From	Channel	1 ..	13.06	cubic ft.	per sec.
"	"	2 ..	15.93	"	"
"	"	3 ..	65.54	"	"
"	"	4 ..	56.72	"	"
		Total	151.25		

Branch Channel 6.

The value of the graphical as a check on the analytical method is well exemplified in the results recorded for this case. The length of channel 6 is 5,610 feet, and the flow velocity 3 feet per second. At the end of the rainfall period the head waters of this channel would have travelled a distance of $720 \times 3 = 2{,}160$ feet down to a point "G." The water would require a further period of $\frac{5610 - 2160}{3} = 1{,}150$ seconds to arrive at point "Z," when the channel would have been emptied down to a point "H," situated $1{,}150 \times 3 = 3{,}450$ feet below the top. The total area then contributing would be $47.5 - \frac{3450 \times 330}{43560} = 21.36$ acres, giving a run-off of $21.36 \times 3.025 = 64.63$ cubic feet per second. Had this area, S.A. 6, been of uniform width throughout, as assumed in the graphical method, the run-off would have been $47.5 \left\{ 1 - \frac{3450}{5610} \right\} \times 3.025 = 55.32$, which agrees with Mr. Vicars' diagram No. 6, a result which is 14.4 per cent. too small.

Main Channel 7.

We have seen that at the end of the storm the waters from point "X" would have reached point "L," situated 570 feet below "Y," or 90 feet above "Z"; so that the run-off from areas S.A. 1 and 2 would not affect channel 7 during the storm. There remains for consideration the flow from sub-areas 3, 4, and 6. The head waters of S.A. 3 and S.A. 4 would each, at the end of storm, have arrived at point "L." By the time these waters had arrived at "Z," these channels would have emptied for a distance of 90 feet below "X" and "F" respectively. This leaves in the case of channel 3 an area of $16.25 - \frac{90 \times 165}{43560} = 15.91$ acres contributing with a flow of

$$15.91 \times 4.033 = 64.17 \text{ cubic feet per second.}$$

the contributing area remaining in the case of channel 4 is $18.75 - \frac{90 \times 330}{43560} = 18.07$ acres, giving a flow of $18.07 \times 3.025 = 54.66$ cubic feet per second.

The total quantity to be accommodated at "Z," main channel 7, is therefore—

From Sub-Area S.A.	3	64.17	cu. ft. per sec.
,, ,,	4	54.66	,, ,,
,, ,,	6	64.63	,, ,,
Total =		183.46	

Examination Under Condition 2.

The worst case which could occur under this condition is that of a rainfall whose duration is equal to the time length of the drainage system. In the case under review, the time required for the head waters of channel 6 to arrive at "Z" = $\frac{5610}{3}$ = 1,870 seconds = 31.16 minutes. The rainfall intensity for Sydney for this period might amount to $\frac{20}{\sqrt{31}}$ = 3.59, say 3.5 inches per hour. The run-off of the sub-areas for a rainfall of 3.5 inches per hour for a period of 31 minutes amounts to—

$$\begin{aligned}
\text{S.A. } 1 &= 15 \times 3.529 \times 0.8 = 42.35 \text{ cu. ft. per sec.}\\
\text{S.A. } 2 &= 18.75 \times 3.529 \times 0.8 = 52.94 \quad ,, \quad ,,\\
\text{S.A. } 3 &= 16.25 \times 3.529 \times 0.8 = 45.88 \quad ,, \quad ,,\\
\text{S.A. } 4 &= 18.75 \times 3.529 \times 0.6 = 39.70 \quad ,, \quad ,,\\
\text{S.A. } 6 &= 47.5 \times 3.529 \times 0.6 = 100.58 \quad ,, \quad ,,\\
&\qquad\qquad \text{Total} \quad 281.45
\end{aligned}$$

The revised figures for the analytical may now be tabulated for comparison with the graphical method:—

DRAIN.	ANALYTICAL METHOD.			GRAPHICAL METHOD.				
	5in. for 12 min.	3·5in. for 31 min.	Max.	3in. for 12 min.	2in. for 2 hrs.	Total.	5in. for 12 min.	Max.
(1) Main AX	60·5	42·35	60·50	36·3	24·2	60·5	60·5	60·5
(2) Branch BX	60·05	52·94	60·05	35·3	30·3	65·6	58·9	65·6
(3) Main XY	...	45·88	...	39·3	26·2	...	65·4	...
(1) + (2) + (3) ...	120·55	141·17	148·17	72·8	80·7	153·5	121·3	153·5
(4) Branch (X)Y ...	56·72	39·70	56·72	34·0	22·7	56·7	56·72	56·72
(5) Main YZ ... (1)+(2)+(3)+(4)+(5)	151·25	180·87	180·87	88·2	103·4	191·6	147·06	191·6
(6) Branch aZ	64·63	100·58	100·58	33·2	57·5	90·7	55·3	90·7
(7) Main Zh ... ... 1+2+3+4+5+6+7	183·46	281·45	281·45	121·4	160·9	282·3	202·3	282·3

Accidentally it happens that the rainfalls considered for condition 2, in both the above methods, are practically identical. Mr. Vicars' rainfall of 3 inches per hour for 12 minutes, plus 2 inches per hour, would give, for a period of 31 minutes, a total fall of 1.63 inches, or a rate of 3.16 inches per hour for 31 minutes, as against the 3.5 inches adopted in the other method.

