THE DESIGN OF STORM-WATER DRAINS.

SECOND PAPER.

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(A Paper read before the Sydney University Engineering Society, on September 11th, 1914).

Since presenting my preliminary paper* on this subject in 1911, I have had numerous enquiries for further elucidation of some points regarding the derivation of formula, which, apparently, had not been dealt with in sufficient detail. Such a result was almost inevitable in dealing with so wide a subject in such limited space; and it is difficult to condense in one place and omit matter in another without sometimes obscuring one's view-point and vista. I, therefore, intend commencing with an explanation which will, I hope, render the subject matter of the preliminary paper more complete and intelligible. This is rendered more easy from the enquiries received, especially from Professor Chapman, of Adelaide University, and Mr. Geo. Pank, formerly my assistant in that city, who made many observations of flood-flow for me.

DERIVATION OF FORMULA.

(1) Other things being equal, the greater the average length of catchment the greater will be the intensity of losses, by virtue of each particle of water having to traverse a greater length of surface. That is, the average intensity of losses will vary directly as the average length of catchment, and the average intensity of run-off will vary inversely as the average length of catchment, or as $\frac{1}{\sqrt{A}}$.

The average length of catchment has been taken as $\sqrt{A}$.

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This makes all shapes equivalent to a square, and, whereas oblong catchments would naturally have a reduced average intensity, yet being longer the flow would take longer to come down, and a more protracted storm might correspondingly increase the volume; also the narrower the catchment the sooner will storm water arrive at the main channel, hence the less the losses and the greater the proportionate volume, and quicker the delivery at outlet relatively. Therefore the above value has been retained.

(2) Other things being equal, the intensity of losses will be less when the velocity is greater; for the quicker the flow the less opportunity is there for absorption. That is, the average intensity of run-off will vary as the velocity; and, other things being equal, the velocity will be governed by the hydraulic depth. Now the average hydraulic depth may clearly be represented by the average intensity of run-off, which it has been shown varies as $\frac{1}{\sqrt{A}}$. Therefore, since the velocity varies as the square root of hydraulic depth $\sqrt{\frac{1}{A^{\frac{1}{2}}}}$ the run-off varies as $\sqrt{\frac{c_1}{\sqrt{A}}}$ or as $\frac{c_2}{A^{\frac{1}{4}}}$

(3) Now as to effect of gradient. Assume a small catchment surrounded by hills say 1,000 feet in height, or any height. Then imagine another catchment, very large, surrounded by equally high hills, or mountain range or plateau, the slope of catchment being uniformly gradual in each case. It is clear the gradient will vary inversely as the average radius or as $\frac{1}{A^{\frac{1}{2}}}$. As previously shown, the proportionate run-off will vary as the velocity, and other things being equal, the velocity will vary as the square root of the gradient or $\sqrt{s}$, where "s" varies as $\frac{1}{A^{\frac{1}{2}}}$. Therefore, run-off varies as $\sqrt{\frac{1}{A^{\frac{1}{2}}}}$ or as $\frac{c_3}{A^{\frac{1}{4}}}$

(4) Further, the co-efficient of run-off "c" for various soils, though generally assumed at the same value for the same soil for large and small areas, should strictly vary in some way with the area of catchment. For, if "c_4" represents the intensity of absorption of a soil, A the area of catchment, X the area which may be considered as surface-sodden (impervious) before maximum intensity of rainfall is experienced, then the loss for catchment may be represented by $c_4\,(A-X)$, and the average intensity of such loss per acre $= \frac{c_4\,(A-X)}{A}$

Therefore, the intensity of run-off, which equals unity when no losses occur, will become, when these losses are considered, $1 - \frac{c_4 (A-X)}{A} = 1 - c_4 + \frac{c_4 X}{A}$ That is, the coefficient of run-off "c" will vary between unity when $X = A$ and $1 - c_4$ when A is large relative to X. This latter is the value usually assigned "c" in formulae, which must be too great for moderate areas. The exponent of A usually adopted counteracts this defect to some extent.

(5) Further, the flood-flow depends directly on the rainfall "r" and the area A.

(6) Therefore, the volume of flow may be expressed by

$$Q = \frac{(c_2 + c_3)\, r\, A}{A^{\frac{1}{4}}} = \left\{ 1 - \frac{c_4(A-X)}{A} \right\} \frac{r\, A}{A^{\frac{1}{4}}} = \left\{ 1 - \frac{c_4(A-X)}{A} \right\} r A^{\frac{3}{4}}$$

$$= \frac{c\, r\, A}{A^{\frac{1}{4}}} = c\, r\, A^{\frac{3}{4}}$$

which is the fundamental formula given in preliminary paper.*

From what has been shown, it will be seen that the values ordinarily assigned to "c" are made to vary with the nature of the soil. More correctly, such values should be determined according to judgment, having due regard also to the area affected. One formula has already been suggested to enable this to be approximated; but, where the formulae $Q = 1{\cdot}57\, C\, r\, A^{\frac{3}{4}}$ or $1{\cdot}11\, C\, R^{\frac{1}{2}}\, A^{\frac{3}{4}}$ are adopted, it is thought safe results will be obtained without the necessity of determining constants on insufficient data. They really apply to grassed areas or virgin country.

