This paper may be published in an open bibliography

LONDON WEATHER CENTRE MEMORANDUM NO. 19

Heavy falls of rain at London Weather Centre

by R.J. Ogden B.Sc. and F.R. Gray

Introduction.

1. Heavy rain is of interest to River Authorities and other organizations. The threshold of operational significance is, however, not universal, varying from area to area according to the porosity of the surface (e.g. urban streets, clay, sand, chalk), and from time to time due to variations in Soil Moisture Deficit, River Flow and so on.

2. The investigation reported in this Memorandum is a pilot study to derive guidelines which will assist in the prediction of occasions of rainfall amounts above a given threshold. It was necessary to select an arbitrary threshold, and the value of 25 mms or more within 24 hours was chosen; within this Memorandum, such a fall will be termed a "heavy fall of rain".

Procedure.

3. The rainfall tabulations for London Weather Centre itself for the 26 year period 1945-1970 inclusive have been studied, and all occasions which met the above criterion have been extracted. The tabulations record rainfall in 12 hour periods from 09-21Z and from 21-09Z, so that the 24 hour periods considered were those both from 09-09Z and from 21-21Z. Cases when 25 mms or more fell within 12 hours (and therefore qualifying falls within two overlapping 24 hour periods) were counted as only one occasion; similarly, the three cases of more prolonged rainfall over 36 hours with falls of 25 mms or more in two overlapping periods of 24 hours were also each counted as only one occasion.

...../2.

4. There were 38 heavy falls which met the above criteria; they are tabulated in Annex A. In 19 of these cases the qualifying fall occurred during a 12 hour period, and in a further 3 cases, qualifying falls occurred during two overlapping 24 hour periods (but each was recorded as only one occasion); these cases are all indicated in the tabulations.

Frequency of occurrence of heavy falls.

5. The number of heavy falls in one calendar year varied from 0 to 5, being distributed as follows:-

0	1	2	3	4	5	6 or more	Total
8	6	7	3	1	1	0	26

The average number of heavy falls per year is thus 1.46.

6. There is reason to expect that heavy falls of rain should follow a Poisson Distribution which with an average of 1.46 would produce the following figures:-

0	1	2	3	4	5	6 or more	Total
6.0	8.8	6.4	3.1	1.0	0.3	0.1	25.8

The actual distribution thus has at least a superficial resemblance to a Poisson Distribution.

7. The figures were therefore submitted to a χ^2 test, and a value of 1.78 corresponding to a probability of more than 60% was obtained. This does not put the matter entirely beyond doubt, but there is certainly no reason to suppose that this is not a Poisson distribution; the distribution at London Weather Centre appears to be as expected, and not out of line with distributions elsewhere.

8. The two firm, albeit rather trite deductions that can be made from these figures are firstly that heavy falls of rain do not occur every year, and secondly that the occurrence of one, two, three or even four heavy falls in one year by no means provides immunity from a further heavy fall in the same calendar year.

Classification of heavy falls.

9. From a study of DWR's and other information, the 38 cases tabulated in Annex A were grouped into four categories as follows:-

.../3.

a. Widespread Heavy rain fell at many places in southeast England (17 cases).

b. Fairly widespread Heavy rain fell at some places in southeast England outside London as well as over the whole London Area (9 cases).

c. Localised Heavy rain fell in southeast England at very few places apart from L.W.C. (11 cases).

d. Isolated Heavy rain appears to have fallen at L.W.C. only (1 case).

As the total number of cases was fairly small, it was decided to regroup the data into two classes:

Widespread/Fairly Widespread	26 cases
Localised/Isolated	12 cases

Monthly distribution of heavy falls

10. The monthly distribution is as follows:

Classification	J	F	M	A	M	J	Jy	A	S	O	N	D	Year
"Widespread"	0	1	0	1	1	4	5	2	5	3	3	1	26
"Localised"	0	0	0	0	0	2	3	3	1	1½	1½	0	12
All cases	0	1	0	1	1	6	8	5	6	4½	4½	1	38

As might have been expected, most of the cases occurred in summer/autumn and few in winter/spring. (The half cases arise from a fall partly on 31st October and partly on 1st November).