It is to be regretted that errors were inadvertently allowed to remain in the calculations in the trade catalogue referred to; but this in no way affects the principle therein demonstrated that a system of stormwater drainage can be properly designed only by determining the critical maximum rainfall for each portion of the scheme, as well as for the whole system, and then analysing the discharge requirements in detail. And this analytical method of determining discharges is not, as Mr. Vicars imagined, inaccurate.

Nor does it ignore the effect of increasing volume at beginning, and of decreasing volume at end, of storm. The graphical method is simply a graphical exposition of the analytical, and so has the inherent virtues of all graphical calculations as well as their faults. For example, in the case of the discharge of main channel 7, Mr. Vicars reads a discharge up-stream at point "Y," 10 chains above the junction of branch channel 6, when he should have obtained the value at or below the said junction.

It would not be necessary, as Messrs. Gummow, Forrest, and Co. state, to calculate and tabulate the discharge requirements for a large number of rainfalls of varying intensities and durations, unless there was a large number of branch channels of varying lengths in the scheme. For, given an equation of the rainfall intensity curve, it is obvious that the time length of the shorter branch drains determines the maximum intensity of rainfall, while that of the longest drain fixes the minimum intensity to be employed in the investigation of discharge requirements. In the case under review, the maximum fall to be considered should have strictly been that for a period of $\frac{1980}{3} = 660$ seconds $=$ 11 minutes, instead of 12 minutes, as adopted.

IV.—W. POOLE, Esq., B.E., A.M.I.C.E., F.G.S., L.S.

Mr. POOLE: The total or maximum intensity of "flow-off" from catchment areas is of great importance to engineers when it is necessary to design engineering works affected by them. The total flow-off is of importance in questions involving the storage or consumption of water and the maximum intensity in questions of flood flow.

The estimation of flood-flow is, as pointed out by Mr. Vicars, beset with many difficulties, on account of the variable nature of the contributing causes. The areas of the catchments may vary from that of the roof of a house to that of one of the mighty rivers of the world.

The surface of the catchment may be wholly or in part of many phases of roughness, capacity for absorption, etc.

The rainfall varies greatly in different districts or localities in duration, frequency and intensity of showers, and also in the annual amount. The problem is still further complicated as to whether it will be sufficient to provide for "frequent" flood-flows or be necessary to provide for unusual, rare, or even phenomenal flows.

The effect of varying areas and surfaces of catchments has been discussed at length, but I think it is opportune to further discuss the rainfall.

It has been my lot to live in many places in four States of the Commonwealth, and be personally acquainted with the conditions of rainfall from North Queensland(in the Tropics) to Tasmania, and from thewet districts of the coasts to the arid ones of the interior.

Mr. H. A. Hunt, Commonwealth Meteorologist, kindly furnished me with the accompanying data. The table of heavy rainfalls at Sydney is not, however, included, as a similar one is attached to Mr. Vicars' paper. Mr. Hunt also gives interesting data in Federal Handbook on Australia, prepared for the recent meeting of the British Association.

A comparison of these data discloses many interesting features. The intensity of rainfall varies from very great in the Tropics, to light in higher latitudes—it is more frequent on the east coast (except in Tasmania) and mountain ranges near the coast than inland. It is more continuous in various localities that are greatly influenced by local topography. In Queensland the greatest falls occur during the tropical wet season (December to March), light falls during the winter months, and sudden heavy falls during the thunderstorm season (September to December).

In the southern States the larger portion of the rain falls during the winter months, while New South Wales is subject in a lesser degree to all three influences.

During the wet season in Queensland, especially on the coast, the showers are often very heavy, frequent, and of long duration. When all three factors are simultaneously great, phenomenal storms, such as those on the Brisbane River watershed, in 1903 (60 inches in three days), or in the Cairns district, in 1911, when 73 inches fell in three days at Kuranda. During the same storm, 31.53 inches fell at Port Douglas in the 24 hours on April 1st.

Inland the showers are often of great intensity, but less frequent and of less duration. The falls of rain during tropical and sub-tropical thunderstorms are of still greater intensity during the short time they last. Thus, storm drains for small areas require to be as ample in size at Charters Towers as at Innisfail, though their annual rainfall and maximum fall in one day are so dissimilar, because the former place is subject to very heavy thunderstorms of short duration.

The coastal districts of New South Wales are frequently visited by rainstorms of tropical nature (see curves of rainfall intensity for Sydney), though it rarely happens that the factors of intensity duration and frequency of showers are simultaneously great. Many such *sporadic* falls of 10 to 22 inches are recorded, but seldom more than one such fall for each place.*

In the southern States, though most of the rain falls during the winter months, the heaviest showers are during summer thunderstorms (see records of Melbourne during the winter months). In these States the frequency and duration of showers are often high, but intensity of fall is low.

