo, 3*s.* cloth boards. [*Just published.*

"In many respects the book is the best that has yet appeared on the subject. We cordially recommend it."—*English Mechanic.*

"The amateur builder will find in this book all that is necessary to enable him personally to construct a perfect organ with his own hands."—*Academy.*

Brewing.

A HANDBOOK FOR YOUNG BREWERS. By HERBERT EDWARDS WRIGHT, B.A. Crown 8vo, 3*s.* 6*d.* cloth.

"A thoroughly scientific treatise in popular language."—*Morning Advertiser.*

"We would particularly recommend teachers of the art to place it in every pupil's hands, and we feel sure its perusal will be attended with advantage."—*Brewer.*

Dye-Wares and Colours.

THE MANUAL of COLOURS and DYE-WARES: their Properties, Applications, Valuation, Impurities, and Sophistications. For the Use of Dyers, Printers, Drysalters, Brokers, &c. By J. W. SLATER. Second Edition. Re-written and Enlarged. Crown 8vo, 7*s.* 6*d.* cloth. [*Just published.*

Grammar of Colouring.

A GRAMMAR OF COLOURING, applied to Decorative Painting and the Arts. By GEORGE FIELD. New edition. By ELLIS A. DAVIDSON. 12mo, 3*s.* 6*d.* cloth.

Woods and Marbles (Imitation of).

SCHOOL OF PAINTING FOR THE IMITATION OF WOODS AND MARBLES, as Taught and Practised by A. R. and P. VAN DER BURG. With 24 full-size Coloured Plates; also 12 Plain Plates, comprising 154 Figures. Folio, 2*l.* 12*s.* 6*d.* bound.

The Military Sciences.

AIDE-MEMOIRE to the MILITARY SCIENCES. Framed from Contributions of Officers and others connected with the different Services. Originally edited by a Committee of the Corps of Royal Engineers. 2nd Edition, revised; nearly 350 Engravings and many hundred Woodcuts. 3 vols. royal 8vo, cloth, 4*l.* 10*s.*

Field Fortification.

A TREATISE on FIELD FORTIFICATION, the ATTACK of FORTRESSES, MILITARY MINING, and RECONNOITRING. By Colonel I. S. MACAULAY, late Professor of Fortification in the R. M. A., Woolwich. Sixth Edition, crown 8vo, cloth, with separate Atlas of 12 Plates, 12*s.* complete.

Delamotte's Works on Illumination & Alphabets.

A PRIMER OF THE ART OF ILLUMINATION; for the use of Beginners: with a Rudimentary Treatise on the Art, Practical Directions for its Exercise, and numerous Examples taken from Illuminated MSS., printed in Gold and Colours. By F. DELAMOTTE. Small 4to, 9*s.* Elegantly bound, cloth antique.

"The examples of ancient MSS. recommended to the student, which, with much good sense, the author chooses from collections accessible to all, are selected with judgment and knowledge, as well as taste."—*Athenæum.*

ORNAMENTAL ALPHABETS, ANCIENT and MEDIÆVAL; from the Eighth Century, with Numerals; including Gothic, Church-Text, German, Italian, Arabesque, Initials, Monograms, Crosses, &c. Collected and engraved by F. DELAMOTTE, and printed in Colours. New and Cheaper Edition. Royal 8vo, oblong, 2*s.* 6*d.* ornamental boards.

"For those who insert enamelled sentences round gilded chalices, who blazon shop legends over shop-doors, who letter church walls with pithy sentences from the Decalogue, this book will be useful."—*Athenæum.*

EXAMPLES OF MODERN ALPHABETS, PLAIN and ORNAMENTAL; including German, Old English, Saxon, Italic, Perspective, Greek, Hebrew, Court Hand, Engrossing, Tuscan, Riband, Gothic, Rustic, and Arabesque, &c., &c. Collected and engraved by F. DELAMOTTE, and printed in Colours. New and Cheaper Edition. Royal 8vo, oblong, 2*s.* 6*d.* ornamental boards.

"There is comprised in it every possible shape into which the letters of the alphabet and numerals can be formed."—*Standard.*

MEDIÆVAL ALPHABETS AND INITIALS FOR ILLUMINATORS. By F. DELAMOTTE. Containing 21 Plates, and Illuminated Title, printed in Gold and Colours. With an Introduction by J. WILLIS BROOKS. Small 4to, 6*s.* cloth gilt.

THE EMBROIDERER'S BOOK OF DESIGN; containing Initials, Emblems, Cyphers, Monograms, Ornamental Borders, Ecclesiastical Devices, Mediæval and Modern Alphabets, and National Emblems. Collected and engraved by F. DELAMOTTE, and printed in Colours. Oblong royal 8vo, 1*s.* 6*d.* ornamental wrapper.

Wood-Carving.

INSTRUCTIONS in WOOD-CARVING, for Amateurs; with Hints on Design. By A LADY. In emblematic wrapper, handsomely printed, with Ten large Plates, 2*s.* 6*d.*

"The handicraft of the wood-carver, so well as a book can impart it, may be learnt from 'A Lady's' publication."—*Athenæum.*

Popular Work on Painting.

PAINTING POPULARLY EXPLAINED; with Historical Sketches of the Progress of the Art. By THOMAS JOHN GULLICK, Painter, and JOHN TIMBS, F.S.A. Fourth Edition, revised and enlarged. With Frontispiece and Vignette. In small 8vo, 5*s.* 6*d.* cloth.

⁂ *This Work has been adopted as a Prize-book in the Schools of Art at South Kensington.*

"Contains a large amount of original matter, agreeably conveyed."—*Builder.*

"Much may be learned, even by those who fancy they do not require to be taught, from the careful perusal of this unpretending but comprehensive treatise."—*Art Journal.*

AGRICULTURE, GARDENING, ETC.

Youatt and Burn's Complete Grazier.

THE COMPLETE GRAZIER, and FARMER'S and CATTLE-BREEDER'S ASSISTANT. A Compendium of Husbandry. By WILLIAM YOUATT, ESQ., V.S. 12th Edition, very considerably enlarged, and brought up to the present requirements of agricultural practice. By ROBERT SCOTT BURN. One large 8vo. volume, 860 pp. with 244 Illustrations. 1*l.* 1*s.* half-bound.

"The standard and text-book, with the farmer and grazier."—*Farmer's Magazine.*

"A treatise which will remain a standard work on the subject as long as British agriculture endures."—*Mark Lane Express.*

History, Structure, and Diseases of Sheep.

SHEEP; THE HISTORY, STRUCTURE, ECONOMY, AND DISEASES OF. By W. C. SPOONER, M.R.V.C., &c. Fourth Edition, with fine engravings, including specimens of New and Improved Breeds. 366 pp., 4*s.* cloth.

Production of Meat.

MEAT PRODUCTION. A Manual for Producers, Distributors, and Consumers of Butchers' Meat. Being a treatise on means of increasing its Home Production. Also treating of the Breeding, Rearing, Fattening, and Slaughtering of Meat-yielding Live Stock; Indications of the Quality, etc. By JOHN EWART. Cr. 8vo, 5*s.* cloth.

"A compact and handy volume on the meat question, which deserves serious and thoughtful consideration at the present time."—*Meat and Provision Trades' Review.*

Donaldson and Burn's Suburban Farming.

SUBURBAN FARMING. A Treatise on the Laying Out and Cultivation of Farms adapted to the produce of Milk, Butter and Cheese, Eggs, Poultry, and Pigs. By the late Professor JOHN DONALDSON. With Additions, Illustrating the more Modern Practice, by R. SCOTT BURN. 12mo, 4*s.* cloth boards.

English Agriculture.

THE FIELDS OF GREAT BRITAIN. A Text-book of Agriculture, adapted to the Syllabus of the Science and Art Department. For Elementary and Advanced Students. By HUGH CLEMENTS (Board of Trade). With an Introduction by H. KAINS-JACKSON. 18mo, 2*s.* 6*d.* cloth.

"A clearly written description of the ordinary routine of English farm-life."—*Land.*

"A carefully written text-book of Agriculture."—*Athenæum.*

"A most comprehensive volume, giving a mass of information."—*Agricultural Economist.*

Modern Farming.

OUTLINES OF MODERN FARMING. By R. SCOTT BURN. Soils, Manures, and Crops—Farming and Farming Economy—Cattle, Sheep, and Horses—Management of the Dairy, Pigs, and Poultry—Utilisation of Town Sewage, Irrigation, &c. New Edition. In 1 vol. 1250 pp., half-bound, profusely illustrated, 12*s.*

"There is sufficient stated within the limits of this treatise to prevent a farmer from going far wrong in any of his operations." *Observer.*

The Management of Estates.

LANDED ESTATES MANAGEMENT: Treating of the Varieties of Lands, Methods of Farming, Farm Building, Irrigation, Drainage, &c. By R. SCOTT BURN. 12mo, 3s. cloth.

"A complete and comprehensive outline of the duties appertaining to the management of landed estates."—*Journal of Forestry.*

The Management of Farms.

OUTLINES OF FARM MANAGEMENT, and the Organization of Farm Labour. Treating of the General Work of the Farm, Field, and Live Stock, Details of Contract Work, Specialties of Labour, Economical Management of the Farmhouse and Cottage, Domestic Animals, &c. By ROBERT SCOTT BURN. 12mo, 3s.

Management of Estates and Farms.

LANDED ESTATES AND FARM MANAGEMENT. By R. SCOTT BURN. (The above Two Works in One Vol.) 6s.

Hudson's Tables for Land Valuers.

THE LAND VALUER'S BEST ASSISTANT: being Tables, on a very much improved Plan, for Calculating the Value of Estates. With Tables for reducing Scotch, Irish, and Provincial Customary Acres to Statute Measure, &c. By R. HUDSON, C.E. New Edition, royal 32mo, leather, gilt edges, elastic band, 4s.

Ewart's Land Improver's Pocket-Book.

THE LAND IMPROVER'S POCKET-BOOK OF FORMULÆ, TABLES, and MEMORANDA, required in any Computation relating to the Permanent Improvement of Landed Property. By JOHN EWART, Land Surveyor. 32mo, leather, 4s.

Complete Agricultural Surveyor's Pocket-Book.

THE LAND VALUER'S AND LAND IMPROVER'S COMPLETE POCKET-BOOK; consisting of the above two works bound together, leather, gilt edges, with strap, 7s. 6d.

"We consider Hudson's book to be the best ready-reckoner on matters relating to the valuation of land and crops we have ever seen, and its combination with Mr. Ewart's work greatly enhances the value and usefulness of the latter-mentioned.—It is most useful as a manual for reference."—*North of England Farmer.*

Grafting and Budding.

