The Tyneside Flood 28th June 2012

Hydrological Report

Yorkshire & North East Region Hydrology
Environment Agency
December 2012

Executive Summary

On 28th June an exceptionally intense storm caused widespread flash flooding across Tyneside. Most of this was due to surface water runoff but fluvial flooding was also experienced in Lanchester on the Smallhope Burn and at Chester le Street, Acomb and Barnard Castle.

Although the source of the flooding was the same, the contributing factors were very different. Antecedent conditions had little impact on the severity of the urban surface water flooding, but contributed to the severity of the fluvial flooding.

Up to and including the 27th June Tyneside had already had around double the normal monthly rainfall. As a result the soils were saturated and the reservoirs were almost full. Rivers levels were also significantly higher than normal for the time of year.

On Thursday 28th June warm, humid air moved northwards bringing cloudy, muggy conditions. Thunderstorms developed in the south-west early in the morning and tracked north, to arrive over Tyneside at 1500 GMT. A line of exceptionally severe thunderstorm cells tracked south eastwards over the area for two hours before moving off into the North Sea. During this short space of time up to 2 inches (50mm) of rain fell with a peak intensity that matched many notable flash floods such as the Boscastle and Carlisle flood events.

The ensuing surface water flooding brought traffic chaos to the city centre and all major routes around Tyneside. There were hundreds of calls to the emergency services as the drainage network failed to cope with the extremely high volumes of rainfall.

Return periods for the short duration rainfall were in excess of 100 years at Whitley Bay and Jesmond Dene and several raingauges recorded totals with a return period over 50 years.

One of the most noteworthy characteristics of this event was the rate of rise experienced in some of the more urban watercourses. The Ouse Burn at Crag Hall rose one metre in an hour and the usually more sedate Derwent rose 1.3m in two hours at Rowlands Gill.

Whilst the impact across Tyneside dominated the media reporting of the event there were some significant rainfall totals and impacts elsewhere in the NE area.

Lanchester in County Durham experienced flooding from both surface water and then, later that evening from the Smallhope Burn as it recorded its highest level in a nine year record. Other level sites also recorded new maxima from as far afield as the Rede at Otterburn and the Chester Burn.

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1. Introduction

This report provides a record and analysis of the hydrology of the flood event in North East England on June 28th 2012. This report presents the data gathered during the event and an analysis of its severity. The analysis of the event uses data up to and including the 28th June 2012. It does not place this event in the context of flood events which happened later in 2012.

In particular it outlines:

- The antecedent conditions across the affected area
- The meteorological conditions
- A overview comparing Tyneside and other affected catchments
- The extreme rates of rise
- The impact of the event on the monitoring network

The darker shading in Figure 1 shows the main catchments where flooding occurred and upon which this report concentrates.

- The Don
- The Derwent
- The Rede
- The Ouseburn
- The lower Tyne
- The Team
- The Browney

The rainfall event which was the cause of the flooding was concentrated over Tyneside but also impacted other catchments to the south and west as it tracked north eastwards. The event was widespread but affected catchments in different ways.

Any hydrological analysis must be selective. Therefore some locations will not be discussed in detail if they lack reliable data or they are not sufficiently unusual in the context of the event.

A note on terminology: the Annual Maxima (AMAX) data used in the analysis of flood events is traditionally described in terms of the Water Year (October to September) rather than Calendar Year. The June 2012 flood event is therefore included in tables and graphs as the AMAX for 2011. However, to avoid confusion, where the event is referenced in the text of this report it will be referred to as the 2012 or June 2012 event.

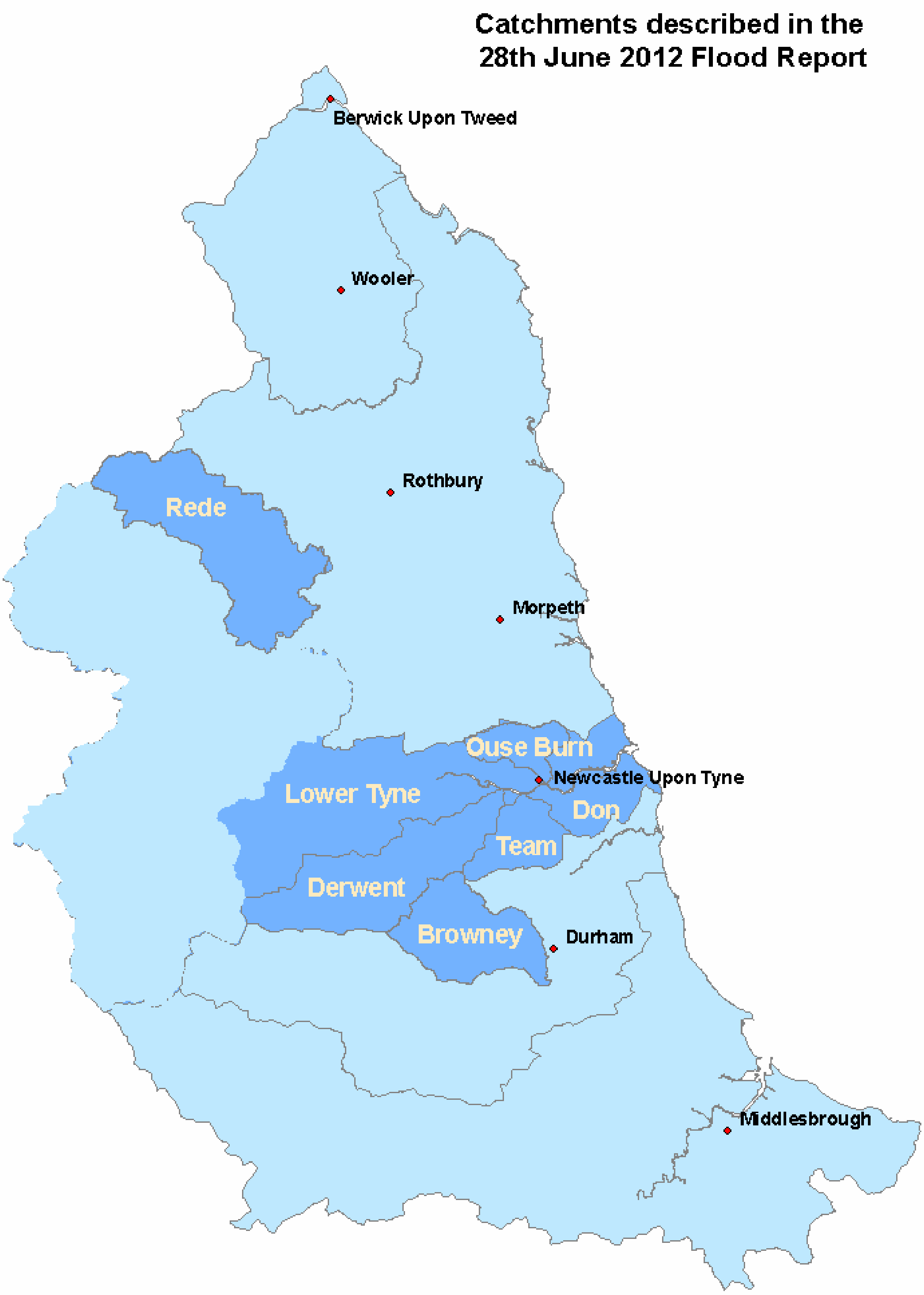

Figure 1: Catchments described in the report

1.1 The historical context of Tyneside flash floods

In ‘Land of Singing Waters’ (Spredden Press) former NRA hydrologist, David Archer, describes the history of several other flash floods over Tyneside which have resulted from summer thunderstorms (chapter 9, pages 188 -194).

The flash flood of the 22nd June 1941 was not recorded in the papers at the time due to war restrictions. However, the published ‘British Rainfall’ notes that a succession of severe thunderstorms passed over Newcastle that afternoon. Between 1425 GMT and 1645 GMT there was a total of 113mm of rain with 95mm falling in just 85 minutes. The area of greatest intensity was west and north of city centre from Gosforth to Denton Burn.

On 18th June 1839 J. Latimer (Local Record) recorded a storm which began at 4pm and lasted two hours. Several sections of the city were affected such as Leases Lane, Barras Bridge, Gallowgate, Town Moor and Westgate. The water flowed down Darn Crook and caused an immense lake in Newgate Street. Sandhill was impassable and Dean Street, The Side and Butcher Bank were all flooded.

Within the wider area affected by the storm described in this report there have also been several other very large events in recent years.

In July 1983 rain gauges in the upper Wear recorded up to 100mm in just two hours (Archer, Walls of Water, BHS circulation, Dec 1994) and on 24th August 1990 some 70 to 100mm was recorded in a single day. The observer at Brignall noted that 86.7mm of rain fell in less than two hours and Smiddy Shaw rain gauge recorded 78mm in two hours (Archer and Wheeler, BHS, 3rd National Hydrology Symposium).

On 3rd August 1994 the rain gauge at Wallington Hall recorded 30mm in 15 minutes, producing a ‘wall of water’ down the Wansbeck as river levels rose over a metre in 15 minutes (Archer, Wall of Water, BHS circulation, Dec 1994).

Records such as these show that, though extreme, the event on the 28th June 2012 was not unique. However, the difference with events such as the 1941 Tyneside event is the impact upon, and the number of, residents affected. The thunderstorm broke over Tyneside at 4pm (BST) just as many schools were finishing and people were beginning to make their way home from work. All of the major roads became blocked or closed and there was widespread disruption to the east coast main line and Metro network. The effect of such severe events on the modern infrastructure of a large city meant that, unlike previous events, the disruption caused to many thousands of Tynesiders extended far beyond the actual flooding which occurred.

2. Antecedent Conditions

The antecedent catchment wetness and river flows were not a major influence on the resulting flood response in Tyneside. Most of the flooding was due to the inability of the surface water drainage system to cope with the extreme volumes of rainwater, rather than from fluvial flooding. However, the catchment conditions of some of the rapid response catchments were relevant as a total of 144 properties were flooded from the Smallhope Burn in Lanchester, the Red Burn at Acomb, the Chester Burn at Chester le Street, the Percy Beck at Barnard Castle and the Team at Team Valley.

2.1 Rainfall

Table 1 details the rainfall recorded from the 1st to 27th June in mm and as a percentage of the monthly long term average (LTA).

Site name	Location	Rainfall (mm) 1st-27th June 2012	Rainfall to 27th June as % of June LTA
Linbriggs	Coquet	122.2	268%
Blyth	Blyth	92.2	184%
Dewlaw	Pont	137.6	275%
Darras Hall	Pont	119.8	226%
Chirdon	North Tyne	121.6	173%
Knarsdale	South Tyne	175.4	236%
Haltwhistle	South Tyne	141.6	211%
Allenheads	Allen	138	224%
Jesmd Dene	Ouse Burn	109.6	201%
Farne School	Ouse Burn	111.6	218%
Howden	coast	84.6	169%
Whitley Bay	coast	103	206%
East Kyo	Team	140.8	227%
Tunstall	Wear	118.8	201%
Knitsley	Browney	109.2	195%
Washington	Wear	175.4	236%
Old Spital	Greta	185.4	293%
Folly House	Tees	143.2	230%
Lartington	Tees	144.8	253%

Table 1: Antecedent rainfall from 1st to 27th June 2012. Total rainfall is for water days (9am to 9am)

Table 1 shows that twice the average rainfall had already been recorded across the NE area before the 28th June. The Coquet, Pont and Greta were especially wet with the heaviest rain falling in fairly long periods of steady rain on the 7th to 10th and the 21st June.

The National Climate Information Centre (NCIC) produces a dataset of aggregated climate data. This information is calculated from a range of climatic parameters based on a 5km x 5km grid and is used to calculate long term averages for a given area. The NCIC dataset shown in Table 2 confirmed that the April to June three month period was the wettest since at least 1910 in all the YNE catchments, with the exception of the Hull (note that this includes the rainfall from the 27th).

Catchment	1mth	3mths	4mths	6mths
Tweed	2	1	2	7
North'ld N Sea	1	1	2	8
Tyne	2	1	3	10
Wear	3	1	1	4
Seaham	3	1	2	11
Tees	2	1	1	8
Swale	3	1	2	8
Ure	3	1	5	18
Nidd	4	1	3	9
Ouse	4	1	1	12
Wharfe	3	1	3	12
Dales N Sea	5	1	3	21
Rye	2	1	1	13
Derwent	5	1	1	16
Aire	3	1	3	8
Calder	3	1	4	13
Don	7	1	2	10
H&H	5	2	2	16
NUMBER OF CATCHMTS RANKED 1	1	**17**	5	

Table 2: NCIC statistics for accumulations ending in June (rank 1 = wettest on record)

2.2 Soil Moisture Deficit

Soil Moisture Deficit (SMD) is a measure that indicates the dryness of the catchment. Data is supplied by the Meteorological Office from their MORECS model, which is a grid based model providing estimates of SMD on a 40km grid. It is a theoretical, modelled value of the soil moisture deficit below field capacity for a median available water content soil under short grassland. It does not account for actual land cover and is therefore not an indicator of actual moisture deficit in situ but is rather a means of comparison of the extent of dry soils across the region. SMD values close to zero are an indication that the soil is saturated and unable to hold any more rainfall.

Above average rainfall throughout most of May and June caused SMD to drop significantly below the normal level. Figure 2 shows that by mid June the SMD across much of the area had decreased and was either zero, or was very close to zero, across North East England. At this point the deficit was at its lowest for the time of year over a period of record dating back to 1971. The soil was so saturated that it was unlikely to provide any significant storage for the approaching rainfall.