From my experience in various places, I am of opinion, and this is confirmed by the data furnished by Mr. Hunt, that there is no approximately definite relation between intensity of fall on a ten-minute or hourly basis and the average annual rainfall. This will be seen if one compares the data given for, say Cairns, Zeehan, and Ballarat. The first two are comparable in annual rainfall, but not in hourly intensity and maximum daily fall; the second and third are comparable in intensity, but not in total annual fall. I am, therefore, not able to accept Mr. Vicars' formula:—

$$Q = 1{\cdot}571\ Cr\ A^{\frac{3}{4}} \text{ (on 10 minute basis).}$$
$$= 2{\cdot}357\ Cr\ A^{\frac{3}{4}} \text{ (on hourly basis).}$$
$$= 1{\cdot}11\ C_R^{\frac{1}{2}}\ A^{\frac{3}{4}} \text{ (on yearly basis).}$$

These alternative formulae, especially the one on the yearly basis, if applied to many places given in the table, give results that are not reliable enough for purposes of design. The intensity of fall over one hour and portion thereof is the most important factor of rainfall to engineers when designing storm drains from small areas.

Curves of intensity of rainfall have been deduced from records in various parts of the world, and these curves may with judicious use be made the basis of estimation for similar places elsewhere where no such records are available.

Mill† gives tables and curves of rainfall for Great Britain. These curves may be approximately represented by the following formulae where "I" is the intensity of fall in inches per hour and "t" is the time in minutes.

* Hunt in Federal Handbook on Australia, B.A.A.S., 1914.

† (See the Control of Water—Parker and Mill British Rainfall).

$$\text{"Very rare" Rainfall} \ldots I = \frac{240}{t + 30} \text{ inches per hour.}$$

$$\text{"Remarkable"} \quad \text{,,} \ldots I = \frac{160}{t + 30} \quad \text{,,} \quad \text{,,}$$

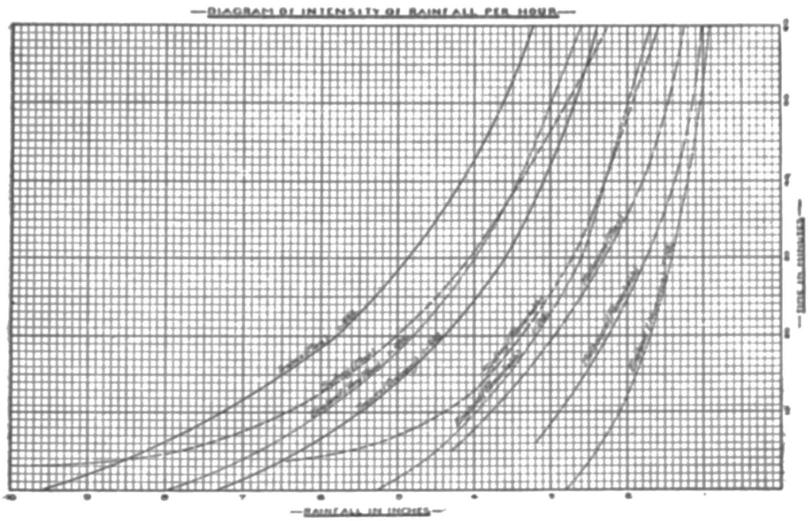
$$\text{"Numerous"} \quad \text{,,} \ldots I = \frac{84}{t + 30} \quad \text{,,} \quad \text{,,}$$

The following curves for falls in the Tropics have been deduced from systematic records for four years at Manila (Philippines).

$$\text{"Maxima"} \ldots I = \frac{290}{t + 30}$$

$$\text{"Ordinary"} \ldots I = \frac{220}{t + 30}$$

As these formulae are based on only four years' records, it may be preferable to use the terms "Remarkable" and "Numerous" instead of "Maxima" and "Ordinary" respectively.



The foregoing five curves have been plotted on the accompanying diagram, together with maximum and remarkable rainfall curves for Sydney and Melbourne. The latter curves are based on the information kindly supplied by Mr. Hunt, the Commonwealth Meteorologist (see accompanying tables).

The curves for both places are steeper than the others. The curves for Sydney show that for short periods the falls may be of full tropical intensity, but the downpours are not so sustained as in the Tropics; therefore the curves show a rapid falling away as compared with those for Manila.

It is to be regretted that fuller records are not available for different parts of the Commonwealth, and it is hoped that autographic instruments will be installed at important meteorological stations, and the records published.

I am of the opinion that in the absence of proper data, the intensity curves deduced for Manila may be safely used for the coastal districts of Queensland for periods not greater than one hour; after that time the formulae will give results which are too small.

It is probable that the same formulae may also be used in Queensland tropical inland districts for estimating the intensity of rainfall of heavy storms of short duration. Ready-made formulae for intensity of fall should not be applied to inland stations in New South Wales without carefully scrutinising both the formulae and the local conditions, as the latter are very variable. The run-off (both storm and ordinary) from large areas should be determined from observed data, such as area cross section of channels, flood height, slope of water-course, or gauging the actual flow; in fact, the last-named method is the only satisfactory one for large streams.

The most of my comments relate to the problems involved in the estimation of the intensity of rainfall and consequent run-off from small areas. On large areas, such as the catchment of a river, the total fall during the rainstorm is more important than the maximum intensity of an individual shower, as is the case on very small areas.

AVERAGE ANNUAL RAINFALL AND MAXIMUM FALL IN ONE DAY AT SEVERAL PLACES IN THE COMMONWEALTH.