(7) The average intensity of rainfall must vary between infinity maximum for smallest area and a small fractional minimum, though not infinitely small (as all catchment areas are finite) for largest area. For, the recording of a single drop would be instanter, giving maximum intensity, which is infinitely great, as the record is instantaneous; and for very large areas the average intensity diminishes constantly as the area increases, so that, in the limit, it might even be considered infinitely small. But as such area as that covered by a single drop is of no consequence, so far as provision for run-off is concerned, it is sufficient to take into consideration the maximum intensity recorded for such an interval of time, as will be sufficient to affect the design of drains. For such purposes the smallest areas may be subject to an intensity of rainfall for 10 minutes even up to three times the maximum actual fall in an hour. Such visitations are usually very rare, and would be classed as phenomenal; but an intensity of 1½ times to twice the maximum actual fall in an hour should be provided for in the case of very small areas, decreasing to an intensity of the actual fall in an

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* Proceedings Sydney University Engineering Society, Vol. xvi., 1911.

hour for larger catchment, because the intensity of rainfall for say 10 minutes exceeds the actual fall in an hour by as much. The maximum rate of flood discharge for any given rainfall may, however, be calculated by the formula, which suitably reduces average intensity according to the area. According to the purpose for which the rate of flow is required, one or other value of maximum rate of rainfall should be employed. For instance, roofs of important buildings, with box gutters, should be designed for the absolute maximum rate recorded for the locality. Of course, cloud-bursts and waterspouts are excepted. In the case of drainage schemes the adoption of such a high rate would increase their cost enormously, and be out of all proportion to the problematic damage such visitations would cause, and to the financial position of the authority. For these reasons, municipalities and other authorities are only expected legally to provide for a fair maximum intensity of rainfall. The determination of this limit is often the cause of considerable litigation, and the law court is the only tribunal which can authoritatively fix it. In Sydney a rate of 4 inches per hour is now accepted as the fair maximum. But here a warning is necessary. The maximum rate of rainfall mentioned is to be used as the basis of calculation, and from it must be determined the percentage of run-off, according to the extent of catchment and nature of soil. The determination of this average rate for any catchment can never be settled to the entire satisfaction of all experts; and the witness-box bears eloquent testimony year in and year out of the conflicting opinions of able men in this respect.

Some attempt to calculate the time taken for storm water to flow off the catchment from the farthest boundary, and then hunt up the meteorological records for the maximum precipitation for such period, and adopt it in the calculation after assigning a factor to cover absorption, retention and evaporation. This method at first sight appears logical, but, as has been previously mentioned, absorption, retention and evaporation will be greatly reduced by the surface saturation of the soil prior to the occurance of the maximum rate. I have known cases where experts have assigned values of .3, .4 and .5 to this co-efficient of run-off for the same catchment, making the flow vary by 70 per cent. One reason for this is that one expert attempts to judge the run-off by a knowledge of the soil of the catchment, another by his knowledge of the formula. In a case within my knowledge the first storm over the catchment could be relied upon to bring down top flood in 12 hours, but a second storm soon after would bring it down in 8 hours. Without this knowledge, how can anyone possibly say or determine the period of flow? Apart altogether from the fact that the longer period of flow enables a protracted storm to supplement the flood volume, while quicker flow reduces losses, it is a nice point to determine which will produce the higher flood. Then what becomes of the time limit, and who can dogmatise as to which one should be attempted? For my own part, I do not believe any man can, with confidence, assign a co-efficient by observation of the nature of a catchment simply. The gauging of the run-off from similar country should, however, permit this to be done, for even the time of run-off is affected very considerably by the intensity of rainfall as well as by the slopes. Having made such gaugings and checked them by formulae, one can adopt that formula which gives the most reliable results. This I have done, and have put forward the formula previously mentioned as in my opinion the best. It has its admitted limitations, *vide* first paper. It may not be applicable to the Sahara; but the results obtained by it in the case of all the catchments referred to in my previous paper are in no case low, or in any case unduly high, and this without the necessity of assigning a problematical value to "c."

(8) The maximum total rainfall for one hour must necessarily include drift. At the commencement of a storm the intensity of rainfall may be light, working up to a maximum and then gradually diminish, as if the rain cloud remained stationary, and the precipitation of its contents gradually exhausted its charge at a diminishing rate, according to its reduced state of saturation. This might give maximum results for small catchments, but would not necessarily produce a maximum fall for say one hour. It is, however, suggested that the rain cloud becomes reinforced by the arrival of fresh supplies, presumably the advent of other rain clouds. This drift, where the cloud envelope drifts, precipitates its contents over the whole area affected with greater uniformity of total fall.