THE ART OF GRAFTING AND BUDDING. By CHARLES BALTET. Translated from the French. With upwards of 180 Illustrations. 12mo, 3s. cloth boards. [*Just published.*

Culture of Fruit Trees.

FRUIT TREES, the Scientific and Profitable Culture of. Including Choice of Trees, Planting, Grafting, Training, Restoration of Unfruitful Trees, &c. From the French of DU BREUIL. Third Edition, revised. With an Introduction by GEORGE GLENNY. 4s. cl.

"The book teaches how to prune and train fruit-trees to perfection."—*Field.*

Potato Culture.

POTATOES, HOW TO GROW AND SHOW THEM. A Practical Guide to the Cultivation and General Treatment of the Potato. By JAMES PINK. With Illustrations. Cr. 8vo, 2s. cl.

Good Gardening.

A PLAIN GUIDE TO GOOD GARDENING; or, How to Grow Vegetables, Fruits, and Flowers. With Practical Notes on Soils, Manures, Seeds, Planting, Laying-out of Gardens and Grounds, &c. By S. WOOD. Third Edition. Cr. 8vo, 5s. cloth.

"A very good book, and one to be highly recommended as a practical guide. The practical directions are excellent."—*Athenæum.*

Gainful Gardening.

MULTUM-IN-PARVO GARDENING; or, How to make One Acre of Land produce £620 a year, by the Cultivation of Fruits and Vegetables; also, How to Grow Flowers in Three Glass Houses, so as to realise £176 per annum clear Profit. By SAMUEL WOOD. 3rd Edition, revised. Cr. 8vo, 2s. cloth.

"We are bound to recommend it as not only suited to the case of the amateur and gentleman's gardener, but to the market grower."—*Gardener's Magazine.*

Gardening for Ladies.

THE LADIES' MULTUM-IN-PARVO FLOWER GARDEN, and Amateur's Complete Guide. By S. WOOD. Cr. 8vo, 3s. 6d.

Bulb Culture.

THE BULB GARDEN, or, How to Cultivate Bulbous and Tuberous-rooted Flowering Plants to Perfection. By SAMUEL WOOD. Coloured Plates. Crown 8vo, 3s. 6d. cloth.

Tree Planting.

THE TREE PLANTER AND PLANT PROPAGATOR: A Practical Manual on the Propagation of Forest Trees, Fruit Trees, Flowering Shrubs, Flowering Plants, Pot Herbs, &c. Numerous Illustrations. By SAMUEL WOOD. 12mo, 2s. 6d. cloth.

Tree Pruning.

THE TREE PRUNER: A Practical Manual on the Pruning of Fruit Trees, their Training and Renovation; also the Pruning of Shrubs, Climbers, &c. By S. WOOD. 12mo, 2s. 6d. cloth.

Tree Planting, Pruning, & Plant Propagation.

THE TREE PLANTER, PROPAGATOR, AND PRUNER. By SAMUEL WOOD, Author of "Good Gardening," &c. Consisting of the above Two Works in One Vol., 5s. half-bound.

Early Fruits, Flowers and Vegetables.

THE FORCING GARDEN: or, How to Grow Early Fruits, Flowers, and Vegetables. With Plans and Estimates for Building Glasshouses, Pits, Frames, &c. By S. WOOD. Crown 8vo, 3s. 6d.

Market Gardening, Etc.

THE KITCHEN AND MARKET GARDEN. By Contributors to "The Garden." Compiled by C. W. SHAW, Editor of "Gardening Illustrated." 12mo, 3s. 6d. cl. bds. [*Just published.*

Kitchen Gardening.

KITCHEN GARDENING MADE EASY. Showing how to prepare and lay out the ground, the best means of cultivating every known Vegetable and Herb, etc. By G. M. F. GLENNY. 12mo, 2s.

'A Complete Epitome of the Laws of this Country.'

EVERY MAN'S OWN LAWYER; a Handy-Book of the Principles of Law and Equity. By A BARRISTER. New Edition. Corrected to the end of last Session. Embracing upwards of 3,500 Statements on Points of Law, Verified by the addition of Notes and References to the Authorities. Crown 8vo, cloth, price 6*s.* 8*d.* (saved at every consultation).

COMPRISING THE RIGHTS AND WRONGS OF INDIVIDUALS, MERCANTILE AND COMMERCIAL LAW, CRIMINAL LAW, PARISH LAW, COUNTY COURT LAW, GAME AND FISHERY LAWS, POOR MEN'S LAW, THE LAWS OF BANKRUPTCY—BILLS OF EXCHANGE—CONTRACTS AND AGREEMENTS—COPYRIGHT—DOWER AND DIVORCE—ELECTIONS AND REGISTRATION—INSURANCE—LIBEL AND SLANDER—MORTGAGES—SETTLEMENTS—STOCK EXCHANGE PRACTICE—TRADE MARKS AND PATENTS—TRESPASS, NUISANCES, ETC.—TRANSFER OF LAND, ETC.—WARRANTY—WILLS AND AGREEMENTS, ETC.

Also Law for Landlord and Tenant—Master and Servant—Workmen and Apprentices—Heirs, Devisees, and Legatees—Husband and Wife—Executors and Trustees—Guardian and Ward—Married Women and Infants—Partners and Agents—Lender and Borrower—Debtor and Creditor—Purchaser and Vendor—Companies and Associations—Friendly Societies—Clergymen, Churchwardens—Medical Practitioners, &c.—Bankers—Farmers—Contractors—Stock and Share Brokers—Sportsmen and Gamekeepers—Farriers and Horse-Dealers—Auctioneers, House-Agents—Innkeepers, &c.—Pawnbrokers—Surveyors—Railways and Carriers, &c., &c.

"No Englishman ought to be without this book."—*Engineer.*

"What it professes to be—a complete epitome of the laws of this country, thoroughly intelligible to non-professional readers. The book is a handy one to have in readiness when some knotty point requires ready solution."—*Bell's Life.*

"A useful and concise epitome of the law."—*Law Magazine.*

Auctioneer's Assistant.

THE APPRAISER, AUCTIONEER, BROKER, HOUSE AND ESTATE AGENT, AND VALUER'S POCKET ASSISTANT, for the Valuation for Purchase, Sale, or Renewal of Leases, Annuities, and Reversions, and of property generally; with Prices for Inventories, &c. By JOHN WHEELER, Valuer, &c. Fourth Edition, enlarged, by C. NORRIS. Royal 32mo, cloth, 5*s.*

"A concise book of reference, containing a clearly-arranged list of prices for inventories, a practical guide to determine the value of furniture, &c."—*Standard.*

Auctioneering.

AUCTIONEERS: THEIR DUTIES AND LIABILITIES. By ROBERT SQUIBBS, Auctioneer. Demy 8vo, 10*s.* 6*d.* cloth.

"Every auctioneer and valuer ought to possess a copy of this valuable work."—*Ironmonger.*

House Property.

HANDBOOK OF HOUSE PROPERTY: a Popular and Practical Guide to the Purchase, Mortgage, Tenancy, and Compulsory Sale of Houses and Land; including the Law of Dilapidations and Fixtures, &c. By E. L. TARBUCK. 2nd Edit. 12mo, 3*s.* 6*d.* cloth.

"We are glad to be able to recommend it."—*Builder.*

"The advice is thoroughly practical."—*Law Journal.*

Metropolitan Rating.

METROPOLITAN RATING: a Summary of the Appeals heard before the Court of General Assessment Sessions at Westminster, in the years 1871–80 inclusive. Containing a large mass of very valuable information with respect to the Rating of Railways, Gas and Waterworks, Tramways, Wharves, Public Houses, &c. By EDWARD and A. L. RYDE. 8vo, 12*s.* 6*d.*

Bradbury, Agnew, & Co., Printers, Whitefriars, London.

WEALE'S RUDIMENTARY SCIENTIFIC SERIES.

Capio Lumen

*** The volumes of this Series are freely Illustrated with Woodcuts, or otherwise, where requisite. Throughout the following List it must be understood that the books are bound in limp cloth, unless otherwise stated; *but the volumes marked with a ‡ may also be had strongly bound in cloth boards for 6d. extra.*

N.B.—In ordering from this List it is recommended, as a means of facilitating business and obviating error, to quote the numbers affixed to the volumes, as well as the titles and prices.

No. ARCHITECTURE, BUILDING, ETC.

16. *ARCHITECTURE—ORDERS*—The Orders and their Æsthetic Principles. By W. H. Leeds. Illustrated. 1s. 6d.

17. *ARCHITECTURE—STYLES*—The History and Description of the Styles of Architecture of Various Countries, from the Earliest to the Present Period. By T. Talbot Bury, F.R.I.B.A., &c. Illustrated. 2s.
*** Orders and Styles of Architecture, *in One Vol., 3s. 6d.*

18. *ARCHITECTURE—DESIGN*—The Principles of Design in Architecture, as deducible from Nature and exemplified in the Works of the Greek and Gothic Architects. By E. L. Garbett, Architect. Illustrated. 2s. 6d.

*** *The three preceding Works, in One handsome Vol., half bound, entitled* "Modern Architecture," *price 6s.*

22. *THE ART OF BUILDING*, Rudiments of. General Principles of Construction, Materials used in Building, Strength and Use of Materials, Working Drawings, Specifications, and Estimates. By E. Dobson, 2s.‡

23. *BRICKS AND TILES*, Rudimentary Treatise on the Manufacture of; containing an Outline of the Principles of Brickmaking. By Edw. Dobson, M.R.I.B.A. With Additions by C. Tomlinson, F.R.S. Illustrated, 3s.‡

25. *MASONRY AND STONECUTTING;* in which the Principles of Masonic Projection and their application to the Construction of Curved Wing-Walls, Domes, Oblique Bridges, and Roman and Gothic Vaulting, are explained. By Edward Dobson, M.R.I.B.A., &c. 2s. 6d.‡

44. *FOUNDATIONS AND CONCRETE WORKS*, a Rudimentary Treatise on; containing a Synopsis of the principal cases of Foundation Works, with the usual Modes of Treatment, and Practical Remarks on Footings, Planking, Sand, Concrete, Béton, Pile-driving, Caissons, and Cofferdams. By E. Dobson, M.R.I.B.A., &c. Fifth Edition, revised. 1s. 6d.

42. *COTTAGE BUILDING.* By C. Bruce Allen, Architect. Ninth Edition, revised and enlarged. Numerous Illustrations. 1s. 6d.

45. *LIMES, CEMENTS, MORTARS, CONCRETES, MASTICS*, PLASTERING, &c. By G. R. Burnell, C.E. Twelfth Edition. 1s. 6d.