Station.	Average Annual Rainfall.	Maximum Fall in One Day.		
Innisfail	151·41 inches	21·22	inches on	29-12-03
		20·50	,,	2-4-12
Cairns	90·90 ,,	20·16	,,	2-4-11
Charters Towers.. ..	25·99 ,,	4·15	,,	9-6-12
Brisbane	46·61 ,,	18·31	,,	21-1-87
		11·18	,,	14-3-08
Sydney	48·01 ,,	8·90	,,	25-2-73
		8·36	,,	28-5-89
		7·52	,,	27-4-50
Bourke	14·47 ,,	2·17	,,	..
Hay	14·26 ,,	4·39	,,	..
Broken Hill	9·72 ,,	2·25	,,	..
Melbourne	25·60 ,,	3·05	,,	15-3-78
Ballarat	28·76 ,,	2·84	,,	..
Adelaide	21·06 ,,	3·50	,,	5-3-78
		3·15	,,	5-4-60
Port Pirie	13·13 ,,	2·59	,,	21-6-10
Hobart	23·51 ,,	5·02	,,	20-4-07
Zeehan	97·89 ,,	2·94	,,	7-9-12

HEAVY RAINFALLS AT AUSTRALIAN CAPITALS.

Including as far as possible all falls with an intensity of 100 points per hour or over, with alternative limitations of 25 points in amount, and 10 minutes in duration. In all cases duration refers to the period of maximum intensity. For Table for Sydney, see Table attached to Mr. Vicars' Paper pp. 84, 85.

Melbourne, 1862-1911 (Inclusive).

Year.	Date.	Amount in Points.	Duration in Minutes.	Rate per Hour in Points.
1862	December 8th ..	48	25	115
1864	March 2nd	118	30	236
1871	November 22nd ..	62	15	248
1872	November 19th ..	43	20	159
1877	March 10th	100	15	400
1882	December 5th ..	125	60	125
1884	November 6th ..	50	10	300
1885	February 18th ..	95	20	285
1886	January 7th	50	30	100
1887	February 26th ..	75	20	225
1887	April 9th	58	20	174
1887	November 30th ..	100	60	100
1890	November 24th ..	29	10	174
1890	December 18th ..	25	10	150
1890	December 24th ..	35	15	140
1896	January 10th ..	40	10	240
1896	March 15th	55	15	220
1897	January 9th	95	50	114
1897	December 22nd ..	45	20	135
1897	December 22nd ..	35	20	105
1898	April 18th	28	15	112
1900	January 20th ..	58	30	116
1900	January 20th ..	34	20	102
1900	May 18th	44	20	132
1900	May 19th	43	15	172
1900	December 31st ..	29	10	174
1901	March 18th	25	15	100
1901	October 20th.. ..	163	80	122
1901	November 15th ..	72	40	108
1902	December 17th ..	36	20	108
1903	January 21st.. ..	19	10	114
1903	March 4th	27	15	108
1903	March 28th	32	15	128
1903	November 27th ..	49	10	294
1904	January 2nd.. ..	24	10	144
1904	January 14th ..	20	10	120
1904	February 5th ..	25	10	150
1904	February 6th ..	50	26	115
1904	June 21st	40	10	240
1905	December 30th ..	120	42	171
1905	December 30th ..	25	5	300
1906	February 28th ..	25	14	107
1906	September 27th ..	21	12	105
1907	March 4th	25	9	167
1907	November 22nd ..	25	10	150
1908	September 12th ..	20	12	100
1910	November 3rd ..	36	20	108
1911	January 17th ..	32	6	320
1911	February 5th ..	30	5	360
1911	March 7th	42	7	360
1911	March 7th	40	20	120
1911	March 7th	50	13	231
1911	March 7th	43	12	215
1911	March 8th	38	8	285
1911	October 2nd	36	5	432

Heavy Rainfall at Brisbane, 1911-13 (Inclusive).

Year.	Date.	Amount in Points.	Duration in Minutes.	Rate per Hour in Points.
1911	March 11th	94	15	296
,,	August 21st	36	18	120
,,	August 28th	22	12	110
,,	October 4th	28	13	129
,,	October 15th	34	5	408
,,	October 16th	35	7	300
,,	October 16th	24	10	144
,,	December 2nd ..	71	16	266
1912	January 6th	65	17	229
,,	March 15th	53	19	167
,,	October 14th	31	18	103
,,	October 20th	23	11	123
,,	November 8th ..	46	9	307
,,	November 23rd ..	47	21	134
,,	November 25th ..	66	25	158
,,	December 8th ..	30	15	120
,,	December 10th ..	54	14	231
,,	December 11th ..	* { 50	2	1500 }
..	December 11th ..	{ 140	16	525 }
1913	February 17th ..	88	27	196
,,	March 22nd	33	8	248
,,	October 25th ..	25	15	100
,,	November 4th ..	46	6	460
,,	November 4th ..	31	8	233
,,	December 12th ..	52	20	156

* Figures bracketed represent overlapping parts of same shower.

Heavy Rainfalls at Adelaide, 1897 to Date.