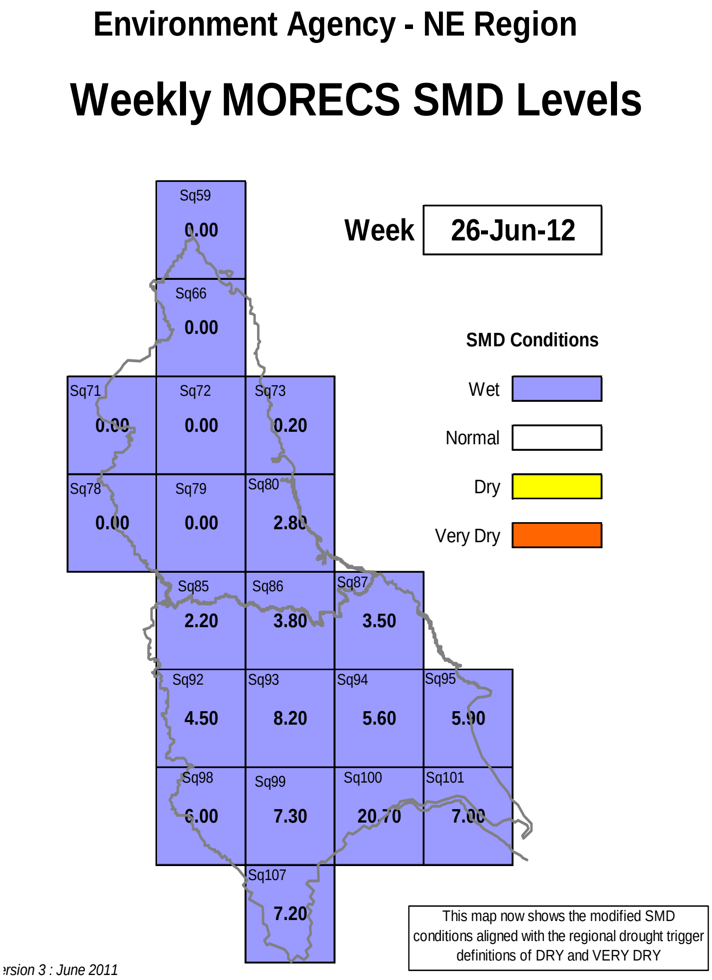

Figure 2: Soil Moisture Deficit (mm) for week ending 26th June 2012.

2.3 River flows

Table 3 shows the river flows for a selection of sites across the affected area prior to June 28th. The flow in the river, expressed as daily mean flow, is compared to the LTA at the site for the time of year.

Site Name	Location	Mean Flow Apr 12			Mean Flow May 12			Mean Daily Flow - 27th June 12		
		cumecs	LTA cumecs	% of LTA	cumecs	LTA cumecs	% of LTA	cumecs	LTA cumecs	% of LTA
Ouseburn										
Woolsington	NZ1939869862	0.186	0.091	204%	0.111	0.036	308%	0.128	0.041	312%
Crag Hall	NZ2540967548	0.866	0.390	222%	0.409	0.222	184%	0.492	0.207	238%
Team										
Team Valley	NZ2496458471	1.28	1.24	103%	0.97	0.93	104%	1.21	0.94	129%
Derwent										
Rowlands Gill	NZ1681558094	4.22	3.13	135%	3.87	2.03	191%	3.83	1.69	227%
Rede										
Otterburn	NY8634194480	4.36	3.56	122%	3.68	2.72	135%	7.19	3.12	230%

Table 3: Antecedent river flows

Flows at the start of the year were exceptionally low with many key gauging stations recording new monthly minimas in March. However, from April 3rd flows increased as the weather turned more unsettled and there were some very wet spells of weather on the 10th May and the 10th and 23rd of June. This later event is the subject of a separate flood event report. Monthly flows in May were between 1½ and 2½ times the LTA in all of the indicator sites on the main rivers in the NE area. In June monthly average flows were around 2½ times the LTA for the time of year. However, Table 3 shows that the river flows in some of the smaller, flashy urban tributaries to the east, such as the River Team, were around average for the time of year.

2.4 Summary of antecedent conditions

The late spring and early summer months of April to June experienced well above average rainfall. Rain over these months fell as long periods of steady rain, with frequent moderate showers in between. This caused a drop in SMD and by mid June soils across the northeast of England were saturated. Above average rainfall during June also increased river and base flows in the main rivers to well above long term average for the time of year.

3. Meteorological Conditions

On Thursday 28th June warm, moist energetic air lying over the UK became destabilized by a cold front which was approaching from the west. Thunderstorms initially developed in the south west early on the 28th, followed by a series of severe thunderstorms across the Midlands and the North East which resulted in torrential downpours, large hail stones, and frequent lightning strikes.

Meteorological Office synoptic (surface pressure) charts are available at six hourly intervals from 0000 GMT each day. For a thunderstorm system these provide the general context but are rarely available for the period of the local thunderstorm. Figure 3 combines the synoptic chart and the Hyrad UKPP 1km 15 minute accumulation radar rainfall images at 1200 GMT and 1800 GMT on the 28th June.

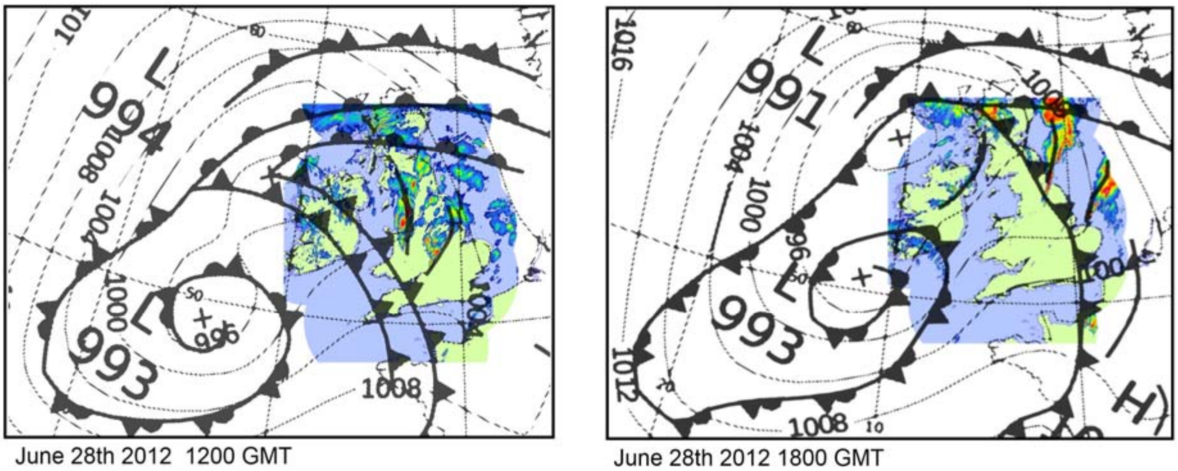

Figure 3: Combined synoptic and radar rainfall (1km 15 min accumulation) for 1200 GMT and 1800 GMT on 28th June 2012

Figure 3 shows that at 1200 GMT two areas of almost equal low pressure were lying to the west of the UK. Their associated frontal systems formed a complex pattern and in the unstable area between the fronts a number of troughs (the thin black lines on the chart) had developed. The radar image at this time shows how the warm fronts lying over Scotland produced a zone of widespread rainfall and the cold fronts over Ireland and Cornwall were producing very little rainfall. The instability between the fronts shows up clearly on the radar as two bands of intense rainfall associated with troughs lying across North-West England and the Midlands.

By 1800 GMT the frontal systems associated with each area of low pressure had merged and travelled north easterly to lie over the east coast of the UK. The radar image shows how the troughs had intensified as the fronts merged and moved, reflecting a period of increasing instability. There is a very clear association between the location of the troughs and the areas of the most intense rainfall on the radar images.

This system is characteristic of a phenomenon known as a Spanish Plume. Strong convection over the Spanish Plateau, combined with orographic uplift over the Pyrenees produces a mass of unstable, warm and moist air. Lines of strongly convective storms develop when this meets further unstable, moist and warm air in frontal systems arriving from the South West Atlantic. The thunder storm cells force large and rapid changes in local wind direction and speed (wind sheer) which causes the further development of storm supercells with violent wind sheer, large hail stones, and intense rainfall.

The association between troughs which develop in unstable frontal systems and areas of unusually intense rainfall has produced a number of notable flood events. The widespread and severe June 2007 floods are an example of intense rainfall associated with troughs which developed as two frontal systems merged.

3.1 The track of the thunderstorm : 1430 GMT to 1700 GMT

Figure 3 shows the general north easterly track of the troughs during the afternoon of the 28th June. However, the Hyrad radar rainfall images of UKPP 1km 15 minute accumulations suggest that for much of the afternoon the trough actually moved south eastwards before resuming a north easterly track in the early evening.

The default Hyrad radar presentation shades a rainfall total of 8mm in orange no matter over what period it accumulates. In the following graphs this is modified so that 8mm in 15 minutes is the same pink colour as the default for 32mm in 1 hour to enhance the visual definition of the storm.

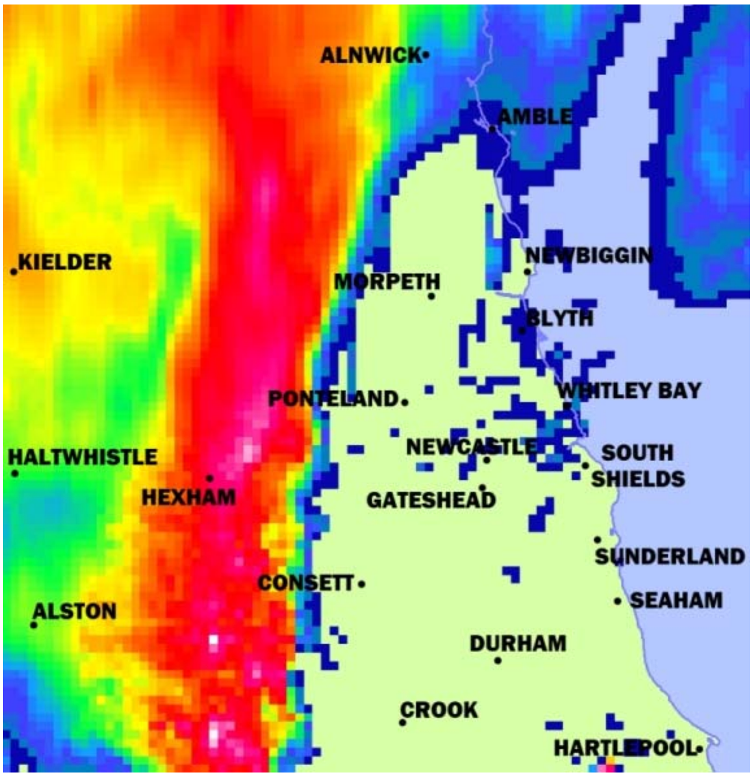

Figure 4 shows that at 1430 GMT the trough was lying roughly in a north to south line over Hexham. Between 1200 GMT and 1430 GMT this trough had travelled eastward with the rainfall gradually becoming more intense and organised into a storm line. By 1430 GMT many places to the west of Hexham had already experienced rain rates of 4mm in 15 minutes (red colour) but not the very intense rainfall associated with the pink (8mm) and white (16mm) colours.

Figure 4: Hyrad UKPP 1km 15 min accumulation 1430 GMT 28th June 2012

Between 1445 GMT and 1515 GMT the band of intense rainfall began to develop a bulge which swung southwards towards Durham. It also began to develop a much greater intensity. The cause is difficult to identify but it may reflect the change in topography over the Cheviot hills.

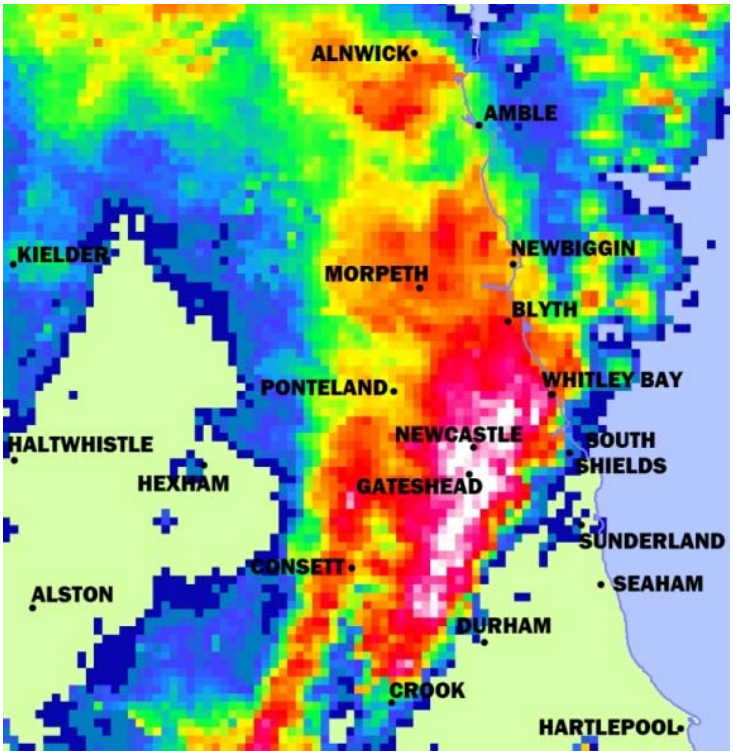

Figure 5 shows that by 1515 GMT the bulge had developed into a single, large and very intense storm. This was centred over Newcastle and Gateshead but stretched as far south as Durham and north to Blyth.

In addition, the trough was also producing more isolated areas of somewhat less intense rainfall over many parts of Northumbria.

Figure 5: Hyrad UKPP 1km 15 min accumulation 1515 GMT 28th June 2012

Between 1445 GMT and 1600 GMT a further intense storm developed to the west of Crook around Tow Law. At the same time the intensity of the initial storm over Newcastle and Durham eased a little.