(9) It has also been suggested that small areas should be calculated on the ten minutes' basis and larger ones on the hourly basis. This I entirely agree with, for it simply means that the larger the area the less the *average* maximum rate should be; and the formula, although based on the rainfall for ten minutes, provides by the slope of curve for reduced effects as the area increases. It must, however, be understood that the adoption of any unit intensity, as measured over any particular period of time, is simply a matter of convenience, and would be governed by the records available. That is, on the ten minutes' basis, the formula is $Q = 1{\cdot}571\ C\ r\ A^{\frac{2}{3}}$, on the hourly basis, $Q = 1{\cdot}571\ C\ r\ A^{\frac{2}{3}} \times 1{\cdot}5 = 2{\cdot}357\ C\ r\ A^{\frac{2}{3}}$, on the yearly basis, $Q = 1{\cdot}11\ C\ R^{\frac{1}{2}}\ A^{\frac{2}{3}}$, or the logarithmic formula could be used. It must, however, be remembered that the intensity of rainfall for ten minutes will tax branch drains most, whilst the rainfall in an hour will tax the main drains most, except when the whole system is small.

SCOPE OF FORMULA.

(10) It has been asked, "Does the formula apply to all kinds of catchments?"

My reply is that it may be safely applied to all kinds of catchments, and it is believed that the waterway based thereon will be ample; but the formula is suggested only for approximating the size of waterway, not the volume of water which can be stored. Indeed, I am aware of catchments, on the Upper Murray and elsewhere, the flood discharge from which is trifling compared with their extent. In some of these cases the water even passes underground for some distance, emerging again in the form of a stream or river miles below. Other instances might be cited where the discharge from catchments of comparable size, and divided by a range of high hills, mountains or tableland, is widely different in volume. It will, however, be generally found in such cases that the nature of rainfall—value of C and most likely R—is as widely different. But let me ilustrate the case by pointing out similar difficulties in connection with the design of retaining walls. Here text-books and competent authorities have assigned definite values to the angle of repose of various soils, for guidance in design; yet what engineer can say by examining the formation of the face of a bank what its angle of repose is? Or can he assess within 10 per cent. the average weight per cubic foot under conditions which might obtain when failure would occur? We know he can only do so approximately, and that the design must make liberal provision for such uncertainty. That is, the engineer, after inspecting and testing formation, can usually assign values to natural slope and weight which will be safe, on the high side. At any rate, he will be wise to do so. If all the elements be definitely known, then tables will give the required dimensions accurately without the exercise of judgment.

Similarly, I say that where all the elements which enter into the question of flood discharge are known for the whole catchment, no formula is needed, and a few figures will suffice to determine the run-off and waterway required; but in the absence of such data, equal provision should be made for all catchments where values of A, R and C are considered comparable. Steep catchments are more frequently liable to high floods than flat ones, but not necessarily to greater floods; also small catchments are more frequently subject to high floods than large catchments. But maximum provision should be made in all cases, for in small catchments frequent floods are a menace to business operations and commerce, while in large catchments the huge flood volume, though experienced at longer intervals, may cause more widespread national loss by inundating large tracts of country, destroying farming and agricultural lands, flocks, means of communication, transport, etc.

McMATH'S FORMULA: EXPLANATION AND APPLICATION.

I have elsewhere referred to McMath's and Burkli Ziegler's formulae, and the following by Allen Hazen fully explains McMath's formula and its application:—

"McMath's formula for determining maximum quantity of rainwater to be removed by a sewer, is $Q = c\ r\ A^{\frac{4}{5}}\ S^{\frac{1}{5}}$, in which Q is the quantity in cubic feet per second, "c" is the proportion of rainfall that will reach sewers; that is, it makes allowance for loss by evaporation, absorption and retention. Its value for any locality is a matter of judgment, taking into consideration the season at which the heaviest rainfall occurs; the condition of the surface, paved or naked; the soil, porous or impermeable; the kind of ground, whether urban or suburban, park or lawn. For St. Louis the proportion is three-fourths of the rainfall; "r" is the number of cubic feet of water falling upon an acre of surface per second during the greatest intensity of rain, and practically it is the same as the rate of rainfall in inches per hour. For St. Louis, "r" is taken as 2.75; "s" is the mean surface grade in feet in a thousand; A is the area in acres.

"The surface slope "s" is taken by McMath for St. Louis at 0.015. No precise rule for determining the value of "s" has been given, and *uncertainty of this determination is one of the most unsatisfactory matters connected with the use of this formula.* Fortunately, considerable variation in "s" makes only a relatively small difference in the amount of discharge, so that a roughly approximate value of "s" is sufficient.