Year.	Date.	Amount in Points.	Duration in Minutes.	Rate per Hour in Points.
1898	April 17th	20	10	120
1902	December 17th ..	40	20	120
1906	April 25th	20	10	120
1906	December 16th ..	35	15	140
1906	December 17th ..	28	10	168
1910	June 27th	39	8	293
1910	July 23rd	28	10	168
1911	June 18th	19	10	114
1911	July 17th	25	10	150
1911	September 27th ..	32	10	192
1912	April 6th	20	10	120
1913	February 14th ..	188	45	251
1913	April 26th	27	12	135
1913	October 27th ..	36	10	216
1913	December 23rd ..	50	10	300
1914	April 19th	17	10	102

Heavy Rainfalls at Perth, 1910-13 (Inclusive).

Year.	Date.	Amount in Points.	Duration in Minutes.	Rate per Hour in Points.
1910	June 19th	22	12	110
,,	July 24th	* 132	75	106
,,	July 24th	* 93	35	159
,,	October 15th ..	17	10	102
1911	July 19th	20	10	120
,,	August 4th	25	3	500
,,	August 4th	22	12	110
,,	August 31st	17	10	102
,,	October 29th ..	20	12	100
1912	January 13th ..	76	12	380
,,	February 10th ..	36	10	216
,,	September 6th ..	36	15	144
,,	October 20th ..	* 78	45	104
,,	October 20th ..	* 66	15	264
1913	June 15th	41	22	112
,,	June 21st	63	25	151
,,	August 1st	50	30	100
,,	August 5th	30	12	150
,,	September 9th ..	32	15	128
,,	October 23rd ..	19	10	114

* Figures bracketed represent overlapping parts of the same shower.

Heavy Rainfalls at Hobart.

Year.	Date.	Amount in Points.	Duration in Minutes.	Rate per Hour in Points.
1912	November 20th ..	38	5	456
1913	April 26th	72	40	108

REPLY: I am pleased to say that the gentlemen who have contributed to the discussion have supplied those links from their practice which were required to complete the paper. Especially am I indebted to Mr. H. H. Dare, M.E., M.Inst.C.E., Chief Engineer for Irrigation, for valuable data contributed regarding Departmental practice; also to Mr. F. R. Hollings for information regarding a very difficult special case, and observations on formulae generally referred to; to Mr. R. J. Boyd, M.E., A.M.I.C.E., for a critical discussion which I value; and to Mr. W. Poole, B.E., A.M.I.C.E., F.G.S., L.S., for much information regarding records and a discussion as to the value of formulae.

In Reply to Mr. Dare, M.E.: I agree with his conclusions generally. The data which he supplies regarding total run-off are beyond the scope of the paper, as pointed out by him. I am, however, in accord with, and have for years advocated the systematic observation of, flood-flow which he recommends.

The case of the great flood on the Hunter River, which occurred on the 17/5/13, is most interesting, and through the courtesy of Mr. Dare, I give the following data:—Area of catchment, 7,090 square miles, or 4,537,600 acres. Mean rainfall over whole catchment for 24 hours, on 13/5/13, of 0.47 inches; on 14/5/13, of 2.38 inches; on 15/5/13, of 2.98 inches; and on 16/5/13, of 0.17 inches, making a total of 6.00 inches for 96 hours, or $\frac{1}{16}$ inch average per hour. Maximum individual rainfall registered for one day, 5.25 inches. Gauged maximum rate of discharge, 206,780 cusecs.

From the above data, but without making allowance for losses, the calculated rate of discharge is $\frac{4{,}537{,}600}{16} = 283{,}600$ cusecs. By formula $Q = 1.57 \times 5.25\ (4{,}537{,}600)^{\frac{2}{3}} = 225{,}900$ cusecs. According to the direct calculation, the loss 283,600 — 206,780 = 76,820 cusecs, represents 27%; while the formula gives an excess of 9¼%.

Regarding the figures for Leeton, where "r" is the actual rainfall in one hour, if the flood discharge were calculated as suggested in the paper the result would be $Q = 2.357 \times C \times r \times A^{\frac{2}{3}} = 2.357 \times .9 \times 1.9 \times 148^{\frac{2}{3}} = 112.8$ cusecs; and the equivalent value of "r," corresponding to run-off =

$$\frac{2{\cdot}357 \times C \times r}{A^{\frac{1}{3}}} = \frac{2{\cdot}357 \times {\cdot}9 \times 1{\cdot}9}{(148)^{\frac{1}{3}}} = .761 \text{ inches per hour.}$$

In the other case, he allows for run-off an equivalent of 1½ inches of rainfall per hour. Referred to Sydney, this value is applicable to an area, as determined by forumla $\frac{1{\cdot}57 \times {\cdot}9 \times 4}{A^{\frac{1}{3}}} = 1.5$ or "A" = 68 acres. Beyond this area the provision would be ample; but for much smaller areas the provision would seem to be fine. The Board of Water Supply and Sewerage provide for run-off at the rate of 2 inches per hour, which, for a maximum rate of rainfall of 4 inches per hour, would be the equivalent rate for an area of 31 acres. This seems to me a better value for small catchments.

For practical purposes where numerous small schemes have to be designed, this method has advantages, provided the rate adopted is high enough for small catchments, when it will be safe—excessive for larger areas.

In Reply to Mr. F. R. Hollings: No better case could have been cited to exemplify the impracticableness of incorporating a value for slope of surface of catchment in discharge formulae. It is a remarkable case, as the following summarised data show:—Area of catchment, 25,000 acres; length, 11 miles, of which the first 6 miles is flat and marshy, and practically without slope, the margin of catchment ringed by low hills sloping about 1 in 35; rainfall in 24 hours, 8 inches; flood-flow traverses catchment in 20 hours.

