CHAPTER II.

SEWERAGE.

Drains and Sewers.—Drains or sewers may be defined as conduits for carrying off liquids of any kind in any position, but the term is generally understood to refer more especially to underground channels or pipes of metal, stoneware, brickwork, or concrete; the liquid may consist of sewage, and subsoil or other water.

The legal definition is more difficult.

The Public Health Act of 1875, sect. 15, imposes on the local authority the duty of making such sewers as may be necessary for effectually draining their district for the purposes of the Act. Any failure to perform this obligation can be met by **a complaint to the Local Government Board, who, upon inquiry, make an order limiting the time for the performance of the duty, and such order may be enforced by mandamus;** this, however, does not apply to the Metropolis.

In the case of building estates, the sewer in the street is laid by the owner, and it was ruled, in the case of Reg. v. Tynemouth Rural District Council, 1898, that when connections were made with it the local authority must provide the outfall; there are, however, many difficult questions involved in the respective rights of the owner and the local authority in connection with such estates which have not yet been settled.

The legal distinction between **“drains”** and **“sewers”** is an important one, as the duty of repairing a drain and keeping it in good order, so as not to be a nuisance, falls upon the owner or occupier of the premises drained, whereas a sewer belongs to and is vested in the local authority, whose duty it is to ventilate and cleanse it and keep it in such a state as not to create a nuisance.

Every private owner, provided he does not commit a trespass on private property, may connect the drains of his premises with the sewer

* Paper by Mr. Alexander Macmorran, K.C., read before the Auctioneers' Institute. The Surveyor and Municipal and County Engineer, November 11th, 1898.
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on giving due notice and complying with local regulations as to method to be employed in making the connection.

In 1893, in the case of *Ferrand v. Halls Land and Building Co.*, Lord Justice Smith said*: "It will be noticed that a sewer may not necessarily convey sewage matter in order to constitute it a sewer. It would be none the less a sewer within the Act if it conveyed only rain or surface water. The draining off of rain or surface water collected from different premises or different feeders into one main drain would constitute that main drain a sewer within the meaning of the Act."

'The open sewer' is one that is not covered; thus, in the case of *Wheatcroft v. Matlock Local Board*, the drainage of a number of houses being led by a pipe into an open water course which discharged into a brook, the open water course was held to be a sewer.

It was decided in the case of *Falconer v. South Shields* that the character of a natural stream may be so altered by the quantity of sewage discharged into it as to become a sewer.

On referring to the 11 & 12 Vict. c. 112, the Act of 1843 to consolidate and continue the Metropolitan Commissions of Sewers, sect. 147, and the 11 & 12 Vict. c. 63, the Public Health Act of 1848, sect. 2, we find that the word "drain" is in both cases defined as meaning and including any drain of and used for the drainage of one building only, or premises within the same curtilage, and made merely for the purpose of communicating with a cesspool or other receptacle for drainage, or with a sewer into which the drainage of two or more buildings or premises occupied by different persons is conveyed; the word "sewer" meaning and including sewers of every description except drains to which the word "drain" interpreted as aforesaid applies. This definition was re-enacted in the Metropolis Local Management Act of 1865, sect. 250, and in the Public Health Act of 1875, sect. 4, and was confirmed in the case of *Travis v. Utley* in 1893.

The word "curtilage" used in the Act, according to Mr. Macmorran, K.C., "is the enclosure in which a house stands, or perhaps the space of ground which would pass by a simple conveyance of a house and its appurtenances. The drain, therefore, from a dwelling-house and the stables adjoining it, and contained within the same enclosure, would be a drain. A similar channel for drainage from the same house would be a sewer if the drains from the stables and adjoining premises were let into it. It would become a sewer, however, only from the point at which it received the drainage of the second building."

In the case of *Travis v. Utley*, already cited, a number of houses in a

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street belonging to one owner were divided into sets of three for the purpose of drainage; in each set the drain was led from one house through the other two, taking their drainage en roule to the public sewer: the local authority discovered defects in this common drain and called upon the owner to remedy the nuisance caused by these defects, but he declined to take action. The case eventually came before the High Court, and it was ruled that the whole of this drain was a sewer and that the local authority was to execute the necessary repairs and remove the nuisance. The opinion of the judge who tried the case seems to have been that the whole of this common drain from the first house as far as the street was to be considered a sewer; this opinion was afterwards modified in the case of Beckenham Urban District Council v. Wood, in 1898, in so far that a drain of this description is only a sewer from the point at which it receives the drainage of the second house.

The drawback to the situation thus created, as far as the owner is concerned, is that he must give free access to the premises at all times and must not interfere with, and, in urban districts, he must not build over, the drain without the permission of the local authority.

Section 29 of the Public Health Act, 1875, empowers an authority to require the owner or occupier of any house to drain such house into a sewer where such sewer is not more than 100 feet from the site of such house in accordance with the directions of the authority.

The statutes applying to London provide:—By sect. 73 of 18 & 19 Vict. c. 120, that any house may be required to drain to a sewer, if there be a sewer within 100 feet of the house (this distance is extended to 200 feet by sect. 66 of 25 & 26 Vict. c. 103), in a manner to satisfy the vestry or district board, and if the owner neglect during twenty-eight days after notice to commence to comply, the vestry or board may execute the work and recover the cost from the owner.

Section 75 makes it unlawful to erect any house unless its lowest floor can be satisfactorily drained into a sewer.

Section 76 forbids the excavation of any foundations of any new house or the making of any drain until seven days' notice shall have been given to the vestry or board, so that the vestry or board may make their order as to the level of the lowest floor of the house, or as to the making of such a drain.

Drains are generally constructed and maintained by private individuals, and sewers by public authorities, to carry the drainage of more than one building, but a difficulty in a distinct definition arises in the case of certain intermediate portions which in many instances unite the drains to the sewer: on the one hand, when carrying the drainage of more than one building they might be considered as “sewers,” and
on the other, lying as they do for the most part within private premises for the greater portion of their length, and having been constructed in the first place by private individuals, they might be classed as "drains." This leads us to the consideration of "combined drains." Now, as regards a "combined drain," we understand it generally to mean a pipe or culvert of small calibre in continuation of the drains of two or more houses to the sewer. Section 74 of the Act already referred to empowers a vestry or board to order that a group or block of houses be drained by a combined operation if it appear to the vestry or board that such group or block of houses may be drained and improved more economically or advantageously in combination than separately.

In the Metropolis Local Management Act, 1855, sect. 250, it is provided that "the word drain ... shall also include any drain for draining any group or block of houses by a combined operation under the order of any vestry or district board." This definition being subsequently extended by the Act of 1862, sect. 112, to include "any drain for draining a group or block of houses by a combined operation, laid or constructed before the 1st day of January, 1856, pursuant to the order or direction or with the sanction or approval of the Metropolitan Commissioners of Sewers."

This only refers to the Metropolis, and as regards the rest of the country "combined drainage" is not sanctioned at all.

The Amending Act of 1890 recognises the existence of the "single private drain," and by sect. 19 fixes the liability for its maintenance on the owners; but that section only takes effect "Where two or more houses belonging to different owners are connected with a public sewer by a single private drain."

An application may be made under sect. 41 of the Public Health Act, 1875, relating to complaints as to nuisances from drains, and the local authority may recover any expenses incurred by them in executing any works under the powers conferred on them by that section from the owners of houses, in such shares and proportions as shall be settled by their surveyor, or, in case of dispute, by a court of summary jurisdiction.

"For the purposes of this section the expression 'drain' includes a drain used for the drainage of more than one building."

In the case of Bradford v. The Mayor, etc. of Eastbourne, 1896, it was decided that the section is intended to apply to what would otherwise be a sewer draining two or more houses, belonging to different owners but laid in private land, so that the public could not have access to it. This decision has since been followed in Seal v. Merthyr Tydfil, 1897.

The expression "single private drain," which has thus been evolved by the amendment of the law by the Act of 1890, is of very limited application, and simply compels the owners, provided a certain special
procedure is followed, to bear the costs of repairs which would otherwise fall on the local authority. The procedure required is that on receipt of a written complaint from some person that the drain is a nuisance, the local authority must authorize their officer to enter and examine the drain; if he reports it to be in a defective condition, the local authority may then give notice to the owners concerned to do the necessary work, and upon their neglecting or refusing to comply, the local authority may do the work and recover the expenses. If, however, this procedure is not followed, the duty of the local authority is the same as if the amendment had never been made, and the "single private drain" remains a sewer, which the local authority is bound to repair, and which, if necessary, it can be compelled to repair. "This was pointed out by the Court in the case of Reg. v. The Mayor of Hastings, 1897, where the local authority was ordered to do repairs to a common drain, although had the appropriate procedure been adopted it is possible that the owners might have been compelled to do them." A drain may legally become a sewer in consequence of secret and even wrongful connection being made with it, and the local authority is then bound to take charge of it as such.

A curious case was that of a drain which was common to three houses and was thus constituted a sewer, and it actually remained a sewer when the other two houses had been cut off, and only one of the houses was continuing its use. An anomaly arises from the use in this section of the words "belonging to different owners." If the pipe or conduit takes the drainage of two or more houses belonging to the same owner it is a sewer and does not come within the provisions of the section. See the case of Jackson v. Wimbledon Urban Council. In this case the appellant Jackson was the owner of twelve houses and four other houses in the same row belonged to different owners (Fig. 18). At the rear of these sixteen houses ran a common drain which connected with the public sewer by means of a branch drain A B which was carried at right angles from the common

![Fig. 18.](image-url)
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drain: the whole of the drains were on private property. The branch
drain A B ran between the houses belonging to the appellant and those
belonging to other owners. The Divisional Court held that the branch
drain was "a single private drain," but that the portion of the common
drain running at the back of appellant's houses, notwithstanding the
fact that it discharged into "a single private drain," was a sewer. The
effect of this judgment was that a sewer might discharge into a single
private drain.