11. The "localized" cases taken separately show a peak in high summer, suggesting that these cases arise primarily from convection. The distribution of the "widespread" cases shows two separate peaks in July and September with a dip in August. It could be argued that the July peak arises from convective influences (see thunder table below) whilst the September peak arises from increasing cyclonic activity at a time of year when moisture contents are still fairly high. But there is some doubt about the significance of the August dip because it could have arisen purely from the method of analysis.

12. Applying Brook's formula to a sample of 26, one should analyse the data into not more than 7 classes instead of the 12 used above. If one regroups the data into six two-month classes, the figures become:

/4. ....

Classification	J/F	M/A	M/J	Jy/A	S/O	N/D	Year
"Widespread"	1	1	5	7	8	4	26
"Localised"	0	0	2	6	2½	1½	12
All cases	1	1	7	13	10½	5½	38

The double peak in the "widespread" cases has now disappeared, leaving a markedly skew distribution but with a single peak in early autumn. Both convective and cyclonic influences are almost certainly at work, but the above simplified table probably gives a more representative picture of the overall distribution of heavy falls.

Occurrence of thunder

13. The occurrence of thunder with the heavy rain is summarised in the following contingency table:

	Thunder	No Thunder	Totals
"Widespread"	11	15	26
"Localized"	6	6	12
All cases	17	19	38

It is difficult to draw any conclusions from this table except that there is no significant general relation between heavy falls of rain and the occurrence of thunder.

Synoptic situations accompanying widespread heavy falls of rain.

14. The surface and upper air charts in the DWR and DAR were examined for all 24 cases of widespread heavy rain. Brief notes were made for each occasion and these are tabulated in Annex B.

15. The 26 surface situations accompanying heavy rain may be grouped into three categories:

Type A Heavy rain associated with a low* centre which passed within 100 miles of London through the quadrant between SSW and ESE (19 cases).

Type B Heavy rain associated with a low* centre which passed within 100 miles of London but to the north (3 cases).

/5. ....

Type C Heavy rain associated with cold fronts or cold occlusions, perhaps with pre-frontal thundery troughs, but with no low* centre anywhere near London (4 cases).

(*Depression centre, or wave tip with recognisably lower pressure on it though not necessarily a closed isobar).

16. The 19 cases of Type A fell into three distinct sub-types:-

Type A1 Low moved from Bristol Channel on a track between ESE and E (5 cases).

Type A2 Low moved up the English Channel or along the north coast of France on a track between ENE and NE (5 cases).

Type A3 Low moved up from France on a track between NNE and N (9 cases).

One of the cases classified as A1 (Feb 1958) was in some ways a mixture of Types A1 and A2; the parent low moved up Channel, but a secondary development moving ESE from S. Wales, and passing south of London became the major centre.

17. There seems little doubt that convective instability of the warm air was a contributory, if not an essential factor in all these Type A cases. Unfortunately the relevant upper air ascents were not available for study, but the heaviness of the rain alone suggests convection; thunder was actually reported in seven of the cases (2 of Type A1, 1 of Type A2 and 4 of Type A3).

18. In the three Type B cases (Aug 1946 and both cases in October 1949) a depression moved NE across the Midlands, passing to the NW rather than to the SE of London; thunder was not reported in any of these cases. It is interesting to note that no case of this type producing widespread heavy rain has occurred during the past 20 years, although there was a case of localised heavy rain of this type in 1955. The situation itself is by no means unusual, and it may be inferred therefore that it <u>is</u> unusual for this situation to produce 25 mms of rain in 24 hours in London.

19. The Type C cases were somewhat more varied. In the first case (June 1955) a cold occlusion and cold front moved south across England, becoming quasi-stationary near London; the heavy rain was convective and seemed to be a temporary intensification of the frontal rain belt due to the simultaneous advection into the area of warm moist surface air from the Continent, and cold air at high levels from the Atlantic. The next two cases (Sept 1955 and July 1956) were fairly orthodox, involving cold fronts moving across from the west. In both these cases

.../6.

a thundery trough developed ahead of the surface front, and moved north, the heavy rain being primarily associated with this trough rather than with the front itself; these two cases have much in common with Type A3.

