RECORDS OF HEAVY RAINS, SYDNEY WEATHER BUREAU.

Date.	Total Fall and Duration of Storm.			Heaviest Part of Storm.			Heaviest Shower.		
	Total Fall.	Duration.	Rate per Hour	Total Fall.	Duration.	Rate per Hour.	Total Fall.	Duration.	Rate per Hour.
	Inches.	hs. ms.	Inches.	Inches.	hs. ms.	Inches.	Inches.	m. s.	Inches
May 25 ..	3.26	22.0	0.15	1.44	0.45	1.92	0.20	3.45	3.20
Nov. 19 ..	4.23	24.0	0.18	0.95	1.0	0.95	0.08	2.9	2.24
„ 20 ..	1.20	6.45	0.18	0.40	0.13	2.00	0.20	5.0	2.40
1901.									
Jan. 1 ..	1.10	0.42	1.65	0.20	0.4 17/60	2.80	0.40	7.30	3.20
„ 2 ..	1.20	0.50	1.44	0.60	0.15	2.40	0.20	4.17	2.80
„ 21 ..	2.60	1.45	1.48	1.80	0.25	4.32	0.20	1.53	6.40
April 28 ..	3.67	4.0	0.92	2.40	2.0	1.20	0.20	3 30	3.45
1902.									
Oct. 12 ..	6.367	21.0	0.30	1.23	0.30	2.46	0.49	7.0	4.20
1904.									
July 8 ..	4.773	24.0	0.20	0.62	1.0	0.62	0.20	5.27	2.20
„ 9 ..	2.725	24.0	0.11	0.47	1.0	0.47	0.20	8.34	1.40
1905.									
March 3 ..	2.025	24.0	0.09	0.55	0.30	1.10	0.20	3.45	3.20
„ 22 ..	2.405	6.0	0.40	0.80	1.0	0.80	0.20	3.20	3.60
April 2 ..	3.644	9.0	0.40	1.26	0.30	2.52	0.20	2.4	5.80
1906.									
Aug. 31 ..	3.625	18.0	0.20	0.95	1.0	0.95	0.20	5.0	2.40
1907.									
March 16 ..	3.622	22.0	0.17	0.42	1.0	0.42	0.16	7.44	1.24
1908.									
July 28 ..	5.715	24.0	0.24	0.66	1.0	0.66	0.16	7.30	1.28
1910.									
July 18 ..	2.937	9.0	0.33	0.36	1.0	0.36	0.13	2.44	2.86
„ 19 ..	2.072	7.0	0.30	0.79	1.0	0.79	0.16	3.32	2.72
Dec. 1 ..	0.929	1.30	0.62	0.85	0.30	1.70	0.16	2.13	4.27
1911.									
Jan. 12 ..	7.077	24.0	0.30	1.47	1.0	1.47	0.16	1.28	6.56
April 17 ..	2.167	12.30	0.77	1.20	1.15	0.96	0.21	5.0	2.52
Dec. 1 ..	2.175	20.30	0.12	0.65	2.0	0.33	0.10	1.30	4.00
1912.									
Feb. 25 ..	2.892	14.0	0.21	1.32	0.30	2.64	0.38	5.0	4.56
„ 29 ..	4.405	8.0	0.55	1.67	0.30	3.34	0.50	6.0	5.00
March 29 ..	0.780	0.40	1.17	0.78	0.40	1.17	0.20	2.30	4.80
April 10 ..	1.515	17.0	0.09	0.59	1.0	0.59	0.17	3.0	3.40
„ 22 ..	3.371	24.0	0.14	0.70	0.40	1.05	0.28	4 2/7	3.92
May 24 ..	1.655	24.0	0.69	0.70	1.5	0.65	0.15	4.0	2.25
1913.									
Mar. 8 to 9	6.520	17.0	0.38	2.15 1.67	1.0 0.24	2.15 4.18	0.50	3.20	9.00
April 7 ..	3.814	24.0	1.59	0.78	0.41	1.14	0.28	3.0	5.60
May 7 ..	2.019	9.0	0.22	0.67	0.20	2.01	0.40	7.0	3.47
„ 14 ..	1.627	24.0	0.07	0.30	0.31	0.58	0.07	1.0	4.20
„ 15 ..	2.519	24.0	0.11	0.72	1.47	0.49	0.05	1.0	3.00
June 12 ..	2.321	24.0	0.10	0.65	0.46	0.85	0.13	3.30	2.23
July 1 ..	2.471	15.0	0.16	0.38	0.28	0.81	0.07	1.40	2.52
1914.								mins.	
Mar. 20-21	3.371	14.0	0.24	1.68	0.20	5.04	0.50	2 6/7	10.50

For records for Melbourne, Brisbane, Perth and Hobart, see pp. 109, 110, 111.

