REGIONAL FLOODING IN STRATHCLYDE DECEMBER 1994

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Between the 10th and 12th December 1994, major flooding occurred in rivers and urban watercourses across the Glasgow conurbation and its surrounding areas. A slow-moving weather system delivered persistent rain over a 48-hour period and across a wide geographical area, such that previous peak river flow values were exceeded in all major catchments in the region. The River Clyde is thought to have reached its highest level in 150 years, and the total cost of the damage may reach £100 million. The event is the latest in a series of major floods in Scotland and raises questions concerning land use planning and flood hazard management.

Introduction

Major floods always attract considerable public attention when they occur, and with good justification: whole communities are often rendered helpless while uncontrolled waters inundate property, sometimes taking lives in their wake. With damage attributable to flooding throughout the world increasing despite continuing attempts to mitigate their impact, interest in floods and their consequences is as high as ever. In a global context UK floods are small scale and represent only a limited threat to lives and livelihoods. Nonetheless, they can still pose a considerable threat in terms of their economic and social impact.

Yearbooks in the *Hydrological data UK* series have documented several of the most significant floods to occur since 1980: the Tywi flood of 1987[1], the two Truro floods of 1988[2], the Tay floods of 1990[3] and 1993[4] and, in this volume, the Chichester flood of January 1994. December of the same year also witnessed flooding in Strathclyde which became the latest event in a striking list of floods to occur in Scotland since the late 1980s. Flooding on the Ness in 1989[5], and on the Spey[6] and Teith[7] in several recent winters since 1988, combined with the Tay floods and others elsewhere, has caused significant economic and social impact. As in many other parts of the world, possible links between recent hydrological events and climate change are of considerable concern. Whether there is any common cause of this now well-recognised increase in flooding in Scotland[8], it accords well with a general steepening in the north-west/south-east rainfall gradient across Britain[9] which, if sustained, may necessitate significant adjustments in the provision of regional water resource systems and flood defences.

The flooding which forms the focus of this paper was unusual for its geographical extent, involving all the rivers converging on Glasgow and affecting many of its suburbs. Strathclyde Region accommodates 45% of the Scottish population of 5.1 million, with 1.6 million located in the Glasgow conurbation. The resulting pressure on land resources may be considered to contribute to the risk of flooding problems.

The River Clyde is the main river in the Region (Figure 1), draining a catchment which rises to some 750 m in the Southern Uplands. It includes tributaries on the south side of Glasgow, such as the White Cart Water, which fall steeply from their upland headwaters, and others such as the River Kelvin which, although also having some very steep

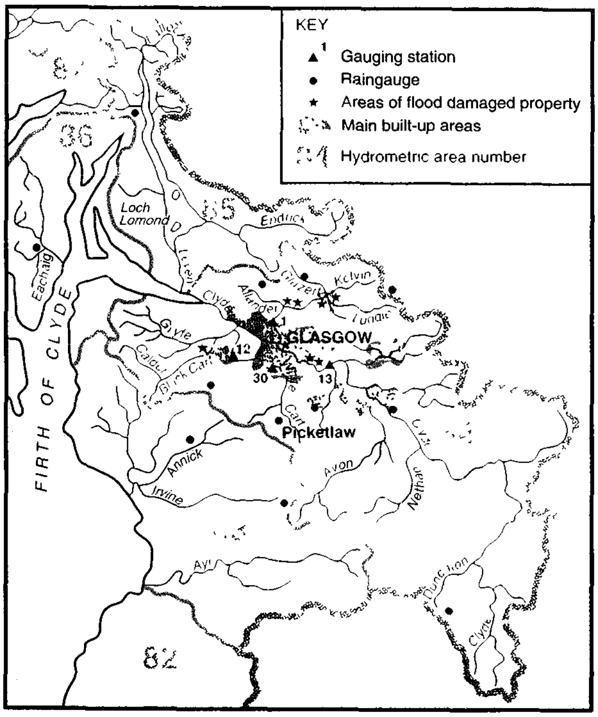

Figure 1 Location map

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headwaters, flows slowly through a gentle floodplain in its middle course to the north-east of Glasgow. Mean annual rainfall varies strongly with altitude, from around 900 mm on the Ayrshire coast and in the middle Clyde valley, to more than 3000 mm in the mountains to the north of Glasgow; hydrological characteristics also vary strongly in response to these controls. When these diverse characteristics are taken into consideration, the response of the rivers of Strathclyde to the heavy December rainfall in 1994 was especially remarkable.