The pipe from A to B was held to be "a single private drain," and
that from B to C a sewer.

Sewers made for profit are those constructed with the object of
realising some advantage beyond any sanitary purpose; such sewers are
not vested in the local authority. Vide Minehead Local Board v. Luttrill.

Drains made for the purpose of land drainage under local Acts may
become sewers in consequence of houses being connected with them, as
in the case of The London and North Western Railway v. Runcorn Rural
District Council, 1898, and yet not vest in the local authority.

Systems of Sewerage.—There are two well recognised systems of
arranging sewers, viz.:—

(1) The combined system in which all the rainwater from roofs,
yards, and streets is admitted into the sewers.

(2) The separate system, in which two distinct sets of sewers and
drains are provided, one to take sewage proper and the other to take
rainwater, and if the subsoil is waterlogged a third set of pipes may be
required to deal with subsoil water.

The separate system when carried out for a complete town is a most
complicated arrangement, and there are very few examples to be found.

A partially separate system is, however, carried out in many towns,
and is growing in favour as it enables the sewage purification problem
to be more easily solved than where the combined system obtains.

In a partially separate system it is usual to connect to the sewage
sewer the rainwater from the back roofs and back-yards of houses.
In a closely built area of cottage houses under modern bye-laws the
rainfall from about one-third of the total area is drained into the
sewage sewers, the remaining two-thirds being dealt with by the rainfall
sewers.

When designing sewers on this system it is usual to calculate the
rainfall upon an area of 10 square yards per head of the population,
and to add to this the sewage proper in order to obtain the quantity of
liquid which the sewage sewers should be capable of discharging.

In the larger towns of this country the sewerage systems have
mostly been laid out on the combined system, and it is only when
dealing with new streets and sewer extensions that the partially separate system can be carried out.

But when remodelling the drainage of small towns the old sewers can often be retained as rainfall sewers, and new sewage sewers on the partially separate system can be laid down.

In new districts like the urban areas which spring up on the outskirts of large cities the separate system in its entirety can be applied.

The chief objections to the separate system are the additional first cost, the danger of drain connections being made to the wrong set of sewers, and the discharge of foul water into the streams from the rainwater sewers due to the first washings from streets and yards.

As to whether it really costs more to instal two sewers and sets of drains there is a considerable difference of opinion amongst engineers; some contend that as the surface-water sewers can be laid at shallow depths and can be made to discharge at numerous outfalls instead of concentrating on one point, they do not cost so much as the saving effected by having smaller sewers for sewage only with a small proportion of rainfall.

The comparison is a difficult one, as the municipality does not bear the cost of making two separate drains from each house, but obviously this element must enter into the calculation.

On the whole the consensus of opinion is in favour of the view that a separate system is more expensive than the combined if the latter is arranged with a proper system of overflows, which will relieve the sewers when a certain degree of dilution of the sewage has been arrived at.

The danger of connections of foul water drains to surface-water sewers is one which should be overcome by close supervision, but those who have had experience of the work know only too well that the danger exists and is difficult to avoid.

The discharge of foul water into streams by the rainwater sewers is a very solid ground of objection; it is well known that the first washings of streets and yards when rain commences to fall are quite as foul as ordinary sewage, and this is particularly true of the poorer and more densely populated parts of great towns; in these places there is a great tendency for the inhabitants to throw slops and other sewage matter into the street gullies.

With a combined system the earlier part of a rainfall is conducted to the sewage disposal works except in the case of very heavy thunderstorms which cause the storm overflows to come into operation at once. These occasions are, however, comparatively few, and when they do occur the streams are usually quickly flooded, and the amount of dilution which then takes place renders the pollution less pronounced.

The chief advantage of the separate system is in the restriction of
the huge variations of flow at the sewage disposal works; this is especially important when the sewage has to be pumped, and when it is dealt with on any system involving tanks, which are often of too small a capacity to deal adequately with the dry weather flow.

It must be borne in mind in this connection that the usual practice of to-day is to provide pumps and purification plant for dealing with six times the dry weather flow, and the surplus over that amount is allowed to run past the works; even with a complete separate system some rainwater will find its way into the sewage sewers, and the rate of flow may be increased two or three times the normal, and with a partial separate system it is quite common to get six or more times the dry weather flow, so that after all it is only a question of how often the normal flow will be materially increased.

With the separate or partially separate system there is much less road grit and mineral matter to be contended with at the sewage works, and this is a distinct advantage, especially on sewage farms and with bacterial systems of purification.

The flushing power of the storm-waters in the combined system is one of the advantages claimed by its advocates, but, on the other hand, it must be pointed out that whilst this does much good and saves ordinary flushing, yet, in the absence of rainfall, when flushing is most required, the velocity of flow is at a minimum owing to the comparatively small quantity of sewage flowing through the huge sewers.

**General Principles.**—Having selected the system on which the drainage of any particular locality is to be carried out, the plans should be carefully prepared, so as to secure uniformity throughout.

The position to which the sewage is to be delivered by the sewers requires careful arrangement, especially where pumping has to be resorted to, so as to minimise the lift, and the consequent cost; in the latter case the minimum gradients consistent with efficiency would be given to the drains.

Intercepting sewers at different levels may also be arranged so as to reduce the cost as far as possible.

A town which is completely and properly sewered will have a system of underground sewage-conduits, formed with even lines and gradients, true in cross-sectional form, and capable of transmitting sewage at rates of from one mile per hour to six or seven miles per hour by flushing. If the town stands upon a site such as Brighton, Bristol, or Liverpool, care should be taken to so plan and execute the main sewers that the area shall be sub-divided by intercepting sewers, or by "ramps" and double ventilation, as in Fig. 3, Plate II.* (p. 24), so as to prevent the lower

* Plate II. is compiled from designs for manholes by Mr. Stephen H. Terry, M.I.C.E., and for flushing gate by Mr. James Mansergh, M.I.C.E.
parts from being flooded with the downward flow of storm-water sewage, and the upper parts of the town being injured by the upward flow of sewage gases. This system of subdividing and intercepting the sewage, and specially ventilating the main sewers, will be found to be of the utmost importance; as if sewers are not so dealt with, suburban houses, however superior in construction and accommodation, may be poisoned by the transmission of sewer gases from the lower parts of the town to the higher parts.

If the sewers have steep gradients, and the flow of sewage is unbroken, a velocity in the sewage is produced, which is liable to be very injurious in its wearing action, and during heavy rains it acquires such a velocity as not only to wear out the invert and blow the joints, but also to burst the sewers. Stoneware pipes, under such circumstances, should be bedded in concrete, and it would be preferable to use iron pipes where steep gradients are required. It is necessary in such sewers to provide means for regulating the flow. In arranging the levels for the various portions of the sewers, it must be remembered that they are all converging to one point, consequently their intersections must be carefully considered. Sewers and drains at junctions and curves should have extra fall from 1 inch to 3 inches to compensate for friction.

Levels.—In order to connect a high level pipe sewer with one at a low level, a ramp, such as that shown in Plate III. (p. 24), is generally employed to prevent the evils of a direct fall. The exit at the high level should be made with a very full throat, to check the tendency of storm-water to leap the opening, and run straight on through the inspection arm, which is only provided for inspection and clearing purposes. The necessity for an inspection arm may be entirely obviated by the introduction of an inspection pit, as shown dotted in Plate III. Plate IV. (p. 26) shows the syphon drops designed on the principle of Sir R. Rawlinson for breaking rapid falls, as adopted at Rochdale.

Where culverts are used, a similar system should be adopted, and in that case, iron pipes of smaller sectional area than that of the upper sewer should be employed for forming the ramp.

Types of sewer outlets for use on the sea coast are given in Plates V. and VI. (p. 26); the latter is only applicable where ample fall is available.

Depth of Sewers, etc.—The depth of the sewers and drains below ground must be regulated so as to enable them to drain the basements of the houses.

Manholes.—There should, if possible, be manholes at all junctions and bends. A manhole fitted with a 21-inch sluice, as used on the

* Plates V. and VI. are from designs by Mr. Stephen H. Terry, M.I.C.E.
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Metropolitan sewerage works, is shown in Plate VII. (p. 28), and the details of the manhole used at Rochdale, in connection with the syphon drops for breaking the velocity of sewage on steep gradients, is shown in Plate VIII. (p. 28).

Plate IX. (p. 28) shows details of manholes, ventilation, shafts and flushing of chambers.

Straight Lines between Manholes.—Unless there is some practical difficulty in the way, each sewer should be laid in straight lines, and with even gradients between manholes and junction-pits (vide Plate X., p. 30).

Valves.—When the outfall of a sewer is subject to a rise of tide, it may be protected by a self-closing flap, or tankard valve, to prevent the sewage from being forced back into the system. All the working parts

![Fig. 14.—Tankard Valve for Sewer.](image)

of a tankard valve should be bushed with gun-metal, to prevent the valve from sticking (see Fig. 14; also Figs. 5, 6, and 7, Plate II., p. 24).