VELOCITY AND DISCHARGE OF CIRCULAR MONIER PIPES RUNNING FULL

V—Velocity in Feet per Second

Grade 1 in	1 ft. 6 in.		1 ft. 9 in.		2 ft. 0 in.		2 ft. 6 in.		3 ft. 0 in.		3 ft. 6 in.		4 ft. 0 in.		4 ft. 6 in.		5 ft. 0 in.		5 ft. 6 in		6 ft. 0 in.		Grade 1 in
	V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	
30	14·61	25·82	16·29	39·18	17·88	56·17	20·84	102.29															30
40	12·65	22·36	14·11	33·93	15·48	48·65	18·05	88·59	20·41	144·24													40
50	11·32	20·00	12·62	30·35	13·85	43·51	16·14	79·23	18 25	129·01	20·23	194·64											50
60	10·33	18·26	11·52	27·70	12·64	39·72	14·73	72·23	16·66	117·51	18·47	177·69	20·16	253·31									60
70	9·56	16·90	10·67	25·65	11·70	36·77	13·65	66·97	15·43	109·03	17·10	164·50	18·66	234·48	20·14	320·35							70
80	8·95	15·81	9·98	23·99	10·95	34·40	12·76	62·64	14·43	102·00	15·99	153·88	17·46	219·38	18·84	299·66	20·17	396·13					80
90	8·44	14·91	9·41	22·62	10·32	32·43	12·03	59·06	13·60	96·16	15·09	145·08	16·46	206·83	17·76	282·52	19·02	373·44	20·21	480·12			90
100	8·00	14·14	8·92	21·46	9·79	30·76	11·41	56·03	12·91	91·22	14·31	137·63	15·61	196 21	16·85	268·03	18·04	354·31	19·18	455·48	20·27	573·05	100
110	7·63	13·48	8·51	20·46	9·34	29·33	10·88	53·42	12·31	86·98	13·64	130·93	14·89	187·08	16 07	255·55	17·24	337·82	18·28	434·29	19·32	546·39	110
120	7·31	12·91	8·15	19·59	8·94	28·08	10·42	51·15	11·78	83·27	13·06	125·64	14·25	179·12	15·38	244·67	16·47	323·44	17·50	415·80	18·50	523·12	120
130	7·02	12·40	7·83	18·82	8·59	26·98	10·01	49·14	11·32	80·01	12·55	120·71	13·69	172 09	14·78	235·07	15·83	310·75	16·81	399·49	17·78	502·60	130
140	6·76	11·95	7·54	18·14	8·28	26·00	9·65	47·35	10·91	77·10	12·09	116·32	13·20	165·82	14·24	226·52	15·25	299·45	16·20	384·95	17·13	484·32	140
150	6·53	11·55	7·29	17·53	8·00	25·12	9·32	45·75	10·54	74·48	11·68	112·38	12·75	160 21	13·76	218·84	14·73	289·29	15·65	371·89	16·55	467·90	150
160	6·33	11·18	7·05	16 97	7·74	24·32	9·02	44·29	10·20	72·12	11·31	108·81	12·34	155·12	13·32	211·90	14·26	280·11	15·16	360·09	16·02	453·04	160
170	6·14	10·85	6·84	16·46	7·51	23·60	8·75	42·97	9·90	69·96	10·97	105·56	11·98	150·49	12·92	205·57	13·84	271·74	14·70	349·34	15·54	439·51	170
180	5·96	10·54	6·65	15·99	7·30	22·93	8·51	41·76	9·62	68·00	10·66	102·57	11·64	146·25	12·56	199·77	13·45	264·09	14·29	339·50	15·11	427·13	180
190	5·80	10·26	6·47	15·57	7·10	22·32	8·28	40·65	9·36	66·18	10·38	99·85	11·33	142·35	12·22	194·45	13·09	257·04	13·91	330·45	14·70	415·84	190
200	5·66	10·00	6·31	15.17	6·92	21·75	8·07	39·62	9·13	64·50	10·12	97·32	11·04	138·74	11·92	189·52	12·76	250·54	13·56	322 07	14·33	405·21	200
210	5·52	9·76	6·16	14·81	6·76	21·23	7·88	38·66	8·90	62·95	9·87	94·97	10·77	135·40	11·63	184·95	12·45	244·51	13·23	314·32	13·99	395·44	210
220	5·39	9·53	6·02	14·47	6·60	20·74	7·70	37·78	8·70	61·50	9·65	92·79	10·53	132·29	11·36	180·62	12·17	238·87	12·93	307·09	13·66	386·34	220
230	5·28	9·32	5·88	14·15	6·46	20·29	7·53	36·94	8·51	60·15	9·43	90·75	10·30	129·38	11·11	176·73	11·90	233·62	12 64	300·34	13·36	377·86	230
240	5·17	9·13	5·76	13·85	6·32	19·86	7·37	36·17	8·33	58·88	9·23	88·84	10·08	126 65	10·88	173·01	11·65	228·71	12 37	294·01	13·08	369·90	240
250	5·06	8·94	5·64	13·57	6·19	19·46	7·22	35·45	8·16	57·69	9·04	87·05	9·87	124·09	10·66	169·52	11·41	224·08	12·12	288·07	12·82	362·42	250
260	4·96	8·77	5·53	13·31	6·07	19·08	7·08	34·75	8·00	56·58	8·87	85·36	9·68	121·69	10·45	166·22	11·19	219·73	11·89	282·48	12·56	355·39	260
270	4·87	8·60	5·43	13·06	5·96	18·72	6·95	34·10	7·85	55·52	8·70	83·76	9·50	119 41	10·26	163·11	10·98	215·63	11·67	277·20	12·33	348·75	270
280	4·78	8·45	5·33	12·82	5·85	18·39	6·82	33·48	7·71	54·52	8·55	82·25	9·33	117·26	10·07	160·17	10·78	211·74	11·46	272·20	12·11	342·46	280
290	4·70	8·30	5·24	12·60	5·75	18·07	6·70	32·90	7·58	53·57	8·40	80·83	9·17	115·22	9·90	157·39	10·60	208·06	11·26	267·47	11·90	336·51	290
300	4·62	8·16	5·15	12·39	5·65	17·76	6·59	32·35	7·45	52·67	8·26	79·46	9·01	113·28	9·73	154·74	10·42	204·56	11·07	262·97	11·70	330·85	300

VELOCITY AND DISCHARGE OF CIRCULAR MONIER PIPES RUNNING FULL.