Rainfall

December 1994 started with generally damp conditions, following on from a November of near-average rainfall. At Picketlaw in the centre of the Clyde River Purification Board (CRPB) area, rain fell on each day of December until the 20th. Daily totals were in the range 1-10 mm on the first six days of the month, but on the 7th and 8th falls of 22.4 and 19.4 mm respectively were recorded. This rainfall ensured that soil moisture levels were at, or approaching, saturation throughout the region.

In the early hours of December 10th, a slow-moving frontal system brought sustained rainfall of 1-5 mm per hour to the whole of west-central Scotland, lasting for about 48 hours. The rain was produced by an unusually wide warm sector, which caused warm, moist air from the west-south-west to be conveyed continuously across the area. More unusual was the coincidence of this rainfall with a large conurbation and, as the rain continued, fears of flooding grew. A similar meteorological situation had been responsible for the damaging Ness and Conon floods of February 1989[10] although, on that occasion, the cold front marking the northern limit of the rainfall was much further to the north.

Table 1 shows the daily rainfall totals recorded across the area while in Figure 2 hourly totals are presented for three sites located around the main Glasgow conurbation. The sustained nature of the rainfall is clearly illustrated, and it can be seen that

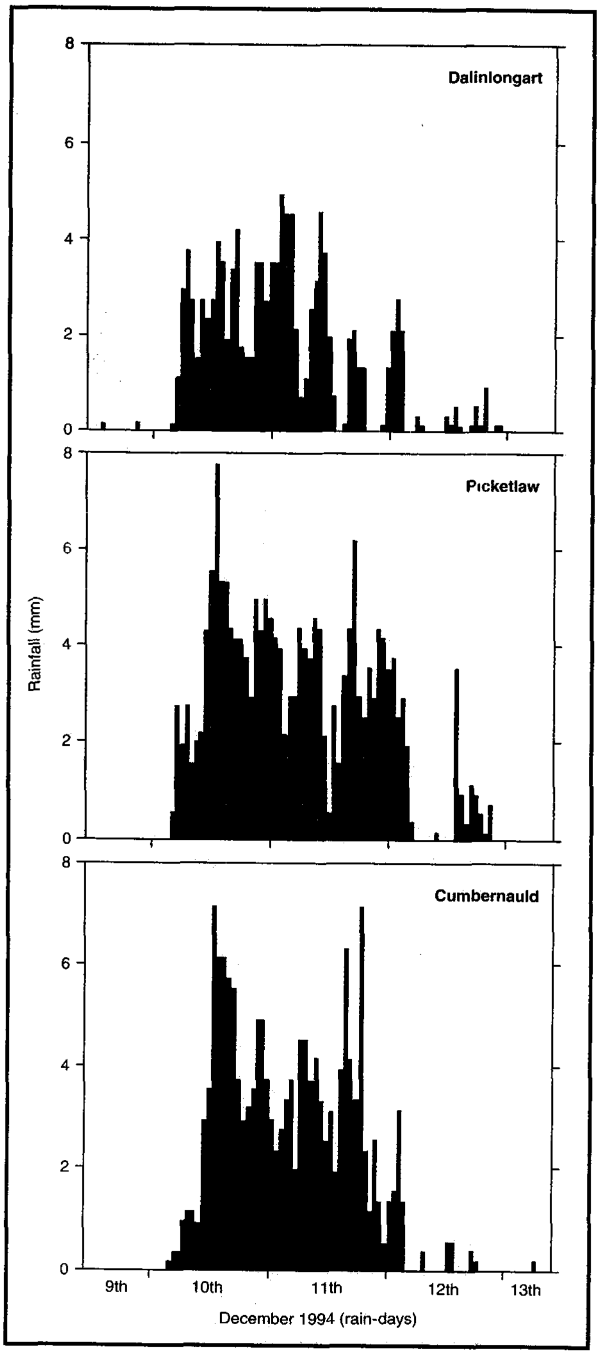

Figure 2 Hourly rainfall for three selected rainguages. (See Table 1 for location)