57. *WARMING AND VENTILATION*, a Rudimentary Treatise on; being a concise Exposition of the General Principles of the Art of Warming and Ventilating Domestic and Public Buildings, Mines, Lighthouses, Ships, &c. By Charles Tomlinson, F.R.S., &c. Illustrated. 3s.

83**. *CONSTRUCTION OF DOOR LOCKS.* Compiled from the Papers of A. C. Hobbs, Esq., of New York, and Edited by Charles Tomlinson, F.R.S. To which is added, a Description of Fenby's Patent Locks, and a Note upon Iron Safes by Robert Mallet, M.I.C.E. Illus. 2s. 6d.

111. *ARCHES, PIERS, BUTTRESSES, &c.:* Experimental Essays on the Principles of Construction in; made with a view to their being useful to the Practical Builder. By William Bland. Illustrated. 1s. 6d.

116. *THE ACOUSTICS OF PUBLIC BUILDINGS;* or, The Principles of the Science of Sound applied to the purposes of the Architect and Builder. By T. Roger Smith, M.R.I.B.A., Architect. Illustrated. 1s. 6d.

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

Architecture, Building, etc., *continued.*

127. *ARCHITECTURAL MODELLING IN PAPER*, the Art of. By T. A. RICHARDSON, Architect. Illustrated. 1s. 6d.

128. *VITRUVIUS—THE ARCHITECTURE OF MARCUS VITRUVIUS POLLO.* In Ten Books. Translated from the Latin by JOSEPH GWILT, F.S.A., F.R.A.S. With 23 Plates. 5s.

130. *GRECIAN ARCHITECTURE*, An Inquiry into the Principles of Beauty in; with an Historical View of the Rise and Progress of the Art in Greece. By the EARL OF ABERDEEN. 1s.

*** *The two preceding Works in One handsome Vol., half bound, entitled* "ANCIENT ARCHITECTURE," *price* 6s.

132. *DWELLING-HOUSES*, a Rudimentary Treatise on the Erection of. Illustrated by a Perspective View, Plans, Elevations, and Sections of a pair of Semi-detached Villas, with the Specification, Quantities, and Estimates, and every requisite detail, in sequence, for their Construction and Finishing. By S. H. BROOKS, Architect. New Edition, with Plates. 2s. 6d.‡

156. *QUANTITIES AND MEASUREMENTS*, How to Calculate and Take them in Bricklayers', Masons', Plasterers', Plumbers', Painters', Paperhangers', Gilders', Smiths', Carpenters', and Joiners' Work. By A. C. BEATON, Architect and Surveyor. New and Enlarged Edition. Illus. 1s. 6d.

175. *LOCKWOOD & CO.'S BUILDER'S AND CONTRACTOR'S* PRICE BOOK, for 1883, containing the latest Prices of all kinds of Builders' Materials and Labour, and of all Trades connected with Building, &c., &c. Revised and Edited by F. T. W. MILLER, Architect and Surveyor. 3s. 6d.; half bound, 4s. [*Just published.*

182. *CARPENTRY AND JOINERY*—THE ELEMENTARY PRINCIPLES OF CARPENTRY. Chiefly composed from the Standard Work of THOMAS TREDGOLD, C.E. With Additions from the Works of the most Recent Authorities, and a TREATISE ON JOINERY by E. WYNDHAM TARN, M.A. Numerous Illustrations. 3s. 6d.‡

182*. *CARPENTRY AND JOINERY. ATLAS* of 35 Plates to accompany the above. With Descriptive Letterpress. 4to. 6s.; cloth, 7s. 6d.

187. *HINTS TO YOUNG ARCHITECTS.* By GEORGE WIGHTWICK. New, Revised, and enlarged Edition. By G. HUSKISSON GUILLAUME, Architect. With numerous Woodcuts. 3s. 6d.‡

188. *HOUSE PAINTING, GRAINING, MARBLING, AND SIGN WRITING:* A Practical Manual of, containing full information on the Processes of House-Painting, the Formation of Letters and Practice of Sign-Writing, the Principles of Decorative Art, a Course of Elementary Drawing for House-Painters, Writers, &c., &c. With 9 Coloured Plates of Woods and Marbles, and nearly 150 Wood Engravings. By ELLIS A. DAVIDSON. Third Edition, revised. 5s. cloth limp; 6s. cloth boards.

189. *THE RUDIMENTS OF PRACTICAL BRICKLAYING.* In Six Sections: General Principles; Arch Drawing, Cutting, and Setting; Pointing; Paving, Tiling, Materials; Slating and Plastering; Practical Geometry, Mensuration, &c. By ADAM HAMMOND. Illustrated. 1s. 6d.

191. *PLUMBING.* A Text-Book to the Practice of the Art or Craft of the Plumber. With Chapters upon House Drainage, embodying the latest Improvements. Fourth Edition, revised and enlarged. With above 330 Illustrations. By W. P. BUCHAN, Sanitary Engineer. 3s. 6d.‡ [*Just published.*

192. *THE TIMBER IMPORTER'S, TIMBER MERCHANT'S,* and BUILDER'S STANDARD GUIDE; comprising copious and valuable Memoranda for the Retailer and Builder. By RICHARD E. GRANDY. Second Edition, Revised. 3s.‡

205. *THE ART OF LETTER PAINTING MADE EASY.* By J. G. BADENOCH. Illustrated with 12 full-page Engravings of Examples. 1s.

206. *A BOOK ON BUILDING, Civil and Ecclesiastical*, including CHURCH RESTORATION. With the Theory of Domes and the Great Pyramid, &c. By Sir EDMUND BECKETT, Bart., LL.D., Q.C., F.R.A.S. Second Edition, enlarged, 4s. 6d.‡

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

Architecture, Building, etc., *continued.*

226. *THE JOINTS MADE AND USED BY BUILDERS* in the Construction of various kinds of Engineering and Architectural Works (A Practical Treatise on). With especial reference to those wrought by Artificers in Erecting and Finishing Habitable Structures. By WYVILL J. CHRISTY, Architect. With upwards of 160 Engravings on Wood. 3s.‡

228. *THE CONSTRUCTION OF ROOFS OF WOOD AND IRON* (An Elementary Treatise on). Deduced chiefly from the Works of Robison, Tredgold, and Humber. By E. WYNDHAM TARN, M.A., Architect. With numerous Illustrations. 1s. 6d.

229. *ELEMENTARY DECORATION:* A Guide to the Simpler Forms of Everyday Art, as applied to the Interior and Exterior Decoration of Dwelling-Houses, &c. By JAMES W. FACEY, Jun. Illustrated with Sixty-eight explanatory Engravings. 2s.

230. *HANDRAILING* (A Practical Treatise on). Showing New and Simple Methods for finding the Pitch of the Plank, Drawing the Moulds, Bevelling, Jointing-up, and Squaring the Wreath. By GEORGE COLLINGS. Illustrated with Plates and Diagrams. 1s. 6d.

CIVIL ENGINEERING, ETC.

219. *CIVIL ENGINEERING.* By HENRY LAW, M.Inst. C.E. Including a Treatise on HYDRAULIC ENGINEERING by GEO. R. BURNELL, M.Inst.C.E. Sixth Edition, revised, WITH LARGE ADDITIONS ON RECENT PRACTICE IN CIVIL ENGINEERING, by D. KINNEAR CLARK, M.Inst. C.E., Author of "Tramways: Their Construction," &c. 6s. 6d., Cloth boards, 7s. 6d.

31. *WELLS AND WELL-SINKING.* By JOHN GEO. SWINDELL, A.R.I.B.A., and G. R. BURNELL, C.E. Revised Edition. With a New Appendix on the Qualities of Water. Illustrated. 2s. [*Just published.*

35. *THE BLASTING AND QUARRYING OF STONE,* for Building and other Purposes. With Remarks on the Blowing up of Bridges. By Gen. Sir JOHN BURGOYNE, Bart., K.C.B. Illustrated. 1s. 6d.

62. *RAILWAY CONSTRUCTION,* Elementary and Practical Instructions on the Science of. By Sir M. STEPHENSON, C.E. New Edition, by EDWARD NUGENT, C.E. With Statistics of the Capital, Dividends, and Working of Railways in the United Kingdom. By E. D. CHATTAWAY. 4s.

80*. *EMBANKING LANDS FROM THE SEA,* the Practice of. Treated as a Means of Profitable Employment for Capital. With Examples and Particulars of actual Embankments, &c. By J. WIGGINS, F.G.S. 2s.

81. *WATER WORKS,* for the Supply of Cities and Towns. With a Description of the Principal Geological Formations of England as influencing Supplies of Water; and Details of Engines and Pumping Machinery for raising Water. By SAMUEL HUGHES, F.G.S., C.E. New Edition. 4s.‡

117. *SUBTERRANEOUS SURVEYING,* an Elementary and Practical Treatise on. By THOMAS FENWICK. Also the Method of Conducting Subterraneous Surveys without the Use of the Magnetic Needle, and other Modern Improvements. By THOMAS BAKER, C.E. Illustrated. 2s. 6d.‡

118. *CIVIL ENGINEERING IN NORTH AMERICA,* a Sketch of. By DAVID STEVENSON, F.R.S.E., &c. Plates and Diagrams. 3s.

197. *ROADS AND STREETS (THE CONSTRUCTION OF),* in two Parts: I. THE ART OF CONSTRUCTING COMMON ROADS, by HENRY LAW, C.E., revised by D. K. CLARK, C.E.; II. RECENT PRACTICE, including pavements of Stone, Wood, and Asphalte, by D. K. CLARK. 4s. 6d.‡

203. *SANITARY WORK IN THE SMALLER TOWNS AND IN VILLAGES.* Comprising:—1. Some of the more Common Forms of Nuisance and their Remedies; 2. Drainage; 3. Water Supply. By CHARLES SLAGG, A.I.C.E. 2s. 6d.‡

212. *THE CONSTRUCTION OF GAS-WORKS,* and the Manufacture and Distribution of Coal Gas. Originally written by SAMUEL HUGHES, C.E. Sixth Edition, re-written and much Enlarged by WILLIAM RICHARDS, C.E. With 72 Illustrations. 4s. 6d.‡

213. *PIONEER ENGINEERING.* A Treatise on the Engineering Operations connected with the Settlement of Waste Lands in New Countries. By EDWARD DOBSON, Assoc. Inst. C.E. 4s. 6d.‡

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

MECHANICAL ENGINEERING, ETC.