When the rainfall for 24 hours = "r_1" is equal to the maximum rate = "r" in formula, the results obtained by the latter method, i.e., adopting "r_1" instead of "r," will lead to higher results than those obtained by calculating the discharge on the basis of average run-off, equivalent to rainfall of $\frac{r_1}{24}$ inches per hour, for areas less than $\frac{r_1}{24} = \frac{1{\cdot}57 \times C \times r_1}{A^{\frac{1}{4}}}$ $= A = 49.320$ acres, say 50,000 acres.

According to formula, the maximum rate of discharge = $Q = 1.57 \times .9 \times 8 \times (25{,}000)^{\frac{3}{4}} = 9{,}653$ cusecs.

By direct calculation, run-off is equivalent to a rainfall at average rate of $\frac{8}{24} = \frac{1}{3}$ inch per hour $\times$ 25,000 acres = 8,333 cusecs. No deduction need be made for losses, for the maximum discharge takes 20 hours to come down, whereas the rainfall continued for 24 hours, and therefore $\frac{1}{5}$ of 8 inches = 1.6 inches are available to provide for any losses before commencement of flow, which produces maximum flood discharge. The slope of surface, no matter how steep, cannot increase, and not matter how flat, cannot decrease the volume and rate of run-off beyond or below that of the rainfall, save by losses due to absorption, etc. For, in this case, the flow from top of catchment to outlet takes 20 hours, and half the rainfall for that period passes off in the same time, or $25{,}000 \times (\frac{1}{3} \times 20 \times 60 \times 60)\frac{1}{2}$ cubic feet in 20 hours, or a rate of $25{,}000 \times (\frac{1}{3} \times 20 \times 60 \times 60)\frac{1}{2} \times \frac{1}{20} \times \frac{1}{60} \times \frac{1}{60}$ cusecs, and the maximum is twice this, as the flow starts with a trickle, therefore maximum discharge rate $= 25{,}000 \times (\frac{1}{3} \times 20 \times 60 \times 60) \times \frac{1}{2} \times \frac{1}{20 \times 60 \times 60} \times \frac{2}{1}$ cusecs $= 25{,}000 \times \frac{1}{3} = 8{,}333$ cusecs, which shows that rate of discharge is independent of time.

The slope of catchment, however, affects time of run-off considerably. In this case a huge pond or lagoon, almost dead level, receives flood-flow, which will be in a sheet, wide, shallow, and slow, starting fanwise, and ending with almost straight face. If the width between banks were known, the height and velocity of bore or flood wave could be calculated, for it would be equivalent to the discharge as for a submerged weir. This volume of flood would represent the rate of increase of volume of lagoon, the rate of flow or discharge from the lagoon depending solely on the size and depth of outlet. If the area of lagoon is one-third of that of catchment, and the rain lasts for 24 hours, we can say that the depth of lagoon will be increased 2 feet, by 8 inches of rain, if there is a higher bar at outlet end, and there will be no discharge. If now an outlet channel be cut 2ft. deep, the lagoon will be emptied in a time measured only by the width of channel, and the width should be sufficient to enable lagoon to empty before another rain is experienced, or in such time as circumstances may make advisable. From this it follows that the lagoon may become a storage reservoir and the outlet a by-pass; also that in such vast reservoirs as Burrinjuck and Cataract the by-pass may never be called upon to discharge flood-waters at the maximum rate of inflow.

Theoretically, where surface slope is uniform and the depth of flood-flow increases at a regular rate by rainfall, the time of run-off will vary as $\frac{1}{A^3}$ or t^3 varies as "A." But where the flow is continually being interrupted and checked, or abruptly diverted as by cascades, etc., the velocity tends to uniformity with $t^2 \times A$. Although my records are scarcely complete enough to warrant me in making any definite statement, I suggest a value of t^3 in hours $= \frac{A}{5}$.

As regards Chamier's formula, I consider it gives results which are low for moderate areas.

In Reply to Mr. R. J. Boyd, M.E.: Mr. Boyd thinks it curious that after criticising the formulae of others, I should be guilty of perpetrating one myself. Perhaps an apology is necessary; but would it not have been more inexcusable if, after attempting to show the difficulties and inconsistencies in the formulae of others, I could not suggest a remedy? However blameworthy in this respect, I have pleasure in acknowledging the splendid criticism of Mr. Boyd and others, whose contributions have materially enhanced the value of the paper. For all that, Mr. Boyd has not grasped the purpose of the paper, which was first to demonstrate the inadequacy of current formulae, and to suggest a fundamental formula—not Burkli-Ziegler's, for it does not contain a factor for slope of surface; but it does contain a variable co-efficient "c" to provide for losses. Further, it being impossible for one man to determine the value of "c" from another's records, another formula based on the fundamental one was devised to enable maxima discharges to be approximated without reference directly to "c," and for areas less than 10,000 acres it is believed to be equally applicable to city conditions as well as to saturated surfaces of open land, where a saturated surface may be considered equivalent to a paved surface for purposes of run-off.