D—Discharge in Cubic Feet per Second

Grade 1 in	1 ft. 6 in.		1 ft. 9 in.		2 ft. 0 in.		2 ft. 6 in.		3 ft. 0 in.		3 ft. 6 in.		4 ft. 0 in.		4 ft. 6 in.		5 ft. 0 in.		5 ft. 6 in.		6 ft. 0 in.		Grade 1 in
	V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	
325	4·44	7·84	4·95	11·90	5·43	17·06	6·33	31·08	7·16	50·60	7·93	76·25	8·66	108·84	9·35	148·67	10·00	196·53	10·63	252·66	11·24	317·87	325
350	4·28	7·56	4·77	11·47	5·23	16·44	6·10	29·95	6·90	48·76	7·65	73·57	8·35	104·88	9·01	143·26	9·64	189·39	10·25	243·47	10·83	306·31	350
375	4·13	7·30	4·61	11·08	5·06	15·88	5·89	28·93	6·66	47·11	7·39	71·07	8·06	101·32	8·70	138·41	9·32	182·96	9·90	235·21	10·47	295·92	375
400	4·00	7·07	4·46	10·73	4·90	15·38	5·71	28·02	6·45	45·61	7·15	68·81	7·81	98·11	8·42	134·01	9·02	177·15	9·58	227·58	10·14	286·39	400
425	3·88	6·86	4·33	10·41	4·75	14·92	5·54	27·18	6·26	44·25	6·94	66·76	7·58	95·18	8·18	130·01	8·75	171·86	9·30	220·94	9·84	277·97	425
450	3·77	6·66	4.21	10·12	4·62	14·50	5·38	26·41	6·09	43·00	6·74	64·88	7·36	92·50	7·95	126·35	8·50	166·90	9·04	214·71	9·56	270·14	450
475	3·67	6·49	4·09	9·85	4·49	14·11	5·24	25·70	5·92	41·85	6·57	63·15	7·17	90·03	7·73	122·98	8·28	162·57	8·80	208·99	9·30	262·93	475
500	3·58	6·33	3·99	9·60	4·38	13·76	5·10	25·06	5·77	40·80	6·40	61·55	6·99	87·75	7·54	119·86	8·07	158·45	8·58	203·70	9·06	256·28	500
525	3·49	6·17	3·89	9·36	4·27	13·43	4·98	24·45	5·63	39·81	6·25	60·07	6·81	85·63	7·35	116·97	7·88	154·63	8·37	198·79	8·84	250·10	525
550	3·41	6·03	3·80	9·15	4·17	13·12	4·87	23·89	5·50	38·90	6·10	58·69	6·66	83·66	7·19	114·29	7·70	151·08	8·17	194·22	8·64	244·35	550
575	3·34	5·90	3·72	8·95	4·08	12·83	4·76	23·36	5·38	38·04	5·96	57·39	6·51	81·83	7·03	111·76	7·52	147·76	7·99	189·95	8·45	238·98	575
600	3·27	5·77	3·64	8·76	4·00	12·56	4·66	22·87	5·27	37·24	5·84	56·19	6·38	80·10	6·87	109·42	7·37	144·64	7·83	185·95	8·27	233·95	600
625	3·20	5·66	3·57	8·58	3·92	12·30	4·57	22·41	5·16	36·49	5·72	55·05	6·25	78·48	6·74	107·21	7·22	141·71	7·67	182·19	8·10	229·22	625
650	3·14	5·55	3·50	8·42	3·84	12·07	4·48	21·97	5·06	35·78	5·61	53·98	6·13	76·96	6·61	105·13	7·07	138·97	7·52	178·65	7·95	224·77	650
675	3·08	5·44	3·43	8·26	3·77	11·84	4·39	21·56	4·97	35·13	5·50	52·97	6·01	75·52	6·49	103·16	6·94	136·37	7·38	175·31	7·80	220·57	675
700	3·02	5·35	3·37	8·11	3·70	11·63	4·31	21·17	4·88	34·48	5·40	52·02	5·90	74·16	6·37	101·24	6·81	133·91	7·25	172·15	7·66	216·59	700
750	2·92	5·17	3·26	7·83	3·58	11·23	4·17	20·46	4·71	33·31	5·22	50·25	5·70	71·65	6·16	97·87	6·59	129·37	7·00	166·32	7·40	209·25	750
800	2·83	5·00	3·15	7.59	3·46	10·87	4·03	19·81	4·56	32·25	5·06	48·66	5·52	69·37	5·96	94·76	6·38	125·36	6·78	161·04	7·17	202·60	800
850	2·74	4·85	3·06	7·36	3·36	10·55	3·91	19·22	4·43	31·29	4·90	47·21	5·35	67·30	5·78	91·93	6·19	121·52	6·57	156·27	6·95	196·55	850
900	2·67	4·71	2·97	7·16	3·26	10·25	3·80	18·68	4·30	30·40	4·77	45·88	5·20	65·40	5·62	89·34	6·02	118·10	6·39	151·83	6·75	191·00	900
950	2·60	4·59	2·89	6·96	3·18	9·98	3·70	18·18	4·18	29·60	4·64	44·65	5·06	63·66	5·47	86·96	5·86	114·95	6·22	147·78	6·57	185·92	950
1000	2·53	4·47	2·82	6·79	3·10	9·74	3·61	17·72	4·08	28·85	4·52	43·52	4·94	62·05	5·33	84·75	5·71	112·04	6·06	144·03	6·41	181·21	1000
1100			2·69	6·47	2·95	9·28	3·44	16·89	3·89	27·51	4·31	41·50	4·71	59·16	5·08	80·81	5·44	106·83	5·78	137·32	6·11	172·79	1100
1200			2·58	6·20	2·83	8·88	3·30	16·18	3·73	26·33	4·13	39·73	4·51	56·64	4·86	77·37	5·21	102·28	5·53	131·49	5·84	165·09	1200
1300					2·72	8·53	3·17	15·54	3·58	25·30	3·97	38·17	4·33	54·42	4·67	74·34	5·00	98·27	5·32	126·33	5·62	158·94	1300
1400					2·62	8·22	3·05	14·97	3·45	24·38	3·83	36·78	4·17	52·44	4·50	71·64	4·82	94·70	5·12	121·74	5·41	153·15	1400
1500					2·53	7·94	2·94	14·48	3·33	23·56	3·70	35·54	4·03	50·66	4·35	69·20	4·66	91·48	4·95	117·60	5·23	147·95	1500
1600							2·85	14·00	3·23	22·80	3·58	34·41	3·90	49·05	4·21	67·01	4·51	88·58	4·79	113·88	5·07	143·26	1600