"The proportion "c" of water reaching the sewers has been frequently discussed. Perhaps as accurate results as any may be obtained by taking "c" = 0.90 for all areas covered by roofs and impervious, or nearly impervious, pavings; and "c" = 0.10 for naked areas of sandy or gravelly materials; and "c" = 0.20 for naked areas of clayey or *but slightly pervious* materials. The areas for which sewers are commonly designed are partly naked and partly covered, and the co-efficient for the combined area may be obtained by applying these factors to the parts and adding them up for the total.

"McMath's formula is the one in most general use. The following tables enable approximate computations to be rapidly made:—

Values of $c\ r\ \sqrt[5]{s}$ in McMath's formula, to be obtained as a preliminary to taking the run-off from the following table by use of the identification letters:—

r TAKEN AS 1·0 INCH PER HOUR.

Percentage of Total Area covered by Roof and Pavements.		Value of C.	Steep Slopes 58 per 1,000.	Average Slopes 15 per 1,000.	Flat Slopes 4 per 1,000.	Very Flat Slopes 1 per 1,000.
Sandy Soil.	Clayey Soil.					
100	100	0·90	2·03A	1·55B	1·18C	·900D
73	70	0·70	1·55B	1·18C	·900D	·688E
53	46	0·50	1·18C	·900D	·688E	·523F
37	28	0·40	·900D	·688E	·523F	·400G
25	15	0·30	·688E	·523F	·400G	·306H
16	5	0·23	·523F	·400G	·306H	·233I
10	...	0·18	·400G	·306H	·233I	·178J
5	...	0·14	·306H	·233I	·178J	·135K
0	...	0·10	·233I	·178J	·135K	·100L

RUN-OFF IN CUBIC FEET PER SECOND PER ACRE CORRESPONDING TO DATA OF PRECEDING TABLE.

Area A in Acres.	Value of $\sqrt[5]{A}$	IDENTIFICATION LETTERS AND CORRESPONDING NUMBERS.											
		A	B	C	D	E	F	G	H	I	J	K	L
		2·03	1·55	1·18	·900	·688	·523	·400	·306	·233	·178	·135	·100
50	2·19	·927	·709	·538	·411	·313	·240	·182	·138	·106	·080	·062	·046
70	2·34	·866	·662	·502	·386	·295	·222	·171	·131	·098	·076	·058	·043
100	2·51	·807	·615	·469	·360	273	·207	·160	120	·091	·069	·055	·040
150	2·72	·746	·567	·433	·331	·251	·193	·146	·113	084	·066	·051	·037
200	2·89	·702	·535	·407	·313	·236	·182	·138	·106	·080	·062	·047	·035
300	3·13	·647	·495	·378	·287	218	·167	·127	·098	·073	·058	·044	·032
500	3·46	·586	·447	·342	·258	196	·153	·116	·087	·066	·051	·040	·029
700	3·71	·546	·418	·316	·244	·186	·142	·109	·084	·062	·047	·036	·027
1,000	3·98	·509	·389	·295	·226	·171	·131	·102	·076	·058	·044	·034	·025
1,500	4·32	·469	·360	·273	·207	·160	·120	·091	·069	·055	·041	·031	·023
2,000	4·57	·444	338	·258	·196	·149	·113	·087	·066	·051	039	·029	·022
3,000	4·96	·407	·313	·236	·182	·138	·106	·080	·062	·047	·036	·026	·020
5,000	5·49	·371	·280	·215	·164	·124	·095	·073	·055	·044	·033	·025	·018
7,000	5·88	·346	·266	·200	·153	·116	·091	·069	·051	040	·029	·022	·017
10,000	6·31	·320	·244	·186	·142	·109	·084	·062	·047	·036	·028	·021	·016

"To use tables, select "c" to suit case from first table; also, on same line, value and letter under suitable slope column. Then, in second table on line of nearest area, find value in column under that letter. Multiply this value by area in acres, and by rainfall in inches per hour; the product will be the required volume to be provided for. *The result is only roughly approximate, and is to be accepted with caution.*"

Col. W. E. Cutshaw, City Engineer of Richmond, Va., makes the following remarks respecting run-off formulae:—

"The run-off depends on such conditions that the variations of formulae, as well as the difficulties of applying them to small city areas and to large country areas alike, make the applications unsatisfactory. The same imperviousness of surface and the same degree of saturation will not obtain for like areas; and the surface slope varies to such an extent with the rolling features of the country that the constants introduced into all these formulae are difficult to settle upon, even after comparisons with extended observations of rainfalls and channel discharges.

"Formulae now applying approximately well for city areas do not apply to country areas, where the storm discharges are carried off by creeks and rivers.