A properly constructed tide valve should be entirely self-acting, and should regulate the discharge of the sewers at the outfall of which it is fixed.

A detail of self-closing tidal gates for large sewers is given in Plate XI., p. 30. In large sewers of this class it is desirable to have two sets of self-closing gates, one behind the other, so that in the event of one gate failing to close by reason of some obstruction the sewer shall not be flooded by salt water.

Storage Tank.—When sewers deliver in such a position as to be liable to be covered by a rise of water, the pressure being insufficient to overcome the obstruction, or when it would be objectionable to discharge the sewage with a rising tide, the lower end of the sewer must be

* Plate VII. is from a design by Mr. James Mansergh, M.I.C.E.
made large enough to store the sewage whilst the outlet is closed (vide Plate XII., p. 32). An overflow outlet should also be provided for flood-water.

In the storage tanks made for tidal outfalls, valves of specially large area must be provided, to give a rapid discharge at the proper phase of the tide. These valves are often very cumbersome and heavy to lift, and a mechanical means of opening them is often desirable.

Fig. 15 is an illustration of one of a set of twelve large sluice valves, 3 feet by 3 feet 9 inches waterway, constructed by Messrs. J.

![Sluice Valve, Portsmouth Sewer Outfall Works.](image)

Blakeborough and Sons, Brighouse, for the Portsmouth Sewer Outfall Works.

The valves are capable of being opened by turbines actuated by the flow of sewage, or alternatively by hand, and are used in connection with sewage tanks in which the sewage is held up until the outgoing tide and then discharged into the sea.

A square opening is provided on the outlet side of the valve to which pipes are connected and carried up to top water line, thus serving as an overflow from the tank.

The weight of the valve plug is relieved by a balance weight, which is attached by chains to the shackles on the rods shown in the
illustration, the chains and weights being supported by chain pulleys carried by brackets built into the crown of the tanks.

The auxiliary sluice or inlet to turbine is opened by hand and is worked by spur gearing from the spindle on the right hand of the illustration. As the auxiliary sluice rises it actuates a friction clutch underneath the spur gearing on the valve, and thus causes the large valve to be opened by the motion imparted by the turbine.

The arrangements of parts is, however, such that the clutch does not come into operation until the turbine has got up full speed, so that the large valve may be opened quickly.

A circular plate is attached to the bottom of the plug of the large valve, and when the valve is full open the circular plate closes the outlet of the turbine, thus stopping its action.

Inverted Syphons.—Where it is found necessary that a sewer should cross a river, stream, or valley in its passage towards the outfall, and it is inconvenient to bridge the stream at the level at which the sewer must be constructed, inverted syphons are generally adopted.

To effect this the pipes, which should be of strong wrought iron, are laid, in the case of rivers and streams, in three ways, viz., by means of barges or lighters, by forming cofferdams, or by tunnelling the bed of the channel.

For this purpose it is customary to provide manholes on both banks of the channel to be crossed, which also serve as convenient places for the removal of any obstruction that may occur.

There is a considerable difference of opinion as to the form inverted syphons should take, and the method to be adopted in their construction.

In some cases pipes are made to follow the sectional outline of the river or channel, by which arrangement there are usually two sloping lengths and one flat length of pipe. If such a syphon be used for crude sewage, and the volume be intermittent and uncertain, there is a liability of choking, owing to heavy matter carried by the sewage being deposited in the flat length.

It is usual, therefore, during construction to pass a chain through the pipes and secure the ends in the manholes on the adjoining banks, so that it may be drawn backwards and forwards, and thus stir up and set in motion any sedimentary substances that may have been deposited.

Syphons should be laid in duplicate, with penstock chambers at each end, so that the sumps can be cleared of débris. When constructing long inverted syphons, ventilation must be provided at the descending leg of the syphon, otherwise air will accumulate there, and will probably interfere very seriously with its discharging power. This
may be effected by carrying pipes from the bend up to such a level that, even when the flow is interrupted, they will not overflow.

It is usual to relieve such syphons from having to carry storm-water, by providing suitable overflows into the river.

Junctions.—When laying out the junctions of sewers, in no case should the main line of intersection of the two sewers make an angle of less than a right angle, and the floor of the manhole should be constructed with curved inverts as shown in Plate III., p. 24, and Plate IX., p. 20. The house drains must not join the sewers directly at right angles; in fact, such junctions should always be avoided.

If a manhole is used for the junction, the bottom can always be constructed so as to give the required curve in the direction of the flow of the current, as shown in Figs. 139—132 (p. 132); by this means as little disturbance as possible is caused to the proper flow of the liquids along their respective channels.

Sewers of unequal sectional diameters should not join with level inverts, but the lesser, or tributary sewer, should have a fall into the main at least equal to the difference in the sectional diameter, or in other words the soffits or covers of the sewers should be kept in the same line. Where pipe junctions are used, the socket should be slightly tilted, and the first length of pipe discharging into it be given extra fall, to check the tendency to backflow in the branch.

Cross Sections.—When the ordinary flow of sewage is sufficient to keep a sewer of circular section half full, that form is the best, being the strongest and cheapest.

When the flow is variable, and at times very small, the egg-shaped section may be adopted, as it gives greater depth for small flows than could be obtained with the circular section, the capacity for the maximum flow being the same in each case.

Thus, with a variable discharge, the hydraulic mean depth is a maximum for each section of liquid flowing through the sewer.

Area of.—The area of the cross section of sewers must be governed by the amount of sewage which they have to convey, their fall, and whether periodically flushed. Sewage, when fresh, causes no nuisance, but after about 24 hours, according to the weather, decomposition sets in, and it becomes putrefactive, producing deleterious gases. The capacity of the sewers should thus be sufficient to carry off in 24 hours the maximum quantity that may pass into them. In a town, the hourly flow of sewage varies considerably during the day in accordance with the domestic habits of the community; where baths are provided, there will be a corresponding discharge of soiled water into the sewer in the early
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morning; during the forenoon the water-closets and sinks will be contributing liquid of a more or less foul nature, whereas in the afternoon, the discharge will be principally from sinks and urinals; manufacturers' refuse is poured in irregularly both by day and night; thus there are continual fluctuations in the hourly discharge. The flow of sewage is at its maximum during the day and minimum during the night. The maximum flow in an hour has been found by gaugings in many towns to be double the mean flow and this must be kept in view when arranging the capacity of the sewers. If, on the other hand, the sewers are too large, there will not be a sufficient flow through them to clear away any sediment and prevent deposit; consequently, care must be taken not to impair the efficiency of the sewer by making it too large a bore. Under ordinary circumstances, they should run about two-thirds full when taking rainfall. Sewers should not be less than six inches in internal diameter, as house drains in this country are never less than four inches in diameter; the sewer should, as a general rule, be larger than its tributaries, but this may in special cases be modified by the gradient. Drains for liquids only may, in some cases, be as small as three inches, but no drain receiving the contents of a soil-pipe should be less than four inches, which is a suitable size.

Fig. 16, p. 30, shows a series of curves representing the rate of flow of sewage during different hours of the day in various towns.

The curves are drawn to a scale from which can be measured the variations in percentages of the mean flow.

The Leeds curve represents a mean daily flow of 17,250,000 gallons, and the gaugings were taken over a weir on the arrival of the sewage at the works.

The Saltley outfall sewer of the Birmingham Sewage Works is for a mean flow of 18,750,000 gallons. This diagram does not represent the quantity of water coming down to the works, but is a measure of the rate of flow down the main conduit between the septic tanks and the bacteria beds. The fluctuation in the rate of flow is therefore somewhat modified before reaching the point at which the gaugings were taken.

The Cole Valley sewer is a small sewer tributary to the Birmingham Sewage Works which deals with the sewage of a separate area. It has a mean flow of about 1,250,000 gallons per day, and the curve represents the rate of flow in the sewer as it reaches the works.

The Cheltenham curve represents the rate of flow at the works with a mean flow of 1.09 million gallons per day.

The Rochdale curve represents the rate of flow in the sewage flowing to the Castleton Sewage Disposal Works, the mean rate of flow of which is some 200,000 gallons per day.
The Yardley curve gives a measure of the rate of flow at the Cole Hall Sewage Works, which is 850,000 gallons per day.

Amount of sewage.—The next point to be considered is the amount of sewage to be dealt with, as on this depends, to a great extent, the size and shape of the cross section, and also the current necessary for the sewer or house drain. A careful survey must be made of the whole
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locality to be drained, including any neighbouring districts whose sewage may have to be included.

**Estimate of.**—It is customary to base the estimate of the quantity of sewage to be dealt with at so much per head of population for the discharge in 24 hours. An allowance must also be made for the prospective increase of population; in the case of a town, its present rate of increase as obtained from the census returns of the past two decades would be considered a guide; this rate would, however, require modification according to a carefully formed opinion as to whether the same rate of increase was likely to be maintained. Attention should also be given to the industrial and manufacturing possibilities of the locality, as they may not only affect the amount of sewage to be dealt with but also its character. The estimate should be framed so as to provide for the probable requirements during the next twenty-five to thirty years of the different portions of the district to be drained, as it is not always practicable to maintain a constant allowance throughout.

**Water Supply as Guide.**—The water supply of the district may be considered as affording a constant daily supply of sewage of equal amount.

**Admission of Rainfall.**—The admission of the rainfall to the drains complicates the question, as it is difficult to calculate the exact amount of rainfall to be allowed for, even when it is limited to that collected from roofs, back-yards, paved surfaces, etc., as a considerable proportion finds some other outlet.