33. *CRANES*, the Construction of, and other Machinery for Raising Heavy Bodies. By JOSEPH GLYNN, F.R.S. Illustrated. 1s. 6d.
34. *THE STEAM ENGINE.* By Dr. LARDNER. Illustrated. 1s. 6d.
59. *STEAM BOILERS:* their Construction and Management. By R. ARMSTRONG, C.E. Illustrated. 1s. 6d.
67. *CLOCKS, WATCHES, AND BELLS*, a Rudimentary Treatise on. By Sir EDMUND BECKETT, LL.D., Q.C. Seventh Edition, revised and enlarged. 4s. 6d. limp; 5s. 6d. cloth boards. [*Just published.*
82. *THE POWER OF WATER*, as applied to drive Flour Mills, and to give motion to Turbines, &c. By JOSEPH GLYNN, F.R.S. 2s.‡
98. *PRACTICAL MECHANISM*, the Elements of; and Machine Tools. By T. BAKER, C.E. With Additions by J. NASMYTH, C.E. 2s. 6d.‡
139. *THE STEAM ENGINE*, a Treatise on the Mathematical Theory of, with Rules and Examples for Practical Men. By T. BAKER, C.E. 1s. 6d.
162. *THE BRASS FOUNDER'S MANUAL;* Instructions for Modelling, Pattern-Making, Moulding, Turning, Filing, Burnishing, Bronzing, &c. With copious Receipts, &c. By WALTER GRAHAM. 2s.‡
164. *MODERN WORKSHOP PRACTICE*, as applied to Marine, Land, and Locomotive Engines, Floating Docks, Dredging Machines, Bridges, Cranes, Ship-building, &c., &c. By J. G. WINTON. Illustrated. 3s.‡
165. *IRON AND HEAT*, exhibiting the Principles concerned in the Construction of Iron Beams, Pillars, and Bridge Girders, and the Action of Heat in the Smelting Furnace. By J. ARMOUR, C.E. 2s. 6d.‡
166. *POWER IN MOTION:* Horse-Power, Toothed-Wheel Gearing, Long and Short Driving Bands, and Angular Forces. By J. ARMOUR, 2s. 6d.‡
167. *IRON BRIDGES, GIRDERS, ROOFS, AND OTHER WORKS.* By FRANCIS CAMPIN, C.E. 2s. 6d.‡
171. *THE WORKMAN'S MANUAL OF ENGINEERING DRAWING.* By JOHN MAXTON, Engineer. Fourth Edition. Illustrated with 7 Plates and nearly 350 Woodcuts. 3s. 6d.‡
190. *STEAM AND THE STEAM ENGINE*, Stationary and Portable. By JOHN SEWELL and D. K. CLARK, M.I.C.E. 3s. 6d.‡
200. *FUEL*, its Combustion and Economy. By C. W. WILLIAMS, With Recent Practice in the Combustion and Economy of Fuel—Coal, Coke, Wood, Peat, Petroleum, &c.—by D. K. CLARK, M.I.C.E. 3s. 6d.‡
202. *LOCOMOTIVE ENGINES.* By G. D. DEMPSEY, C.E.; with large additions by D. KINNEAR CLARK, M.I.C.E. 3s.‡
211. *THE BOILERMAKER'S ASSISTANT* in Drawing, Templating, and Calculating Boiler and Tank Work. By JOHN COURTNEY, Practical Boiler Maker. Edited by D. K. CLARK, C.E. 100 Illustrations. 2s.
216. *MATERIALS AND CONSTRUCTION;* A Theoretical and Practical Treatise on the Strains, Designing, and Erection of Works of Construction. By FRANCIS CAMPIN, C.E. 3s.‡
217. *SEWING MACHINERY:* Its Construction, History, &c., with full Technical Directions for Adjusting, &c. By J. W. URQUHART, C.E. 2s.‡
223. *MECHANICAL ENGINEERING.* Comprising Metallurgy, Moulding, Casting, Forging, Tools, Workshop Machinery, Manufacture of the Steam Engine, &c. By FRANCIS CAMPIN, C.E. 2s. 6d.‡
224. *COACH BUILDING*, A Practical Treatise, Historical and Descriptive. By J. W. BURGESS. 2s. 6d.‡
235. *PRACTICAL ORGAN BUILDING.* By W. E. DICKSON, M.A., Precentor of Ely Cathedral. Illustrated. 2s. 6d.‡ [*Just published.*
236. *DETAILS OF MACHINERY.* Comprising Instructions for the Execution of various Works in Iron in the Fitting-Shop, Foundry, and Boiler-Yard. By FRANCIS CAMPIN, C.E. 3s.‡ [*Just published.*
237. *THE SMITHY AND FORGE;* including the Farrier's Art and CoachSmithing. By W. J. E. CRANE. Illustrated. 2s. 6d.‡ [*Just published.*

THE SHEET-METAL WORKER'S GUIDE; a Practical Handbook for Tinsmiths, Coppersmiths, Zincworkers, &c., comprising numerous Geometrical Diagrams and Working Patterns, with Descriptive Text. By W. J. E. CRANE. [*In the press.*

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

SHIPBUILDING, NAVIGATION, MARINE ENGINEERING, ETC.

51. *NAVAL ARCHITECTURE*, the Rudiments of; or an Exposition of the Elementary Principles of the Science, and their Practical Application to Naval Construction. Compiled for the Use of Beginners. By JAMES PEAKE, School of Naval Architecture, H.M. Dockyard, Portsmouth. Fourth Edition, corrected, with Plates and Diagrams. 3s. 6d.‡

53*. *SHIPS FOR OCEAN AND RIVER SERVICE*, Elementary and Practical Principles of the Construction of. By HAKON A. SOMMERFELDT, Surveyor of the Royal Norwegian Navy. With an Appendix. 1s. 6d.

53**. *AN ATLAS OF ENGRAVINGS* to Illustrate the above. Twelve large folding plates. Royal 4to, cloth. 7s. 6d.

54. *MASTING, MAST-MAKING, AND RIGGING OF SHIPS*, Rudimentary Treatise on. Also Tables of Spars, Rigging, Blocks; Chain, Wire, and Hemp Ropes, &c., relative to every class of vessels. With an Appendix of Dimensions of Masts and Yards of the Royal Navy. By ROBERT KIPPING, N.A. Fifteenth Edition. Illustrated. 2s.‡

54*. *IRON SHIP-BUILDING.* With Practical Examples and Details for the Use of Ship Owners and Ship Builders. By JOHN GRANTHAM, Consulting Engineer and Naval Architect. 5th Edition, with Additions. 4s.

54**. *AN ATLAS OF FORTY PLATES* to Illustrate the above. Fifth Edition. Including the latest Examples, such as H.M. Steam Frigates "Warrior," "Hercules," "Bellerophon;" H.M. Troop Ship "Serapis," Iron Floating Dock, &c., &c. 4to, boards. 38s.

55. *THE SAILOR'S SEA BOOK:* a Rudimentary Treatise on Navigation. Part I. How to Keep the Log and Work it off. Part II. On Finding the Latitude and Longitude. By JAMES GREENWOOD, B.A. To which are added, the Deviation and Error of the Compass; Great Circle Sailing; the International (Commercial) Code of Signals; the Rule of the Road at Sea; Rocket and Mortar Apparatus for Saving Life; the Law of Storms; and a Brief Dictionary of Sea Terms. With numerous Woodcuts and Coloured Plates of Flags. New, thoroughly revised and much enlarged edition. By W. H. ROSSER. 2s. 6d.‡

80. *MARINE ENGINES, AND STEAM VESSELS*, a Treatise on. Together with Practical Remarks on the Screw and Propelling Power, as used in the Royal and Merchant Navy. By ROBERT MURRAY, C.E., Engineer-Surveyor to the Board of Trade. With a Glossary of Technical Terms, and their Equivalents in French, German, and Spanish. Seventh Edition, revised and enlarged. Illustrated. 3s.‡

83*bis*. *THE FORMS OF SHIPS AND BOATS:* Hints, Experimentally Derived, on some of the Principles regulating Ship-building. By W. BLAND. Seventh Edition, revised, with numerous Illustrations and Models. 1s. 6d.

99. *NAVIGATION AND NAUTICAL ASTRONOMY*, in Theory and Practice. By Professor J. R. YOUNG. New Edition, including the requisite Elements from the Nautical Almanac for working the Problems. Illustrated. 2s. 6d. [*Just published.*

100*. *TABLES* intended to facilitate the Operations of Navigation and Nautical Astronomy, as an Accompaniment to the above Book. By J. R. YOUNG. 1s. 6d.

106. *SHIPS' ANCHORS*, a Treatise on. By G. COTSELL, N.A. 1s. 6d.

149. *SAILS AND SAIL-MAKING*, an Elementary Treatise on. With Draughting, and the Centre of Effort of the Sails. Also, Weights and Sizes of Ropes; Masting, Rigging, and Sails of Steam Vessels, &c., &c. Eleventh Edition, enlarged, with an Appendix. By ROBERT KIPPING, N.A., Sailmaker, Quayside, Newcastle. Illustrated. 2s. 6d.‡

155. *THE ENGINEER'S GUIDE TO THE ROYAL AND MERCANTILE NAVIES.* By a PRACTICAL ENGINEER. Revised by D. F. M'CARTHY, late of the Ordnance Survey Office, Southampton. 3s.

55 & 204. *PRACTICAL NAVIGATION.* Consisting of The Sailor's Sea-Book. By JAMES GREENWOOD and W. H. ROSSER. Together with the requisite Mathematical and Nautical Tables for the Working of the Problems. By HENRY LAW, C.E., and J. R. YOUNG, formerly Professor of Mathematics in Belfast College. Illustrated with numerous Wood Engravings and Coloured Plates. 7s. Strongly half-bound in leather.

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

PHYSICAL SCIENCE, NATURAL PHILOSOPHY, ETC.

1. *CHEMISTRY*, for the Use of Beginners. By Professor GEORGE FOWNES, F.R.S. With an Appendix on the Application of Chemistry to Agriculture. 1s.

2. *NATURAL PHILOSOPHY*, Introduction to the Study of; for the Use of Beginners. By C. TOMLINSON, Lecturer on Natural Science in King's College School, London. Woodcuts. 1s. 6d.

4. *MINERALOGY*, Rudiments of; a concise View of the Properties of Minerals. By A. RAMSAY, Jun. Woodcuts and Steel Plates. 3s.‡

6. *MECHANICS*, Rudimentary Treatise on; being a concise Exposition of the General Principles of Mechanical Science, and their Applications. By CHARLES TOMLINSON. Illustrated. 1s. 6d.

7. *ELECTRICITY;* showing the General Principles of Electrical Science, and the purposes to which it has been applied. By Sir W. SNOW HARRIS, F.R.S., &c. With Additions by R. SABINE, C.E., F.S.A. 1s. 6d.