"The best formulae now used seem to be based on variable areas, variable slopes, and variable rainfalls; the powers, roots and constants used in each giving it its special merit.

"Even with the three best formulae—Hawksley's, McMath's and Burkli-Ziegler's—it will be noticed give curves for small areas (under five acres), showing more run-off than rainfall; and yet Burkli-Ziegler's and McMath's are more generally used, because of a better agreement with observed run-off from areas, say above 50 or 60 acres. None of these formulae, and still worse, none of the various flood-discharge formulae, are satisfactory in very large country areas."

The following table was prepared by Mr. Roe from results of reliable observations extending over a period of 20 years, as ascertained in the Holborn and Finsbury districts, London.

Quantity of paved or covered surface, from which circular sewers, with junctions properly connected, will convey away the water from a fall of rain of one inch in one hour.

Gradient.	Diameter of Pipes and Sewers in inches.											
	24	30	36	48	60	72	84	96	108	120	132	144
	Area of Catchment in Acres.											
Level.	38¾	67¼	120	277	570	1,020	1,725	2,850	4,125	5,825	7,800	10,100
in. ft. ¼ in 10 1 in 480	43	75	135	308	630	1,117	1,925	3,025	4,425	6,250	8,300	10,750
½ in 10 1 in 240	50	83	150	355	735	1,318	2,225	3,500	5,100	7,175	9,550	12,400
¾ in 10 1 in 160	63	113	203	460	950	1,692	2,875	4,500	6,575	9,250	12.300	15,950
1 in 10 1 in 120	78	143	257	590	1,200	2,180	3,700	5,825	7,850	11,050	14,700	19,085
1½ in 10 1 in 80	80	165	295	670	1,385	2,486	4,225	6,625				
2 in 10 1 in 60	115	182	318	730	1,500	2,675	4,550	7,125				

It is pointed out that the above table is only applicable to the combined system, in which the whole of the rainfall is admitted to the sewers. That is, otherwise the provision made will be excessive.

Although the above table includes provision for sewage, I include it as being of value for reference; but it would not be wise to make double provision for two inches of rainfall per hour, for volume of sewage would not be increased, and the probable volume is not stated.

Whatever method is followed in the design of drains, it is necessary to assume some maximum precipitation for which the system will be designed, and then, from local conditions, estimate the run-off to be cared for by the drain or sewers.

BALCOMB'S METHOD.

A method of determining the run-off and size of sewers has been developed by Mr. J. B. Balcomb for Kansas City, Mo.* :—

"According to his system, the term "sewer length" is the time required for water to flow through sewer. Where grades are fairly steep, time intervals for main, branch and lateral sewers may be tentatively assumed at forty, twenty and ten minutes. For cities having practically flat streets, the periods may easily be sixty, thirty and fifteen minutes, or in extreme cases, two hours, one hour, and half an hour, unless sewers are very short.

"The time periods depend on both absolute and relative length of the different sewers, as well as on the general shape of a city's typical rain curve.

"It is now pretty generally admitted that no general arrangement of co-efficients is possible which shall take into account all of the varying conditions and at the same time be sufficiently simple in its application; at least, that such efforts can only be a partial success until much more data has been secured from which deductions may be made.

"Mr. Balcomb has attempted to devise a system between these two cases.

"He also considers it necessary to design smaller sewers occasionally, and thus permit flooding of city where funds must be considered.

"Thus, Columbus, Ohio, would build for 4in. if maximum intensity of rainfall were allowed for; St. Louis and Milwaukee would build for 5in. if maximum intensity of rainfall were allowed for; Kansas City would build for 7in. if maximum inten-

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* *Engineering Record.*

sity of rainfall were allowed for. These rates were reached during ten years, as averaged for ten, twenty and forty minutes respectively.

The variation in intensity of rainfall varies greatly. In
Shreeveport, being about 5% for 40 minutes.
Kansas City and Topeka 15% ,,
St. Louis .. .. 40% ,,

"Whatever method is used in computing the required capacities, it is necessary either directly or indirectly to decide how frequently a city can afford to have its storm drains flooded rather than to build them larger, and by so doing further increase its burden of debt and expenditure.

"Perviousness of ground should be reckoned in inches per hour, not in percentage of rainfall, for a soil will absorb as much water whatever the rate of fall. Even from paved surfaces the run-off never equals the total precipitation.

"Balcomb adopts for Kansas a rate per hour of 0.50in. absorption for paved surfaces at start of storm, decreasing to 0.25in. in 15 mins., and to 0 in 60 mins; 0.75in. for lawns and grassed surfaces, decreasing to 0.50in. in 30 mins., and to 0 in 120 mins.; 1.00in. for gardens and barren soils, decreasing to 0.75in. in 30 mins., and to 0 in 120 mins. The time required for surface saturation depends on distance to catch-basin and mean slope of surface. For Kansas City, over paved surfaces, velocity of flow was assumed = 200 feet per minute for 5% slope. For unpaved surfaces = 100 feet per minute for 5% slope.