20. The fourth case of Type C (Dec 1968) was somewhat unusual, and was at first assigned to a modification of Type B. A deep depression with marked circulation to high levels moved into Southern Ireland from the Atlantic and then drifted slowly SE to Cornwall whilst the heavy rain, accompanied by thunder, occurred in London; the centre itself was never nearer to London than about 250 miles. No fronts at all were drawn on the DWR charts anywhere near southern England, but the thickness pattern showed, to the east of the surface centre, a very marked warm tongue which moved east through London during the period of heavy rain; this warm tongue was entirely typical of an occlusion pattern, so the case was assigned to Type C.

21. Disappointingly little emerged from the study of the upper air charts in the DAR's. The upper air patterns accompanying widespread heavy rain can be broadly categorized into three types - right entrance/left exit features associated with a strong baroclinic zone, slightly diffluent areas ahead of an upper centre, and regions near or on the forward side of upper troughs. But with the exception of the first three Type C cases (which were all associated with upper troughs), each of these three broad categories of upper air pattern occurred with at least one occasion of heavy rain in each of the A1, A2, A3 and B Types. There is thus no single upper air pattern associated with heavy rain resulting from a recognisable type of surface development.

Synoptic situations accompanying localized heavy falls of rain.

22. The surface and upper air charts in the DWR and DAR were examined for all 12 cases of localized heavy rain. Brief notes were made for each occasion, and these are tabulated in Annex C.

23. It had been expected that a preponderence of these cases would arise from air mass convection, with no fronts or centres involved, but this did not prove to be so; only one out of the twelve cases (Aug 1970) seemed to be of this type:

Type D Heavy rain resulting from air mass convection.

.../7.

24. The other eleven cases all occurred in situations already found to be typical of widespread heavy rain (1 Type A1, 4 Type A2, 1 Type B and 5 Type C); they might therefore be described as 'near-miss' cases of widespread heavy rain. The fact that these cases resulted in localised rather than widespread heavy rain is further evidence of the fact that precipitation associated with fronts and centres is often patchy in character.

Summary of conclusions from the synoptic studies.

25. The most useful facts which emerged from this 26 year study of heavy rain are:

a. A high proportion of cases of heavy rain occurred when a surface low centre passed, within 100 miles, through the quadrant between ESE and SSW of London (73% of widespread cases, 42% of localised cases).

b. The other major contribution arose from cold fronts or cold occlusions (15% of widespread cases, 42% of localised cases).

c. Eliminating those cases under (a) in which a centre or wave tip passed near London, there was not one single case in 26 years when heavy rain was associated with the passage of a warm front unless there were marked waves on the warm front.

d. A small minority of cases (12% of widespread and 8% of localised falls) arose from the passage within 100 miles of London of a low centre which moved across the country to the north of London. As this situation is fairly common, but heavy rain in London in association with it is not, it seems likely that the warm air must be very warm and moist for the time of year. Three of these cases occurred during October and one in August; none was accompanied by thunder.

e. Convection (most probably convective instability) was probably a contributory cause of the majority of all occasions of heavy rain, but air mass convection alone, unaccompanied by fronts or centres, produced only one case of (localised) heavy rain during the 26 years. Thunder was reported in this case, and also in most (but not all) of the cases involving fronts; only about half of the cases involving low centres were accompanied by thunder.

L.W.C.
12 March 1971.