VELOCITY AND DISCHARGE OF OVIFORM MONIER PIPES RUNNING FULL

V—Velocity in Feet per Second

D—Discharge in Cubic Feet per Second

Grade 1 in	1ft. 3in. x 10in.		1ft. 6in. x 1ft 1in.		1ft. 9in. x 1ft. 4in.		2ft. 1in. x 1ft. 6½in.		2ft. 5in. x 1ft. 9in.		2ft.9in. x 1ft.11½in		3ft. 3in. x 2ft 2in.		3ft. 6in. x 2ft. 4in.		Grade 1 in
	V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	
30	10·76	8·71	12·62	15·68	14·36	25·38	16·04	38·83	17·57	55·76	19·04	76·69	20·57	107·16	21·73	132·42	30
40	9·32	7·54	10·93	13·58	12·43	21·98	13·89	33·63	15·21	48·29	16·49	66·42	17·81	92·81	18·82	114·68	40
50	8·34	6·75	9·78	12·14	11·12	19·66	12·42	30·08	13·60	43·18	14·75	59·41	15·94	83·01	16·83	102·57	50
60	7·61	6·16	8·93	11·09	10·15	17·95	11·34	27·46	12·42	39·43	13·46	54·23	14·55	75·77	15·37	93·63	60
70	7·04	5·70	8·27	10·26	9·40	16·62	10·50	25·42	11·50	36·50	12·46	50·20	13·47	70·15	14·23	86·69	70
80	6·59	5·33	7.73	9·61	8·80	15·54	9·83	23·78	10·75	34·15	11·66	46·96	12·60	65·62	13·31	81·09	80
90	6·21	5·03	7·29	9·05	8·29	14·66	9·26	22·42	10·14	32·19	10·99	44·28	11·88	61·87	12·55	76·45	90
100	5·89	4·77	6·91	8·59	7·86	13·90	8·78	21·27	9·62	30·54	10·43	42·11	11·27	58·70	11·90	72·53	100
110	5·62	4·55	6·60	8·19	7·50	13·25	8·38	20·28	9·17	29·12	9·94	40·05	10·74	55·96	11·35	69·16	110
120	5·38	4·35	6·31	7·84	7·18	12·69	8·02	19·41	8·78	27·88	9·52	38·35	10·29	53·58	10·87	66·21	120
130	5·17	4·18	6·06	7·54	6·90	12·19	7·70	18·65	8·44	26·79	9·15	36·84	9·88	51·48	10·44	63·61	130
140	4·98	4·03	5·84	7·26	6·65	11·75	7·42	17·98	8·14	25·81	8·81	35·50	9·52	49·61	10·06	61·30	140
150	4·81	3·89	5·64	7·01	6·42	11·35	7·17	17·37	7·86	24·94	8·51	34·30	9·20	47·92	9·72	59·22	150
160	4·66	3·77	5·47	6·79	6·22	10·99	6·95	16·81	7·61	24·14	8·25	33·21	8·91	46·40	9·41	57·34	160
170	4·52	3·66	5·30	6·59	6·03	10·66	6·74	16·31	7·38	23·42	8·00	32·22	8·65	45·01	9·13	55·62	170
180	4·39	3·55	5·16	6·40	5·86	10·37	6·55	15·85	7·17	22·76	7·77	31·31	8·40	43·75	8·88	54·06	180
190	4·28	3·46	5·02	6·23	5·71	10·09	6·38	15·43	6·98	22·16	7·56	30·47	8·17	42·58	8·64	52·62	190
200	4·17	3·37	4·89	6·07	5·56	9·83	6·21	15·04	6·80	21·59	7·37	29·70	7·97	41·50	8·42	51·28	200
210	4·07	3·29	4·77	5·92	5·43	9·60	6·06	14·67	6·64	21·05	7·20	28·99	7·78	40·50	8·21	50·05	210
220	3·98	3·22	4·66	5·79	5·31	9·37	5·92	14·34	6·49	20·59	7·03	28·32	7·60	39·58	8·03	48·90	220
230	3·89	3·15	4·56	5·66	5·19	9·17	5·79	14·03	6·35	20·14	6·88	27·70	7·43	38·70	7·85	47·82	230
240	3·81	3·08	4·46	5·54	5·08	8·98	5·67	13·73	6·21	19·71	6·73	27·11	7·27	37·89	7·68	46·82	240
250	3·73	3·02	4·37	5·43	4·97	8·80	5·56	13·45	6·09	19·32	6·60	26·57	7·13	37·12	7·53	45·87	250
260	3·65	2·96	4·29	5·33	4·88	8·62	5·45	13·19	5·97	18·94	6·47	26·05	6·99	36·40	7·38	44·98	260
270	3·58	2·90	4·21	5·23	4·79	8·46	5·35	12·94	5·85	18·59	6·35	25·56	6·86	35·72	7·25	44·14	270
280	3·52	2·85	4·13	5·13	4·70	8·31	5·25	12·71	5·75	18·25	6·23	25·10	6·74	35·08	7·12	43·35	280
290	3·46	2·80	4·06	5·04	4·62	8·16	5·16	12·49	5·65	17·93	6·13	24·67	6·62	34·47	6·99	42·59	290
300	3·40	2·76	3·99	4·96	4·54	8·03	5·07	12·28	5·55	17·63	6·03	24·25	6·51	33·89	6·88	41·87	300

VELOCITY AND DISCHARGE OF OVIFORM MONIER PIPES RUNNING FULL

V—Velocity in Feet per Second | D—Discharge in Cubic Feet per Second.

Grade 1 in	1ft. 3in. x 10in.		1ft. 6in. x 1ft. 1in.		1ft. 9in. x 1ft. 4in.		2ft. 1in. x 1ft. 6½in.		2ft. 5in. x 1ft. 9in.		2ft. 9in. x 1ft. 11½in.		3ft. 3in. x 2ft. 2in.		3ft. 6in. x 2ft. 4in.		Grade 1 in
	V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	
325	3·27	2·65	3·84	4·77	4·36	7·71	4·87	11·80	5·34	16·94	5·79	23·30	6·25	32·56	6·60	40·23	325
350	3·15	2·55	3·70	4·59	4·20	7·43	4·70	11·37	5·14	16·32	5·58	22·45	6·02	31·37	6·36	38·77	350
375	3·04	2·47	3·57	4·43	4·06	7·18	4·54	10·98	4·97	15·77	5·39	21·69	5·82	30·31	6·15	37·45	375
400	2·95	2·39	3·46	4·29	3·93	6·95	4·39	10·63	4·81	15·27	5·22	21·00	5·63	29·34	5·95	36·26	400
425	2·86	2·32	3·35	4·17	3·82	6·76	4·26	10·32	4·67	14·81	5·06	20·38	5·47	28·47	5·77	35·18	425
450	2·78	2·25	3.26	4·05	3·72	6·57	4·14	10·02	4·53	14·40	4·92	19·80	5·31	27·67	5·61	34·19	450
475	2·71	2·19	3·17	3·94	3·62	6·39	4·03	9·76	4·41	14·01	4·79	19·27	5·17	26·93	5·46	33·28	475
500	2·64	2·13	3·09	3·84	3·52	6·22	3·93	9·51	4·30	13·66	4·66	18·78	5·04	26·25	5·33	32·44	500
525	2·58	2·08	3·02	3·75	3·43	6·07	3·83	9·28	4·20	13·33	4·55	18·33	4·92	25·62	5·20	31·65	525
550	2·52	2·04	2·95	3·66	3·35	5·93	3·74	9·07	4·11	13·02	4·45	17·91	4·80	25·03	5·08	30·92	550
575	2·46	1·99	2·89	3·58	3·28	5·80	3·66	8·87	4·02	12·74	4·35	17·51	4·70	24·48	4·96	30·24	575
600	2·40	1·95	2·83	3·51	3·21	5·68	3·59	8·68	3·93	12·47	4·26	17·15	4·60	23·96	4·86	29·61	600
625	2·36	1·91	2·77	3·44	3·14	5·56	3·52	8·51	3·85	12·22	4·17	16·80	4·50	23·48	4·76	29·02	625
650	2·31	1·87	2·72	3·37	3·08	5·45	3·45	8·34	3·77	11·98	4·09	16·47	4·42	23·02	4·67	28·45	650
675	2·27	1·83	2·66	3·31	3·02	5·35	3·38	8·19	3·70	11·75	4·01	16·17	4·34	22·59	4·59	27·91	675
700	2·23	1·80	2·61	3·25	2·97	5·26	3·32	8·04	3·64	11·54	3·94	15·87	4·26	22·18	4·51	27·42	700
750			2·52	3·14	2·87	5·08	3·21	7·77	3·51	11·15	3·81	15·34	4·12	21·43	4·35	26·48	750
800			2·44	3·04	2·78	4·92	3·11	7·52	3·40	10·80	3·69	14·85	3·99	20·75	4·21	25·64	800
850			2·37	2·95	2·70	4·77	3·01	7·30	3·30	10·48	3·58	14·41	3·87	20·12	4·09	24·88	850
900			2·30	2·87	2·62	4·64	2·93	7·09	3·21	10·18	3·48	14.00	3·76	19·56	3·97	24·17	900
950			2·24	2·79	2·55	4·51	2·85	6·90	3·12	9·91	3·38	13·63	3·66	19·05	3·86	23·53	950
1000					2·49	4·40	2·78	6·72	3·04	9·66	3·30	13·28	3·56	18·56	3·76	22·94	1000
1100					2·37	4·19	2·65	6·41	2·90	9·21	3·14	12·67	3·40	17·70	3·59	21·87	1100
1200					2·27	4·01	2·54	6·14	2·78	8·82	3·01	12·13	3·25	16·94	3·44	20·94	1200
1300							2·44	5·90	2·67	8·47	2·89	11·65	3·12	16·28	3·30	20·12	1300
1400							2·35	5·68	2·57	8·16	2·78	11·23	3·01	15·69	3·18	19·38	1400
1500							2·27	5·49	2·49	7·88	2·69	10·84	2·91	15·15	3·07	18·72	1500
1600							2·20	5·32	2·41	7·63	2·61	10·50	2·82	14·67	2·98	18·13	1600