TABLE 1 DAILY RAINFALL TOTALS FOR SELECTED CLYDE RPB RAINGAUGES

Raingauge	Catchment	NGR	Alt (m aOD)	Water-day rainfall totals 9th	10th	11th
Dunlop	Annick Water	NS412489	148	16.4	88.0	57.2
Saughall	Irvine	NS598364	222	6.9	80.5	54.3
Leadhills	Clyde	NS888151	384	3.2	65.8	46.5
East Kilbride	Clyde	NS638535	178	9.4	69.0	48.0
Clyde Park SW	Clyde	NS772539	30	3.4	42.2	29.4
Picketlaw	White Cart	NS568515	220	14.0	100.8	57.6
Gleniffer Braes	Black Cart	NS435595	183	22.7	165.4	54.6
Mugdock Park	Allander/Kelvin	NS546779	164	11.9	126.0	53.4
Glenmill	Glazert/Kelvin	NS605794	99	18.1	89.3	57.3
Cumbernauld*	Kelvin	NS783770	85	5.4	99.6	52.6
Dalinlongart TS	Eachaig	NS138813	60	15.8	73.4	23.2
Inveruglas	Loch Lomond	NN320091	13	36.9	100.4	28.5

Note: Almost all the rain was received within 48 hours at each gauge.

* Operated by Forth RPB

most of the rain fell within the water days (09.00-09.00) of the 10th and 11th. An assessment of the rarity of the 2-day falls by CRPB staff has produced estimated return periods of over 500 years for some sites. It is striking that five of the six 2-day totals exceeding 140 mm were at sites below 200 m aOD, with two of these being below 100 m.

Hydrological Response, Hydrometric Network Operation and Flood Warning

The first rivers to show a significant response to the rainfall were those draining the urban areas to the south of Glasgow. The CRPB flood warning staff were monitoring the situation, as they had been given a heavy rain warning by the Met Office on the 9th, predicting between 18 and 25 mm of rain in the area.

The first telemetry alarm was received at 11.45 on Saturday 10th December from the White Cart system, and at 15.05 Strathclyde Police were officially warned that flooding was likely in parts of Cathcart, southern Glasgow. The White Cart initially peaked at 18.30 but by 23.00 had started to rise again, eventually peaking at Overlee gauging station at 01.30 on Sunday 11th (Figure 3). The White Cart (84030) has a long history of flooding, a result of the steep nature of the catchment and its tributaries, causing a rapid response to rainfall. However, as the rainfall in this event was of long duration but only moderate intensity, the flows at Overlee in the middle of the catchment were not exceptional, the peak level being more than 0.5 m less than the previous recorded maximum in a record commencing in 1981.

Further down the catchment at Hawkhead (on the outskirts of Paisley), where the peak flows are sometimes less than those at Overlee due to attenuation down the channel, a new maximum flow of 193 m^3s^{-1} was recorded at 04.45 on Sunday 12th, with the recorded level being almost 0.7 m above the previous recorded maximum (Table 2). This clearly demonstrates one of the most striking features of this event, namely that the prolonged duration of the rainfall ensured that the effects were greatest in the larger catchments where peak flows from tributaries were able to coincide. The Black Cart, which joins the White Cart below Paisley, peaked at 18.00 on the 11th (Table 2), the coincidence of the high flows in both rivers causing significant flooding and backing up along the main channels.

Once the warnings had been issued for the White Cart, attention turned to other rivers in the region. It had been observed early on the 10th that the rivers draining the Campsie Fells to the north of Glasgow were very high, and they were the next group to reach peak levels, typically around 03.00 on the 11th. Many of these rivers drain into the Kelvin which, because of its large, flat middle section, was unable to effectively drain the coincident peak flows. Flows in the Kelvin were the most notable in the region, with a peak flow at Killermont (84001) gauging station estimated to be more than twice the previous maximum (in a 47-year record). There were such large volumes of water contained in the floodplain that the river did not finally peak until 07.00 on Monday 12th, more than 48 hours after it had started to rise (Figure 3). The Kelvin caused widespread flooding at Kirkintilloch in the centre of the large floodplain, and downstream in Glasgow, particularly following ingress into a disused railway tunnel (see below).