The nature of the surface drained, and its inclination, must be considered in connection with the question of admission of surface water.

The surface water from rural or uncovered areas only arrives at the sewers by slow degrees, and a great deal passes off as subsoil water, and by evaporation.

The surface water of towns is for the most part so impure as to necessitate its being treated as foul water.

One inch rainfall in an hour only occurs in very severe storms, such as happen only at distant intervals of time in any part of England, and as in ordinary urban areas with a large proportion of paved streets only 50 per cent. of this quantity will find its way to the sewers, an allowance of that amount to be carried off in an hour should be ample; and even when greater rainfalls have been recorded, it would not be advisable on that account to further increase the size of the sewers, as the increased section would injure their efficiency under ordinary circumstances, and any excessive rainfall, being of short duration, would pass off in a few hours. Mr. Symons, at Camden Town, in 1878, gauged a rainfall at the rate of 12 inches an hour; this intensity was, however, only maintained for 30 seconds.
It is found that in practice these exceptional rainfalls are very local in area, and extend over such short periods of time that it is not necessary to take them into consideration.

The following table gives in convenient form particulars of the quantities relating to rainfalls of different intensities:—

<table>
<thead>
<tr>
<th>Rainfall, Inches</th>
<th>Tons per acre</th>
<th>Cubic feet per acre</th>
<th>Gallons per acre</th>
<th>Gallons per square yard</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>308</td>
<td>10,880</td>
<td>67,866</td>
<td>14:011</td>
</tr>
<tr>
<td>2</td>
<td>202</td>
<td>7,240</td>
<td>45,244</td>
<td>9:374</td>
</tr>
<tr>
<td>1 1/4</td>
<td>151:5</td>
<td>5,430</td>
<td>33,933</td>
<td>7:021</td>
</tr>
<tr>
<td>1</td>
<td>101</td>
<td>3,820</td>
<td>22,622</td>
<td>4:657</td>
</tr>
<tr>
<td>1 1/8</td>
<td>88:57</td>
<td>3,167</td>
<td>19,785</td>
<td>4:099</td>
</tr>
<tr>
<td>1 1/16</td>
<td>75:75</td>
<td>2,715</td>
<td>16,967</td>
<td>3:314</td>
</tr>
<tr>
<td>1 1/32</td>
<td>63:12</td>
<td>2,262</td>
<td>14,140</td>
<td>2:228</td>
</tr>
<tr>
<td>1 1/64</td>
<td>50:60</td>
<td>1,810</td>
<td>11,511</td>
<td>2:343</td>
</tr>
<tr>
<td>1 1/128</td>
<td>37:37</td>
<td>1,357</td>
<td>8,484</td>
<td>1:766</td>
</tr>
<tr>
<td>1 1/256</td>
<td>25:25</td>
<td>905</td>
<td>5,656</td>
<td>1:171</td>
</tr>
<tr>
<td>1 1/512</td>
<td>19:62</td>
<td>452</td>
<td>2,823</td>
<td>0:985</td>
</tr>
<tr>
<td>1 1/1024</td>
<td>10:10</td>
<td>362</td>
<td>2,262</td>
<td>0:460</td>
</tr>
</tbody>
</table>

For house drains taking surface water from roofs, a rainfall of two inches per hour is sometimes provided, on account of the suddenness with which it will pass into the drains.

The Metropolitan sewers were constructed on the assumption that they would have to convey a rainfall of 0.01 inch per hour in addition to the allowance of five cubic feet of sewage per head of the population per diem. Five-eighths of this rainfall only was expected to reach the sewers, the remaining three-eighths being absorbed or evaporated.

Estimate of Sewage and Rainfall combined.—When estimating the amount of sewage to be dealt with in any particular case, the records of other places will be found good guides; but as a general rule a minimum daily allowance is made of five cubic feet or 31:16 gallons per head of population. The maximum during the day is assumed to be one-half of this amount, flowing off in six hours, or 8 per cent. per hour; this includes the rainfall from roofs and a limited amount of foul water from back-yards, courts, etc.

It has been found by observation that it is only in exceptional cases that the average discharge exceeds 50 gallons per head per day, and the design for the Lower Thames Valley main drainage was based upon an allowance of 40.2 gallons per head, or 250 gallons per house of six inhabitants and under, including rainfall.

When providing a new system of sewers for the city of Edinburgh,
the allowance was increased to 42 gallons per head per diem, one-half to pass off in eight hours, the rainfall being taken at two inches.

The amount will, of course, vary considerably with the rainfall, the density of the population of the district, and the proportion of the rainfall admitted to the sewers.

In the Metropolis in 1884 the population varied from 7.3 per acre in the suburban districts to 258 per acre in the more densely populated parts, the corresponding volumes of sewage being 0.4 and 0.3 cubic feet per acre per minute, and quantities per head 50 gallons and 30 gallons per diem respectively.

Rainfall in Sewers.—In the city of Leeds the system of sewers is carried out strictly on the combined system, and the sewers are relieved with overflow sewers as frequently as possible.

When laying out sewers in new areas which are likely to become closely built up with cottage houses and paved streets, the sewers above the overflows have for a number of years been calculated on the following scale prepared by the late city engineer, Mr. Thomas Hewson, M.Inst.C.E.

**Table 3.**

<table>
<thead>
<tr>
<th>Area in acres</th>
<th>Inches of Rainfall per hour</th>
<th>Area in acres</th>
<th>Inches of Rainfall per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>1.00</td>
<td>225</td>
<td>0.40</td>
</tr>
<tr>
<td>23</td>
<td>0.95</td>
<td>250</td>
<td>0.39</td>
</tr>
<tr>
<td>25</td>
<td>0.90</td>
<td>275</td>
<td>0.35</td>
</tr>
<tr>
<td>29</td>
<td>0.85</td>
<td>300</td>
<td>0.37</td>
</tr>
<tr>
<td>32</td>
<td>0.80</td>
<td>325</td>
<td>0.36</td>
</tr>
<tr>
<td>33</td>
<td>0.75</td>
<td>350</td>
<td>0.33</td>
</tr>
<tr>
<td>35</td>
<td>0.70</td>
<td>375</td>
<td>0.34</td>
</tr>
<tr>
<td>41</td>
<td>0.65</td>
<td>400</td>
<td>0.33</td>
</tr>
<tr>
<td>44</td>
<td>0.60</td>
<td>425</td>
<td>0.32</td>
</tr>
<tr>
<td>47</td>
<td>0.55</td>
<td>450</td>
<td>0.31</td>
</tr>
<tr>
<td>50</td>
<td>0.50</td>
<td>475</td>
<td>0.30</td>
</tr>
<tr>
<td>75</td>
<td>0.37</td>
<td>500</td>
<td>0.29</td>
</tr>
<tr>
<td>100</td>
<td>0.35</td>
<td>525</td>
<td>0.28</td>
</tr>
<tr>
<td>125</td>
<td>0.41</td>
<td>550</td>
<td>0.27</td>
</tr>
<tr>
<td>150</td>
<td>0.45</td>
<td>575</td>
<td>0.26</td>
</tr>
<tr>
<td>175</td>
<td>0.42</td>
<td>600</td>
<td>0.25</td>
</tr>
<tr>
<td>200</td>
<td>0.41</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It should be noted that in Leeds the rainfall is rather high, and that with the existing by-law houses can be built without back-yards; as the streets are all paved and flagged with Yorkshire stone jointed with pitch grouting the whole surface in a cottage street is practically impervious, and the rainwater is passed very rapidly into the sewers.

The scale is designed to meet the requirements of heavy rainfalls of a local character which frequently occur in hilly districts; a rainfall at

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D
the rate of one inch per hour for a short period is often recorded on a small area, when, unless the sewers are of ample dimensions, flooding of basements is liable to occur.

The question of the proportion of storm-water entering the sewers was the subject of investigation in Birmingham by Mr. D. E. Lloyd Davies, Assoc.M.Inst.C.E., and the results obtained were communi-

cated to the Institution of Civil Engineers by him in a valuable paper * from which the following notes are taken.

A diagram (Fig. 17) here reproduced shows the rate of rainfall at the Edgbaston Observatory, Birmingham, for four years from October 13th, 1900, to October 18th, 1904. From this it will be seen that falls at the rate of one inch per hour are not uncommon for periods up to half an hour in duration, and one record shows 0.45 inch in ten minutes equal to a rate of 2.70 inches per hour.

The following table refers to the same set of observations:

| Maximum Duration of Precipitation in minutes | 0.1  | 0.2  | 0.3  | 0.4  | 0.5  | 0.6  | 0.7  | 0.8  | 0.9  | 1    | 1.1  | 1.2  | 1.3  | 1.4  | 1.5  | 1.6  | 1.7  | 1.8  | 1.9  | 2    | 2.5  |
|--------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 5                                          | 378  | 235  | 164  | 101  | 67   | 51   | 38   | 29   | 25   | 20   | 13   | 12   | 9    | 8    | 5    | 5    | 4    | 3    | 2    | 2    | 1    |
| 10                                         | 325  | 182  | 116  | 65   | 38   | 30   | 20   | 15   | 12   | 9    | 4    | 3    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    |
| 15                                         | 263  | 125  | 76   | 38   | 20   | 15   | 12   | 9    | 8    | 6    | 1    |      |      |      |      |      |      |      |      |      |      |
| 20                                         | 229  | 104  | 63   | 30   | 16   | 12   | 9    | 7    | 5    | 5    | 1    |      |      |      |      |      |      |      |      |      |      |
| 25                                         | 210  | 81   | 46   | 21   | 10   | 8    | 5    | 3    | 2    | 1    |      |      |      |      |      |      |      |      |      |      |      |
| 30                                         | 193  | 70   | 41   | 19   | 10   | 8    | 5    | 3    | 2    | 1    |      |      |      |      |      |      |      |      |      |      |      |
| 40                                         | 180  | 61   | 25   | 10   | 4    | 3    | 1    |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| 50                                         | 160  | 44   | 20   | 10   | 4    | 3    | 1    |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| 60                                         | 149  | 43   | 20   | 10   | 4    | 3    | 1    |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
The following tables show the results of gaugings of the discharge of sewers during different rates of rainfall.