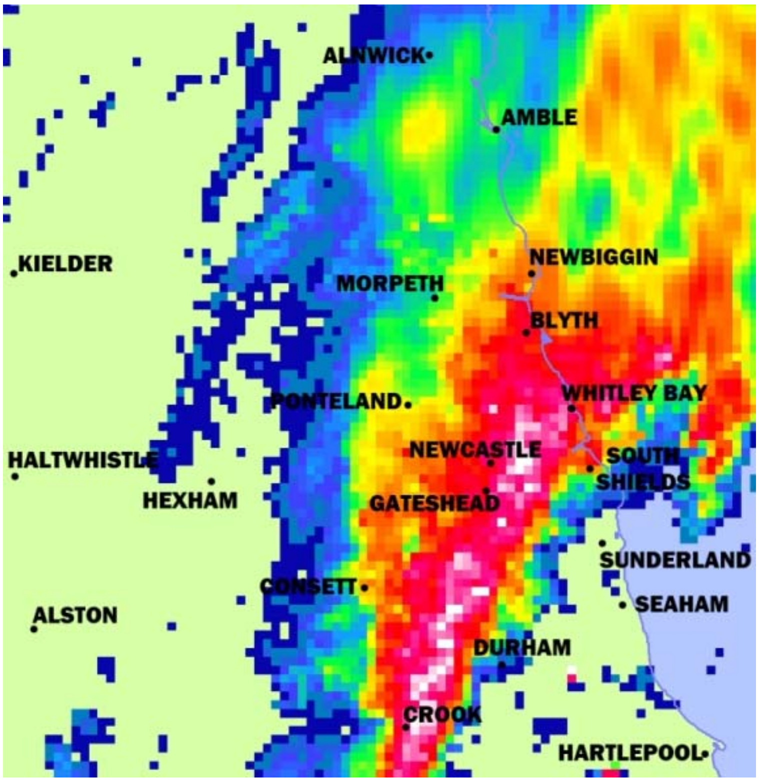

Figure 6 shows that the storm line had continued to track south eastwards. By 1615 GMT it had once again intensified over Tyneside and merged with the storm over Crook to form an almost continual line of very intense of storm cells stretching from the Tees to the Tyne.

Between 1615 and 1700 the radar images suggest development of a further line of storms behind the original storm line. This feature is similar to that which caused the Boscastle Floods in August 2004.

Figure 6: Hyrad UKPP 1km 15 min accumulation 1615 GMT 28th June 2012

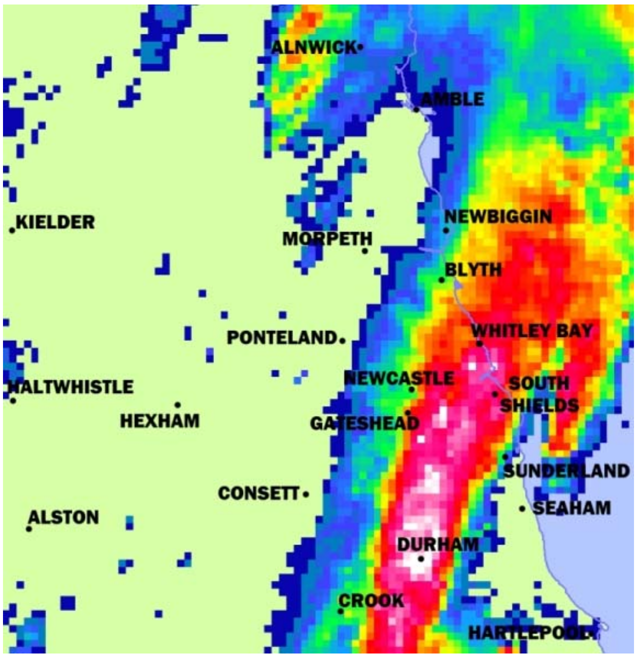

Figure 7 shows that by 1700 GMT the storm had moved further to the south east but lost little of it's intensity. The most intense rainfall had concentrated into a slightly narrower band running from Durham to Whitley Bay.

By 1715 GMT the most intense rainfall had ceased and the trough started to move more rapidly north eastwards once more. As it did so it broke into more isolated areas of intense rainfall, one of which remained over Whitley Bay for a further hour.

Figure 7: Hyrad UKPP 1km 15 min accumulation 1700 GMT 28th June 2012

Newcastle University operate a weather station on the roof of the Drummond Building in the centre of Newcastle which records event rainfall, air temperature and wind direction. Data provided by Newcastle University clearly show the passage of several storm cells between 1500 GMT and 1700 GMT.

Figure 8 shows the air temperature dropped to 14.5^{o}C just after 1500 GMT and Figure 9 shows the rapid change in wind direction by almost 270° in 15 minutes, veering from south easterly, through westerly, to almost due north. These data indicate the passage of a very strong gust front ahead of the thunderstorm. Whilst gust fronts are not unusual, this is particularly pronounced and shows the severity of the coming storm. Between 1500 GMT and 1700 GMT the temperature remained some 4°C lower than it had been and the wind direction switched rapidly several times as each storm cell passed.

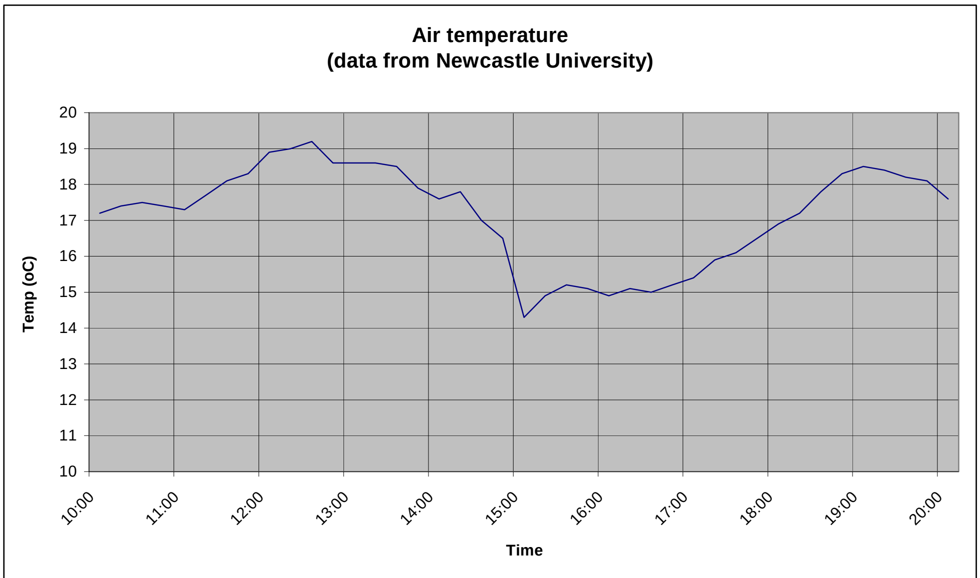

Figure 8: Air temperature recorded at Newcastle University on June 28th 2012

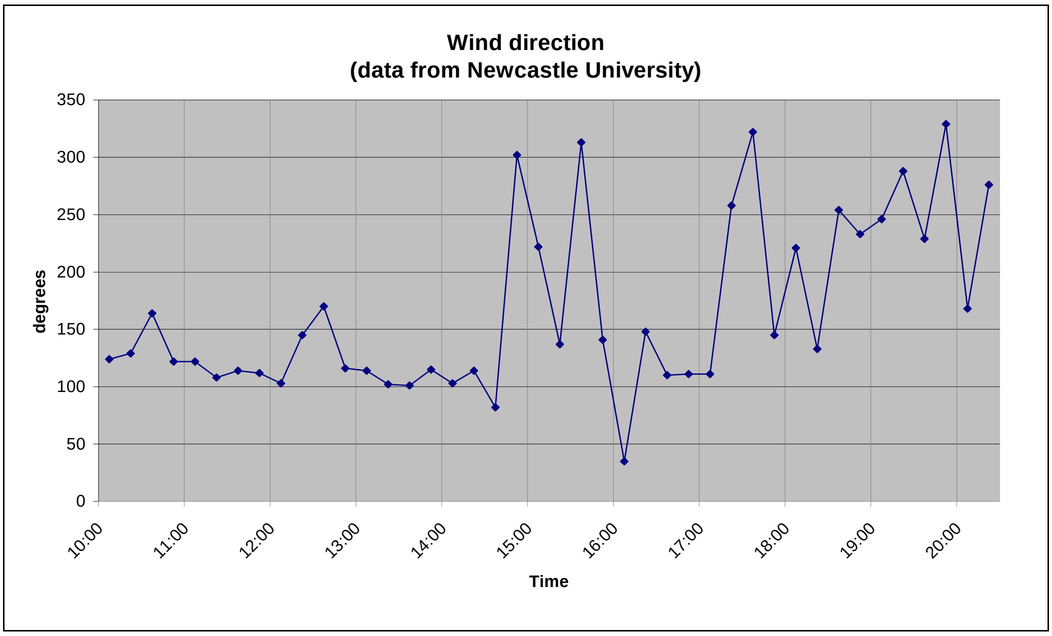

Figure 9: Wind direction recorded at Newcastle University on June 28th 2012

Rainfall at Newcastle University Drummond Building is recorded using a standard tipping bucket raingauge (TBR) and also a disdrometer. A disdrometer measures the rain drop size and rain rate. Some caution is required as the gauges are located on the roof of a building but they do provide an indication of the passage of the storm cells over Newcastle

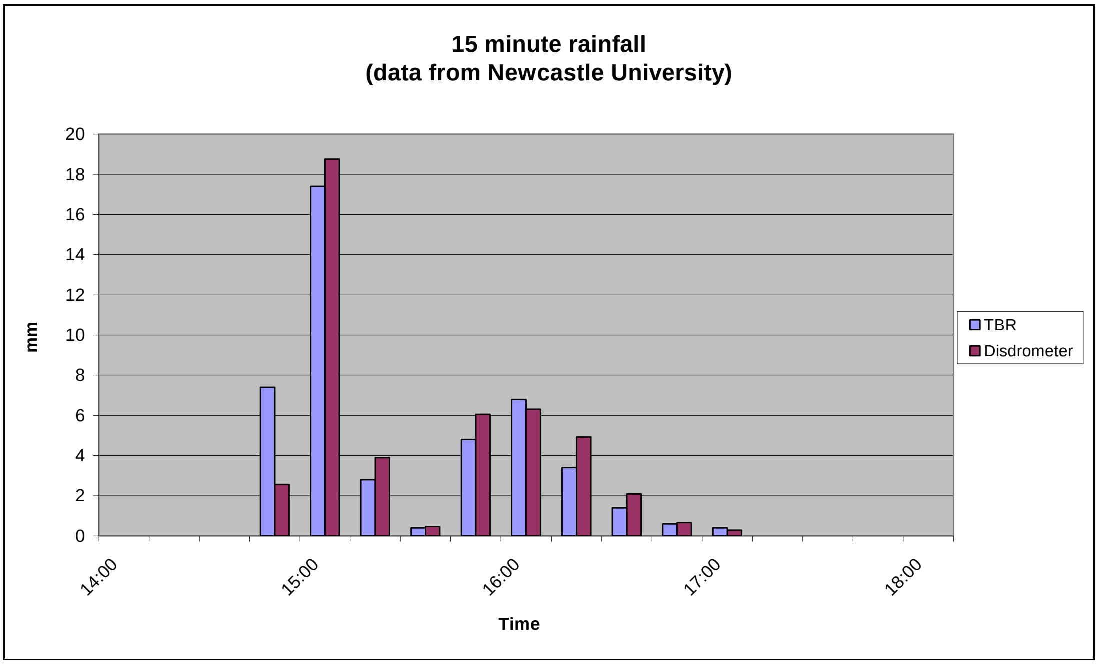

Figure 10: Rainfall recorded at Newcastle University June 28th 2012 (15 minute accumulations)

In Figure 10 both gauges show two periods of intense rainfall. The first and most intense storm cell occurs between 1445 GMT and 1515 GMT. This is followed by a second storm period between 1545 GMT and 1615 GMT. There is reasonable correspondence between the gauges; the disdrometer recorded 43.4mm in two hours compared to 38mm from the TBR.

4. North East Area Overview

This section of the report aims to provide an overview of the most notable aspects of the event across the North East area. Details of the rainfall, river level and flow, along with the associated return periods, are summarised below to provide a broad understanding of the event.

4.1 Rainfall

Figures 12 and 13 show the total amount of rain which fell across the North East area of the Yorkshire & North East Region during the 24 hour period between 0900 GMT and 0845 GMT on the 28th to 29th June. Selecting this time period allows data from our network of daily gauges to be used but in reality over 90% of this rain fell in the two hours from 1500 GMT on the 28th, as shown on Figure 11.

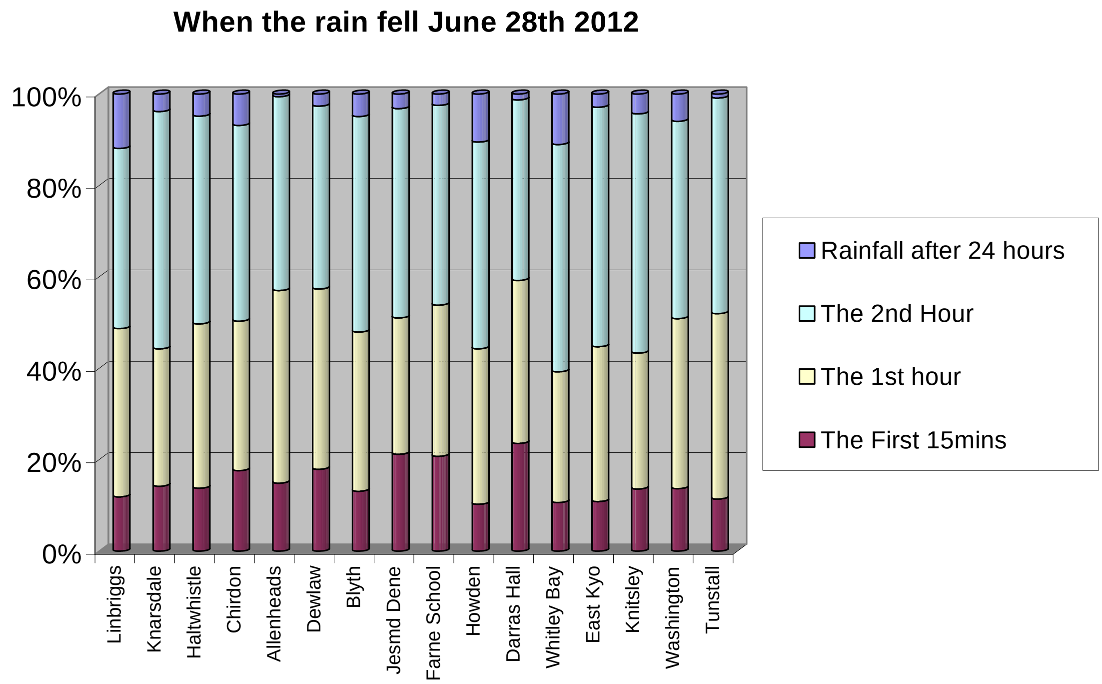

Figure 11: Analysis of rainfall accumulation from 1500 GMT on 28th June 2012

Table 4 shows the rainfall distribution at selected rain gauges across the affected areas. This table shows the maximum amount of rain which fell in selected periods and the associated return period. In addition, the rainfall as a percentage of the June LTA is given.