Heavy falls of rain at LWC 1945 - 1970 Annex A

(25 mms or more in 24 hours)

Year	Widespread	Fairly Widespread	Total	Localized	Isolated	Total	All Types
1945	15 July *		1			0	1
1946	9/10 Aug.		1			0	1
1947			0		17 July +	1	1
1948			0			0	0
1949	23 Oct* 26 Oct		2			0	2
1950			0			0	0
1951		27/28 Sept	1	17 Nov		1	2
1952			0			0	0
1953			0			0	0
1954			0	31 Oct/ 1 Nov		1	1
1955		27 May; 8 Jun* 22/23 Sept	3	19 Oct		1	4
1956	9 July * 19/20 July 1 Oct		3			0	3
1957			0			0	0
1958	5 Apr; 27 Jun * 2 Nov	24/25 Feb	4	10 Jun *		1	5
1959			0			0	0
1960	11 Aug + 16 Sept		2	1 Sept*		1	3
1961		10/11 Nov	1	12/13 Jun		1	2
1962			0	26 July *		1	1
1963			0			0	0
1964			0			0	0
1965		3 Sept*	1	20 July *		1	2
1966	23 Jun *		1	30 Aug*		1	2
1967		25 Jun *	1			0	1
1968	15 Sept *	17 Dec *	2			0	2
1969	6/7 July; 29 July*		2	3 Aug*		1	3
1970	14 Nov +		1	8 Aug*		1	2
			26			12	38

* Heavy fall occurred during 12 hours

+ Heavy fall occurred during two overlapping periods of 24 hours

Cases of Widespread Heavy Rain

Annex B

Date	Surface situation	Category	Thunder	Upper Air Situation
15 July 1945 x See P.5.	Depression formed on a cold front over France and moved N from Cherbourg to NW England, passing very close to London.	A3	Yes	The surface low lay in a slightly diffluent area ahead of an upper cold pool and centre which moved north from Biscay to Valley
23 Oct 1949	Wave depression moved NE across the Midlands	B	No	Wave was associated with the left exit of WSW'ly jet. An associated 500 mb centre moved east across England at about 55 N, following the wave.
26 Oct 1949	Almost a repeat of the situation of 23 Oct. A further wave depression moved NE across the Midlands, and a secondary wave on the cold front followed.	B,	No	A further 500 mb centre moved east across the country leaving a flat trough behind it in which the secondary wave formed; this flat trough sharpened considerably and swing across the country behind the secondary wave.
27-28 Sept 1951	A Cold front lying N-S became slow moving near London, and at least two waves developped on the front over France and moved NNE across SE England. The heavy rain belt was quite narrow.	A3	No	The waves developped just ahead of an upper trough which sharpened and moved slowly east through London after the waves had run north.
27 May 1955	A depression formed on a triple point in the Bristol Channel, and moved ESE to Boulogne.	A1	No	There was an Omega block pattern over the British Isles with the upper high centred N of Thorshavn. A cold cut-off centre formed in the trough on the west side of the block, the triple point lying in the diffluent region just ahead of the upper centre. The upper centre then moved quite quickly east and 12 hours later was part of the trough from Scandinavia on the east side of the block.

/8 June 1955

8 June 1955	Cold fronts moved slowly S over the UK, the forward. front becoming Q-S near London as a surface low moved SE across Biscay. Warmer surface air was advected N to S England ahead of this low.	C	Yes	Essentially a col pattern over SE England, with an upper low moving SE across Biscay. A cold pool in association with this low moved into France near Brest and helped to increase the instability. The rain on the front was intensified as convection became more pronounced.
22-23 Sept 1955	A cold front with a surface trough ahead of it, moving slowly E.	C	Yes	Anticyclinic trough disruption. The northern part of the trough relaxed and moved away NE, whilst the southern part sharpened and an upper centre formed over Central France. The heavy rain was associated with the slow passage of the sharp upper trough.
9 July 1956	A shallow thundery trough moving E across Southern England ahead of a cold front	C	Yes	The rain was associated the passage of a sharp upper trough.
19-20 July 1956	Depression moved slowly ENE near the N coast of Frnace, through the Straits and into the Low Countries.	A2	Yes	The surface centre was associated with an upper low centre and cold pool which moved slowly E at about 49 N.
1 Oct 1956	Wave depression moved fairly quickly NE across Southern England, the warm front was Q-S near London for some time before the arrival of the centre, accounting for the prolonged rain in a situation where the low moved quickly.	A2	No	The wave appeared to lie in a strong baroclinic zone, and moved quickly. It's position was not associated with any jet entrances or exits during the period of heavy rain.

x See P.5.