**TABLE 5—COMPARING RAINFALL, PRECIPITATION OVER, AND STORM-WATER DISCHARGE FROM, THE MOSELEY STREET AREA, BIRMINGHAM.**

Drainage area, 312.5 acres. Population, 39,000. Whole of drainage area impermeable. Number of buildings (including New Street Station and public institutions), 7,866. Street area, 67,317 acres = 22 per cent. House area, 241.638 acres = 78 per cent. Impermeable area to each house, 0.0311 acre. Average fall of area, 1 in 63. Sowers gauged, 5 ft. 9 in. by 5 ft. 6 in. "Old Birmingham" egg-shaped foul sewer and 5 ft. 3 in. circular storm-water relief culverts. Minimum time for concentration of storm-water from the farthest boundaries of district, 18 minutes.

<table>
<thead>
<tr>
<th>Date</th>
<th>Maximum Intensity of Rainfall during time of concentration of Storm-water to gauge.</th>
<th>Maximum Rate of Storm-water Discharge (dry-weather flow at time of storm being deducted).</th>
<th>Maximum Intensity of Rainfall during time of concentration gauged in Sewers.</th>
</tr>
</thead>
<tbody>
<tr>
<td>10th January, 1904</td>
<td>0.330</td>
<td>0.001</td>
<td>92</td>
</tr>
<tr>
<td>14th January, 1904</td>
<td>0.374</td>
<td>0.033</td>
<td>103</td>
</tr>
<tr>
<td>29th January, 1904</td>
<td>0.129</td>
<td>0.101</td>
<td>83</td>
</tr>
<tr>
<td>27th January, 1904</td>
<td>0.210</td>
<td>0.147</td>
<td>70</td>
</tr>
<tr>
<td>30th January, 1904</td>
<td>0.260</td>
<td>0.262</td>
<td>94</td>
</tr>
<tr>
<td>4th February, 1904</td>
<td>0.198</td>
<td>0.246</td>
<td>124</td>
</tr>
<tr>
<td>8th February, 1904</td>
<td>0.297</td>
<td>0.262</td>
<td>111</td>
</tr>
<tr>
<td>13th February, 1904</td>
<td>0.250</td>
<td>0.252</td>
<td>90</td>
</tr>
<tr>
<td>8th March, 1904</td>
<td>0.100</td>
<td>0.085</td>
<td>88</td>
</tr>
<tr>
<td>29th March, 1904</td>
<td>0.132</td>
<td>0.160</td>
<td>123</td>
</tr>
<tr>
<td>14th April, 1904</td>
<td>0.165</td>
<td>0.124</td>
<td>75</td>
</tr>
<tr>
<td>16th April, 1904</td>
<td>0.182</td>
<td>0.139</td>
<td>105</td>
</tr>
<tr>
<td>2nd May, 1904</td>
<td>0.297</td>
<td>0.299</td>
<td>97</td>
</tr>
<tr>
<td>21st May, 1904</td>
<td>0.195</td>
<td>0.179</td>
<td>90</td>
</tr>
<tr>
<td>27th May, 1904</td>
<td>0.726</td>
<td>0.735</td>
<td>109</td>
</tr>
<tr>
<td>28th July, 1904</td>
<td>0.866</td>
<td>0.836</td>
<td>96</td>
</tr>
<tr>
<td>8th August, 1904</td>
<td>0.462</td>
<td>0.133</td>
<td>42</td>
</tr>
<tr>
<td>3rd September, 1904</td>
<td>0.066</td>
<td>0.013</td>
<td>65</td>
</tr>
<tr>
<td>12th September, 1904</td>
<td>0.326</td>
<td>0.110</td>
<td>34</td>
</tr>
<tr>
<td>1st October, 1904</td>
<td>0.099</td>
<td>0.074</td>
<td>75</td>
</tr>
<tr>
<td>7th November, 1904</td>
<td>0.029</td>
<td>0.065</td>
<td>66</td>
</tr>
<tr>
<td>10th November, 1904</td>
<td>0.139</td>
<td>0.105</td>
<td>76</td>
</tr>
<tr>
<td>21st November, 1904</td>
<td>0.299</td>
<td>0.127</td>
<td>55</td>
</tr>
<tr>
<td>4th December, 1904</td>
<td>0.109</td>
<td>0.065</td>
<td>60</td>
</tr>
<tr>
<td>5th December, 1904</td>
<td>0.264</td>
<td>0.021</td>
<td>34</td>
</tr>
<tr>
<td>10th December, 1904</td>
<td>0.073</td>
<td>0.073</td>
<td>97</td>
</tr>
<tr>
<td>12th December, 1904</td>
<td>0.145</td>
<td>0.110</td>
<td>76</td>
</tr>
<tr>
<td>14th December, 1904</td>
<td>0.063</td>
<td>0.083</td>
<td>89</td>
</tr>
</tbody>
</table>

Average percentage for one year .......... 83
TABLE 6.—COMPARING RAINFALL PRECIPITATION OVER, AND STORM-WATER DISCHARGE FROM, THE CHARLOTTE ROAD AREA, BIRMINGHAM.

Drainage area, 232 acres. Population, 4,000. Number of buildings, 500. Street and road area, 10 per cent. Estimated amount of impermeable area, 18 per cent, increasing to 42 per cent, as the permeable area becomes saturated. Storm sewers, 3 ft. 6 in. by 3 ft. 6 in. Old Birmingham egg-shaped foul sewer, and 3 ft. circular storm-water relief culvert. Minimum time for concentration of storm-water from the farthest boundaries of district, 12 minutes.

<table>
<thead>
<tr>
<th>Date</th>
<th>Maximum Intensity of Rainfall during time of concentration of Storm-water to gauge</th>
<th>Maximum Rate of Storm-water Discharge (liters per hour at time of storm being deflected)</th>
<th>Maximum Intensity of Rainfall during time of concentration gauged in Sewers.</th>
</tr>
</thead>
<tbody>
<tr>
<td>14th January, 1904</td>
<td>0.274</td>
<td>0.054</td>
<td>20.0</td>
</tr>
<tr>
<td>25th January, 1904</td>
<td>0.122</td>
<td>0.025</td>
<td>20.0</td>
</tr>
<tr>
<td>27th January, 1904</td>
<td>0.210</td>
<td>0.040</td>
<td>19.0</td>
</tr>
<tr>
<td>30th January, 1904</td>
<td>0.230</td>
<td>0.071</td>
<td>20.0</td>
</tr>
<tr>
<td>4th February, 1904</td>
<td>0.198</td>
<td>0.059</td>
<td>20.0</td>
</tr>
<tr>
<td>5th February, 1901</td>
<td>0.217</td>
<td>0.061</td>
<td>27.0</td>
</tr>
<tr>
<td>13th February, 1904</td>
<td>0.230</td>
<td>0.049</td>
<td>17.0</td>
</tr>
<tr>
<td>8th March, 1904</td>
<td>0.150</td>
<td>0.029</td>
<td>29.0</td>
</tr>
<tr>
<td>29th March, 1904</td>
<td>0.132</td>
<td>0.030</td>
<td>23.0</td>
</tr>
<tr>
<td>14th April, 1904</td>
<td>0.165</td>
<td>0.032</td>
<td>20.0</td>
</tr>
<tr>
<td>16th April, 1904</td>
<td>0.150</td>
<td>0.010</td>
<td>22.0</td>
</tr>
<tr>
<td>2nd May, 1904</td>
<td>0.297</td>
<td>0.072</td>
<td>24.0</td>
</tr>
<tr>
<td>21st May, 1904</td>
<td>0.198</td>
<td>0.030</td>
<td>15.0</td>
</tr>
<tr>
<td>27th May, 1904</td>
<td>0.650</td>
<td>0.181</td>
<td>27.0</td>
</tr>
<tr>
<td>26th July, 1904</td>
<td>0.010</td>
<td>0.027</td>
<td>24.0</td>
</tr>
<tr>
<td>5th August, 1904</td>
<td>0.075</td>
<td>0.012</td>
<td>19.0</td>
</tr>
<tr>
<td>17th August, 1904</td>
<td>0.035</td>
<td>0.061</td>
<td>15.0</td>
</tr>
<tr>
<td>22nd August, 1904</td>
<td>0.165</td>
<td>0.043</td>
<td>29.0</td>
</tr>
<tr>
<td>3rd September, 1904</td>
<td>0.100</td>
<td>0.025</td>
<td>29.0</td>
</tr>
<tr>
<td>12th September, 1904</td>
<td>0.040</td>
<td>0.008</td>
<td>28.0</td>
</tr>
<tr>
<td>1st October, 1904</td>
<td>0.175</td>
<td>0.049</td>
<td>28.0</td>
</tr>
</tbody>
</table>

Average for 9 months ................................... 22.4

The writer of the paper drew certain conclusions from these observations, which are as follows:

1. That the storm-water discharge from any defined district is directly proportional to the percentage of impermeable area comprised in it.