Rainfall return periods have been calculated using the UK standard methods set out in the Flood Estimation Handbook by depth-duration-frequency modelling.

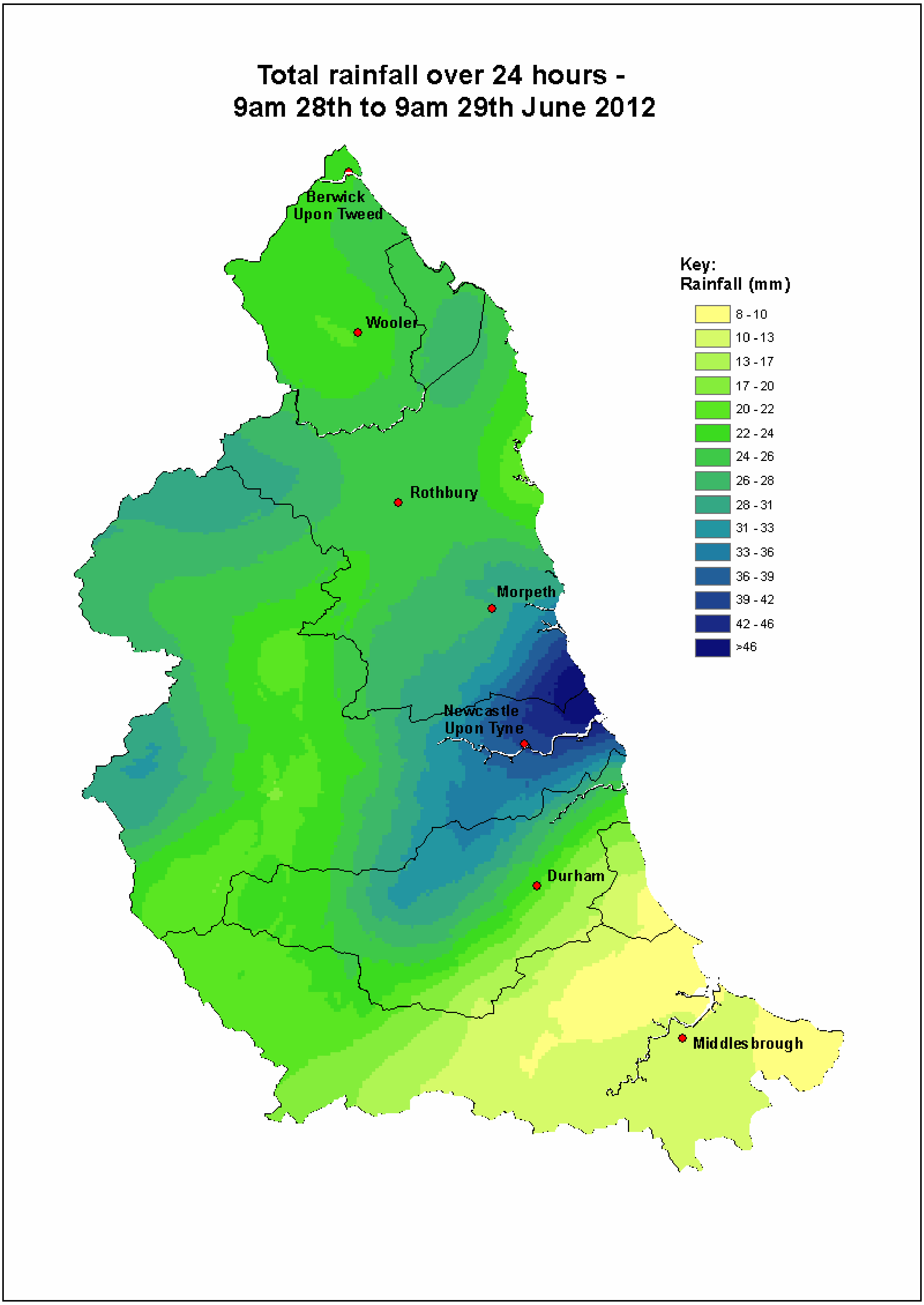

Figure 12: Total rainfall recorded between 0900GMT and 0845 GMT on the 28th to 29th June 2012.
Virtually all of this rain fell in 3 hours.

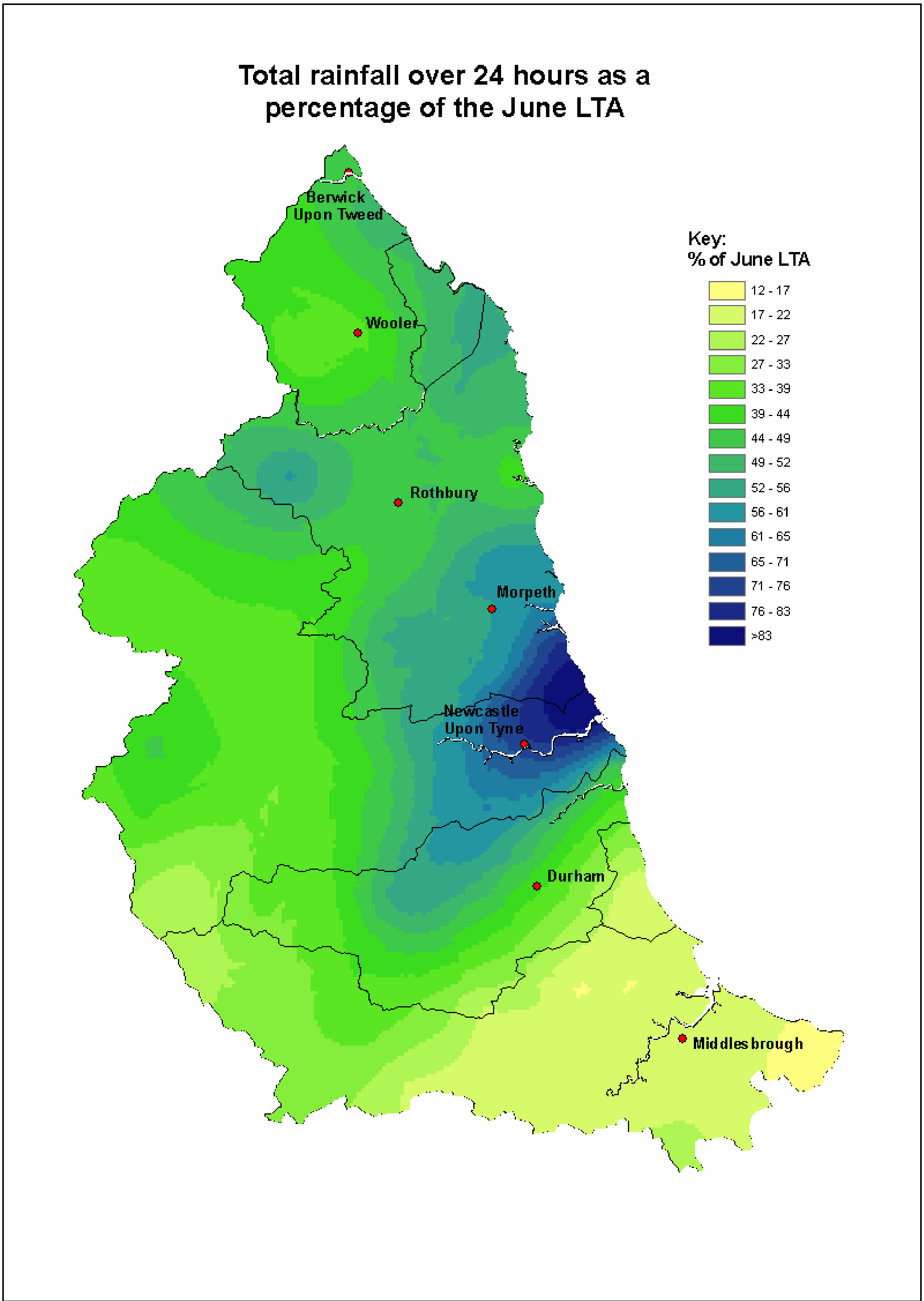

Figure 13: Rainfall for the 28th June 2012 as a percentage of the June LTA

Figure 12 and Table 4 show that the largest totals and most intense rain was centred over Newcastle and North Tyneside. This is most clearly demonstrated in the high totals recorded at the gauge at Whitley Bay. The amount of rain generally decreased further west, ranging from 28mm at Chirdon on the North Tyne to 20mm at Old Spittal on the Greta.

Another concentration of intense rain was situated across the South Tyne. Table 4 shows that Knarsdale recorded almost 40mm in three hours. This increased river levels at Featherstone to a point which would have been a record in other years but were not as high as those of the 23rd June 2012 event; as described in the 23rd June South Tyne Flood Hydrology Report.

Figure 13 shows that high percentages (greater than 50%) of the June LTA rainfall were recorded across much of the eastern coastal area. In the areas of most intense rainfall more than the whole June LTA fell in a three hour period. The values were generally lower over the far north west of the area, over the North Tyne and Tees catchments.

Rainfall return periods in excess of 30 years occurred at many locations across very short durations and are highlighted in Table 4. The return periods for the two hour event range from around 160 years at Whitley Bay on the North Tyneside coast, to 10 years in the Pont and Blyth catchments. These data clearly show how the most intense rainfall was concentrated in particular locations and, at those locations, it was a very short event of exceptional intensity.

28 June event (peak intensities)	Northumberland catchments								Tyneside					Wear			Tees		
	Linbriggs	Blyth	Dewlaw	Darras Hall	Chirdon	Knarsdale	Haltwhistle	Allenheads	Jesmond Dene	Farne Sch	Howden	Whitley Bay	East Kyo	Tunstall	Knitsley	Washington	Old Spittal	Folly House	Lartington
mm rainfall																			
30 min	16.4	14.4	24.2	18	12.2	16	19.8	18.6	26.4	21.6	15.6	19.8	18.8	22.8	16.8	16	15	23.8	18.8
1 hour	25.4	17	26.8	22.4	20	22	28.2	30	31.8	24.2	29.8	29	21.2	37	19.2	22	18	29.4	21.4
75 mins	27.2	21.2	26.8	22.4	21.2	27.8	30.8	30.2	40.2	29.8	37	33.8	28	40.8	27.2	27.8	19.6	30.8	22
1.5 hours	28.8	22.2	26.8	23.6	23.8	36.2	33.2		44	31.6	38.2	35.2	32.8	43	33.6	36.2		31	
2 hour	31	23.4	27.2	24.8	26.2	38	35.6		48.8	32	39.6	50.4	32.8	43	33.8	38			
2.5 hour	31.4				27.2	38.6	36.4		50.8	32	45	56.4							
3 hour	31.4				27.4	39.4			50.8	32.2		58.6							
return period																			
30 min	18	10	55	19	5	11	22	15	68	34	11	26		42	15	11		45	
1 hour	38	8	38	17	12	12	35	32	59	23	48	45	14	98	10	14	6	43	14
75 mins	37	13	30	13	11	21	37	25	109	37	83	61	28	107	25	17	6	39	12
1.5 hours	30	12	24	12	14	44	40		123	38	77	58	39	104	43	14		33	
2 hour	21	10	18	10	14	37	37		131	28	64	162	27	72	30	10			
2.5 hour	16				12	29			117		81	196							
3 hour	17				10	25			94		74	185							
% of LTA June rainfall																			
30 min	36%	29%	48%	34%	17%	22%	30%	30%	49%	42%	31%	40%	30%	39%	30%	22%	24%	38%	33%
1 hour	56%	34%	54%	42%	28%	30%	42%	49%	58%	47%	60%	58%	34%	63%	34%	30%	28%	47%	37%
75 mins	60%	42%	54%	42%	30%	37%	46%	49%	74%	58%	74%	68%	45%	69%	48%	37%	31%	50%	38%
1.5 hours	63%	44%	54%	45%	34%	49%	50%		81%	62%	76%	70%	53%	73%	60%	49%		50%	
2 hour	68%	47%	54%	47%	37%	51%	53%		90%	62%	79%	101%	53%	73%	60%	51%			
2.5 hour	69%				39%	52%	54%		93%	62%	90%	113%							
3 hour	69%				39%	53%			93%	63%		117%							

Table 4: Analysis of June 28th 2012 rainfall totals, return periods and % of long term June average.

Return periods of between 30 to 50 years are highlighted in tan between 50 to 100 years in **orange** and in excess of 100 years in **red**.

4.1.1 *Comparison of rainfall from radar, TBR and daily read gauges*

Table 5 is an analysis which compares the UKPP 15 minute accumulated rainfall radar with that recorded at selected raingauges. The greatest two hour total was recorded in the pixel which overlies the Jesmond Dene raingauge (44.3mm).

These data show that, for this event, at the 15 minute time step used by both the radar and recording TBRs, the radar rainfall underestimates of peak rainfall. For the gauges in Tyneside the percentage under estimation reduces as the duration increases, from around 40% for the peak 15 minute reading to less than 15% over three hours. In other parts of the area there is no pattern to the underestimation which varies from 1% at Howden to 46% at Tunstall.