7*. *GALVANISM*, Rudimentary Treatise on, and the General Principles of Animal and Voltaic Electricity. By Sir W. SNOW HARRIS. New Edition, with considerable Additions by ROBERT SABINE, C.E., F.S.A. 1s. 6d.

8. *MAGNETISM;* being a concise Exposition of the General Principles of Magnetical Science, and the Purposes to which it has been applied. By Sir W. SNOW HARRIS. New Edition, revised and enlarged by H. M. NOAD, Ph.D., Vice-President of the Chemical Society, Author of "A Manual of Electricity," &c., &c. With 165 Woodcuts. 3s. 6d.‡

11. *THE ELECTRIC TELEGRAPH;* its History and Progress; with Descriptions of some of the Apparatus. By R. SABINE, C.E., F.S.A. 3s.

12. *PNEUMATICS*, for the Use of Beginners. By CHARLES TOMLINSON. Illustrated. 1s. 6d.

72. *MANUAL OF THE MOLLUSCA;* a Treatise on Recent and Fossil Shells. By Dr. S. P. WOODWARD, A.L.S. Fourth Edition. With Appendix by RALPH TATE, A.L.S., F.G.S. With numerous Plates and 300 Woodcuts. 6s. 6d. Cloth boards, 7s. 6d.

79**. *PHOTOGRAPHY*, Popular Treatise on; with a Description of the Stereoscope, &c. Translated from the French of D. VAN MONCKHOVEN, by W. H. THORNTHWAITE, Ph.D. Woodcuts. 1s. 6d.

96. *ASTRONOMY*. By the late Rev. ROBERT MAIN, M.A., F.R.S., formerly Radcliffe Observer at Oxford. Third Edition, revised to the Present Time. By WILLIAM THYNNE LYNN, B.A., F.R.A.S. 2s.

97. *STATICS AND DYNAMICS*, the Principles and Practice of; embracing also a clear development of Hydrostatics, Hydrodynamics, and Central Forces. By T. BAKER, C.E. 1s. 6d.

138. *TELEGRAPH*, Handbook of the; a Manual of Telegraphy, Telegraph Clerks' Remembrancer, and Guide to Candidates for Employment in the Telegraph Service. By R. BOND. Fourth Edition, revised and enlarged: to which is appended, QUESTIONS on MAGNETISM, ELECTRICITY, and PRACTICAL TELEGRAPHY, for the Use of Students, by W. MCGREGOR, First Assistant Supnt., Indian Gov. Telegraphs. 3s.‡

173. *PHYSICAL GEOLOGY*, partly based on Major-General PORTLOCK'S "Rudiments of Geology." By RALPH TATE, A.L.S., &c. Woodcuts. 2s.

174. *HISTORICAL GEOLOGY*, partly based on Major-General PORTLOCK'S "Rudiments." By RALPH TATE, A.L.S., &c. Woodcuts. 2s. 6d.

173 & 174. *RUDIMENTARY TREATISE ON GEOLOGY*, Physical and Historical. Partly based on Major-General PORTLOCK'S "Rudiments of Geology." By RALPH TATE, A.L.S., F.G.S., &c. In One Volume. 4s. 6d.‡

183 & 184. *ANIMAL PHYSICS*, Handbook of. By Dr. LARDNER, D.C.L., formerly Professor of Natural Philosophy and Astronomy in University College, Lond. With 520 Illustrations. In One Vol. 7s. 6d., cloth boards.

*** *Sold also in Two Parts, as follows:—*

183. ANIMAL PHYSICS. By Dr. LARDNER. Part I., Chapters I.—VII. 4s.

184. ANIMAL PHYSICS. By Dr. LARDNER. Part II., Chapters VIII.—XVIII. 3s.

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

MINING, METALLURGY, ETC.

117. *SUBTERRANEOUS SURVEYING*, Elementary and Practical Treatise on, with and without the Magnetic Needle. By THOMAS FENWICK, Surveyor of Mines, and THOMAS BAKER, C.E. Illustrated. 2s. 6d.‡
133. *METALLURGY OF COPPER*; an Introduction to the Methods of Seeking, Mining, and Assaying Copper, and Manufacturing its Alloys. By ROBERT H. LAMBORN, Ph.D. Woodcuts. 2s. 6d.‡
134. *METALLURGY OF SILVER AND LEAD*. By Dr. R. H. LAMBORN. Woodcuts. 2s. 6d.‡
135. *ELECTRO-METALLURGY*; Practically Treated. By ALEXANDER WATT, F.R.S.S.A. 8th Edition, revised, with additional Matter and Illustrations, including the most recent Processes. 3s.‡ [*Just published.*
172. *MINING TOOLS*, Manual of. For the Use of Mine Managers, Agents, Students, &c. By WILLIAM MORGANS. 2s. 6d.‡
172*. *MINING TOOLS, ATLAS* of Engravings to Illustrate the above, containing 235 Illustrations, drawn to Scale. 4to. 4s. 6d.; cloth boards, 6s.
176. *METALLURGY OF IRON*. Containing History of Iron Manufacture. Methods of Assay, and Analyses of Iron Ores, Processes of Manufacture of Iron and Steel, &c. By H. BAUERMAN, F.G.S. 5th Edition, revised and enlarged. 5s.‡ [*Just published.*
180. *COAL AND COAL MINING*, A Rudimentary Treatise on. By WARINGTON W. SMYTH, M.A., F.R.S. Fifth Edition, revised and enlarged. With numerous Illustrations. 3s. 6d.‡
195. *THE MINERAL SURVEYOR AND VALUER'S COMPLETE GUIDE*, with new Traverse Tables, and Descriptions of Improved Instruments; also the Correct Principles of Laying out and Valuing Mineral Properties. By WILLIAM LINTERN, Mining and Civil Engineer. 3s. 6d.‡
214. *SLATE AND SLATE QUARRYING*, Scientific, Practical, and Commercial. By D. C. DAVIES, F.G.S., Mining Engineer, &c. With numerous Illustrations and Folding Plates. 3s.‡
215. *THE GOLDSMITH'S HANDBOOK*, containing full Instructions for the Alloying and Working of Gold. By GEORGE E. GEE, Goldsmith and Silversmith. Second Edition, considerably enlarged. 3s.‡
225. *THE SILVERSMITH'S HANDBOOK*, containing full Instructions for the Alloying and Working of Silver. By GEORGE E. GEE. 3s.‡
220. *MAGNETIC SURVEYING, AND ANGULAR SURVEYING*, with Records of the Peculiarities of Needle Disturbances. Compiled from the Results of carefully made Experiments. By WILLIAM LINTERN, Mining and Civil Engineer and Surveyor. 2s.

FINE ARTS.

20. *PERSPECTIVE FOR BEGINNERS*. Adapted to Young Students and Amateurs in Architecture, Painting, &c. By GEORGE PYNE. 2s.
40 & 41. *GLASS STAINING, AND THE ART OF PAINTING ON GLASS*. From the German of Dr. GESSERT and EMANUEL OTTO FROMBERG. With an Appendix on THE ART OF ENAMELLING. 2s. 6d.
69. *MUSIC*, A Rudimentary and Practical Treatise on. With numerous Examples. By CHARLES CHILD SPENCER. 2s. 6d.
71. *PIANOFORTE*, The Art of Playing the. With numerous Exercises & Lessons from the Best Masters. By CHARLES CHILD SPENCER. 1s. 6d.
69-71. *MUSIC AND THE PIANOFORTE*. In one volume. Half bound, 5s.
181. *PAINTING POPULARLY EXPLAINED*, including Fresco, Oil, Mosaic, Water Colour, Water-Glass, Tempera, Encaustic, Miniature, Painting on Ivory, Vellum, Pottery, Enamel, Glass, &c. With Historical Sketches of the Progress of the Art by THOMAS JOHN GULLICK, assisted by JOHN TIMBS, F.S.A. Fourth Edition, revised and enlarged. 5s.‡
186. *A GRAMMAR OF COLOURING*, applied to Decorative Painting and the Arts. By GEORGE FIELD. New Edition, enlarged and adapted to the Use of the Ornamental Painter and Designer. By ELLIS A. DAVIDSON. With two new Coloured Diagrams, &c. 3s.‡

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

AGRICULTURE, GARDENING, ETC.

131. *MILLER'S, MERCHANT'S, AND FARMER'S READY* RECKONER. With approximate values of Millstones, Millwork, &c. 1s.

140. *SOILS, MANURES, AND CROPS.* (Vol. 1. OUTLINES OF MODERN FARMING.) By R. SCOTT BURN. Woodcuts. 2s.

141. *FARMING & FARMING ECONOMY*, Notes, Historical and Practical, on. (Vol. 2. OUTLINES OF MODERN FARMING.) By R. SCOTT BURN. 3s.

142. *STOCK; CATTLE, SHEEP, AND HORSES.* (Vol. 3. OUTLINES OF MODERN FARMING.) By R. SCOTT BURN. Woodcuts. 2s. 6d.

145. *DAIRY, PIGS, AND POULTRY*, Management of the. By R. SCOTT BURN. With Notes on the Diseases of Stock. (Vol. 4. OUTLINES OF MODERN FARMING.) Woodcuts. 2s.

146. *UTILIZATION OF SEWAGE, IRRIGATION, AND* RECLAMATION OF WASTE LAND. (Vol. 5. OUTLINES OF MODERN FARMING.) By R. SCOTT BURN. Woodcuts. 2s. 6d.

*** Nos. 140-1-2-5-6, in One Vol., handsomely half-bound, entitled "OUTLINES OF MODERN FARMING." By ROBERT SCOTT BURN. Price 12s.

177. *FRUIT TREES*, The Scientific and Profitable Culture of. From the French of DU BREUIL. Revised by GEO. GLENNY. 187 Woodcuts. 3s. 6d.‡

198. *SHEEP; THE HISTORY, STRUCTURE, ECONOMY, AND* DISEASES OF. By W. C. SPOONER, M.R.V.C., &c. Fourth Edition, enlarged, including Specimens of New and Improved Breeds. 3s. 6d.‡

201. *KITCHEN GARDENING MADE EASY.* Showing how to prepare and lay out the ground, the best means of cultivating every known Vegetable and Herb, &c. By GEORGE M. F. GLENNY. 1s. 6d.‡

207. *OUTLINES OF FARM MANAGEMENT, and the Organization of Farm Labour:* Treating of the General Work of the Farm; Field and Live Stock; Details of Contract Work; Specialities of Labour, &c., &c. By ROBERT SCOTT BURN. 2s. 6d.‡

208. *OUTLINES OF LANDED ESTATES MANAGEMENT:* Treating of the Varieties of Lands, Methods of Farming, Farm Buildings, Irrigation, Drainage, &c. By R. SCOTT BURN. 2s. 6d.‡

*** *Nos. 207 & 208 in One Vol., handsomely half-bound, entitled* "OUTLINES OF LANDED ESTATES AND FARM MANAGEMENT." By R. SCOTT BURN. *Price* 6s.