Further south, the River Irvine peaked in the early hours of Sunday 11th, causing flooding in the town of Irvine, and localised, minor flooding was also reported on the Ayr. As the rain moved to the south-east, the River Clyde itself began to cause concern. This had been much slower to rise, given its greater catchment area, but quickly made up for lost time and eventually recorded a new maximum at Daldowie (84013) at 06.15 on Monday 12th (Figure 3). Peak levels were more than a metre above any previous level, with the corresponding flows estimated to be between 1100 and 1300 m^3s^{-1}, compared to a previous maximum of 803 m^3s^{-1}.

A total of 27 gauging stations recorded new maximum levels during the event, including 17 with 25 or more years of record (Table 2). Several instrument huts were inundated, a number of

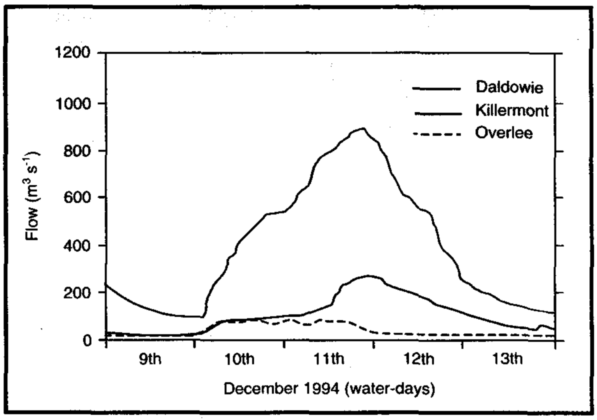

Figure 3 Flows at three gauging stations in the Clyde basin (see map)

Plate 1 Redlees gauging station on the Rotten Calder Photo: Clyde RPB

TABLE 2 MAXIMUM LEVELS/ESTIMATED FLOWS RECORDED IN DECEMBER 1994: CRPB STATIONS WITH 25+ YEARS OF RECORD*

River	Station	First Yr of Record	Catchment area (km²)	Day	Time	Max. Level (m)	Flow (m^3s^{-1})	Previous max. level (m)
Duneaton	Maidencots	1966	110	11	23.59	2.126	120	2.092
Clyde	Sills	1957	742	12	10.29	3.113	403	3.023
Clyde	Tulliford Mill	1969	933	12	05.59	2.843	539	2.592
Clyde	Hazelbank	1956	1093	12	06.35	3.778	606	3.637
Nethan	Kirkmuirhill	1966	66	11	21.28	2.239	75.0	2.308
Avon	Fairholm	1964	266	11	01.00	3.173	289	3.916
South Calder	Forgewood	1965	93	12	06.44	1.147	26.5	1.682
Clyde	Blairston	1958	1704	12	05.41	4.038	>830	3.480
North Calder	Calderbank	1968	61	11	20.29	1.684	27.3	1.821
North Calder	Calderpark	1963	130	12	03.11	2.674	134	2.278
Rotten Calder	Redlees	1966	51	11	17.11	1.820	44.6	2.119
Clyde	Daldowie	1963	1903	12	06.15	5.903	>1100	4.815
White Cart	Hawkhead	1963	227	12	04.43	4.372	193	3.680
Black Cart	Milliken Park	1967	103	11	18.14	2.012	110	1.383
Gryfe	Craigend	1963	71	11	05.13	2.618	129	2.007
Glazert	Milton of Campsie	1968	52	11	02.32	2.089	87.1	1.972
Luggie	Condorrat	1966	34	11	19.53	2.280	51.3	1.835
Kelvin	Dryfield	1960	235	12	08.44	5.223	104	4.586
Kelvin	Killermont	1948	335	12	07.11	3.781	>300	2.255
Falloch	Glen Falloch	1970	80	11	02.29	2.665	176	2.746
Endrick	Gaidrew	1963	220	11	06.59	3.606	134	3.744
Leven	Linnbrane	1963	784	13	00.28	2.370	138	2.996
Little Eachaig	Dalinlongart	1968	31	11	02.13	1.271	31.1	2.310
Eachaig	Eckford	1968	140	11	03.28	2.661	126	2.477
Ayr	Catrine	1970	166	10	22.29	2.993	201	2.704
Irvine	Glenfield	1914	218	11	01.23	2.895	437	2.106