DISCUSSION.

I.—H. H. DARE, Esq., M.E., M.Inst.C.E.

Mr. DARE: In Mr. Vicars' previous paper he reviewed the various formulae which have been invented for dealing with the run-off from catchment areas. I am quite in accord with him in discarding the majority of these as being unsuitable except for local application. With regard to the remainder, it is necessary to make assumptions not only as to the rainfall, but also as to the slope of the catchment, and a co-efficient has then to be applied, which varies with the nature of the catchment. The slope of the catchment is, as a rule, quite variable. In large catchments the probability is that the upper end where the main stream takes its rise is steep and rough, and is also the country forming the sources of tributaries joining the lower portion of the stream; whereas, the catchment along the lower portions of the streams may be comparatively level. The correct value for "S" in such cases is most difficult to estimate, as is also the allowance to be made for "C," the coefficient.

As instancing the wide range that exists in the percentage run-off from catchments, the following examples are submitted:—

During the great flood in the Hunter in May, 1913, an average of 6 inches of rain fell in four days over a catchment of 7,090 square miles. The run-off was about 42 per cent., or 29 cusecs per square mile.

In January, 1911, a heavy rainfall occured over the catchment area of the Cataract Dam, 54 square miles. The run-off was estimated at 70 per cent. of the rainfall, and at the maximum period of discharge the run-off was 697 cusecs per square mile. The average run-off for this catchment for the years 1906-10 was 25.8 per cent. of the rainfall.

Compare this latter figure with the run-off on the Goulburn River, the main tributary of the Hunter River. Above Rosemount, near the junction, the catchment is 3,100 square miles, and the gauged run-off for six years (1907-12) averaged only 2¼ per cent.

This is not very different from the discharge of all the rivers in the South African Union, which has recently been estimated to average about 3½ per cent. of the rainfall.

The run-off in the Manchester Lake district is stated to be about 80 per cent.

In a recent paper read before the Institution of Civil Engineers on catchment areas in Scotland, the run-off from five small catchments ranging from 1,166 to 6,180 acres each showed remarkable results, varying from 76 to practically 100 per cent. of the annual rainfall over a period of years.

The annual yield of the River Derwent, in Derbyshire, with a catchment area of 31,288 acres, ranged from 85½ to 90 per cent. of the rainfall for the years 1906-12 inclusive.

While the matter under discussion is the maximum, and not the average run-off, these figures will serve to emphasise the enormous difference that exists in the conditions attaching to large catchment areas, and the necessity for the greatest caution in estimating the discharge therefrom.

For dealing with large catchments I am sure that Mr. Vicars will agree with me that there is only one satisfactory method, and that is to establish a stream gauge and take current meter observations.

Unfortunately, such information is not always available, and some attempt must be made to approximate to the run-off by other means. In this connection the formula proposed by Mr. Vicars has a decided advantage, inasmuch as by dispensing with "S" he gets rid of the most difficult factor to estimate, while at the same time fixing a constant which removes the responsibility of giving a value to "C" for a strange catchment.

With regard to its application to storm-water drainage, I mave made a rough comparison for a scheme recently prepared for Leeton township.

Where A = 148 acres.
r = 1.9 inches per hour falling.
C = .40.
S = 30 feet per 1,000.

The latter three were assumed for purpose of comparison.

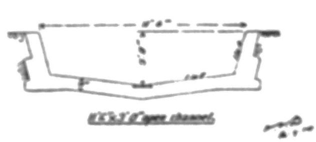
The run-off was then worked out to be:—

By Burkli-Ziegler formula, 75.5 cusecs.
By McMath formula, 81.7 cusecs.
By Vicars' formula, 83.5 cusecs.

It is probable that someone else, estimating the value of "S," would give it a quite different value; but the figures are given for what they are worth. The combined value of "c r" I have taken to be ¾in., which is the assumed run-off per hour for which the scheme was actually designed, and which gave 108 cusecs at the lower end of the main stormwater channel. I am not clear whether the formula should be taken as applying for a low maximum hourly rainfall, such as the above, which is much less than the 4in. maximum given for cities. Probably with some experience in working with the formula a modification would be made.

The direct method of allowing a certain run-off in inches per hour over the whole catchment is that which I have always used for stormwater drains. The maximum figure for city or suburban areas has usually been taken as 1½ inches per hour. I submit a sketch, showing how the capacity at various points of a £10,000 stormwater channel constructed recently in one of the suburbs of Sydney was arrived at, allowing for 1½in. per hour run-off. So far as I am aware the many stormwater channels round Sydney designed by this method of arbitrary assumption as to run-off per hour have given satisfaction.