The uncertainty is most likely to be the result of the inability of the radar to accurately quantify the extremely intense rainfall cells. Radar estimates are subject to under recording as a result of poor correlation between the atmospheric water movement and rainfall, spurious returns generated by atmospheric phenomena, interference of the radar beam from the ground, and image processing inaccuracies.

Despite the uncertainties in the recorded totals, the radar analysis does support the picture of rainfall distribution described by the TBRs in figures 12 and 13.

Location	Peak Rainfall (mm)							
	15 min	30 min	45 min	1 hour	75 min	90 min	2 hours	3 hours
Jesmond Radar Pixel	13.38	18.5	23.3	24.8	32.9	37.7	44.3	44.3
Jesmond Raingauge	22.6	26.4	29	31.8	40.2	44	48.8	50.8
Radar Under estimate (mm)	-9.2	-7.9	-5.7	-7.0	-7.3	-6.3	-4.5	-6.5
Radar Under estimate (%)	-40.8%	-30.0%	-19.7%	-21.9%	-18.2%	-14.4%	-9.2%	-12.8%
Farne Sch Radar Pixel	10.28	14.72	15.03	17.91	23.88	25.94	27.3	
Farne Raingauge	15.2	21.6	22	24.2	29.8	31.6	32	
Radar Under estimate (mm)	-4.9	-6.9	-7.0	-6.3	-5.9	-5.7	-4.7	
Radar Under estimate (%)	-32%	-32%	-32%	-26%	-20%	-18%	-15%	
Whitley Bay Radar pixel	9.25	14.28	19.72	24.78	26.56	29.31	40.9	45.8
Whitley Bay Raingauge	10.8	19.8	22.8	29	33.8	35.2	50.4	58.6
Radar Under estimate (mm)	-1.6	-5.5	-3.1	-4.2	-7.2	-5.9	-9.5	-12.8
Radar Under estimate (%)	-14%	-28%	-14%	-15%	-21%	-17%	-19%	-22%
Howden Radar pixel	8.3	15.4	21.3	28.3	32.6	35.0	37.6	44.6
Howden Raingauge	9	15.6	22.2	29.8	37	38.2	39.6	46.4
Radar Under estimate (mm)	-0.7	-0.2	-0.9	-1.5	-4.4	-3.2	-2.0	-1.8
Radar Under estimate (%)	-8%	-1%	-4%	-5%	-12%	-8%	-5%	-4%
Tunstall Radar pixel	7.5	12.4	17.5	22.5	27.2	30.1	30.2	
Tunstall Raingauge	10.4	22.8	26.6	37	40.8	43	43	
Radar Under estimate (mm)	-2.9	-10.4	-9.1	-14.5	-13.6	-12.9	-12.8	
Radar Under estimate (%)	-28%	-46%	-34%	-39%	-33%	-30%	-30%	

Radar over estimates in BLACK, under estimates in RED

Table 5: Comparison of radar and recorded rainfall at selected locations on June 28th 2012

Following the risk based approach to site visits most of the check gauges associated with our tipping bucket gauges are now read on a monthly instead of daily basis. This restricts the number of sites where it is possible to determine the accuracy of the TBRs during a single event. Table 6 shows comparison with those sites for the 28th June where this is possible.

Site No.	Site Name	Grid Ref.	Daily Total (mm)	TBR daily total (mm)	TBR as % daily
008236	Blyth	NZ3089179669	48.2	25.4	53%
007532	Darras Hall	NZ1469171218	27.7	25.6	92%
014554	Haltwhistle	NY6801164061	42.8	39.4	92%
015346	Allenheads	NY8585745609	36.2	30.6	85%
017652	Farne School	NZ2028267317	37	33.8	91%

Table 6: Comparison of daily totals from daily read gauges and tipping bucket gauges at selected locations

In general the daily read gauges and TBRs recorded similar rainfall totals for the 28th June. The daily read gauge at Blyth is not at the same location as the TBR, although it is less than 3 km to the south east. This variation in the daily totals further illustrates the highly localised nature of the rainfall even within the generally widespread thunder storm line.

4.2 River level

This section of the report examines river levels in the affected catchments. The river level is a measurement of water surface elevation above a datum at the site. It is not necessarily related to ordnance datum or to any other local measurement such as height above a weir or the river bed. To this end, it is not a comparable measurement between sites; a level of 10m at one site is not necessarily a higher river level than a level of 5m at a site elsewhere. This measure relative to an onsite datum is termed stage.

Table 7 shows the rank order of water years based on their peak stage. The water year runs from October to September, ensuring that a single winter season does not span two calendar years - thus the June 2012 event falls within the 2011 water year.

Table 8 shows the peak levels for each water year in rank order. In combination with Table 7 these tables illustrate the differing effects of the event across the North East.

The 28th June 2012 event had a significant impact on the urban, flashy catchments in the lower Tyne and Wear, with many gauges recording the highest river levels in their respective records. The isolated extent of gauges recording their highest level is indicative of the intense nature of the thunderstorm that caused this event.

The most severe impacts were seen in the areas of most intense rainfall, in particular on the River Team and the Smallhope Burn. In these catchments, unprecedented levels were recorded at all gauges on the respective watercourses.

- In the Team catchment, both gauges recorded unparalleled levels. Tanfield has a record length of just over ten years and the previous maximum recorded here was exceeded by over 1.4m. Team Valley has a AMAX series beginning in 1974, although the record length is 33 years as four years are omitted. It is not possible to compare river levels throughout the entire record as the site was moved in 1991, but the previous highest flow exceeded by around 4 cumecs.

- In the Smallhope Burn catchment unprecedented levels were recorded at both Lanchester Front Street (which has a nine year record) and Knitsley Mill (which has an eight year record). It was also the highest event recorded at Lanchester on the Browney which has a 23 year record. Levels exceeded all previous events by around 0.5m at Lanchester and 0.9m at Knitsley Mill.

- The Ouseburn was also affected, with the third highest levels on record at both Woolsington and Crag Hall. Of particular note is the rapid rate of rise in the Ouseburn at Crag Hall which rose one metre in 30 minutes. This is discussed in more detail in Section 6.

- On the Cockshaw Burn water levels were over 0.2m above the previous highest event at Tanners Row and Maidens Croft, both of which have eleven year records. On the Don at Hylton Bridge the level was 0.9m higher than the previous record in a seven year series.

- On the Rede the Otterburn flow gauge and Otterburn Mill river level site marginally recorded their highest levels in 13 and 17 year records respectively.

	Derwent		Coquet	Wansbeck	Ouseburn			Tyne							Wear			
Rank	Blackhall Mill	Rowland's Gill	Alwinton Bridge	Middleton Bridge	Woolsington	Crag Hall	Gosforth	Maidenscroft	Tanners Row	Team Valley	Tanfield	Hylton Bridge	Otterburn Mill	Otterburn	Knitsley Mill	Lanchester	Lanchester Front St	Chester Burn
record length (years)	11	50	12	10	28	28	5	11	11	30	11	7	17	13	8	28	9	4
1	2007	2007	2008	2007	2007	2007	2007	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011
2	2008	2000	2007	2001	1999	2004	2011	2010	2010	1999	2010	2010	2004	2008	2008	2008	2008	2008
3	2011	2011	2011	2011	2011	2011	2010	2009	2009	1992	2009	2009	2001	2001	2004	1978	2004	2010
4	2004	2008	2009	2009	2000	2000	2009	2008	2008	2004	2008	2008	2008	2004	2007	2007	2007	2009
5	2009	1967	2004	2003	1991	1991	2008	2007	2007	2000	2007	2007	2009	2009	2009	2009	2003	
6	2003	1962	2005	2002	2009	1992		2006	2006	2008	2006	2006	1998	2005	2010	1970	2009	
7	2010	1965	2003	2010	1995	1999		2005	2005	2007	2005	2005	2005	2000	2006	2003	2010	
8	2005	1999	2000	2005	1992	1995		2004	2004	1991	2004		2010	2010	2005	1982	2005	
9	2002	1992	2001	2008	2001	2006		2003	2003	2003	2003		2002	2007		1976	2006	
10	2006	1985	2002	2006	2010	2008		2002	2002	1995	2002		2007	2002		2010		
11	2001	1987	2006		1998	1998		2001	2001	1996	2001		2003	2003		1968		
12		2004	2010		1976	2001				1998			1999	1999		1971		
13		1978			2005	1997				1997			1995	2006		1975		
14		1970			1997	2010				2001			1997			2004		
15		2009			1996	1985				2006			1994			2002		
16		1963			2008	1996				2009			2006			2005		
17		1976			1993	2003				1993			1996			1969		
18		1981			2002	2005				2010						2006		
19		1968			1985	2009				1994						1967		
20		1982			2008	2002				2005						1972		
21		1993			1985	1986				2002						1977		
22		1991			1994	1990				1990						1980		
23		1994			2006	1988										1973		
24		1997			1986	1993										1979		
25		2001			1984	1994										1981		
26		1996			1977	1989										1974		
27		1998			1983	1987										2001		
28		1984			1979	1987												
29		1964			1981													
30		2003			1987													
31		1977			1980													

Table 7: Rank order AMAX values in water years
28th June 2012 event highlighted in **red**, September 2008 event highlighted in **orange**, Nov 2000 event highlighted in **blue**

Rank	Derwent		Coquet	Wansbeck	Ouseburn			Tyne							Wear			
	Blackhall Mill	Rowland's Gill	Alwinton Bridge	Middleton Bridge	Woolsington	Crag Hall	Gosforth	Maidenscroft	Tanners Row	Team Valley	Tanfield	Hylton Bridge	Otterburn Mill	Otterburn	Knitsley Mill	Lanchester	Lanchester Front St	Chester Burn
record length (years)	11	50	12	10	28	28	5	11	11	30	11	7	17	13	8	23	9	4
1	2.566	2.37	2.763	2.17	1.682	1.79	2.2	0.776	1.09	1.55	2.78	2.47	4.154	3.508	2.09	2.806	2.245	2.59
2	2.306	1.979	2.733	1.913	1.592	1.497	1.72	0.527	1.32	1.3	1.35	1.51	4.149	3.502	1.15	2.233	1.722	1.91
3	2.053	1.788	2.467	1.847	1.515	1.451	1.33	0.473	1.34	1.3	1.36	1.61	4.122	3.49	0.882	1.338	1.556	1.63
4	1.566	1.758	2.039	1.781	1.498	1.444	1.46	0.353	0.606	1.27	1.94	1.97	4.119	3.458	0.784	1.251	1.421	1.52
5	1.486	1.63	1.979	1.699	1.338	1.404	1.55	0.576	1.12	1.21	1.84	1.94	3.975	3.4	0.689	1.205	1.338	
6	1.266	1.6	1.915	1.668	1.335	1.393		0.675	0.905	1.12	1.37	1.39	3.96	3.372	0.593	1.19	1.266	
7	1.13	1.47	1.906	1.64	1.256	1.314		0.192	0.599	1.07	1.19	1.25	3.926	3.317	0.573	1.154	1.014	
8	1.066	1.367	1.893	1.539	1.23	1.311		0.182	0.246	1.07	2.04		3.839	3.304	0.552	1.111	0.877	
9	1.046	1.332	1.657	1.287	1.182	1.218		0.178	0.537	1.05	1.29		3.832	3.259		1.094	0.829	
10	1.046	1.326	1.496	1.242	1.154	1.171		0.175	0.404	1.05	1.17		3.813	3.223		1.079		
11	0.646	1.292	1.472		1.116	1.119		0.189	0.266	1.02	0.855		3.694	3.18		1.04		
12		1.262	1.422		1.111	1.109				0.984			3.672	3.025		1.04		
13		1.242			1.104	1.085				0.954			3.58	2.986		1.038		
14		1.214			1.085	1.082				0.952			3.46			1.009		
15		1.192			1.042	1.079				0.914			3.456			0.989		
16		1.19			1.022	1.063				0.909			3.297			0.96		
17		1.16			0.965	1.052				0.877			2.68			0.95		
18		1.144			0.962	1.035				0.799						0.949		
19		1.13			0.92	1.034				0.794						0.93		
20		1.128			0.907	1.006				0.793						0.86		
21		1.122			0.906	1.004				0.784						0.828		
22		1.109			0.882	0.947				0.429						0.826		
23		1.077			0.841	0.926										0.81		
24		1.01			0.826	0.917										0.783		
25		0.978			0.819	0.858										0.76		
26		0.967			0.813	0.844										0.746		
27		0.947			0.792	0.643										0.664		
28		0.934			0.79	0.458												
29		0.93			0.79													
30		0.923			0.748													
31		0.918			0.703													

Table 8: Rank order of AMAX in peak stage (m)
*28th June 2012 event highlighted in **red**, September 2008 event highlighted in **orange**, Nov 2000 event highlighted in **blue***

4.3 River flows

River flows are measured in cubic metres per second or 'cumecs' ($m^3 s^{-1}$). River flows are obtained either directly from the on site instrumentation or, more commonly, derived from the measured river level using a stage-discharge or rating equation. Rating equations often become increasingly uncertain at higher flows, due to complex flow patterns, changing hydraulic controls, out of bank flows and the scarcity of good quality flood gaugings for calibration. This limits the number of sites for which flow frequency calculations can be made.

4.3.1 Flow measurements

Table 9 lists the sites for which flow data are available. A simple four category system has been used to indicate the accuracy of the sites. For some sites we are unlikely to be able to arrive at an accurate flow estimate.

- Not applicable to high flows. — Site is not designed, or is unable to be used, to calculate high flows.
- Rating review required to calculate flow — Rating is currently not able to be used to calculate flows for this event without further review
- Acceptable at high flows, with caution — Rating can be used to calculate high flows but may not be applicable or may need additional information for this event
- Good at high flows — Rating can be used to calculate flows for this event

Table 9 shows that the calculated flows are based on ratings derived from a variety of sources and of variable certainty.