2. That, subject to a time allowance being added for the entrance of the rain into the system, the discharge of storm-water from underground channels is proportional to the aggregate rainfall during the time of concentration of the water through the conduits, from the extreme boundaries of the district to the point of observation.

3. That the maximum rate of flow is reached when the greatest cumulative rainfall occurs that is applicable to the duration of the minimum time of concentration and to the district considered.
(4) That the total volume of storm-water received is proportional to the maximum rate of flow.

And he framed a formula to express these conclusions in mathematical terms:—

Let $Q$ denote the discharge of storm-water in cubic feet per minute; $t$ denote the time of concentration in minutes (i.e. time of flow through the longest line of sewers in the district plus entrance allowance).

Let $r$ denote the total rainfall precipitation in inches during $t$ (this can be obtained from curves similar to those given in Figs. 17 and 18).

$A_p$ denote the percentage of impermeable or partially permeable* area in acres comprised by the district (which can be taken from the curves in Figs. 19 and 20).

Then $Q = (60.5 \times \frac{60}{t} \times r) \times A_p$.

The curve plotted in Fig. 17, p. 34, illustrates maximum rainfall intensity, and will give too high a result for actual work. A suggested economical intensity curve is shown in Fig. 18 compared with other rainfall-frequency curves of storms per year which are drawn from the data of Table 4. The vertical ordinates represent the rates of rainfall in inches per hour, the actual rainfall in inches ($r$) for the formula being given by the equation

$$r = \frac{s t}{60} \times R,$$

* "Impermeable" is applied in this paper to such areas as roofs, streets, yards, &c.; "partially permeable" is applied to areas such as lawns, gardens, fields, &c.
where \( R \) denotes the rate of rainfall in inches per hour, and \( t \) denotes the time of concentration in minutes. To estimate the value of \( t \) only the lengths and gradients of the sewers are necessary.

The time of concentration is divided into two periods—the entrance into and the flow through the sewers. For the first a little judgment is required. If the roofs are connected directly with the sewers the minimum time is about one minute, but if the flow has to pass down the street gutters the allowance is increased to about three minutes. For the second period, if the velocity of flow for the various lengths of sewer is assumed to be equal to that obtaining when they are one-half full, it can be estimated with sufficient accuracy for all practical purposes. If the sewers are subject to surcharge, the hydraulic gradient should be ascertained and the velocity computed.

To facilitate the estimation of impermeable area in relation to the population per acre, the curves given in Figs. 19 and 20 have been prepared. For storms of short duration, that is, about equal to the time of concentration, the percentage of the area contributing storm-water is practically directly proportional to the population per acre. After the time of concentration has been exceeded, in districts not entirely impermeable, the impermeable percentage gradually increases with the duration of the rainfall, but inversely to the amount of impermeable area existing—a result of the absorbent power of the subsoil and the storage capacity of the surface becoming slowly exhausted. Although of rare occurrence, a short and heavy fall following a long and moderate one will evidently produce the maximum discharge.

While the impossibility of establishing a precise law applicable to the many variable conditions met with is acknowledged, the curve for partially permeable areas is designed to afford approximate guidance for districts
with moderate average surface slope. Should the slope be steep, between 25 per cent. and 50 per cent. of the difference between the respective “permeable” and “partially permeable” ordinates should be added to the “partially permeable” curve, a similar deduction being made for a flat district. The extreme sines of inclination are assumed as 0.02 and 0.001, and the percentage varies with the absorption of the subsoil.

The average proportions of impermeable area draining to the respective sewers under the “partially separate system” have been computed by the late City Engineer of Birmingham to be 62 per cent. to the foul sewer and 38 per cent. to the surface water sewer. On these data the formula would be—

\[ Q = (60.5 \times \frac{60}{I} \times r) \times 0.62 \ A_p \] for the foul sewer and

\[ Q = (60.5 \times \frac{60}{I} \times r) \times 0.38 \ A_p \] for the surface water sewer.

In order to ascertain the discharge from parks, which are often comprised in districts from which storm-water flow has to be calculated, the discharge from a connection draining a portion of Summerfield Park, Birmingham, was observed. The results obtained showed that the maximum rate of discharge was between 6 per cent. and 8 per cent. of the corresponding rate of rainfall for falls of short duration.

On November 8th, 1904, 0.32 inch of rain fell steadily in five hours, and on this date the maximum rate of flow was equivalent to the average rate of rainfall. It appears, however, that if 5 to 10 per cent. of park area, according to the adequacy of the land drains, is considered as partially permeable, sufficient capacity will be provided for the discharge likely to obtain during heavy storms of moderate duration.

In designing an entirely new sewerage system, the preliminary lines and gradients having been laid out and the various areas computed in the usual way, the value of \( A_p \) can be estimated from the impermeable-area percentage curves, and be modified to meet local conditions.

Reference to Table 4, p. 35, will show that, for periods of concentration not exceeding thirty minutes, which will cover most cases met with, the rate of rainfall will vary between 2 inches and 1 inch per hour. Taking the average rate 1.5 inch per hour, and calculating \( Q \) from \( A_p \), \( V \) can be ascertained approximately from sewer discharge tables. In order to calculate the capacities of the mains and branches correctly, the volume reaching each length must be ascertained, beginning at the extreme boundaries of the district, and working towards the outfall.

If \( L \) denote the length in feet of the particular section under consideration:
V the velocity found in feet per second; and \( t \) be the time of concentration in minutes,

Then \( t = \frac{L}{V} \).

Hence \( t \) being approximately known and the entrance time being added, \( r \) is measured from the rainfall intensity curve, and the formula is applied as before. In a similar manner for times of concentration varying between thirty and sixty minutes the rainfall rate fluctuates between 1 inch and 0.5 inch per hour, the average rate being 0.75 inch per hour. If judgment is used much closer extreme rates can be adopted and the estimation of \( t \) will be consequently more accurate. In practice, however, the foregoing range is sufficiently precise for the design of works to carry off storm-water.

Discharge formulas have been proposed by many persons. Whilst some of them are applicable to surface discharge, and are useful for water-storage and for flow in large rivers, only three of them are applicable generally to sewerage works.

These are:

- Burkli-Ziegler: \( Q = Rc \sqrt[4]{\frac{S}{A}} \).
- McMath: \( Q = R^2 \sqrt[4]{\frac{S}{A}} \).

Where \( Q \) denotes cubic feet per second per acre reaching sewers:
- \( R \) \( \) , average rate of rainfall during heaviest fall in cubic feet per acre.
- \( c \) \( \) , a constant = 0.75 for paved streets and 0.31 for macadamised streets.
- \( S \) \( \) , general fall of area per 1,000.
- \( A \) \( \) , drainage area in acres.

Kuehbling: \( Q = Aat (b - ct) \)

Where \( Q \) denotes discharge in cubic feet per second:
- \( A \) \( \) , drainage area in acres.
- \( t \) \( \) , duration in minutes of the intensity \((b - ct)\).
- \( b \) \( \) , 21.
- \( c \) \( \) , 0.0205 for Rochester, N.Y.
- \( a \) \( \) , proportion of impervious surface.

The Burkli-Ziegler formula and McMath's modification of it can only be termed crude approximations for the following reasons: The rainfall rate is assumed to be constant for all types of area; the constant for impermeable surface is based on the streets alone, and only two variations are given to meet all cases; the general slope of
the ground can, under the most favourable conditions, be but roughly estimated for areas of any considerable extent, and when calculated it is of no great use excepting for "entrance time" computations. In fact, surface slope, which is such an important factor in many of the rules, appears to be included in an attempt to frame a formula from models originally intended only for calculations of watershed discharge. The great divergence of the results obtained by the use of this formula is not likely to create surprise when its construction is compared with recent experience.

Mr. Emil Krichling was the first to recognise that the rainfall intensity varies with the extent of the area, and the importance of the time of concentration. He, however, carried out his experiments without the aid of a recording rain-gauge, and subsequently framed his formula in a form which has tended to prohibit its general use. The derivation of the three empirical constants contained in it is obscure, and these figures are only applicable to a particular locality.

When giving evidence before the Royal Commission on Sewage Disposal in 1901, the late Mr. G. R. Strachan, M.Inst.C.E., gave particulars of the quantity of rainfall which found its way into the sewers of Chiswick on the partially separate system.

The rainfalls were given in inches per day, but no information was given as to the length of time over which the fall extended.

January 29, 1883.—Rainfall 0.40 inch, sewer discharged for over an hour at the rate of 170 to 180 gallons per head of the population per day.

February 10, 1883.—Rainfall 0.52 inch and twice during the day sewer discharged at about the same rate as on January 29th.

February 11, 1883.—Rainfall 0.23 inch ; for three periods of one hour, one and a half hours, and one hour respectively, the discharge was at the rate of 170 to 180 gallons per head.

April, 1885.—Rainfall 0.71 inch. Discharge at the rate of 300 gallons per head per day.

July 21, 1885. For five hours the sewers discharged at the rate of 300 gallons per head per day, or about twelve times the dry weather flow.

In the year 1906 Mr. Baldwin Latham, M.Inst.C.E., when addressing the Association of Managers of Sewage Disposal Works, gave the following information with regard to the discharge of rainfall into sewers.