At Point	Catchment above point. Acres.	Estimated Discharge. Cusecs.	Grade.	Size of Channel.
A	359	540	1 in 55	11'6"×3'0"
B	359	540	1 in 55	11'6"×3'0"
C	294	440	1 in 60	10'0"×3'0"
D	239	360	1 in 80	9'6"×3'0"
E	187	280	1 in 60	6'6"×3'0"
F	121	183	1 in 76	6'6"×2'6"
G	61	92	1 in 76	5'9"×2'6"
H	66	100	1 in 70	4'6"×2'3"



The diagrams accompanying Mr. Vicars' paper are worthy of careful study, and I regret that time has not admitted of their application, for comparison, in the above example. Their value will, I consider, be especially apparent in connection with law suits for stormwater damage, when the evidence of careful analysis of the discharge of the drains, afforded by an exhibition of the diagrams, should carry great weight with a jury.

II.—F. R. HOLLINGS, Esq.

Mr. HOLLINGS: I shall confine my few remarks to the application of formulae to the flood discharge from large catchments, and compare Mr. Vicars' formula with two or three of those in common use, as judged from the view-point of one who has only to make practical use of such a formula occasionally, and has no intimate knowledge of the locality.

To begin with, the formulae by Col. Dickens, Fanning, McCoomb, and others, which only apply a co-efficient to a certain power of the area in square miles, such as $825\ M^{\frac{3}{4}}$ are only constructed on experience gained in one locality, and would be useless in our case.

To be in a position to apply any formula, it would, of course, be necessary to make a close inspection of the catchment, and determine a value for "C." The next factor to be determined would be the rainfall, and in this connection it is generally possible to obtain reliable information as to the actual fall in 24 hours, as required by the Vicars' formula; but it is not so for the maximum fall in one hour as required by the Burkli-Ziegler and McMath's formulae, and it would seem that a day's rain is more reasonably associated with a large catchment than that for an hour. But the principal advantage, which will specially appeal to men who do not make this class of work a speciality, is the fact that Mr. Vicars makes it possible to work intelligently, and to feel that, provided Mr. Vicars has done his part well in constructing the formula, the rest depends on judgment; and there is a feeling of security, born of the fact that one knows what Mr. Vicars intended.

Such is not the case with the Burkli-Ziegler and McMath's formulae, and others which involve the average slope of the catchment. Take, for example, Burkli-Ziegler

$$- \ Q = ARC\sqrt[4]{\frac{S}{A}} \quad \text{or McMath } Q = ARC\sqrt[5]{\frac{S}{A}}$$

A = Area in acres.
R = Maximum rainfall in one hour.
C = Co-efficient of run-off, which accounts for loss by evaporation and absorption.

S = The average slope of the catchment in feet per 1,000 feet.

Q = Discharge in cubic feet per second.

r = Actual rainfall in 24 hours.

Would any engineer who wanted to get an idea of the quantity of water running off an area, which he knew every inch of, be able to satisfy himself as to what these authors intended him to call the average slope of the catchment?

I have lately been concerned with a law case, in which the Government were called on to defend their action in constructing a system of swamp drainage works under the Water and Drainage Act, which it was said caused a small area near the outlet to be flooded more often than previously. In the defence, it was proposed to show that the main channel was merely a drain, which made no pretence of carrying off flood water, and that, although its capacity was systematically and proportionately dealt with sufficiently to enable the swamp being used for pastoral purposes, still the capacity of the drain was insignificant in comparison with the natural discharge of the valley, and that there would be no difference during flood periods.

The area of the whole catchment was 25,000 acres, running back about 11 miles from outlet, with the swampy area. 8,000 acres, situated two-thirds of the way back. The gradient along the valley for the first two miles was about 1 in 2,000, and for the next 5 or 6 miles, almost level; whilst the slopes all around the swamp and right back to the boundaries of the catchment were something like 1 in 30 or 40. I am still wondering what "average slope of catchment" these authors intended should be used in this case. I shall be much indebted to any of the members present for a practical suggestion.

I observe, in passing, that expert witnesses in dealing with ordinary undulating country for the purposes of railway openings, and also for streams in flatter country, seem to have a chronic inspiration that the slope of every catchment is 10ft. per 1,000ft. When we remember that we invariably use logs in evaluating the formula, it makes one pause and banish the thought that the log of 10 being 1 may possibly account for the slope of a considerable portion of the world's surface.

A formula by Mr. Chamier (proceedings Inst. C.E., part iv., 1897-9) strikes out on new lines as regards the treatment of the rainfall. The formula is:—

$$Q = 640\ R.C.M.^{\frac{3}{4}}$$

Where R = the average fall per hour, taken over an estimated period of run-off.

M = Area in square miles.

In applying this formula, Mr. Chamier first estimates the time that it will take water falling on the remote parts of the catchment to reach the outlet; then, having ascertained the maximum rainfall for 24 hours, which is assumed to fall at the following rates, viz.:—

¼	maximum fall for 24 hours in	1	hour.
½	,,	4	,,
¾	,,	12	,,
1	,,	24	,,

this is plotted and joined by a curve, and the number of inches corresponding to the estimated period of run-off scaled off the curve, from which the average rainfall in inches per hour to be used in the formula is found.

This formula does not seem to be applicable to an area such as that previously described, because it would be impossible to estimate the period, owing to the excessively steep grade running down to the enormous level swamp, and it would therefore be necessary to resort to the oldest inhabitant for the information. It also seems to me that it would be more reasonable to consider the period of run-off from the centre of the area than that from the remote parts. It was ascertained, from a much more reliable source than the oldest inhabitant, that the flood water takes about 20 hours to reach the outlet, and traverses the flat valley, more or less, like a tidal wave; and, as the maximum day's rain is 8 inches, the average will be found to be 0.375 inches per hour.

I have worked out the discharge by all these formulae, "assuming" the average slope of catchment as 15 per 1,000 (you must never say you guess in a law court; always assume or estimate), and taking "C" as 0.5, the results are given below. Of course, I am not certain that the date is what was intended by the authors, or that any of them would consider my experience in these matters sufficient to warrant my entering into this discussion; but I am not professing to do so from the point of view of a specialist.

Burkli-Ziegler ... $Q = ARC\sqrt[4]{\frac{S}{A}} = 25000 \times 2 \times \cdot 5 \times \sqrt[4]{\frac{15}{25000}} = 3912$ Cusecs.

McMath ... ... $= ARC\sqrt[5]{\frac{S}{A}} = 25000 \times 2 \times \cdot 5 \times \sqrt[5]{\frac{15}{25000}} = 5670$ Cusecs.

$$\text{Vicars} = 1{\cdot}57\,CrA^{\frac{2}{3}} = 1{\cdot}57 \times {\cdot}5 \times 8 \times \sqrt[3]{25000^2} = 5369 \text{ Cusecs.}$$

$$\text{Chamier } 640 \text{ aver. } RCM^{\frac{3}{4}} = 640 \times {\cdot}375 \times {\cdot}5 \times \sqrt[4]{41^3} = 1944 \text{ Cusecs.}$$

The value of "C" was fixed at 0.5, after careful inspection and consideration of the area, the excessively steep slopes, the permanently wet condition of the swamp and valley, and the size of the area. It is obvious that in dealing with comparatively small areas, consideration would be necessary in the direction of increasing the values correspondingly.