* Some of the featured levels and flows result from site investigations and may involve the use of special high flow stage-discharge relations; moderate differences from the routinely processed flows may occur.

cableways were damaged and flood debris created considerable flow measurement difficulties (Plate 1). Some telemetry lines were affected by water, but the system as a whole was robust enough to allow the CRPB staff to keep both the emergency services and the Met. Office advised of conditions as the event progressed. It is worth noting that the rainfall radar station at Corse Hill (to the south of Glasgow) was not working through the event, due to a technical fault, yet sufficient information was available from the CRPB's telemetry raingauges to map the rainfall.

Due to the exceptionally high flows it was not possible to current meter many of the peak river flows, especially where station huts were inundated. However, many new high level gaugings were completed whilst still ensuring that the network continued to operate. Low flow gaugings during the following summer have revealed that some of the stations will require recalibration as a result of channel erosion or deposition during the event.

Flood Impact

It was inescapable that flows of the magnitude experienced would cause considerable impact across the area. Damage was caused to properties over an area more than 50 km wide, as a result of the widespread nature of the rainfall and associated runoff. Three lives were lost: two when a car plunged from a submerged and collapsed bridge over the Kelvin near Twechar, and the other on the River Nith to the south. At the height of the floods 80 roads were closed and, in central Glasgow, Argyll Line and Glasgow Underground rail services were halted when tunnels became flooded. Ten months were required to repair damage on the Argyll Line - caused by ingress of floodwaters from the Kelvin via a disused tunnel. Water from the same source inundated part of the Scottish Exhibition & Conference Centre, a hotel (see Plate 2) and the Glasgow Expressway.

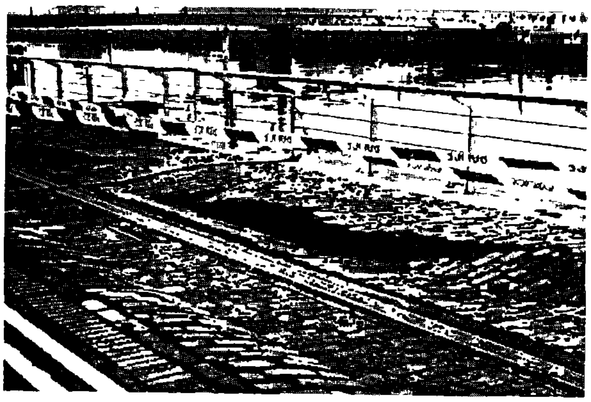

Plate 2 Walkway in front of Moat House Hotel, Finnieston, Glasgow, undermined by floodwater
Photo: Clyde RPB

Inundation of residential property was one of the most prominent features of the floods, affecting properties of a wide range of ages. Some 700 homes were flooded, with many families needing to be evacuated. Residential flooding was most extensive in Paisley and Kirkintilloch, and occurred in a range of circumstances. In Paisley much of the flooding appears to have occurred as a result of the culvert capacity of a small watercourse being exceeded, causing ponding in a deep hollow. Some houses were inundated by up to 4.5 m of floodwater. Most of the flooding in Kirkintilloch occurred on, and along the margins of, the wide floodplain of the River Kelvin. While some flooding is experienced in many winters, historical sources suggest that the levels reached in this event may not have been exceeded for more than 100 years. Much of the damage centred on a 1960s development at Hayston, and the new Summerfield Gate housing estate, where house building was still in progress (Plate 3).