"In the year 1901, at Rhyl, North Wales, out of an annual rainfall of 26.52 inches, 12.30 inches flowed off exclusive of leakage, or 46.38 per cent. In 1891, with a rainfall of 20.46 inches, 10.83 inches flowed off exclusive of leakage, or 52.93 per cent. from an area of 152 acres. At
SEWERAGE.

Deal, in eighteen months ended February, 1903, it was found that with 33·5 inches of rain falling in the period, 13·71 inches flowed off by the sewers from an area of 100 acres, or the flow off was 40·92 per cent. of the rainfall. At the Croydon outfall, continuous gaugings were carried on from 1876 to 1888, and seven of these years have been worked out and give an average flow off of 38·92 per cent. of the rain falling, varying from 43·96 per cent. in 1880 to 36·12 per cent. in 1881 from an area varying from 817·68 acres in 1880 to 877·48 acres in 1886, or an area which has been ascertained to be equal to 300 super feet per head of the existing population.

"The quantity of rain actually received into the sewers of any normal district in the course of twelve months will be found to be considerably less than the volume of sewage itself, yet under Local Government Board regulations the provision to be made for rain or storm water is far in excess of that required for the disposal of the sewage. Take the case of a district in which the area per head of the population is 300 feet, the rainfall is 30 inches, and assume 50 per cent. flows off by the sewers in the course of the year. We also assume that the volume of dry-weather sewage is 5 cubic feet per head per day. The volume of rain contributed to the sewers throughout the year would be 375 cubic feet per head, but the volume of sewage would be 1,825·25 cubic feet, or the sewage is nearly five times as much as the rainfall, so that in this case the area contributing rainfall or the rainfall itself could be enormously increased or the percentage of flow off increased before the rain would be equal to one volume of sewage throughout the year."

He also stated that a review of the past fifty years' experience showed that inadequate provision had often been made for rainfall in sewers.

Mr. Latham stated that he had had a recording rain gauge at work at Croydon since 1880, and that the experience of the twenty-six years showed that the rate of rainfall varied at Croydon from an average hourly intensity of 0·0727 of an inch in 1894 to 0·270 of an inch per hour in 1883, the average rate of fall during the whole twenty-six years being 0·0467 inch per hour, and the average annual depth of rain falling was 25·19 inches.

The greatest average rate of rainfall at Croydon occurred in the month of July, when the average over twenty-six years was 0·067 inch per hour, and in August, 1895, the average hourly rate of fall was 0·144 inch.

He also pointed out as heavy rates of fall that, in August, 1888, rain fell at the rate of 8 inches per hour; in August, 1889, at the rate of 10½ inches per hour; and in January, 1890, at the rate of 7·2 inches per hour.

He also stated that the Croydon outfall sewer on the 30th July, 1888,
between the hours of 5 and 6 P.M., discharged about twenty times the dry weather flow of sewage, and on the 28th August, 1888, the outfall sewer between 5 and 6 P.M. was discharging at the rate of 2,103 cubic feet per minute, the dry weather flow of the sewage being 194 cubic feet per minute; on that day there was 0·62 inch of rainfall, of which 0·4 fell in five minutes.

Further gaugings at the Croydon outfall sewer showed that the following increase of flow was due to rainfall:

<table>
<thead>
<tr>
<th>Rainfall per hour</th>
<th>Increase in average flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>In inches</td>
<td></td>
</tr>
<tr>
<td>0·05</td>
<td>4 times</td>
</tr>
<tr>
<td>0·10</td>
<td>5½</td>
</tr>
<tr>
<td>0·15</td>
<td>6½</td>
</tr>
<tr>
<td>0·20</td>
<td>7</td>
</tr>
<tr>
<td>0·25</td>
<td>7½</td>
</tr>
<tr>
<td>0·30</td>
<td>7¾</td>
</tr>
</tbody>
</table>

The Croydon Sewerage Works are carried out on the partially separate system.

He further stated that he had used the Croydon sewer gaugings as a basis for calculating the probable volume of storm-water that would be discharged by the storm overflow under certain conditions of dilution.

The result ascertained was that when heavy rainfalls occur the volume escaping in excess of three times the dry weather flow was 18·22 per cent. of the dry weather flow; the volume escaping in excess of four times the dry weather flow was 9·58 per cent.; the volume escaping in excess of five times the dry weather flow was 5·84 per cent.; and the volume escaping in excess of six times the dry weather flow was 2·90 per cent.

This indicated that the volume of storm-water escaping by the storm overflows was not one of serious importance, especially having regard to the state of dilution of the overflowing sewage.

As illustrating the Continental practice with reference to the provision of sewers for rainfall, the new sewerage system of the city of Dresden may be quoted.

In that case the maximum rainfall provided for is 0·7 inch per hour, and the proportion of this reaching the sewers has been divided into four classes:

1. For the old town, densely built upon, 0·71 cubic feet per acre per second.
2. Densely built upon, but less than No. 1, 0·57 cubic feet per acre per second.
3. Open building, 0·43 cubic feet per acre per second.
4. Parks, gardens, etc., 0·03 to 0·21 cubic feet per acre per second.
At Frankfort-on-Main, when calculating the size of the sewers, a provision for rainfall of 16 gallons per second and per acre, or about 2\(\frac{1}{4}\) inches of rain per hour was made, of which amount it is assumed that from one-third to one-half would be discharged by the sewers; the former value being taken only in the case of the flat suburban portions with a small population.

In view of the importance of this subject, it is to be regretted that more engineers do not keep recording gauges for rainfall and sewage discharge. Messrs. Jennings manufacture a water-level recorder, which is useful for this purpose, and which is in use at Leicester.

![Diagram](image)

**Fig. 21.—Method of intercepting Large and Pure Rainfalls from Sewers, and admitting Small and Impure Rainfalls.**

Yarmouth, Hornsey, and other places, and similar appliances are made by Messrs. Ham, Baker & Co., the Glenfield Iron Company, and the Palatine Engineering Company.

Where a town is situated upon a river or stream, the water of which is used for drinking purposes, the rainwater should be separated from the sewage to the fullest possible extent, but towns situated on the sea coasts, on estuaries, and on rivers, the water of which is not used for domestic purposes, may be satisfactorily drained by means of one system of sewers provided with storm-overflows.

The interceptor shown in Fig. 21 is suitable for this purpose; it was first introduced by Mr. J. F. Bateman, C.E., F.R.S., in the Manchester Waterworks. The arrangement is self-acting, and where there is only a small amount of rain or surface water from the road-gutters it passes into the sewer proper, but as soon as the rainfall increases and the surface water becomes sufficiently clean, it leaps over
the opening to the sewer and into the channel for surface water leading it into a river or watercourse. A more elaborate arrangement is shown in Fig. 22. The width of the opening is capable of adjustment, so as to admit a greater or less amount to the sewer and shut it off altogether if desired. The ball and lever with a float at the other end is intended for automatically closing the entrance to the sewer should the surface water channel get flooded.

For the width, etc., of the opening required, see Chap. VI., p. 191.

An adjustable modification of this form of overflow is shown in Plate XIII., Figs. 1 and 2.

The objection to this type of overflow is that with a high velocity of discharge the whole of the sewage and rainfall combined may be diverted from the sewage sewer and sent into the stream, and this is in contravention of the Local Government Board requirements, which are to the effect that where sewage purification works are provided they must be kept in full operation no matter what the rate of rainfall.

The ordinary form of overflow required by the Local Government Board consists of a weir over which no discharge shall take place until a pre-determined degree of dilution has been reached, but the balance of
sewage and rainfall combined still continues to flow on to the sewage works along the ordinary channel.

The objection to this arrangement is that the greater the rainfall the greater the quantity flowing down to the purification works, because although the overflow weir comes into operation the water still continues to rise and a greater volume is passed forward to the sewage purification works.

To meet this objection a form of overflow was designed by Mr. D. E. Lloyd Davies, Assoc. M.Inst.C.E., and adopted at Birmingham, to give a constant flow of sewage to the works after the overflow comes into operation, and this is illustrated in Fig. 23.

It will be seen that a horizontal iron plate A, is fixed across the sewer at such a height as to allow of the flow beneath it of a pre-determined quantity of water which should be six times the average dry weather flow. To this horizontal shield is fixed a vertical deflecting plate B, at an angle of about 30 degrees with the line of the sewer.

When the flow of sewage and rainfall combined exceeds the pre-determined quantity the excess passes over the horizontal plate A, and is deflected by the shield B, into the overflow sewer C, whilst the remainder passes under the horizontal plate A, to the sewage purification works, and is maintained at practically a constant quantity.

A deflecting screen formed of wires placed at half-inch centres is used
to deflect rags, paper, etc., floating in the sewage below the horizontal plate A, and to prevent the accumulation of rubbish taking place on the edge of the plate A.

This type of overflow must be systematically inspected to remove the rubbish from the deflecting screen, otherwise an accumulation will take place which will interfere with the free discharge of storm-water, or by collecting on the edge of the cut plate the rubbish may cause the overflow to come into operation sooner than it should do.

**Gradient and Velocity of Flow.**—Small sewers require a greater inclination than large ones; pipe sewers require a less inclination than brick drains. The gradients must not be excessive, so as to avoid damage to the sewer.

**Minimum Velocities.**—It is usually considered that in order to prevent deposit in small sewers or drains from 6 inches to 9 inches in diameter, a velocity of not less than 2 feet per second should exist; for sewers 12 inches to 24 inches, the velocity should not be less than 2½ feet; and for large sewers, 2 feet per second.