/5 April 1958.

5 April 1958	Complex low pressure area over UK and N. France. A small centre moved from Paris to Belgium. The surface air probably had a Mediterranean origin.	A3	No	The heavy rain was associated with the passage of an upper trough and cold pool.
27 June 1958	Low moved NNE from Bordeaux to Dover to Norfolk, passing just to the E of London.	A3	No	The low formed in the slightly diffluent area ahead of an upper low and cold pool which moved E from Brest to Paris.
2 Nov 1958	A small low formed over S. Wales on th the tip of an inner warm sector; the wave then moved E to Ostend, passing near London.	A1	No	The low may have formed at the right entrance to a thermal jet, but throughout the heavy rain period it was moving fairly quickly (but directly towards London) in a strong baroclinic zone. By the time the low reached Belgium it had crossed under the jet and was in a left exit.
11 Aug 1960	Low moved ENE from Brest along the N. coast of France to the Low Countries.	A2	No	Low formed in the diffluent region ahead of an upper trough, and moved E with the trough.
16 Sept 1960	Low moved from Paris to near London and then recurved to Devon.	A3	No	The low formed in a slow moving diffluent area associated with an upper low; it was steered westwards in the thermals on the N side of the cold trough.
10-11 Nov 1961	Low developped N of Cornwall and moved ESE past Cherbourg then turned ENE to the Straits	A1	Yes	Low formed ahead of an upper trough in association with the formation of a cold pool near the surface centre
3 Sept 1965	Low near Paris transferred N by development to the Southern N. Sea S.E. England was in a northerly throughout. The surface trough swung E when the main centre became established at about 55 N.	A3	No	Low formed just ahead of an upper cold low, and remained in this postion relative to the upper trough.

/23 June 1966.

23 June 1966	Low near Rouen moved N to Norfolk	A3	Yes	Low formed in a diffluent area ahead of an upper trough as cold air moved into France from Biscay.
25 June 1967	Low centred throughout off SW Ireland. Have moved NE quickly from Bordeaux to Dieppe to Humber.	A3	Yes	Strong baroclinic zone SSW over Biscay. Low moved in this, and crossed under the jet into a left exit diffluent region over SE England
15 Sept 1968 (Southeast England Floods)	Low moved E into France from Biscay. An associated trough, possibly with minor centres in it, moved slowly N over the Eastern Channel and SE England.	A3	Yes	Cold pool near Cherbourg moved NNE slowly. The surface trough lay in a diffluent area. Upper winds were very light, so movement was very slow.
17 Dec 1968	Low moved slowly E to the South of Ireland and later drifted SE. Although the low was drawn with no fronts, there was almost certainly an occlusion on its eastern flank which caused the rain as it edged slowly E	C	Yes	The upper low centre also lay well to the west. Very marked thermal ridge (associated with an occlusion?) moved slowly east through the area during the heavy rain.
6-7 July 1969	Low moved ENE from Brest along the N. France coast to Belgium,	A2	No	Heavy rain associated with the passage of a sharpening upper trough.
29 July 1969	Low moved ENE from Brest to Cherbourg to the Southern N. Sea	A2	No	The low remained just ahead of the upper cold trough axis; it was probably a right entrance feature.
14 Nov 1970	Low formed in Bristol Channel and moved E to Thames Esturary and Southern N. Sea.	A1	Yes	Left exit formation resulting from NW'ly jet from Greenland. Once formed, the low moved with the diffluent region just ahead of the upper trough axis.

9/10 Aug 1946	A deepening secondary cold front wave moved E to Scilly and then turned NE across the Midlands to become associated with the triple point of the parent system.	B	No	The wave developed on the cold side of the sw'ly jet ahead of an upper trough, and moved to the left exit region; a 500 mb centre formed with the surface low.
24/25 Feb 1958	A low moved in from the Atlantic S of Ireland. A forward breakaway low formed and moved ESE from S. Wales, absorbing the old centre into an elongated trough extending southwestwards to the Channel.	A1	No	The breakaway appeared to form in the right entrance region of a NW'ly jet, and moved into the upper trough extending SW from the main 500 centre over Scandinavia. The upper trough sharpened dramatically behind the surface low.