"For Kansas City, three typical areas were adopted:—(1) having 20% paved surface, two-thirds remainder barren, one-third lawn; (2) having 50% paved surface, one-half remainder barren, one-half lawn; (3) having 80% paved surface, one-third remainder barren, two-thirds lawn. These areas give one, two and three blocks of 330ft. x 660ft. as respective distances, which require five minutes with 5% slope.

"Absence of reliable data as to rainfall is the most serious difficulty to be encountered, and Mr. Balcomb's method is only possible when reliable records have been kept of intensities of rainfall at five minutes intervals."

One must admit that Mr. Balcomb has devised a very elaborate method as well as one easy of comprehension and carrying out, provided the data are available. At the same time, one cannot help reflecting on the intensities of absorption adopted, paved surfaces starting at 0.5 inch and ending up saturated in one hour; while gardens and barren soils start at 1.0 inch and end with saturation in two hours. The rate of flow adopted for 5% slope is 200 feet per minute for paved surfaces and 100 feet per minute for unpaved surfaces. Therefore, the average distance within which a storm of one hour duration in the first case, and two hours in the second, would cause saturation of entire surface, is 12,000 feet in each case. And after saturation of such areas, if the storm continued for one hour and two hours in the respective cases, a flood flow might be expected under conditions of no loss. That is, the maximum rate of runoff might be expected for a storm of two hours' duration in the case of paved surface, and four hours in the case of unpaved surfaces. To my mind, the adoption of any such values for absorption, especially for small areas, is always faced with the above difficulty, and I see little use in their adoption at all, unless they are greater than can be satisfied by a rainfall of any experienced duration and intensity. Even then, their inclusion is of doubtful value.

ANALYTICAL METHOD.

Extract from Messrs. Gummow, Forrest's catalogue:—

HYDROGRAPHIC CONSIDERATIONS.

The quantity of rainwater to be carried off depends not only on the quantity of rain falling on a given area, but also on the shape, extent, slope and condition of its surface. Under the term "rainfall" we have to distinguish between intensity, duration and frequency. From experience we know that duration and frequency stand in indirect relation to the intensity of the rain. The heaviest downpours only last minutes.

As intensity, duration and frequency are varying factors according to the geographical position, it is necessary to obtain these data for the district in question when contemplating important Drainage Works.

To lend the utmost comprehensibility to this information, the data should be graphically reproduced on the following lines:—

1. The rainfall in inches as ordinates and the time in minutes as abscissæ.
2. The rainfall in inches as ordinates and the time in hours as abscissæ.
3. The rate of rainfall in inches per hour as ordinates and the time in minutes as abscissæ.

By means of 1 and 2 we are enabled to determine the rainfall curve, by means of 3 the intensity curve of the district.

Figs. 4, 5 and 6 represent the graphical reproduction of the rain data for Sydney, with the rain curve and intensity curve produced therein respectively.

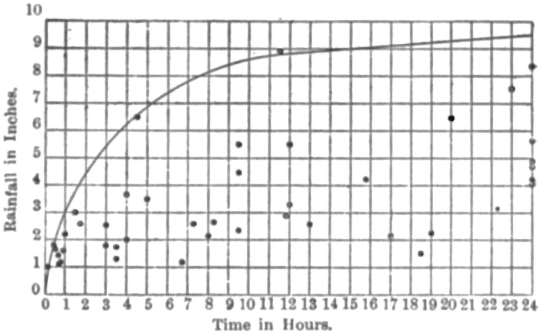

Fig. 4—Rainfall Curve for Sydney.

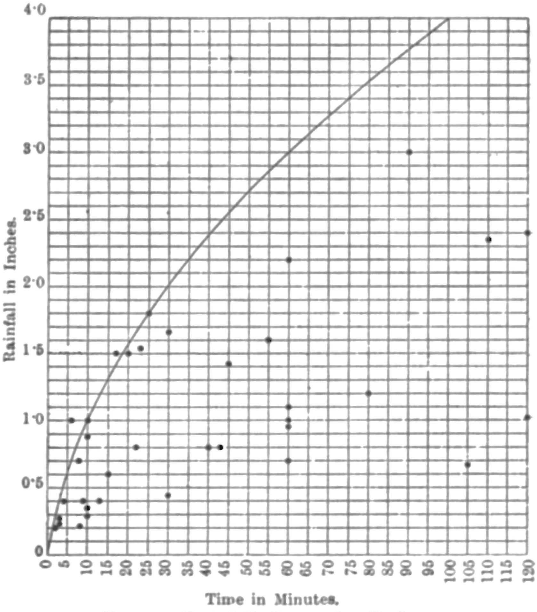

Fig. 5—Rainfall Curve for Sydney.