Browney Catchment At Lanchester (site number 24007) the flow site closed in October 1983 and was reopened in May 2002 as a level only flood warning site. It was not possible to apply the old rating to the new stage record due to the accumulation of gravel during the intervening period. The provenance of the stage AMAX record is unknown as it is not in the old station file or in WISKI.

Derwent Catchment On the River Derwent at Rowland's Gill check gaugings have only been carried out at low flows. The rating has been calibrated using a physical model and is assumed to be applicable at high flows, however it is necessary to apply some caution.

Catchment	Site	Gauged Level (m)	Wrack level (m)	Highest Check Gauging (m)	Rating Equation Status	Flow ($m^3 s^{-1}$)	Comment
Browney	Lanchester	2.806	-	0.52	Not applicable at high flows	-	Reopened as level only site in 2002
Derwent	Rowland's Gill	1.788	-	0.42	Acceptable at high flows, with caution	115	Only check gauged at low flows but calibrated with physical model, assumed to be applicable to highest flows. Loss of accuracy around peak.
Ouseburn	Woolsington	1.515	-	0.79	Acceptable at high flows, with caution	5.81	Combined weir and ultrasonic rating. Uncertainty above Qmed – not quantified by many gaugings but new rating developed in 2009 provides better fit to the gaugings that exist.
	Crag Hall	1.451	-	0.38	Rating review required to calculate flow	*17.11*	No high flow check gaugings. Bypassing of weir by Ouseburn Interceptor and trunk sewers affects high flows. JBA modelling study 2002.
Tyne	Otterburn ultrasonic	3.508	-	2.7	Rating review required to calculate flow	*194*	Unmeasured flow over floodplain when stage in excess of 3.2m. Current rating overestimates flow at high levels – see rating review
	Team Valley	1.256	1.55	0.93	Good at high flows	32.67	Site moved in 1991 so level record not comparable. Wrack mark fits with trace when compared with Tanfield level site upstream.

Table 9: River flow gauging station data for 28th June 2012.

Ouse Burn Catchment At Woolsington on the Ouse Burn an informal flat V weir has been in use since 1973. In 1991 the site was relocated a short distance downstream when the Metro train line was constructed. In 2001 an ultrasonic gauge was installed for the purpose of calibrating high flows at the site and was subsequently removed in 2007. The weir drowns at moderate flows and water frequently overtops the wing walls of the structure. A flow of 5.8 cumecs was measured for the 2012 event, using a new combined theoretical and ultrasonic rating developed in 2009.

At Crag Hall, further down the Ouse Burn, the assessment of river flow is complicated by the operation of the Ouseburn interceptor and trunk sewer which bypass the gauging station. The current estimate of the flow that can by-pass the weir is the maximum capacity of the sewers which totals 4.4 cumecs (JBA Ouseburn Flood Study Report May 2002).

Tyne Catchment, River Team The calculated flow series for the Team Valley gauging station is a combination of records from two different sites. The original Team Valley gauge was located at Walter Wilson in the Team Valley Trading Estate. This was in a straight, engineered section with clay banks and a silty bed. However, the construction of the 1990 Gateshead Garden Festival lowered the bed level, exposing the inlet pipe and so the station was closed. This site had a theoretical rating, supplemented by current meter gaugings at high flows. The present station was installed further upstream in June 1991, leaving a discontinuity in the record. This means that the level record from one site cannot be compared to the other, however, as both sites have a reasonably well gauged flow record it is possible to combine the flow records to provide a single flow data series.

Tyne Catchment, River Rede On the River Rede at Otterburn there are two level sites and one flow site. On the River Rede itself, the level site at Otterburn Mill (23024) has a record from 1994 whilst the former ultrasonic flow gauge which is now a rated section at Otterburn (23033) has a shorter record from 2000. Otterburn Bridge (23048) which is located on the Otter Burn records river levels and has a record dating from 2003.

Both sites on the River Rede (Otterburn and Otterburn Mill), recorded their highest levels on record during the June 2012 event, narrowly exceeding those recorded in January 2002 and January 2005. The top three events at the Otterburn (23033) flow measuring site are all within 1cm of each other at around 3.5m. This is because the flow goes out of bank at around 3.2m and bypasses the site, ungauged, flowing across the floodplain.

4.3.2 Flood frequency analysis

Table 10 shows the return period estimates for the small number of sites where the flow estimates are considered sufficiently robust to use in Flood Estimation Handbook (FEH) analysis.

On the River Derwent at Rowlands Gill the peak flow of 115.3 cumecs. A return period of 30 years was determined using the FEH single site analysis approach.

In the Ouseburn catchment a flow of 5.8 cumecs was recorded at Woolsington. A pooling group assessment was carried out which indicated that the return period is from 15 to 20 years.

The degree of urbanisation, coupled with the effect of the interceptor means that it has not been possible to assess the return period of the event at Crag Hall. It was considered that the FEH statistical method would not provide a very accurate answer due to the difficulty in assessing the amount of flow in the sewer. It might be possible to ignore the sewer flow and carry out a FEH statistical analysis, assuming the sewer behaves the same way in every event. This would allow the measured flow for this event to be compared with design estimates of the measured flow to estimate the return period. However, it may generate problems with pooling the catchment based on it's catchment characteristics. A second option would be to use a revised form of the ReFH which has been applied to urban catchment, essentially separating out the rural and urban parts of the catchment and modelling them separately. However, this would be very time consuming and, given that the event was only ranked the third highest in the 28 years of gauged record, it was decided that this was not justified.

The level gauge failed to record the peak stage at Team Valley. The estimated peak flow of this event of 32.67 cumecs was calculated from the level derived from the wrack mark on site. This is discussed in more detail in section 5.1.2. This was the greatest flow on record at Team Valley, with an associated return period of 80 years.

There have been 18 events with a peak stage above 3.2m since the Otterburn flow site was opened in June 2000. The peak flow for this event was estimated to be 194 cumecs but due to the ungauged bypass flow it has not been possible to calculate an associated return period.

Catchment	Site	Peak Flow ($m^3\ s^{-1}$)	Estimated Return period (yrs)
Derwent	Rowland's Gill	115	30
Ouseburn	Woolsington	5.81	15 to 20
Team	Team Valley	32.67	80

Table 10: Flow return periods for June 28th 2012

5. The Catchments in Detail

This section of the report deals with the main areas affected in turn: Tyneside and specific tributaries in other catchments. Information gathered from the Environment Agency's hydrometric network is used to discuss how the event unfolded in each catchment and the resulting effects.

5.1 Tyneside

Tyneside was the area most severely affected by the June 2012 flood event. The conurbation covers the catchments of:

- The Ouse Burn;
- The lower Team;
- The Don.

There are several TBRs located across Tyneside, plus information received from the centre of Newcastle from the Geography department of the University of Newcastle. Analysis of the rainfall over Tyneside has been carried out based on the data from the Jesmond Dene, Whitley Bay and Howden TBRs.

5.1.1 The Ouse Burn

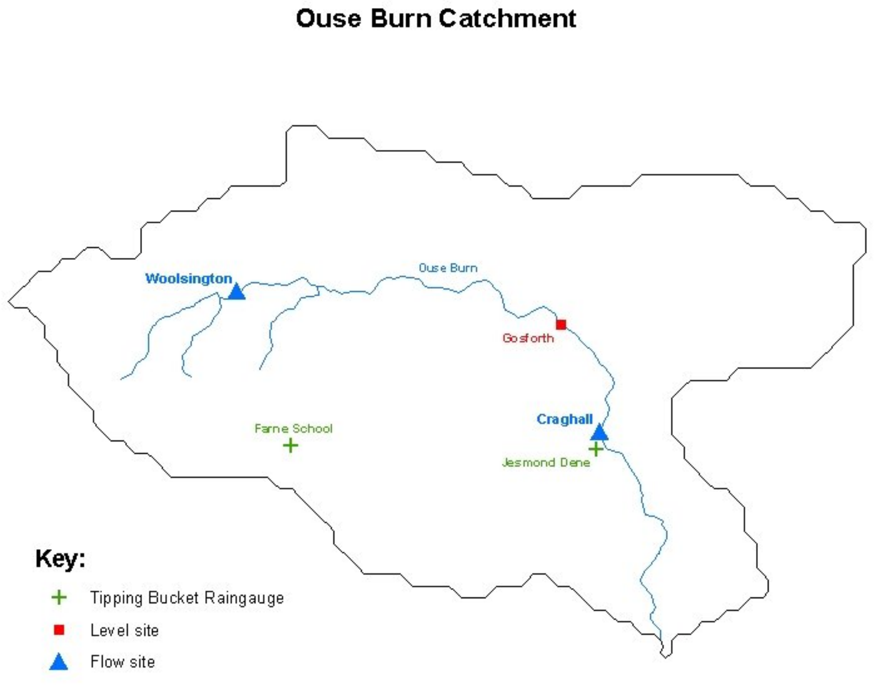

Figure 14: Ouse Burn catchment map

The Ouse Burn rises to the north of Newcastle and has a highly urbanised catchment. The northern edge of the catchment borders that of the River Pont. The river flows south-east, through Newcastle to its confluence with the River Tyne.

Rainfall
There are two TBRs in the Ouse Burn: Farne School TBR is located in the headwaters of the Ouse Burn, whilst Jesmond Dene is located in the mid catchment.

Figure 15 shows the rainfall rate, expressed in mm / hr, in one minute intervals at Jesmond Dene. There was a very intense pulse of rainfall at 1500 GMT followed by a second pulse of 10mm around 1600 GMT. Within this overall pattern the rainfall in the first six minutes after 1456 GMT was very intense; a rain rate of 200mm/hr being similar to that during the Boscastle and Carlisle flash floods.

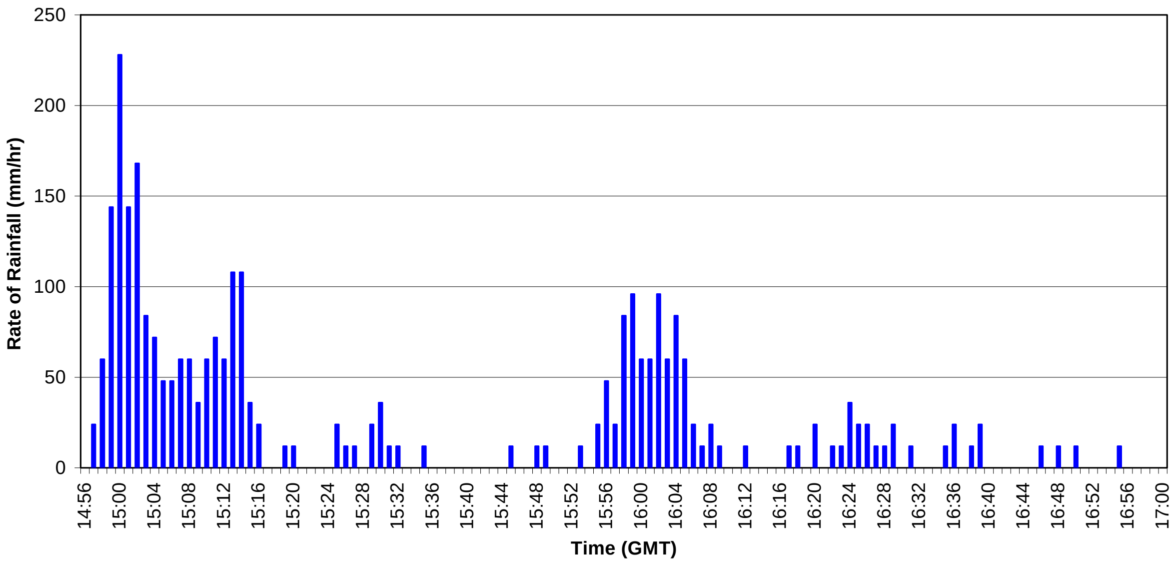

Figure 15: One minute rainfall rate at Jesmond Dene from 1456 GMT to 1700 GMT on June 28th

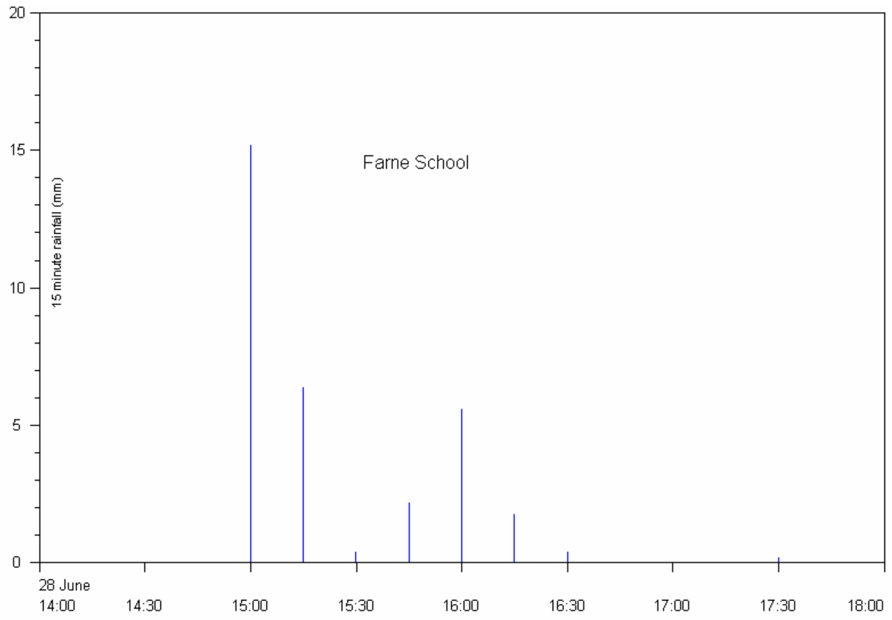

Figure 16: Farne School 15 minute rainfall total from 1400 to 1800 on 28th June

Figure 16 shows that, as at Jesmond Dene, the rainfall at Farne School started suddenly at 1500 on the 28th June and had almost ended by 1630. During this 90 minute period almost 32mm of rain fell. However, as the extract from Table 4 shows, the localised nature of the event meant that the rainfall recorded at Farne School was significantly less than that at Jesmond Dene.