Cases of localized heavy rain — Annex C

Date	Surface situation	Category	Thunder	Upper air situation
17 July 1947	Fronts moving across from the west became quasi-stationary near London. Frontal precipitation was intensified as a thundary low developed ahead and moved N near the East Coast.	C	Yes	Marked cold advection at high levels moved into France ahead of the main upper trough; this led to the formation of an upper low centre over NE France which later moved quickly S. The upper flow over SE England was light E to SE, with W to NW flow over West and Central France.
17 Nov 1951	Fast moving wave on a cold front moved NE up channel to the North Sea, passing near London.	A2	Yes	Wave development associated with right entrance of jet (135 Kts) over Southern England, and moved under the jet as it propagated east wards.
31 Oct - 1 Nov 1954	Main low centre slow moving west of Biscay with a warm front from the centre, to SE England, to Denmark. Minor waves moved ENE along the front	A2	No	Main upper centre moving SE over Atlantic west of Irland. There was a broadly diffluent area in the SW Approaches ahead of the upper trough, and a confluent ridge ahead; the wave seems to have moved ENE with the confluent ridge.
19 Oct 1955	Slow moving occluding depression near West Ireland with associated warm sector over England and Wales. The heavy rain was associated with an inner warm sector of exceptionally warm moist air; the wave tip passed N of London.	B	No	The inner warm sector lay on the southern flank of a strong baroclinic zone. There was nothing very striking to distinquish this from many situations which do not give heavy rain in London, and the high moisture content of the warm air was probably the major factor.
10 June 1958	Cold front moving down from the N became quasi-stationary near London. Frontal precipitation was intensified as a small low with associated cold front moved SE from Donegal, the cold front eventually clearing London from the west.	C	No	The surface analysis does not accord at all well with the upper air charts. The most significant feature on the latter is probably a small cold tongue which moved across Southern England from the west. A 500 mb centre moved quickly E from Cornwall to Central Germany during the heavy rain period.

1 Sept 1960	Quasi-stationary warm front from Anglesey to Thames Estuary, with minor wave moving down it passing near London. The warm air was very warm and moist.	C	Yes	This wave was most probably associated with the right entrance of very modest WNW'ly jet ahead of an upper ridge. The main upper low centre was over the Baltic.
12/13 June 1961	Wave depression moved E from Bristol Channel to the Low Countries, passing near London.	A1	No	The upper low moved south from the Norwegian Sea to the North Sea, and the associated trough sharpened and swung east through London in association with the heavy rain.
26 July 1962	A small low developed between Brest and Scilly and moved slowly up Channel to the Straits along the axis of a low pressure trough	A2	Yes	Surface low developed in the diffluent area ahead of an upper centre. The upper trough relaxed and moved east with the surface feature.
20 July 1965	Flat low pressure area over Channel and Western Approaches. The low centre was gradually transferred up channel to the Southern North Sea by development rather than movement.	A2	Yes.	The surface low formed in the diffluent area near an upper centre. The axis of the upper trough moved east, with the upper centre at 50/49 N.
30 Aug 1966	Main low centre over Southern Ireland moving slowly E, with a frontal trough to NE France which swing slowly N. A secondary formed in the frontal trough near London and moved with it northwards to just E of Norfolk.	C	No	Rather flat diffluent area over the channel ahead of upper low of Pembroke which moved across to the North Sea. The heavy rain was associated with the upper trough.

/3 Aug. 1969

3 Aug 1969	Cold front moving NE towards London was delayed by the formation of a pre-frontal thundary low centre which moved slowly N. The heavy rain was mostly associated with the thundary trough.	C	No	Main low centre over the Atlantic with flat trough to the channel; this trough swing NE through London.
8 Aug 1970	Shallow low centre over the Low Countries, with a weak non-frontal trough to Southern England in which intense convenction developed.	D	Yes	Vigorus convection associated with a cold pool.