209. *THE TREE PLANTER AND PLANT PROPAGATOR.* A Practical Manual on the Propagation of Forest Trees, Fruit Trees, Flowering Shrubs, Flowering Plants, &c. By SAMUEL WOOD. 2s.‡

210. *THE TREE PRUNER.* A Practical Manual on the Pruning of Fruit Trees, including also their Training and Renovation; also the Pruning of Shrubs, Climbers, and Flowering Plants. By SAMUEL WOOD. 2s.‡

*** *Nos. 209 & 210 in One Vol., handsomely half-bound, entitled* "THE TREE PLANTER, PROPAGATOR AND PRUNER." By SAMUEL WOOD. *Price* 5s.

218. *THE HAY AND STRAW MEASURER:* Being New Tables for the Use of Auctioneers, Valuers, Farmers, Hay and Straw Dealers, &c., forming a complete Calculator and Ready-Reckoner, especially adapted to persons connected with Agriculture. Fourth Edition. By JOHN STEELE. 2s.

222. *SUBURBAN FARMING.* The Laying-out and Cultivation of Farms, adapted to the Produce of Milk, Butter, and Cheese, Eggs, Poultry, and Pigs. By Prof. JOHN DONALDSON and R. SCOTT BURN. 3s. 6d.‡

231. *THE ART OF GRAFTING AND BUDDING.* By CHARLES BALTET. With Illustrations. 2s. 6d.‡ [*Just published.*

232. *COTTAGE GARDENING;* or, Flowers, Fruits, and Vegetables for Small Gardens. By E. HOBDAY. 1s. 6d. [*Just published.*

233. *GARDEN RECEIPTS.* Edited by CHARLES W. QUIN. 1s. 6d. [*Just published.*

234. *THE KITCHEN AND MARKET GARDEN.* By Contributors to "The Garden." Compiled by C. W. SHAW, Editor of "Gardening Illustrated." 430 pp. 3s.‡ [*Just published.*

DRAINING AND EMBANKING. By PROFESSOR JOHN SCOTT. Being the first of a Series of Seven Text-Books intended to cover the whole ground of Farm Engineering. [*In the press.*

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

ARITHMETIC, GEOMETRY, MATHEMATICS, ETC.

32. *MATHEMATICAL INSTRUMENTS*, a Treatise on; in which their Construction and the Methods of Testing, Adjusting, and Using them are concisely Explained. By J. F. HEATHER, M.A., of the Royal Military Academy, Woolwich. Original Edition, in 1 vol., Illustrated. 1s. 6d.

*** *In ordering the above, be careful to say, "Original Edition" (No. 32), to distinguish it from the Enlarged Edition in 3 vols. (Nos. 168-9-70.)*

60. *LAND AND ENGINEERING SURVEYING*, a Treatise on; with all the Modern Improvements. Arranged for the Use of Schools and Private Students; also for Practical Land Surveyors and Engineers. By T. BAKER, C.E. New Edition, revised by EDWARD NUGENT, C.E. Illustrated with Plates and Diagrams. 2s.‡

61*. *READY RECKONER FOR THE ADMEASUREMENT OF* LAND. By ABRAHAM ARMAN, Schoolmaster, Thurleigh, Beds. To which is added a Table, showing the Price of Work, from 2s. 6d. to £1 per acre, and Tables for the Valuation of Land, from 1s. to £1,000 per acre, and from one pole to two thousand acres in extent, &c., &c. 1s. 6d.

76. *DESCRIPTIVE GEOMETRY*, an Elementary Treatise on; with a Theory of Shadows and of Perspective, extracted from the French of G. MONGE. To which is added, a description of the Principles and Practice of Isometrical Projection; the whole being intended as an introduction to the Application of Descriptive Geometry to various branches of the Arts. By J. F. HEATHER, M.A. Illustrated with 14 Plates. 2s.

178. *PRACTICAL PLANE GEOMETRY*: giving the Simplest Modes of Constructing Figures contained in one Plane and Geometrical Construction of the Ground. By J. F. HEATHER, M.A. With 215 Woodcuts. 2s.

179. *PROJECTION*: Orthographic, Topographic, and Perspective: giving the various Modes of Delineating Solid Forms by Constructions on a Single Plane Surface. By J. F. HEATHER, M.A. [*In preparation.*

*** *The above three volumes will form a* COMPLETE ELEMENTARY COURSE OF MATHEMATICAL DRAWING.

83. *COMMERCIAL BOOK-KEEPING*. With Commercial Phrases and Forms in English, French, Italian, and German. By JAMES HADDON, M.A., Arithmetical Master of King's College School, London. 1s. 6d.

84. *ARITHMETIC*, a Rudimentary Treatise on: with full Explanations of its Theoretical Principles, and numerous Examples for Practice. For the Use of Schools and for Self-Instruction. By J. R. YOUNG, late Professor of Mathematics in Belfast College. Tenth Edition, corrected. 1s. 6d.

84*. A KEY to the above, containing Solutions in full to the Exercises, together with Comments, Explanations, and Improved Processes, for the Use of Teachers and Unassisted Learners. By J. R. YOUNG. 1s. 6d.

85. *EQUATIONAL ARITHMETIC*, applied to Questions of Interest,
85*. Annuities, Life Assurance, and General Commerce; with various Tables by which all Calculations may be greatly facilitated. By W. HIPSLEY. 2s.

86. *ALGEBRA*, the Elements of. By JAMES HADDON, M.A., Second Mathematical Master of King's College School. With Appendix, containing miscellaneous Investigations, and a Collection of Problems in various parts of Algebra. 2s.

86*. A KEY AND COMPANION to the above Book, forming an extensive repository of Solved Examples and Problems in Illustration of the various Expedients necessary in Algebraical Operations. Especially adapted for Self-Instruction. By J. R. YOUNG. 1s. 6d.

88. *EUCLID*, THE ELEMENTS OF: with many additional Propositions
89. and Explanatory Notes: to which is prefixed, an Introductory Essay on Logic. By HENRY LAW, C.E. 2s. 6d.‡

*** *Sold also separately, viz.:—*

88. EUCLID, The First Three Books. By HENRY LAW, C.E. 1s. 6d.
89. EUCLID, Books 4, 5, 6, 11, 12. By HENRY LAW, C.E. 1s. 6d.

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

Arithmetic, Geometry, Mathematics, etc., *continued.*

90. *ANALYTICAL GEOMETRY AND CONIC SECTIONS*, a Rudimentary Treatise on. By JAMES HANN, late Mathematical Master of King's College School, London. A New Edition, re-written and enlarged by J. R. YOUNG, formerly Professor of Mathematics at Belfast College. 2s.‡

91. *PLANE TRIGONOMETRY*, the Elements of. By JAMES HANN, formerly Mathematical Master of King's College, London. 1s. 6d.

92. *SPHERICAL TRIGONOMETRY*, the Elements of. By JAMES HANN. Revised by CHARLES H. DOWLING, C.E. 1s.

*** *Or with "The Elements of Plane Trigonometry," in One Volume*, 2s. 6d.

93. *MENSURATION AND MEASURING*, for Students and Practical Use. With the Mensuration and Levelling of Land for the Purposes of Modern Engineering. By T. BAKER, C.E. New Edition, with Corrections and Additions by E. NUGENT, C.E. Illustrated. 1s. 6d.

102. *INTEGRAL CALCULUS*, Rudimentary Treatise on the. By HOMERSHAM COX, B.A. Illustrated. 1s.

103. *INTEGRAL CALCULUS*, Examples on the. By JAMES HANN, late of King's College, London. Illustrated. 1s.

101. *DIFFERENTIAL CALCULUS*, Elements of the. By W. S. B. WOOLHOUSE, F.R.A.S., &c. 1s. 6d.

105. *MNEMONICAL LESSONS*.—GEOMETRY, ALGEBRA, AND TRIGONOMETRY, in Easy Mnemonical Lessons. By the Rev. THOMAS PENYNGTON KIRKMAN, M.A. 1s. 6d.

136. *ARITHMETIC*, Rudimentary, for the Use of Schools and Self-Instruction. By JAMES HADDON, M.A. Revised by ABRAHAM ARMAN. 1s. 6d.

137. A KEY TO HADDON'S RUDIMENTARY ARITHMETIC. By A. ARMAN. 1s. 6d.

168. *DRAWING AND MEASURING INSTRUMENTS*. Including—I. Instruments employed in Geometrical and Mechanical Drawing, and in the Construction, Copying, and Measurement of Maps and Plans. II. Instruments used for the purposes of Accurate Measurement, and for Arithmetical Computations. By J. F. HEATHER, M.A., late of the Royal Military Academy, Woolwich, Author of "Descriptive Geometry," &c., &c. Illustrated. 1s. 6d.

169. *OPTICAL INSTRUMENTS*. Including (more especially) Telescopes, Microscopes, and Apparatus for producing copies of Maps and Plans by Photography. By J. F. HEATHER, M.A. Illustrated. 1s. 6d.

170. *SURVEYING AND ASTRONOMICAL INSTRUMENTS*. Including—I. Instruments Used for Determining the Geometrical Features of a portion of Ground. II. Instruments Employed in Astronomical Observations. By J. F. HEATHER, M.A. Illustrated. 1s. 6d.

*** *The above three volumes form an enlargement of the Author's original work, "Mathematical Instruments: their Construction, Adjustment, Testing, and Use," the Thirteenth Edition of which is on sale, price* 1s. 6d. (*See No.* 32 *in the Series.*)

168.
169.
170. } *MATHEMATICAL INSTRUMENTS*. By J. F. HEATHER, M.A. Enlarged Edition, for the most part entirely re-written. The 3 Parts as above, in One thick Volume. With numerous Illustrations. 4s. 6d.‡

158. *THE SLIDE RULE, AND HOW TO USE IT;* containing full, easy, and simple Instructions to perform all Business Calculations with unexampled rapidity and accuracy. By CHARLES HOARE, C.E. With a Slide Rule in tuck of cover. 2s. 6d.‡

185. *THE COMPLETE MEASURER;* setting forth the Measurement of Boards, Glass, &c., &c.; Unequal-sided, Square-sided, Octagonal-sided, Round Timber and Stone, and Standing Timber. With a Table showing the solidity of hewn or eight-sided timber, or of any octagonal-sided column. Compiled for Timber-growers, Merchants, and Surveyors, Stonemasons, Architects, and others. By RICHARD HORTON. Fourth Edition, with valuable additions. 4s.; strongly bound in leather, 5s.