Respecting co-efficient "c," Mr. Boyd adversely criticises values given in my first paper, and apparently recommends those in Messrs. Gummow, Forrest's catalogue. In the first place, he forgets that the formula in each case is quite different. All the same, I consider the data contained in the Trade Catalogue the best previously available. The values adopted by me were taken from American sources. Professor Patton recommends values of "c," varying between .30 and .75, for use with Burkli-Ziegler's formula; and Trautwein advises .31 to .75; while Allen Hazen uses .9 to .1 with McMath's formula. But, except for paved surface, I consider these latter quite inadequate for great storms, and, if accurate (using that formula) for large catchments, they must be greatly excessive for small ones.

In the American Civil Engineers' Handbook, Professor Gardiner S. Williams gives the following values for percolation in percentages of rainfall from both American and European sources. The other columns I have added for comparison:—

	G. S. Williams.		Value of "c."					
	Percolation.	Run-off.	Williams.	Patton.	Trautwein.	Vicars.	Gummow Forrest.	Hazen.
Ordinary ground, bare ..	29·2%	70·8%	·7	·6	..	..	..	·2
Loam, bare	36	64	·64		..	..	..	..
Ordinary soil with sod	33	67	·67	to	..	·5	·2	..
Sand, bare	65 – 85	35 – 15	·35 – ·15		..	·3	..	·1
Mixed forest	74	26	·26	·25	..	..	·1	..
Old City Areas, closely built over					·75	.75	·8	·9
New City Areas					·625	..	·6	..
Areas less closely built over, suburbs and country towns					·31	..	·4 to ·5	..
Villa Suburbs					..	..	·3 to ·4	..

Although applied to different formulae, I believe there is sufficient diversity in the values of "c" in the above list to make any lawyer gloat and engineers shudder. But I do not think that anyone will seriously find fault with the value I have assigned to "c" for country land on the ground of it being too high after reading the data supplied by Mr. Dare; for the actual gauging of maximum rate of discharge of flood-flow from a typical catchment of 7,090 square miles was 73% of the average intensity of rainfall, and the total run-off—a totally different thing—was 29% of the total precipitation. I believe the Trade Catalogue values are more applicable to the latter determination. Further, I myself have gauged results of 50% for such country, and I have checked the capacity of drains from paved areas—completely built over or paved, including roads—and have not recorded 80% in any case; but to be quite fair, these were not gauged during maximum rate of rainfall, and more extensive gaugings might establish higher values for "c" of .3, .6, .9 respectively, although Patton and Trautwein think otherwise.

In Burkli-Ziegler's formula, a slope of 5% is frequently allowed for = 50 per 1,000 and $\sqrt[4]{50} = 2.66$, and 16ft. per 1,000 gives $\sqrt[4]{16} = 2.0$, i.e., the co-efficients in this formula must be multiplied by, from, say 2 to 2.66, to compare with the co-efficients I have adopted for my fundamental formula, which omits term $\sqrt[4]{1000s}$. If this were done, it would bring Mr. Boyd's idea as to co-efficients fairly into line with mine. This affords another reason for disagreeing with the above type of formulae; for it is quite contrary to common sense to virtually make the co-efficient less for flat slopes than steep ones.

As regards Mr. Boyd's remarks re my graphical method and the slight error involved through assuming each catchment to be of uniform width, they are quite correct; although, if the straight lines enclosing figures had been curved exactly to represent the areas at each point along the time-base course of drain, even this small error would vanish; but it would have made it less easy for me to explain the method. I am glad Mr. Boyd has taken the trouble to correct the mistake in the analytical method given by Gummow, Forrest, for, though involved, the solution presented is very good. At the same time, the reference to discharge of main channel 7 by the graphical method is a misconception, for, being on a time basis, the time lengths of all sections overlap in places, though the actual drains do not, yet the results prove the method to be quite correct. The diagrams correctly show how the flow from preceding sections affect the succeeding, not vice versa. The supposed error of 124 per cent. in my table disappears when comparison is made with Mr. Boyd's corrected results.

The three curves for determining the maximum intensity of rainfall for Sydney are valuable, and are on a basis which compare well with similar determinations for rainfall in England and America, where Mills and de Bruyn-Kops have analysed many records in this way, i.e., $r = \frac{k}{t + c}$; but it is considered that for periods of time greater than three or four hours this equation is quite inapplicable, and I suggest that it may really be a special formula, with a limited range, adapted to one portion of a general curve; and that by carefully studying the curves for longer periods some fundamental formula might be discovered, capable of general application. The curves such as

$r = \frac{20}{\sqrt{t}}$ are now used in connection with the drainage schemes of some cities in America, as for instance, in Chicago, where $r = \frac{16}{\sqrt{t}}$; but, like the other equation, the scope of its application is quite limited.

I appreciate Mr. Boyd's thorough criticism, and trust he will at no distant date prepare a paper embodying further detailed information on and extension of this subject, in which his experience is recognised.