	Tyneside	
28 June event (peak intensities)	Jesmond Dene	Farne Sch
mm rainfall		
30 min	26.4	21.6
1 hour	31.8	24.2
75 mins	40.2	29.8
1.5 hours	44	31.6
2 hour	48.8	32
return period		
30 min	68	34
1 hour	59	23
75 mins	109	37
1.5 hours	123	38
2 hour	131	28
% of LTA June rainfall		
30 min	49%	42%
1 hour	58%	47%
75 mins	74%	58%
1.5 hours	81%	62%
2 hour	90%	62%

Extract from table 4 showing rainfall analysis in the Ouseburn Catchment

River Levels

The extract from Table 8 shows that the event resulted in the third highest levels on record in the Ouse Burn catchment but were considerably lower than those recorded in the 2008 event.

	Ouseburn		
Rank	Woolsington	Crag Hall	Gosforth
record length (years)	28	28	5
1	1.682	1.79	2.2
2	1.592	1.497	1.72
3	1.515	1.451	1.33
4	1.498	1.444	1.46
5	1.338	1.404	1.55
6	1.335	1.393	

Extract from table 8 showing rank order of AMAX peak stage
June 2012 event highlighted in **red**, September 2008 event highlighted in **orange**, Autumn 2000 event highlighted in **blue**

Figure 17 shows that the river levels in the Ouse Burn responded exceptionally quickly to the intense burst of rainfall occurring at 1500 GMT. Indeed, one of the most remarkable features of the event was the exceptional rate of rise recorded at Crag Hall of one metre in 30 minutes.

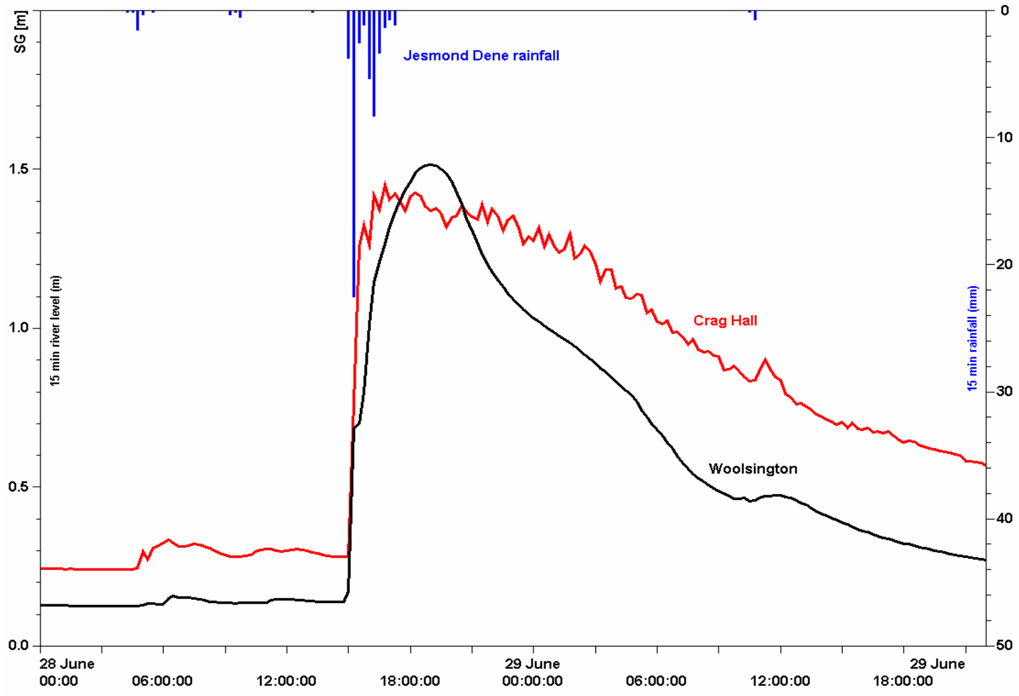

Figure 17: River levels in the Ouse Burn

The urbanisation of the middle and lower reaches caused a faster reaction to the intense rainfall than further upstream in the more rural catchment. The peak at Crag Hall was more sustained as flows from upstream maintained the high river levels.

5.1.2 North Tyneside

Although not strictly a hydrological unit, North Tyneside was the area most badly affected by surface water resulting from the storm and so warrants a particular mention. However, there are no river level recorders in this area as most of the urban catchments are very localised and often culverted. This section therefore examines the rainfall and the implications for surface water flooding.

The extract from Table 4 overleaf shows that the TBR at Whitley recorded the most rainfall of the event, both in absolute terms and as a percentage of the LTA, with the average total for June falling in just 2 hours.

Figure 18 provides a clear picture of the minute by minute distribution of the rainfall. Whilst not reaching the very high rainfall rate as recorded at Jesmond Dene there appear to be a greater number of storm cells, particularly after 1625 GMT.

	Tyneside	
28 June event (peak intensities)	**Howden**	**Whitley Bay**
mm rainfall		
30 min	15.6	19.8
1 hour	29.8	29
75 mins	37	33.8
1.5 hours	38.2	35.2
2 hour	39.6	50.4
return period		
30 min	11	26
1 hour	48	45
75 mins	83	61
1.5 hours	77	58
2 hour	64	162
% of LTA June rainfall		
30 min	31%	40%
1 hour	60%	58%
75 mins	74%	68%
1.5 hours	76%	70%
2 hour	79%	101%

Extract from table 4 showing rainfall analysis over Tyneside coastal areas

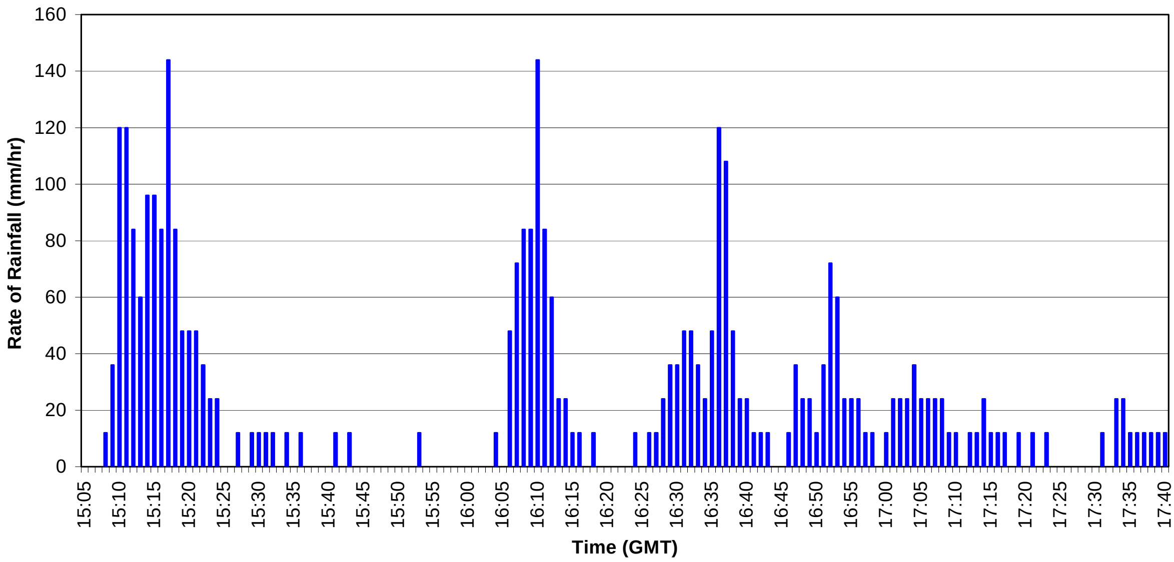

Figure 18: Whitley Bay one minute interval rainfall rate from 1505 to 1740 (GMT) on June 28th

The data for Whitley Bay are also supported by the TBR at Howden which is also on the coast.

Figure 19 graphs the rainfall totals each minute at Howden, rather than the rainfall rate, but the pattern of rainfall is similar. The amount of rainfall is lower than at Jesmond Dene but there are a larger number of storm cells passing the site. However, the initial thunderstorm at Howden is significantly less severe.

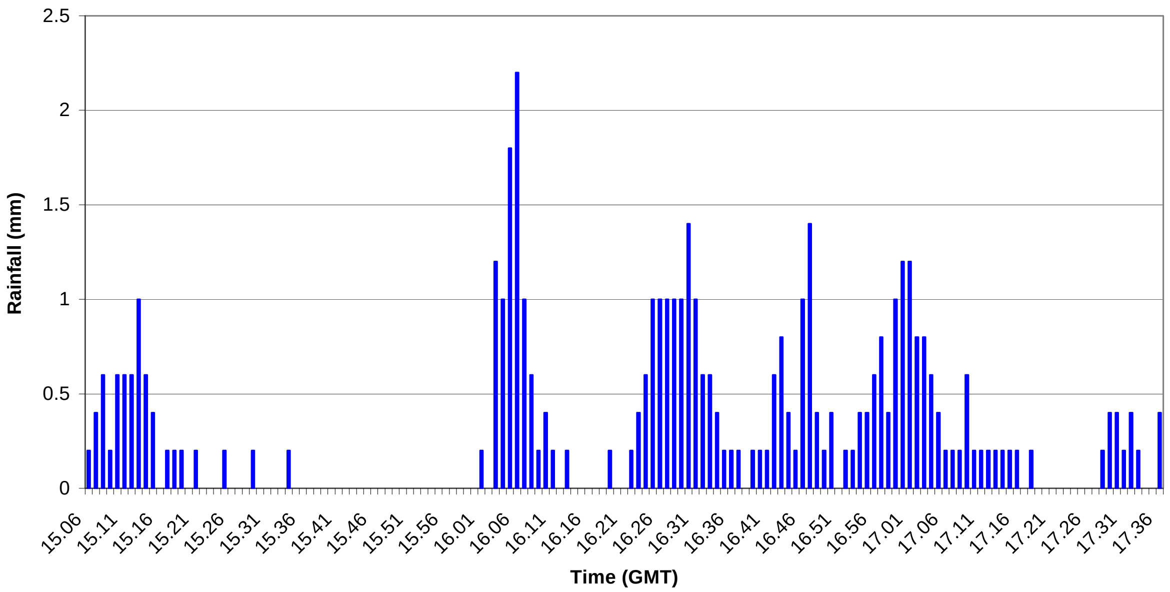

Figure 19: Howden one minute rainfall totals from 1600 to 1740 (GMT) on June 28th

These data correspond with the UKPP 15 minute radar accumulations shown in Figures 6 and 7 for 1630 GMT and 1700 GMT respectively. Figures 6 and 7 show the storm line having continued south eastwards away from central Tyneside but as it did so it also brought storms in over the coastal area.

The pattern of an initial intense storm, followed by a series of short duration but momentarily heavy rainfall episodes is likely to result in a large volume of surface water accumulating over a short period. The periods between each storm cell passing are often less than 10 minutes which gives insufficient time for lying water to drain down. Although each storm cell is only overhead for a short duration, the cumulative effect is as if a significant storm had remained in situ for more than 90 minutes. This effect is reflected in the very high two hour rainfall totals.

Surface water flooding in this catchment is most likely to be the result of the volume of water produced over the 90 minute period rather than the intensity of any single storm cell. This contrasts to that at Jesmond Dene where the very rapid response of the river to the very intense initial storm will have been reflected in the surface water drainage systems as well.

5.1.2 River Team

The River Team is the second of the main tributaries draining urban Tyneside. It rises near Annfield Plain, flows under the Causey Arch as the Causey Burn near Tanfield and then into the Team Valley. Partly culverted, it flows through the Team Valley Trading Estate before it discharges into the tidal section of the Tyne in Dunston. Upstream of Team Valley, near Lamesley. the natural flow regime is impacted upon by significant sewage works and mine water discharges.

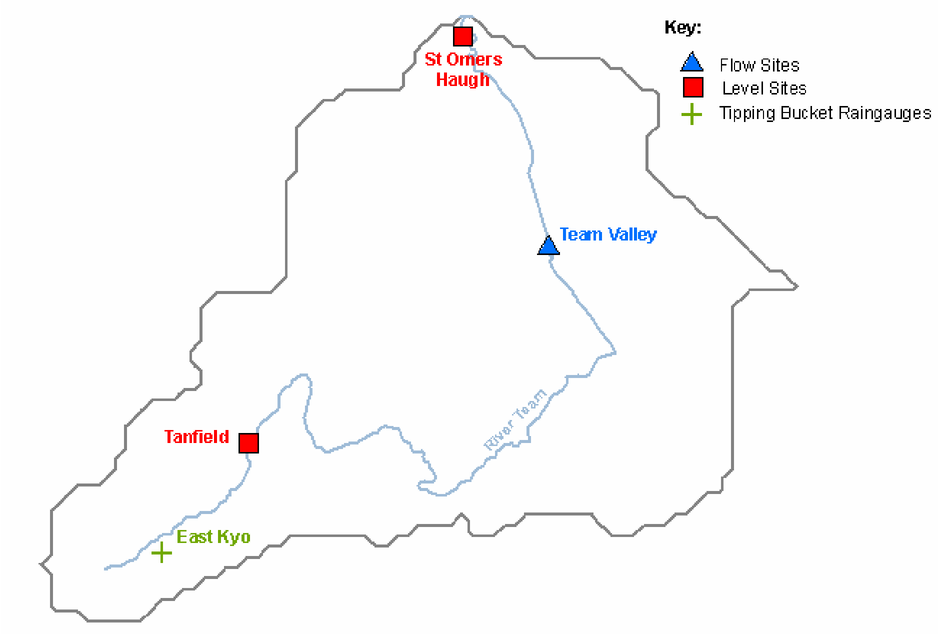

Figure 20: River Team catchment map

Rainfall

There is only one TBR in the Team catchment, located in the headwaters near Stanley at East Kyo.