196. *THEORY OF COMPOUND INTEREST AND ANNUITIES*; with Tables of Logarithms for the more Difficult Computations of Interest, Discount, Annuities, &c. By FÉDOR THOMAN. 4s.‡

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

Arithmetic, Geometry, Mathematics, etc., *continued.*

199. *INTUITIVE CALCULATIONS;* or, Easy and Compendious Methods of Performing the various Arithmetical Operations required in Commercial and Business Transactions; together with Full Explanations of Decimals and Duodecimals, several Useful Tables, &c. By DANIEL O'GORMAN. Twenty-fifth Edition, corrected and enlarged by J. R. YOUNG, formerly Professor of Mathematics in Belfast College. 3s.‡

204. *MATHEMATICAL TABLES,* for Trigonometrical, Astronomical, and Nautical Calculations; to which is prefixed a Treatise on Logarithms. By HENRY LAW, C.E. Together with a Series of Tables for Navigation and Nautical Astronomy. By J. R. YOUNG, formerly Professor of Mathematics in Belfast College. New Edition. 3s. 6d.‡

221. *MEASURES, WEIGHTS, AND MONEYS OF ALL NATIONS,* and an Analysis of the Christian, Hebrew, and Mahometan Calendars. By W. S. B. WOOLHOUSE, F.R.A.S., F.S.S. Sixth Edition, carefully revised and enlarged. 2s.‡

227. *MATHEMATICS AS APPLIED TO THE CONSTRUCTIVE ARTS.* Illustrating the various processes of Mathematical Investigation, by means of Arithmetical and Simple Algebraical Equations and Practical Examples; also the Methods of Analysing Principles and Deducing Rules and Formulæ, applicable to the Requirements of Practice. By FRANCIS CAMPIN, C.E., Author of "Materials and Construction," &c. Second Edition, revised and enlarged by the Author. 3s.‡ [*Just published.*

MISCELLANEOUS VOLUMES.

36. *A DICTIONARY OF TERMS used in ARCHITECTURE, BUILDING, ENGINEERING, MINING, METALLURGY, ARCHÆOLOGY, the FINE ARTS, &c.* By JOHN WEALE. Fifth Edition. Revised by ROBERT HUNT, F.R.S., Keeper of Mining Records. Numerous Illustrations. 5s. cloth limp; 6s. cloth boards.

50. *THE LAW OF CONTRACTS FOR WORKS AND SERVICES.* By DAVID GIBBONS. Third Edition, enlarged. 3s.‡

112. *MANUAL OF DOMESTIC MEDICINE.* By R. GOODING, B.A., M.D. Intended as a Family Guide in all Cases of Accident and Emergency. Third Edition. 2s.‡

112*. *MANAGEMENT OF HEALTH.* A Manual of Home and Personal Hygiene. By the Rev. JAMES BAIRD, B.A. 1s.

150. *LOGIC,* Pure and Applied. By S. H. EMMENS. 1s. 6d.

153. *SELECTIONS FROM LOCKE'S ESSAYS ON THE HUMAN UNDERSTANDING.* With Notes by S. H. EMMENS. 2s.

154. *GENERAL HINTS TO EMIGRANTS.* Containing Notices of the various Fields for Emigration. With Hints on Preparation for Emigrating, Outfits, &c., &c. With Directions and Recipes useful to the Emigrant. With a Map of the World. 2s.

157. *THE EMIGRANT'S GUIDE TO NATAL.* By ROBERT JAMES MANN, F.R.A.S., F.M.S. Second Edition, carefully corrected to the present Date. Map. 2s.

193. *HANDBOOK OF FIELD FORTIFICATION,* intended for the Guidance of Officers Preparing for Promotion, and especially adapted to the requirements of Beginners. By Major W. W. KNOLLYS, F.R.G.S., 93rd Sutherland Highlanders, &c. With 163 Woodcuts. 3s.‡

194. *THE HOUSE MANAGER:* Being a Guide to Housekeeping. Practical Cookery, Pickling and Preserving, Household Work, Dairy Management, the Table and Dessert, Cellarage of Wines, Home-brewing and Wine-making, the Boudoir and Dressing-room, Travelling, Stable Economy, Gardening Operations, &c. By AN OLD HOUSEKEEPER. 3s. 6d.‡

194. *HOUSE BOOK (The).* Comprising:—I. THE HOUSE MANAGER.
112. By an OLD HOUSEKEEPER. II. DOMESTIC MEDICINE. By RALPH GOODING,
& M.D. III. MANAGEMENT OF HEALTH. By JAMES BAIRD. In One Vol.,
112*. strongly half-bound. 6s.

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

EDUCATIONAL AND CLASSICAL SERIES.

HISTORY.

1. **England, Outlines of the History of;** more especially with reference to the Origin and Progress of the English Constitution. By WILLIAM DOUGLAS HAMILTON, F.S.A., of Her Majesty's Public Record Office. 4th Edition, revised. 5s.; cloth boards, 6s.

5. **Greece, Outlines of the History of;** in connection with the Rise of the Arts and Civilization in Europe. By W. DOUGLAS HAMILTON, of University College, London, and EDWARD LEVIEN, M.A., of Balliol College, Oxford. 2s. 6d.; cloth boards, 3s. 6d.

7. **Rome, Outlines of the History of:** from the Earliest Period to the Christian Era and the Commencement of the Decline of the Empire. By EDWARD LEVIEN, of Balliol College, Oxford. Map, 2s. 6d.; cl. bds. 3s. 6d.

9. **Chronology of History, Art, Literature, and Progress,** from the Creation of the World to the Conclusion of the Franco-German War. The Continuation by W. D. HAMILTON, F.S.A. 3s.; cloth boards, 3s. 6d.

50. **Dates and Events in English History,** for the use of Candidates in Public and Private Examinations. By the Rev. E. RAND. 1s.

ENGLISH LANGUAGE AND MISCELLANEOUS.

11. **Grammar of the English Tongue,** Spoken and Written. With an Introduction to the Study of Comparative Philology. By HYDE CLARKE, D.C.L. Fourth Edition. 1s. 6d.

11*. **Philology:** Handbook of the Comparative Philology of English, Anglo-Saxon, Frisian, Flemish or Dutch, Low or Platt Dutch, High Dutch or German, Danish, Swedish, Icelandic, Latin, Italian, French, Spanish, and Portuguese Tongues. By HYDE CLARKE, D.C.L. 1s.

12. **Dictionary of the English Language,** as Spoken and Written. Containing above 100,000 Words. By HYDE CLARKE, D.C.L. 3s. 6d.; cloth boards, 4s. 6d.; complete with the GRAMMAR, cloth bds., 5s. 6d.

48. **Composition and Punctuation,** familiarly Explained for those who have neglected the Study of Grammar. By JUSTIN BRENAN. 17th Edition. 1s. 6d.

49. **Derivative Spelling-Book:** Giving the Origin of Every Word from the Greek, Latin, Saxon, German, Teutonic, Dutch, French, Spanish, and other Languages; with their present Acceptation and Pronunciation. By J. ROWBOTHAM, F.R.A.S. Improved Edition. 1s. 6d.

51. **The Art of Extempore Speaking:** Hints for the Pulpit, the Senate, and the Bar. By M. BAUTAIN, Vicar-General and Professor at the Sorbonne. Translated from the French. 7th Edition, carefully corrected. 2s. 6d.

52. **Mining and Quarrying,** with the Sciences connected therewith. First Book of, for Schools. By J. H. COLLINS, F.G.S., Lecturer to the Miners' Association of Cornwall and Devon. 1s.

53. **Places and Facts in Political and Physical Geography,** for Candidates in Examinations. By the Rev. EDGAR RAND, B.A. 1s.

54. **Analytical Chemistry,** Qualitative and Quantitative, a Course of. To which is prefixed, a Brief Treatise upon Modern Chemical Nomenclature and Notation. By WM. W. PINK and GEORGE E. WEBSTER. 2s.

THE SCHOOL MANAGERS' SERIES OF READING BOOKS,

Adapted to the Requirements of the New Code. Edited by the Rev. A. R. GRANT, Rector of Hitcham, and Honorary Canon of Ely; formerly H.M. Inspector of Schools.

INTRODUCTORY PRIMER, 3d.

	s. d.		s. d.
FIRST STANDARD . . .	0 6	FOURTH STANDARD	1 2
SECOND " . . .	0 10	FIFTH "	1 6
THIRD " . . .	1 0	SIXTH "	1 6

LESSONS FROM THE BIBLE. Part I. Old Testament. 1s.

LESSONS FROM THE BIBLE. Part II. New Testament, to which is added THE GEOGRAPHY OF THE BIBLE, for very young Children. By Rev. C. THORNTON FORSTER. 1s. 2d. *** Or the Two Parts in One Volume. 2s.

FRENCH.

24. **French Grammar.** With Complete and Concise Rules on the Genders of French Nouns. By G. L. STRAUSS, Ph.D. 1s. 6d.
25. **French-English Dictionary.** Comprising a large number of New Terms used in Engineering, Mining, &c. By ALFRED ELWES. 1s. 6d.
26. **English-French Dictionary.** By ALFRED ELWES. 2s.
25,26. **French Dictionary** (as above). Complete, in One Vol., 3s.; cloth boards, 3s. 6d. *** Or with the GRAMMAR, cloth boards, 4s. 6d.
47. **French and English Phrase Book:** containing Introductory Lessons, with Translations, several Vocabularies of Words, a Collection of suitable Phrases, and Easy Familiar Dialogues. 1s. 6d.

GERMAN.

39. **German Grammar.** Adapted for English Students, from Heyse's Theoretical and Practical Grammar, by Dr. G. L. STRAUSS. 1s.
40. **German Reader:** A Series of Extracts, carefully culled from the most approved Authors of Germany; with Notes, Philological and Explanatory. By G. L. STRAUSS, Ph.D. 1s.
41-43. **German Triglot Dictionary.** By NICHOLAS ESTERHAZY S. A. HAMILTON. In Three Parts. Part I. German-French-English. Part II. English-German-French. Part III. French-German-English. 3s., or cloth boards, 4s.
41-43 & 39. **German Triglot Dictionary** (as above), together with German Grammar (No. 39), in One Volume, cloth boards, 5s.

ITALIAN.