In Reply to Mr. W. Poole, B.E.: I would not say that equal waterway should be provided in drains for small areas in Charters Towers and Innisfail, unless authentic records showed these towns to be subject to storms of equal intensity. From the meagre information presented, I should absolutely doubt it. Mr. Poole also says the annual rainfall in Cairns and Zeehan is comparable, but not so the hourly intensity and maximum daily fall. From the records which he appends, the first and last statements are substantiated. There is, however, no record as to hourly intensity; but even grant it to be correct, it is in one respect—neglecting "c"—wide of the purpose of the formula based on annual rainfall, and has no bearing whatever on the formula based on maximum intensity per hour. Again, Zeehan and Ballarat, he says (but submits no records), are comparable in intensity—and then I say the intensity formula applies—but he points out they are not comparable in annual fall. Now, I should think the deduction to be drawn from all this is simply that there are extreme cases in which the analogy between the formula for annual fall and for maximum intensity does not hold. Such statements are wholly insufficient on which to say even that the formula for annual fall will not give correct results in both cases; but I stated this formula was put forward for application where sufficient records of intensity of rainfall for short periods were not available.

Mr. Poole has ably discussed the variations in annual, daily, and hourly rainfall as affected by latitude; and if reference be made to my first paper, it will be seen that I not only recognised this fact, but also stated that the variable coefficient "C" was adopted to cover such variations, and has nothing whatever to do with "c" in the fundamental formula which represents proportion of run-off. Again, the formula for annual rainfall makes ample provision for fair maximum rate of rainfall, which may be adopted with confidence for the design of stormwater drains. This maximum is specially referred to, and has no bearing on phenomenal falls, which must be specially allowed for by the appropriate formula. For instance, if one knows the total amount of rainfall producing top flood, it is only necessary to divide this by the time in hours and multiply by the area of catchment in acres to ascertain fairly accurately the maximum discharge in cusecs; if the duration of rainfall to produce maximum flood discharge be not known, it can be approximated by the formula I have suggested in reply to Mr. Hollings, and then approximate the mean hourly fall from records, and proceed as before. While I do not pretend that exceptions will not occur to any formula, the fact that mine has given such good results wherever I have applied it to cases quoted in my first paper where reliable records exist, all over New South Wales, Victoria, Tasmania, and South Australia, gives me confidence in using it, and has induced me to make it known to others in the hope that someone will thereby be induced to do better. Indeed, as no one has challenged the fundamental formula or the method of deduction, I conclude that the only contention concerns the derived formula; and I trust that an effort will be made to check it with actual records, which, after all, is the only conclusive method.

The formulae quoted by Mr. Poole were known to me; but, as reliable authorities state that they have a very limited application, they could not be utilised in a general formula, and Mr. Poole himself limits them to one hour, as regards accuracy.

General: As stated in my first paper, I believe that, for small catchments, the formulae based on hourly rates may be safely used; but in large catchments, for which sufficient short time records are not available, the formula based on annual rainfall will give good results; and in all the cases referred to by me for temperate and sub-tropical Australia, very good results have been obtained, and the variable co-efficient "C" provides for adjustment to suit different latitudes, etc. There is, however, one aspect that I have lost sight of to some extent, in applying formulae to large catchments in my first paper. I mentioned that in the case of large catchments the less frequent and greater floods should be provided for in these cases, and to do this, the constant should be increased by 25%, i.e., to $Q = 1.40 \times C \times R^{1/4} A^{3/4}$ and the equivalent in other formulae; but when dealing with cases where the actual amount of rainfall for the period causing top flood is registered, it is proper to use $Q = c\,r\,A$ when "r" is the mean fall per hour; for, where the flow is uniform, the variation in average intensity of rainfall from hour to hour does not materially affect this result. If the rainfall starts at maximum rate and ends at zero, the resultant discharge will be the same as though the storm continued throughout at the mean rate.

If, however, you wish to analyse the run-off from any catchment under particular conditions, it would be proper to use fundamental formula $Q = crA^{3/4}$ evaluating "c"; or by $Q = cr_1A$ where r_1 is the mean hourly rate during period to cause maximum flood

discharge. The latter is simply a particular case of the former, where, instead of having to calculate $r_1 = \frac{r}{A^{\frac{1}{3}}}$ the value is already known from records.

SUMMARY.

In designing, calculate maximum rate of run-off by one or other formula, according to information or records available:—

$Q = 1{\cdot}57\ Cr\ A^{\frac{2}{3}}$ where records of intensity for 10 minutes are available.

$= 2{\cdot}36\ Cr\ A^{\frac{2}{3}}$ where records of intensity for 1 hour are available.

$= 1{\cdot}1\ CR^{\frac{1}{3}}\ A^{\frac{2}{3}}$ where records of intensity 1 year only are available.

$= 1{\cdot}4\ CR^{\frac{1}{3}}\ A^{\frac{2}{3}}$ for large catchments (not municipal drainage).

Value of $C = {\cdot}9$ suggested for N.S.W., Victoria, Tasmania, and South Australia.

$= cr\ A$ where average fall per hour over catchment is available for period causing maximum flood conditions. Usually $c = {\cdot}7$ gives good results.

$= cr\ A^{\frac{2}{3}}$ where it is desired to analyise the run-off from catchments where "c" can be evaluated.

Having determined the rate of run-off for each catchment in cusecs, the size of drains may be determined by usual hydraulic formulae, such as Kutter's or the Logarithmic; or, having determined the equivalent intensity of rainfall for each catchment $= Q/A$ by then proceeding by either the Analytical method of Gummow, Forrest, as corrected by Mr. Boyd, or by the Graphic Method described above.