According to Table 8, p. 49, these velocities would require an inclination of 1 in 36 for a 4-inch pipe, 1 in 70 for a 6-inch pipe, and 1 in 130 for a pipe 9 inches in diameter; from 1 in 200 to 1 in 820 for pipes from 13 inches to 24 inches in diameter, and less than 1 in 1,250 for larger sewers.

Where possible, however, circular sewers from 19 to 45 inches in diameter should not have a less inclination than 1 in 600 to provide for reduced velocity with minimum discharge, although a considerably smaller gradient is admissible with egg-shaped sewers.

It must be remembered that the velocities here spoken of are mean velocities; the minimum velocity is at the bottom of the channel, or over the invert of a sewer, and for practical purposes may be taken as 76 per cent. of the mean velocity; it is this velocity upon which the scouring of the channel depends. It varies inversely with the depth of the flow; in the case of large sewers, it should never be less than 2 feet per second, requiring mean velocities of 2½, 2¼, and 3 feet per second when running one-third, one-half, and three-quarters full respectively; for further information see Chap. VI., p. 193.

In actual practice it is frequently impossible to obtain the inclinations here indicated, and the author has found that sewers laid to the following limiting gradients will maintain themselves in a clean condition with the assistance of the ordinary flushing which is given to sewers in every town :—
Maximum Velocities.—Rankine states that the velocity of the flow in a sewer should never exceed $\frac{4}{4}$ feet per second, and Rawlinson gives it as his opinion that 4 feet is a proper limit of velocity, which, if increased to 6 feet, would destroy any sewer; this latter velocity is, therefore, often taken as the limit for stoneware drains.

These opinions do not appear to be borne out by more recent experience. Sewers and drains are constantly now laid at far steeper gradients than the limit of velocity of 6 feet per second would allow, without producing damage to the fabric of the sewer, and for drains and small sewers this element need not be taken into consideration.

House Drains are usually less than half full; the pipes, in order to be self-cleansing, should therefore have a greater inclination than that for 3 feet velocity.

Inclinations of Pipes for Special Velocities.—The following table, compiled from Table 81, p. 250, gives the fall required to produce certain velocities in pipes of different sizes when running full or half full, where the coefficient of roughness, $n = 0.013$.

### TABLE 8.

<table>
<thead>
<tr>
<th>Diameter of Sewer</th>
<th>Limiting Gradient</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 inches diameter</td>
<td>1 in 175</td>
</tr>
<tr>
<td>9 &quot; &quot; &quot;</td>
<td>1 in 225</td>
</tr>
<tr>
<td>12 &quot; &quot; &quot;</td>
<td>1 in 400</td>
</tr>
<tr>
<td>15 &quot; &quot; &quot;</td>
<td>1 in 600</td>
</tr>
<tr>
<td>18 &quot; &quot; &quot;</td>
<td>1 in 800</td>
</tr>
<tr>
<td>21 &quot; &quot; &quot;</td>
<td>1 in 1,000</td>
</tr>
</tbody>
</table>

Flushing.—In cases where the available fall from the head of the drain to the junction with the main sewer is less than that required to produce the minimum velocity of 3 feet per second, it becomes necessary to cleanse the drain occasionally by flushing. Under these circumstances, special apparatus and appliances would have to be used to suit the particular case.
Tables of Sizes of Sewers: Combined System.—Table 9, of sizes of sewers at different inclinations for various urban areas, is taken from the Minutes of the General Board of Health, July, 1852, p. 67.

**TABLE 9—SHOWING THE QUANTITY OF PAVED OR COVERED SURFACE FROM WHICH CIRCULAR SEWERS (WITH JUNCTIONS PROPERLY CONNECTED) WILL CONVEY AWAY THE WATER COMING FROM A FALL OF RAIN OF ONE INCH IN ONE HOUR, WITH HOUSE DRAINAGE, AS ASCERTAINED IN THE HOLBORN AND FINSBURY DIVISIONS.**

<table>
<thead>
<tr>
<th>Diameter of Pipes and Sewers in Inches</th>
<th>24</th>
<th>30</th>
<th>48</th>
<th>60</th>
<th>72</th>
<th>84</th>
<th>96</th>
<th>108</th>
<th>120</th>
<th>132</th>
<th>144</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level ...</td>
<td>362</td>
<td>672</td>
<td>129</td>
<td>277</td>
<td>570</td>
<td>1,029</td>
<td>1,725</td>
<td>2,550</td>
<td>4,135</td>
<td>6,250</td>
<td>9,400</td>
</tr>
<tr>
<td>3&quot; in 10' or 1 in 480</td>
<td>43</td>
<td>75</td>
<td>155</td>
<td>306</td>
<td>639</td>
<td>1,117</td>
<td>1,925</td>
<td>3,025</td>
<td>4,425</td>
<td>6,650</td>
<td>9,800</td>
</tr>
<tr>
<td>3&quot; in 19' or 1 in 240</td>
<td>50</td>
<td>83</td>
<td>169</td>
<td>355</td>
<td>735</td>
<td>1,218</td>
<td>2,025</td>
<td>3,050</td>
<td>4,500</td>
<td>7,175</td>
<td>9,850</td>
</tr>
<tr>
<td>3&quot; in 10' or 1 in 160</td>
<td>63</td>
<td>113</td>
<td>223</td>
<td>440</td>
<td>890</td>
<td>1,462</td>
<td>2,375</td>
<td>3,450</td>
<td>4,975</td>
<td>7,590</td>
<td>10,200</td>
</tr>
<tr>
<td>3&quot; in 10' or 1 in 129</td>
<td>78</td>
<td>143</td>
<td>257</td>
<td>500</td>
<td>950</td>
<td>1,601</td>
<td>2,710</td>
<td>3,700</td>
<td>5,225</td>
<td>7,850</td>
<td>10,650</td>
</tr>
<tr>
<td>1 1/2 in 10' or 1 in 80</td>
<td>89</td>
<td>165</td>
<td>293</td>
<td>578</td>
<td>1,055</td>
<td>1,520</td>
<td>2,485</td>
<td>3,450</td>
<td>4,925</td>
<td>6,625</td>
<td>9,290</td>
</tr>
<tr>
<td>2 1/2 in 10' or 1 in 60</td>
<td>115</td>
<td>192</td>
<td>345</td>
<td>670</td>
<td>1,355</td>
<td>2,000</td>
<td>3,020</td>
<td>4,050</td>
<td>5,625</td>
<td>7,125</td>
<td>9,700</td>
</tr>
</tbody>
</table>

It was compiled by Mr. Roe, from results of reliable observations extending over a period of twenty years.

These tables are, of course, only applicable to the combined system, in which the whole of the rainfall is admitted to the sewers; they will be a useful guide under most circumstances, but no fixed rule can be given.

The sizes of the pipes in Table 10 (p. 51), as in the preceding one, are smaller than those given by calculation, as many circumstances, such as those already mentioned with regard to the dimensions of sewers, materially affect the quantities discharged in the several cases.

In order to ascertain the adaptability of a drain or channel of any particular section to the work it will be called upon to perform, it is necessary to be able to calculate the discharge with varying depths of flow, but as this has hitherto been a very troublesome task, hydraulic tables giving more or less fallacious results are resorted to, in order to save time and avoid the drudgery in such calculations. It is, however, necessary in laying out a large system of drainage to study economy and efficiency, and this can only be arrived at by a thorough knowledge of the principles involved.
TABLE 10.—COMBINED SYSTEM SHOWING THE SIZE AND INCLINATION OF MAIN HOUSE DRAINS FOR GIVEN SURFACES, AND THE NUMBER OF HOUSES OF EITHER RATE THEREON, CALCULATED FROM MR. ROE'S TABLE FOR A FALL OF RAIN TWO INCHES IN THE HOUR, AS ASCERTAINED IN THE HOLBORN AND FINSBURY DIVISIONS.

<table>
<thead>
<tr>
<th>Surface occupied.</th>
<th>Number of Houses of either rate, either of which may be respectively dimid.</th>
<th>Diameter and Inclination of Tubes.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acres.</td>
<td>Squares of 100</td>
<td>3-inch.</td>
</tr>
<tr>
<td>1</td>
<td>54</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>112</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>195</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>299</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>448</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>632</td>
<td>11</td>
</tr>
<tr>
<td>1</td>
<td>814</td>
<td>15</td>
</tr>
<tr>
<td>1</td>
<td>912</td>
<td>19</td>
</tr>
<tr>
<td>1</td>
<td>1,094</td>
<td>25</td>
</tr>
<tr>
<td>1</td>
<td>1,200</td>
<td>27</td>
</tr>
<tr>
<td>1</td>
<td>1,370</td>
<td>45</td>
</tr>
<tr>
<td>1</td>
<td>2,100</td>
<td>52</td>
</tr>
<tr>
<td>1</td>
<td>2,384</td>
<td>59</td>
</tr>
<tr>
<td>1</td>
<td>2,432</td>
<td>79</td>
</tr>
<tr>
<td>1</td>
<td>3,276</td>
<td>90</td>
</tr>
<tr>
<td>1</td>
<td>4,404</td>
<td>101</td>
</tr>
<tr>
<td>1</td>
<td>7,400</td>
<td>169</td>
</tr>
<tr>
<td>1</td>
<td>6,700</td>
<td>200</td>
</tr>
</tbody>
</table>