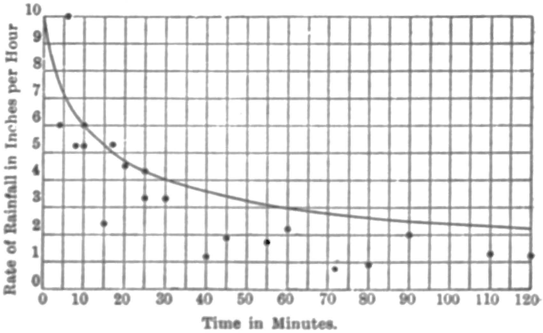

Fig. 6—Rainfall Intensity Curve for Sydney.

For economic reasons these curves must be based more on lines of frequency than extremes and isolated record falls excluded. Having the rain data thus prepared to hand we must decide which rainfall is the critical one for the whole and, if necessary, for portions of the area in question on the following basis:—

A city area necessitates inclusion of all the rain records within the intensity curve on account of the damage to property which may otherwise result. A suburban area may be dealt with on less severe lines, say the severest rainfall per hour. An agricultural area may be dealt with on a basis of an average rainfall for an extended period of rain.

RELATION BETWEEN RAINFALL AND RUN-OFF.

Only a portion of the rain falling on a given area reaches the conduit, the rest is either absorbed or evaporated.

From observations conducted in many parts, the following table has been prepared wherein, according to the condition of the surface of an area, the value of the rain flowing therefrom is expressed as a co-efficient of R, the quantity of rain falling thereon, generally called the "Co-efficient of Run-off."

Description of Drainage Area	Coefficient of Run-off expressed as coefficient of R
Old City Areas closely built over	0·8
New City Areas	0·6
Areas less closely built over, suburbs and Up-Country Towns	0·4 to 0·5
Villa Suburbs	0·3 to 0·4
Clear Building Areas	0·2
Parks, Gardens, Grazing and Agricultural Lands	0·15
Forest Lands	0·1

At the beginning of a period of rain only the area immediately adjoining a given point of the conduit delivers water to same, later on further areas contribute, and, with sufficient duration, the whole of the drainage area situated above this point.

To study this varied condition in regard to the amount of water passing through a conduit, we require to know the time which the water takes to pass through the conduit, and, by eliminating the time the rainwater takes to reach the conduit, we can express the time of passing by $T = t + \frac{l}{v}$

wherein t denotes the duration of rainfall in seconds,
,, l ,, ,, length of the conduit in feet,
,, v ,, ,, velocity of the water in the conduit in feet per sec.

Two conditions present themselves:—

1. The duration of rainfall is shorter than the time of passage, that is, $\frac{l}{v}$ is greater than t, in which case only the run-off of a portion of the drainage area can pass simultaneously through the lower end of the conduit.
2. The duration of rainfall is longer than the time of passage, that is, $\frac{l}{v}$ is smaller than t, in which case the run-off of the whole of the drainage area must pass simultaneously through the lower end of the conduit.

The quantity of water to be provided for for points lower down the conduit is, therefore, not only dependent on the intensity; but also on the duration of the rain and the velocity of the water in the conduits.

This consideration is of the greatest importance when dealing with city areas, which necessitate the inclusion of all the rain records within the intensity curve.

To determine the quantity of water to be provided for at any point of the conduit by means of a co-efficient of reduction or retardation, as advocated by Burkli-Ziegler, Brix and others, is not to be commended, as the main features of the run-off, viz., the extent and shape of the drainage area and the velocity in the conduit are thereby entirely neglected. The most accurate results are obtained by dividing the drainage area into sub-areas in accordance with the direct service rendered by the branch and main conduits, fixing for each such area the run-off co-efficient of the rain falling thereon and calculating each section of the conduit according to:—

1. The quantity of water delivered from the areas above in cubic feet per second.
2. The quantity of water in cubic feet per second delivered to the conduit from the adjoining area in accordance with the intensity, duration and run-off fixed for same.
3. The length of conduit.
4. The velocity of water in the conduit.

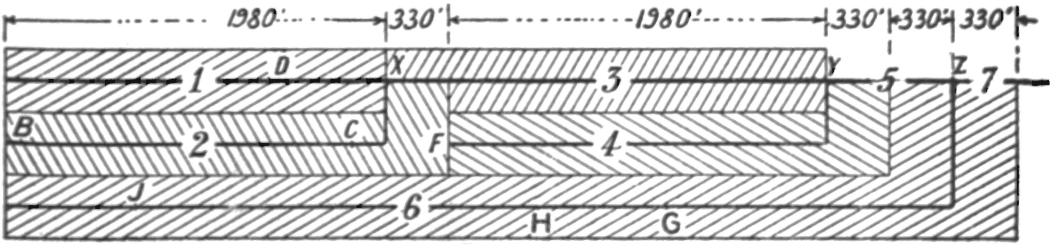

Fig. 7.