Commercial losses also occurred in Kirkintilloch, mostly at a floodplain industrial estate, and at several locations to the south of Glasgow, eg. a whisky distiller's bonded warehouses, industrial units and a public health laboratory, as a result of the Clyde overtopping its banks. An insurance survey of the damage caused by the floods suggests that total damage costs may approach £100 million, with £30 million to be met in insurance claims[11].

Plate 3 Flooding on the Summerfield Estate, Kirkintilloch
Photo: Andrew Black

Discussion

The damage costs associated with these floods suggest that they are probably the most damaging witnessed anywhere in the UK since the 1968 flooding in southern England. The essence of their impact lies in the coincidence of a most unusual near-stationary frontal system with the UK's third-largest urban centre. Costs have been incurred in not only economic but also social terms. In common with other floods such as the Tay event of 1993, those social groups least able to withstand the effects of flooding have often found themselves most exposed to it. In this case the Ferguslie Park area of Paisley, with high unemployment and very low levels of insurance cover, experienced great hardship.

The history of flood defence provision demonstrates that the cost of constructing defences is often worthwhile, in terms of offering protection against the range of losses which flooding causes. However, evidence suggests that many of those defences which have been provided were inadequate in this event. It should be a matter of concern that some of the worst flooding would not have occurred if more thought had gone into the sizing and maintenance of culverts and screens, and the significance of embankments as effective dams. A more coordinated approach may well have been beneficial in this instance.

Elsewhere, however, particularly on land adjacent to the Clyde and Kelvin, the hydrological analysis above suggests that the flood flows experienced were truly exceptional. Such flooding might therefore be considered to lie within the scope of that risk which home-owners and businesses choose to accept when locating in floodplain areas, although it should be noted that the perception of risk does appear to vary according to the length of time since flooding last occurred. Many of these same areas are successfully protected against floods of lower magnitude.

There has been much discussion of the effectiveness of planning controls following these floods; suggestions have been made that much of the flood damage was avoidable. The Scottish Office has subsequently issued a National Planning Policy Guideline[12], directing planning authorities to exercise the precautionary principle by refusing applications for floodplain development, except where other reasons for granting permission take precedence over flood risk. Difficult decisions may need to be taken in assessing the balance between development and the benefits of limiting the potential for flood damage, and the assessment of risk is therefore as important as ever. A well-founded understanding of the nature of flood risk must be an essential input for future development plans to be made on an informed basis. Particularly in the case of a heavily developed conurbation such as Glasgow, the use of floodplain areas may be an essential part of future development and, with control over the types of development permitted and the level of structural protection offered, an equitable distribution of risk may be achieved. New duties of flood survey, and input into planning procedures, for the forthcoming Scottish Environment Protection Agency (SEPA) will aid the future management of flood risk in Scotland. A survey of the flooding[13], commissioned by CRPB with Scottish Office backing, will also be valuable in this regard, and can be seen as anticipating the new duties to be given to SEPA.

Climate change remains a relevant issue in considering this event, as with others. Warm, moist air masses may bring rain such as that experienced in

Strathclyde more frequently to north-western Europe under preferred climate change scenarios. Therefore it would seem appropriate for those involved in risk assessment for new flood defence works, the design of structures, etc. to exercise caution in their assessments. A particular hydrological aspect of this flood which deserves further study is the high percentage runoff which was achieved in some catchments. Inspection of data for the responsive White Cart Water catchment (111.8 km^2) above Overlee shows that, in the 36 hours from 15.00 on the 10th December (Figure 3), the estimated runoff equates to 75% of the point rainfall simultaneously received at Picketlaw in the headwaters of the catchment.

Conclusions

The Strathclyde floods of December 1994 were remarkable for their geographical extent, stretching 50 km across a major conurbation, and for the severity of flooding with some 700 homes and many business properties flooded. The unusually persistent rainfall resulted in previous river flow records being exceeded in all river basins around Glasgow, in both small and large catchments.

In a large conurbation, where development pressures are sure to continue in the foreseeable future, risk assessment is vital in order that floodplain management can offer widely acceptable solutions to the threat of flooding. Through monitoring and research, the role of the hydrologist must be to ensure that the relevant decisions are made on a fully informed basis.

Acknowledgement

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