In conclusion, I am sure that we all feel much indebted to Mr. Vicars for giving us a formula which can be used with as much confidence as those in common use in other branches of engineering; and I feel certain that his patient research and scientific handling of the problem will earn for him the appreciation of engineers, both at home and over-seas.

III.—R. J. BOYD, Esq., M.E., A.M.I.C.E.

Mr. BOYD: Mr. Vicars is to be congratulated upon the further elucidation of the principles involved in his formula for the run-off from catchments. Apart from the intrinsic value of his formula, Mr. Vicars' remarks emphasised the fact that all such formulae, his own included, were to be used with caution. It seems curious to me that, while Mr. Vicars has criticised the formulae of Burkli-Ziegler, McMath, and Adams, because of their area factors $A^{\frac{3}{4}}$, $A^{\frac{4}{5}}$, and $A^{\frac{5}{6}}$ respectively, and demonstrated that the first was correct, he has finally adopted an entirely different one, viz., $A^{\frac{2}{3}}$. Probably similar reasons have actuated the other authorities in their departure from the ideal value.

The paper has referred to the attempt of the law courts of Sydney to fix the fair maximum intensity of rainfall, to be provided for in the design of stormwater drains, and mentions 4 inches per hour as the recognised rate. The duration of this rate is not mentioned. Mr. Vicars has published some records of heavy rainstorms of Sydney, as supplied by the Meteorological Bureau, and some graphs of these, as published in the trade catalogue of Messrs. Gummow, Forrest, and Co., Ltd., I have amplified the figures, obtaining values for intervals of 5 minutes up to 30 minutes, and of 10 up to 120 minutes, in the following manner:—

Take the storm of October 12, 1902. Following is the official record:—

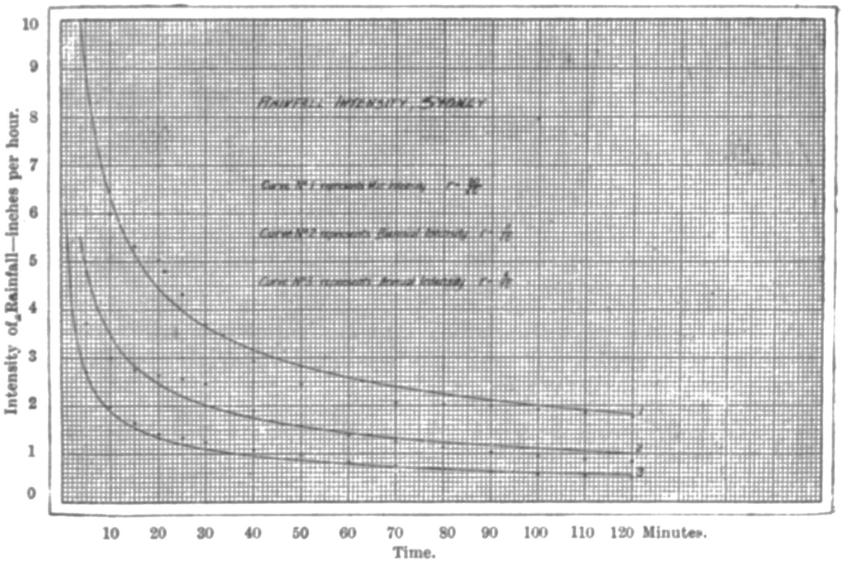
Time...	**7m.**	**30m.**	**21 hrs.**
Rainfall, inches	**0·49**	**1·23**	**6·367**
Rate, inches per hour	**4·20**	**2·46**	**0·30**

For purposes of interpolation, the amount of rainfall is assumed to increase uniformly from Zero, at 0 minutes to 0.49 at 7 minutes; and from 0.49 at 7 minutes to 1.23 at 30 minutes; and so on. So the rainfall at 5 minutes would be taken as—

$$\frac{5 \times 0{\cdot}49}{7} = 0{\cdot}35$$

and at 10 minutes—

$$0{\cdot}49 + \frac{(1{\cdot}23 - 0{\cdot}49)}{(30 - 7)} \times (10 - 7) = 0{\cdot}59$$



From these figures the values of intensities were computed, and then plotted or written down in order of magnitude. This has been done for the year 1873 to 1914; the record for 1844 was not obtained at Observatory Hill, but at South Head. It will be noticed that, proportionately, much fewer records were supplied for the years of last century than for this. Given the maximum intensities, it is a simple matter to write an equation, which expresses the relation of intensity to time with sufficient accuracy. This relation has been expressed by Talbot in the equation—

$$r = \frac{k}{t + c}$$ where r = rate of rainfall in inches per hour.

t = time of fall in minutes.

k = constant = approx. 25 times the maximum fall in one day in a 20-year period.

c = a constant.

For Sydney, for the maximum intensity of rainfall for periods of from 10 to 120 minutes, this formula would become—

$$r = \frac{270}{t + 35} \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

But it has the disadvantage of being too small for shorter periods than 10 and for longer periods than 100 minutes. I would suggest the following as a simple and sufficiently accurate equation:—

$$r = \frac{20}{\sqrt{t}} \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

This applies to any interval up to 24 hours.

For rainfalls occuring every 2 years—

$$r = \frac{11}{\sqrt{t}} \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

and for yearly falls—

$$r = \frac{6}{\sqrt{t}} \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

The latter equations (3) and (4) are based upon the records of years 1901 to 1914 only.

As might be anticipated, maxima intensities of precipitation for periods up to 2 hours almost invariably occur in years of less than average rainfall.

The following parallel columns illustrate a wide disparity in the co-efficients of run-off for nature of ground, as adopted by various authorities.

Co-efficients Quoted by Mr. Vicars in Proc. S.U.E.S., Vol. xvi., 1911.

Nature of Catchment.	Co-efficient.
Paved surface as in city and steep open country. ..	0.75
Open-grassed country,	0.5
Sandy loam soil and heavily timbered country	0.3

Quoted by Messrs. Gummow Forrest, and Co., Ltd.