EXAMPLE.

A certain city area of the shape and dimensions shown in Fig. 7 is to be provided with a system of stormwater channels. The positions of these are indicated by 1, 3, 5 and 7 as sections of the main channel, and 2, 4 and 6 as branch channels, while the sub-drainage areas served by them are hatched differently for better distinction and named by their respective numbers.

To determine the maximum size of the channels, we make an examination under each of the two conditions presenting themselves for shorter and longer durations of rainfall, viz:—

1. The duration of rainfall is shorter than the time of passage.
2. The duration of rainfall is longer than the time of passage.

EXAMINATION UNDER CONDITION 1.

Let the drainage area be subject to a rainfall at the rate of five inches per hour extending over twelve minutes equal to 5.0416 cubic feet per second per acre.

The sub-areas consist partly of old city areas closely built over and partly new city areas with a run-off of 0.8 and 0.6 respectively of the quantity of rain falling thereon, amounting for the former to 0.8 × 5.0416 = 4.033 cubic feet per second per acre, and for the latter to 0.6 × 5.0416 = 3.025 cubic feet per second per acre.

The acreages of the sub-areas are—

S.A. 1 = 1980 × 330 = 653,400 sq. feet ... ... = 15·00 ac. Old City Area
S.A. 2 = 1980 × 330 + 495 × 330 = 816,750 sq ft. = 18·75 ,, ,, ,, ,,
S.A. 3 = 1980 × 330 + 165 × 330 = 707,850 ,, = 16·25 ,, ,, ,, ,,
S.A. 4 = 1980 × 330 + 495 × 330 = 816,750 ,, = 18·75 ,, New ,, ,,
S.A. 6 = 4620 × 330 + 825 × 660 = 2,069,100 ,, = 47·5 ,, ,, ,, ,,

116·25 Acres

The run-off of the sub-areas amounts to—

S.A. 1 = 15 × 4·033 = 60·5 cubic feet per second.
S.A. 2 = 18·75 × 4·033 = 75·625 ,, ,, ,, ,,
S.A. 3 = 16·25 × 4·033 = 65·54 ,, ,, ,, ,,
S.A. 4 = 18·75 × 3·025 = 56·72 ,, ,, ,, ,,
S.A. 6 = 47·5 × 3·025 = 143 69 ,, ,, ,, ,,

402·075 ,, ,, ,, ,,

We shall now determine the maximum quantity of rainwater which each channel or portion thereof will have to discharge, and, to simplify matters, we shall eliminate the time of run-off.

MAIN CHANNEL, SECTION 1.

The duration of the rainfall being 12 minutes = 720 seconds, the rainwater entering at the head of Section 1 at A will have covered, on completion of that period, with an average velocity of 3 lineal feet per second, a distance of 720 × 3 = 2,160 lineal feet. As the length of Section 1 is only 1,980 lineal feet, the profile of same above point X must be capable of discharging the whole of the run-off of sub-area S.A. 1 = 60.5 cubic feet per second.

BRANCH CHANNEL 2.

This branch channel has a length of 2,310 lineal feet, and the rainwater entering at the head of same at point B will have covered, on completion of the period of rainfall, with an average velocity of 2.5 lineal feet per second, a distance of 720 × 2.5 = 1,800 lineal feet and reached a point C which lies 510 feet above junction X. The water accumulated during this passage, being the run-off of $18.75 - \frac{510 \times 330}{43560}$ = 14.89 acres and amounting to 14.89 × 4.033 = 60.05 cubic feet per second, forms the maximum amount to be discharged by Branch Channel 2.

MAIN CHANNEL, SECTION 3.

The waters of Branch Channel 2, in order to reach junction X from C, will have to cover a distance of 510 lineal feet which occupies with a velocity of 2.5 lineal feet per second $\frac{510}{2.5} = 204$ seconds. During this interval Section 1 of the main channel, with a velocity of 3 lineal feet per second, will have discharged the waters for a length of 204 × 3 =612 lineal feet up to point D, leaving a balance of sub-drainage area S.A. 1 of $15 - \frac{612 \times 330}{43560} = 10.36$ acres still contributing with a maximum run-off of 10.36 × 4.033 = 41.78 cubic feet per second. The total quantity of water reaching junction X simultaneously from points C and D is, therefore, 41.78 + 60.05 = 101.83 cubic feet per second, and provision must be made for this amount below point X. The waters draining directly into Section 3 of the main channel do not come into consideration as, in the interval between the stoppage of the rainfall and the time when the waters reach the junction X, viz., 204 seconds, the run-off from sub-area S.A. 3