27. **Italian Grammar,** arranged in Twenty Lessons, with a Course of Exercises. By ALFRED ELWES. 1s. 6d.
28. **Italian Triglot Dictionary,** wherein the Genders of all the Italian and French Nouns are carefully noted down. By ALFRED ELWES. Vol. 1. Italian-English-French. 2s. 6d.
30. **Italian Triglot Dictionary.** By A. ELWES. Vol. 2. English-French-Italian. 2s. 6d.
32. **Italian Triglot Dictionary.** By ALFRED ELWES. Vol. 3. French-Italian-English. 2s. 6d.
28,30, 32. **Italian Triglot Dictionary** (as above). In One Vol., 7s. 6d. Cloth boards.

SPANISH AND PORTUGUESE.

34. **Spanish Grammar,** in a Simple and Practical Form. With a Course of Exercises. By ALFRED ELWES. 1s. 6d.
35. **Spanish-English and English-Spanish Dictionary.** Including a large number of Technical Terms used in Mining, Engineering, &c., with the proper Accents and the Gender of every Noun. By ALFRED ELWES. 4s.; cloth boards, 5s. *** Or with the GRAMMAR, cloth boards, 6s.
55. **Portuguese Grammar,** in a Simple and Practical Form. With a Course of Exercises. By ALFRED ELWES. 1s. 6d.
56. **Portuguese-English and English-Portuguese Dictionary,** with the Genders of each Noun. By ALFRED ELWES. [*In the press.*

HEBREW.

46*. **Hebrew Grammar.** By Dr. BRESSLAU. 1s. 6d.
44. **Hebrew and English Dictionary,** Biblical and Rabbinical; containing the Hebrew and Chaldee Roots of the Old Testament Post-Rabbinical Writings. By Dr. BRESSLAU. 6s.
46. **English and Hebrew Dictionary.** By Dr. BRESSLAU. 3s.
44,46. 46*. **Hebrew Dictionary** (as above), in Two Vols., complete, with the GRAMMAR, cloth boards, 12s.

LATIN.

19. **Latin Grammar.** Containing the Inflections and Elementary Principles of Translation and Construction. By the Rev. THOMAS GOODWIN, M.A., Head Master of the Greenwich Proprietary School. 1s.

20. **Latin-English Dictionary.** By the Rev. THOMAS GOODWIN, M.A. 2s.

22. **English-Latin Dictionary;** together with an Appendix of French and Italian Words which have their origin from the Latin. By the Rev. THOMAS GOODWIN, M.A. 1s. 6d.

20,22. **Latin Dictionary** (as above). Complete in One Vol., 3s. 6d.; cloth boards, 4s. 6d. *** Or with the GRAMMAR, cloth boards, 5s. 6d.

LATIN CLASSICS. With Explanatory Notes in English.

1. **Latin Delectus.** Containing Extracts from Classical Authors, with Genealogical Vocabularies and Explanatory Notes, by H. YOUNG. 1s. 6d.

2. **Cæsaris** Commentarii de Bello Gallico. Notes, and a Geographical Register for the Use of Schools, by H. YOUNG. 2s.

3. **Cornelius Nepos.** With Notes. By H. YOUNG. 1s.

4. **Virgilii** Maronis Bucolica et Georgica. With Notes on the Bucolics by W. RUSHTON, M.A., and on the Georgics by H. YOUNG. 1s. 6d.

5. **Virgilii** Maronis Æneis. With Notes, Critical and Explanatory, by H. YOUNG. New Edition, revised and improved. With copious Additional Notes by Rev. T. H. L. LEARY, D.C.L., formerly Scholar of Brasenose College, Oxford. 3s.

5* ——— Part 1. Books i.—vi., 1s. 6d.

5** ——— Part 2. Books vii.—xii., 2s.

6. **Horace;** Odes, Epode, and Carmen Sæculare. Notes by H. YOUNG. 1s. 6d.

7. **Horace;** Satires, Epistles, and Ars Poetica. Notes by W. BROWNRIGG SMITH, M.A., F.R.G.S. 1s. 6d.

8. **Sallustii** Crispi Catalina et Bellum Jugurthinum. Notes, Critical and Explanatory, by W. M. DONNE, B.A., Trin. Coll., Cam. 1s. 6d.

9. **Terentii** Andria et Heautontimorumenos. With Notes, Critical and Explanatory, by the Rev. JAMES DAVIES, M.A. 1s. 6d.

10. **Terentii** Adelphi, Hecyra, Phormio. Edited, with Notes, Critical and Explanatory, by the Rev. JAMES DAVIES, M.A. 2s.

11. **Terentii** Eunuchus, Comœdia. Notes, by Rev. J. DAVIES, M.A. 1s. 6d.

12. **Ciceronis** Oratio pro Sexto Roscio Amerino. Edited, with an Introduction, Analysis, and Notes, Explanatory and Critical, by the Rev. JAMES DAVIES, M.A. 1s.

13. **Ciceronis** Orationes in Catilinam, Verrem, et pro Archia. With Introduction, Analysis, and Notes, Explanatory and Critical, by Rev. T. H. L. LEARY, D.C.L. formerly Scholar of Brasenose College, Oxford. 1s. 6d.

14. **Ciceronis** Cato Major, Lælius, Brutus, sive de Senectute, de Amicitia, de Claris Oratoribus Dialogi. With Notes by W. BROWNRIGG SMITH, M.A., F.R.G.S. 2s.

16. **Livy:** History of Rome. Notes by H. YOUNG and W. B. SMITH, M.A. Part 1. Books i., ii., 1s. 6d.

16*. ——— Part 2. Books iii., iv., v., 1s. 6d.

17. ——— Part 3. Books xxi., xxii., 1s. 6d.

19. **Latin Verse Selections,** from Catullus, Tibullus, Propertius, and Ovid. Notes by W. B. DONNE, M.A., Trinity College, Cambridge. 2s.

20. **Latin Prose Selections,** from Varro, Columella, Vitruvius, Seneca, Quintilian, Florus, Velleius Paterculus, Valerius Maximus Suetonius, Apuleius, &c. Notes by W. B. DONNE, M.A. 2s.

21. **Juvenalis** Satiræ. With Prolegomena and Notes by T. H. S. ESCOTT, B.A., Lecturer on Logic at King's College, London. 2s.

GREEK.

14. **Greek Grammar**, in accordance with the Principles and Philological Researches of the most eminent Scholars of our own day. By HANS CLAUDE HAMILTON. 1s. 6d.

15,17. **Greek Lexicon.** Containing all the Words in General Use, with their Significations, Inflections, and Doubtful Quantities. By HENRY R. HAMILTON. Vol. 1. Greek-English, 2s. 6d.; Vol. 2. English-Greek, 2s. Or the Two Vols. in One, 4s. 6d.: cloth boards, 5s.

14,15. 17. **Greek Lexicon** (as above). Complete, with the GRAMMAR, in One Vol., cloth boards, 6s.

GREEK CLASSICS. With Explanatory Notes in English.

1. **Greek Delectus.** Containing Extracts from Classical Authors, with Genealogical Vocabularies and Explanatory Notes, by H. YOUNG. New Edition, with an improved and enlarged Supplementary Vocabulary, by JOHN HUTCHISON, M.A., of the High School, Glasgow. 1s. 6d.

2, 3. **Xenophon's Anabasis**; or, The Retreat of the Ten Thousand. Notes and a Geographical Register, by H. YOUNG. Part 1. Books i. to iii., 1s. Part 2. Books iv. to vii., 1s.

4. **Lucian's Select Dialogues.** The Text carefully revised, with Grammatical and Explanatory Notes, by H. YOUNG. 1s. 6d.

5-12. **Homer, The Works of.** According to the Text of BAEUMLEIN. With Notes, Critical and Explanatory, drawn from the best and latest Authorities, with Preliminary Observations and Appendices, by T. H. L. LEARY, M.A., D.C.L.

THE ILIAD:	Part 1. Books i. to vi., 1s. 6d.	Part 3. Books xiii. to xviii., 1s. 6d.
	Part 2. Books vii. to xii., 1s. 6d.	Part 4. Books xix. to xxiv., 1s. 6d.
THE ODYSSEY:	Part 1. Books i. to vi., 1s. 6d	Part 3. Books xiii. to xviii., 1s. 6d.
	Part 2. Books vii. to xii., 1s. 6d.	Part 4. Books xix. to xxiv., and Hymns, 2s.

13. **Plato's Dialogues**: The Apology of Socrates, the Crito, and the Phædo. From the Text of C. F. HERMANN. Edited with Notes, Critical and Explanatory, by the Rev. JAMES DAVIES, M.A. 2s.

14-17. **Herodotus**, The History of, chiefly after the Text of GAISFORD. With Preliminary Observations and Appendices, and Notes, Critical and Explanatory, by T. H. L. LEARY, M.A., D.C.L.
Part 1. Books i., ii. (The Clio and Euterpe), 2s.
Part 2. Books iii., iv. (The Thalia and Melpomene), 2s.
Part 3. Books v.-vii. (The Terpsichore, Erato, and Polymnia), 2s.
Part 4. Books viii., ix. (The Urania and Calliope) and Index, 1s. 6d.

18. **Sophocles**: Œdipus Tyrannus. Notes by H. YOUNG. 1s.

20. **Sophocles**: Antigone. From the Text of DINDORF. Notes, Critical and Explanatory, by the Rev. JOHN MILNER, B.A. 2s.

23. **Euripides**: Hecuba and Medea. Chiefly from the Text of DINDORF. With Notes, Critical and Explanatory, by W. BROWNRIGG SMITH, M.A., F.R.G.S. 1s. 6d.

26. **Euripides**: Alcestis. Chiefly from the Text of DINDORF. With Notes, Critical and Explanatory, by JOHN MILNER, B.A. 1s. 6d.

30. **Æschylus**: Prometheus Vinctus: The Prometheus Bound. From the Text of DINDORF. Edited, with English Notes, Critical and Explanatory, by the Rev. JAMES DAVIES, M.A. 1s.

32. **Æschylus**: Septem Contra Thebes: The Seven against Thebes. From the Text of DINDORF. Edited, with English Notes, Critical and Explanatory, by the Rev. JAMES DAVIES, M.A. 1s.

40. **Aristophanes**: Acharnians. Chiefly from the Text of C. H. WEISE. With Notes, by C. S. T. TOWNSHEND, M.A. 1s. 6d.

41. **Thucydides**: History of the Peloponnesian War. Notes by H. YOUNG. Book 1. 1s.

42. **Xenophon's Panegyric on Agesilaus.** Notes and Introduction by LL. F. W. JEWITT. 1s. 6d.

43. **Demosthenes.** The Oration on the Crown and the Philippics. With English Notes. By Rev. T. H. L. LEARY, D.C.L., formerly Scholar of Brasenose College, Oxford. 1s. 6d.

[redacted]