Nature of Catchment.	Co-efficient.
Old city areas closely built over . ..	0.8
New city areas .. .	0.6
Areas less closely built over — suburbs and country towns ..	0.4 to 0.5
Villa suburbs ..	0.3 to 0.4
Clear building areas	0.2
Parks, gardens, grazing, and agricultural land	0.15
Forest lands.	0.1

It is difficult to see how any satisfactory general formula could be evolved to embrace all these varying conditions without introducing a separate factor for nature of catchment. Mr. Vicars stated, in paragraph 6, that his formula really applied to grassed areas or virgin country. That being so, there could be no point in introducing it in a comparison with an analytical determination of the run-off from a city area. This was proved by the fact that it gave results which varied from 9 per cent. below to 124 per cent. above those obtained by the other method.

Mr. Vicars has rendered excellent service in proffering his graphical method of determining the run-off to be provided for in a scheme of drainage. The advantages of such a method are obvious, especially as an adjunct to and a check on the analytical method illustrated in the trade catalogue of Messrs. Gummow, Forrest, and Co., Ltd. Several errors and omissions in the calculations in the trade catalogue were revealed. For example, the paragraph re Branch Channel 2 might have read:—

"This branch channel has a length of 2,310 feet, and the water 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 feet per second, a distance of 720 x 2.5 (1,800) feet, and reach a point "C," which is 510 feet above junction "X." While this water travels from "C" to "X," the upper end of the channel will have emptied for a length of 510 feet down to a point "P." The maximum flow then to be accommodated at "X" from channel 2 is the full flow from the area below "P," which is equal to—

$$18.75 - \frac{510 \times 330}{43560} = 14.89 \text{ acres, giving a flow of}$$

$14.89 \times 4.033 = 60.05$ cubic feet per second."

Had the area contributing been strictly proportional to the length of the drain throughout, the above amount would have been $18.75\left(1 - \frac{510}{2310}\right) \times 4.033 = 58.9$ cubic feet per second, as given by the graphical method. This latter is, therefore, inexact, unless applied in detail to portions of drains where the contributing area is of uniform width relatively to the drain.

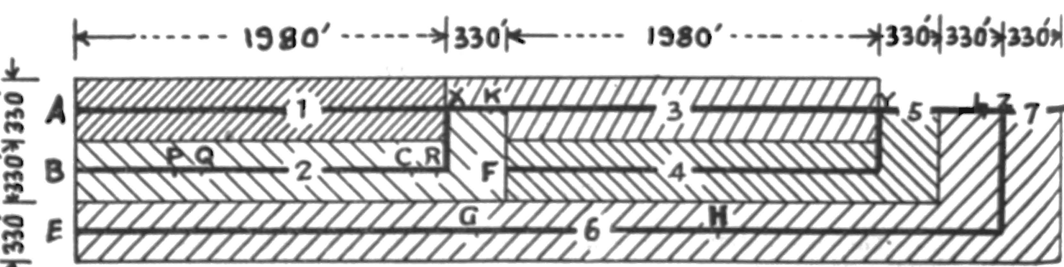
Main Channel 3.

The calculations for main channel 3 in the trade catalogue might have been extended to embrace a consideration of the flow occurring at a point "K," at which the head waters of channel 1 would have reached at the end of the storm. The length of channel 1 being 1,980 feet, velocity of flow 3 feet per second, and storm period 720 seconds, the period elapsing after these waters passed point "X" would have been $720 - \frac{1980}{3}$ $= 60$ seconds; thus point "K" would be $60 \times 4 = 240$ feet below "X." Now, at point "K," provision has to be made for the maximum discharge of channel 1 and partial discharges of channels 2 and 3. Now, at the end of rainfall, the head waters of channel 2 have arrived at "C," 510 feet above "X." When the waters from "C" have passed to "K," requiring a time interval of $\frac{510}{2{\cdot}5} + \frac{240}{4} = 264$ seconds, the channel 2 will have emptied itself down to a point "Q," situated $264 \times 2.5 = 660$ feet below "B," leaving the following area, contributing $= 18.75 - \frac{660 \times 330}{43560} = 13.75$ acres, giving a run-off of $13.75 \times 4.033 = 55.46$ cubic feet per second, to be provided for at "K."

The quantity of water contributed by main channel 3 at point "K," at completion of storm, is the run-off of $\frac{240 \times 165}{43560} = 0.91$ acres, giving $.91 \times 4.033 = 3.67$ cubic feet per second. The total capacity required at point "K" is therefore—

From Channel 1	..	60.50	cubic ft. per sec.
" " 2	..	55.46	" "
" " 3	..	3.67	" "
		119.63	

At point "X," provision would be required for $60.5 + 60.05 = 120.55$ cubic feet per second.



Branch Channel 4.

The two methods give identical figures for branch channel 4.

Main Channel, Section 5.

Beside the condition examined in Messrs. Gummow, Forrest, and Co's. treatment of this problem, is that of the local influence of the flow from sub-areas S.A. 3 and S.A. 4. For, considering the conditions at point "Y" at the end of the rainfall period, main channel 5 would be receiving water from sub-areas S.A. 1, 2, 3, and 4. The head waters of channel 1 would have arrived at "K." For these waters to arrive at "Y," would require $\frac{2310 - 240}{4} = 517.5$ seconds, and by that time channel 1 would have emptied for a length of $517.5 \times 3 = 1{,}552.5$ feet, leaving an area contributing of $\frac{(1980 - 1552 \cdot 5) \times 330}{43560} = 3.24$ acres, giving a run-off of $3.24 \times 4.033 = 13.06$ cubic feet per second.

At the end of the storm, the head waters of channel 2 would have arrived at "C," 510 feet above "X." It would take $\frac{510}{2 \cdot 5} + \frac{2310}{4} = 781.5$ seconds for the water to travel from "C" to "Y." and at the end of that time channel 2 would have emptied for a length of $781.5 \times 2.5 = 1{,}953.75$ feet feet down to point "R," leaving an area still contributing of $18.75 - \frac{1953 \cdot 75 \times 330}{43560} = 3.95$ acres, giving a run-off of $3.95 \times 4.033 = 15.93$ cubic feet per second.

Had S.A. 2 been uniformly wide, this latter figure would have been $18.75 \left\{ 1 - \frac{1953 \cdot 75}{2310} \right\} \times 4.033 = 11.66$ cubic feet per second.

The head waters of sub-drainage area S.A. 3, entering channel 3 at "X" at commencement of storm, would have travelled to point "L," situated $2{,}310 \sim 720 \times 4 = 570$ feet below "Y," so that at end of the rainfall channel 3 would be contributing its maximum run-off of 65.54 cubic feet per second to the main channel 5.

Channel 4, being of similar length and velocity of flow to channel 3 would, at the end of storm, also be contributing its full maximum discharge of 56.72 cubic feet per second to channel 5.

The total capacity, therefore, required at point "Y" in main channel 5 is:—