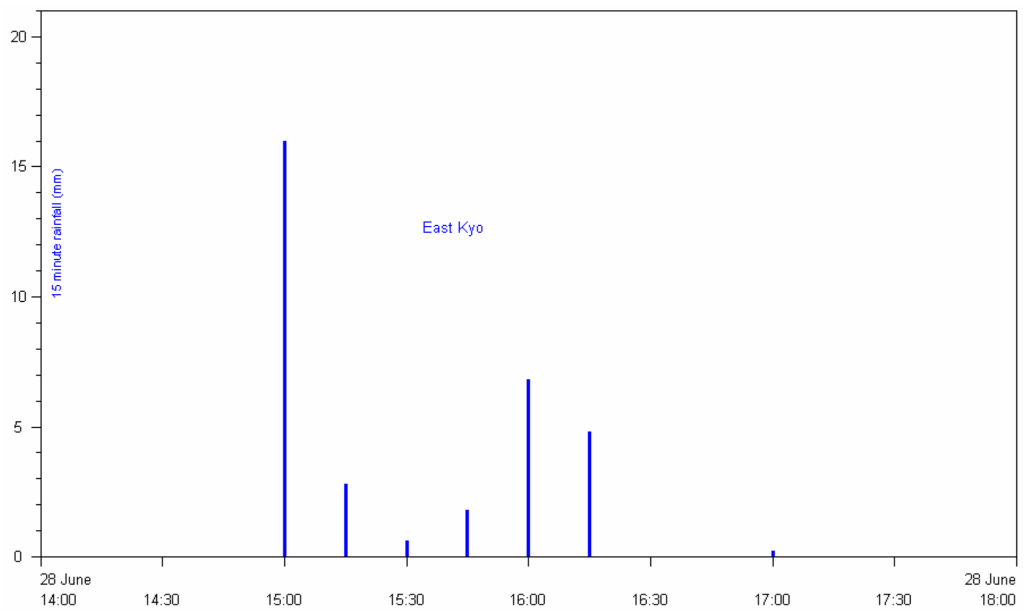

Figure 21: East Kyo 15 minute rainfall totals from 1400 to 1800 on 28th June

Figure 21 shows that the rainfall was even more short lived on the Team than over the Ouseburn, lasting only 1½ hours. The extract from Table 4 shows that the maximum return period for the event was almost 40 years, with over half of the average rainfall for June falling in 90 minutes.

28 June event (peak intensities)	Tyneside East Kyo
mm rainfall	
30 min	18.8
1 hour	21.2
75 mins	28
1.5 hours	32.8
2 hour	32.8
return period	
30 min	
1 hour	14
75 mins	28
1.5 hours	39
2 hour	27
% of LTA June rainfall	
30 min	30%
1 hour	34%
75 mins	45%
1.5 hours	53%
2 hour	53%

Extract from table 4 showing rainfall analysis over the Team

River level

There are two level sites on the River Team, one of which is affected by the tide, and one flow measurement site.

Figure 22 shows that the level site at Tanfield recorded the event extremely well, rising 2.4m in the 3½ hours between 1445 GMT and 1815 GMT.

The flow gauge further downstream at Team Valley failed to capture the peak; possibly due to the large amount of trash that was washed into the river channel during the event. It was possible to survey the wrack which had accumulated at the site, which gave an estimated peak level of 1.55m. This ties in well with the hydrograph recorded upstream at Tanfield and so can be considered to be reasonable estimate of the likely peak value.

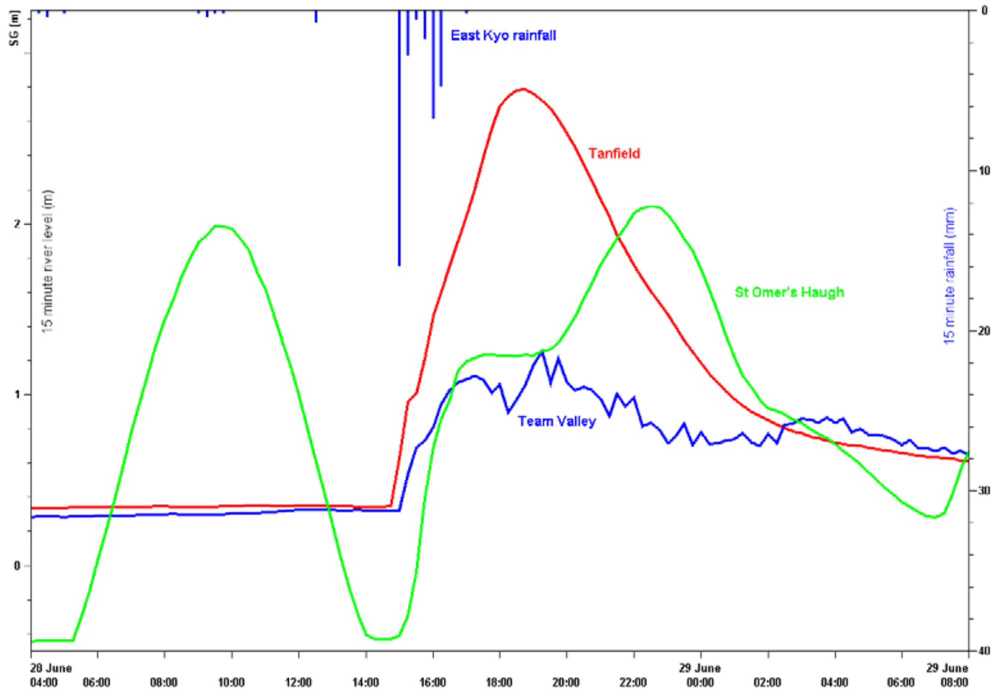

Figure 22: River levels on the Team

In the tidal section the fluvial peak flows fortunately coincided with low tide. The impact of the high flows can be seen in Figure 23. At St Omer's Haugh this resulted in a short-lived low tide on the 28th which lasted thirty minutes instead of the usual three hours. The low tide the following morning was also held higher than expected as the Team continued to drain down following the storm. If both the tidal and fluvial peaks had coincided then the impact would have been far more severe as tide lock would have prevented the fluvial discharge from the River Team.

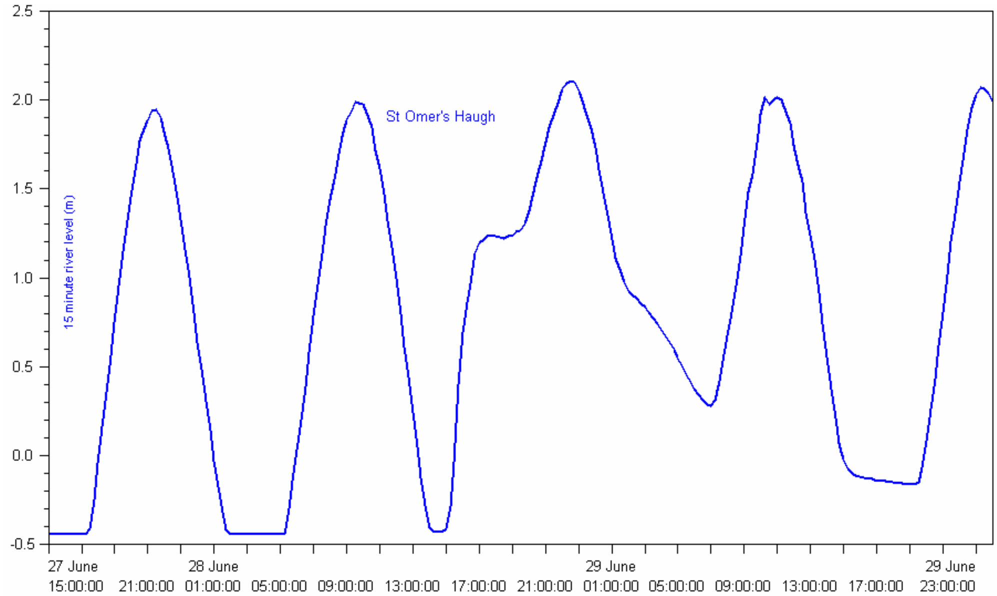

Figure 23: Tidal levels on the lower Team at St Omer's Haugh

The extract from Table 8 shows that the event was the largest on record in the Team, beating the previous maximum recorded levels at the site of the current Team Valley gauge in May 1993 and June 2000 by approximately 25cm.

	Tyne	
Rank	Team Valley	Tanfield
record length (years)	22	11
1	1.55	2.78
2	1.3	2.04
3	1.3	1.94
4	1.27	1.84
5	1.21	1.37
6	1.12	1.36
7	1.07	1.35
8	1.07	1.29
9	1.05	1.19
10	1.05	1.17
11	1.02	0.855
12	0.984	
13	0.954	
14	0.952	
15	0.914	
16	0.909	
17	0.877	
18	0.799	
19	0.794	
20	0.793	
21	0.784	
22	0.429	

Extract from table 8 showing rank order of AMAX peak stage.

June 2012 event highlighted in **red**, September 2008 event highlighted in **orange**, Autumn 2000 event highlighted in **blue**

It is worth noting however that, although the data has not been commented on in WISKI, there is some oscillation around these peaks and no evidence of any wrack marks being surveyed after the events to corroborate the readings. The level site at Tanfield was not installed until 2002 so there is no upstream information available to check the shape of these earlier Team Valley hydrographs and the actual peaks may have been higher than the recorded peaks.

Levels recorded before 1991 cannot be compared to the current record as the site was moved.

5.2 Other affected catchments

Whilst most of the disruption was caused over Tyneside there were some notable impacts in other parts of the North East area:

- Middle Rede;
- Upper Browney

5.2.1 River Rede

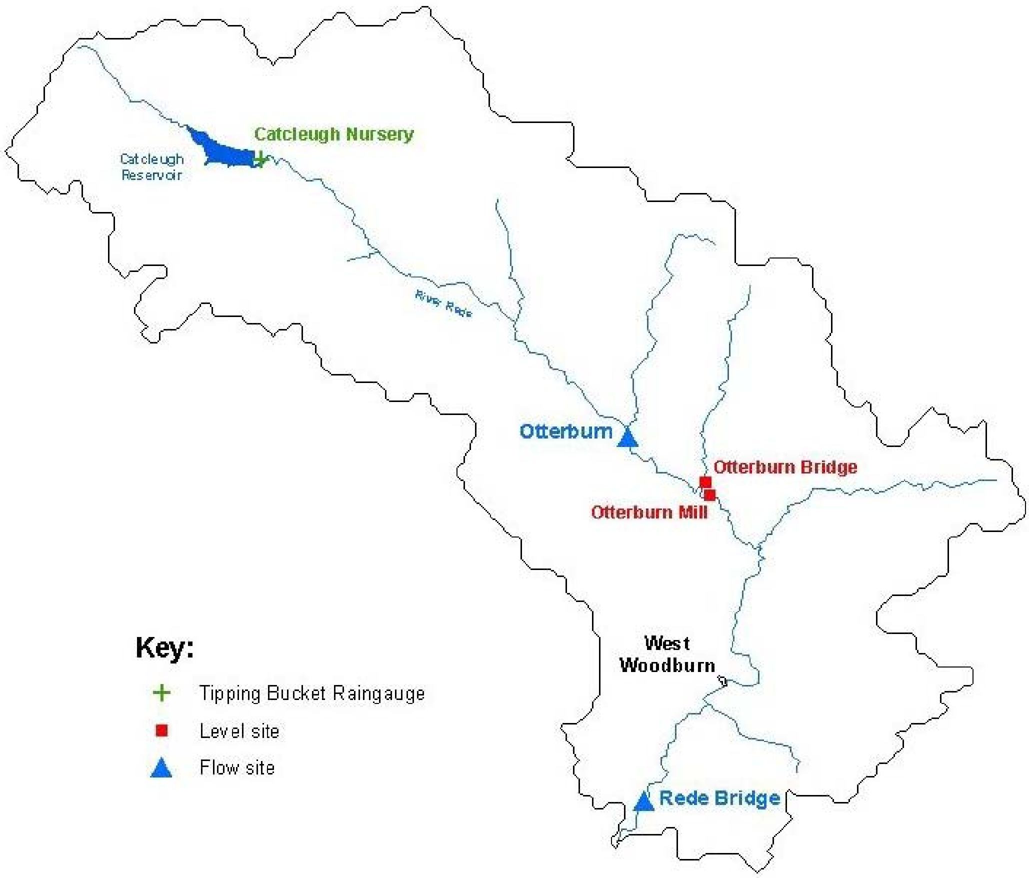

Figure 24: River Rede catchment map

The River Rede is a tributary of the River North Tyne which flows from the Cheviot Hills in the north, through Otterburn, to the confluence with the North Tyne in the south. The catchment is almost entirely rural and includes Catcleugh reservoir in the upper reaches, which impounds 40 km^2 of catchment.

Rainfall

Sub daily rainfall in the Rede catchment is measured at Catcleugh Nursery in the uplands of the catchment. The pattern of rainfall at Catcleugh is different from those more southerly and easterly catchments described previously.

Rainfall began on the morning of the 28th at around 1115 GMT and had ended by 1515 GMT. There were no particularly intense periods of rain with 35.6 mm of rain falling in just over four hours. The rainfall measured during this period on the 28th is in contrast to more southerly catchments, where far more intense downpours were observed.

During this event the maximum rainfall return period observed in the Rede catchment was a comparatively low 19 year event for the 4 hour total of 35.2mm. However, despite the low rainfall return period, the resulting river levels around Otterburn were the highest on record. This indicates that the catchment was particularly saturated, leading to almost all rainfall being converted to runoff and contributing to levels in the river. Figure 12, the map of rainfall distribution suggests that the rainfall in the north east of the catchment may have been greater in relation to the long term record than that recorded at Catcleugh.

River Level

Figure 25 shows river levels at Otterburn and Otterburn Mill, approximately half way along the River Rede, and Rede Bridge which is just above the confluence with the North Tyne. The upper stretch of the River Rede is a relatively steep and fast moving watercourse. In contrast, the lower stretch is flat and much slower to react to changes in flow.

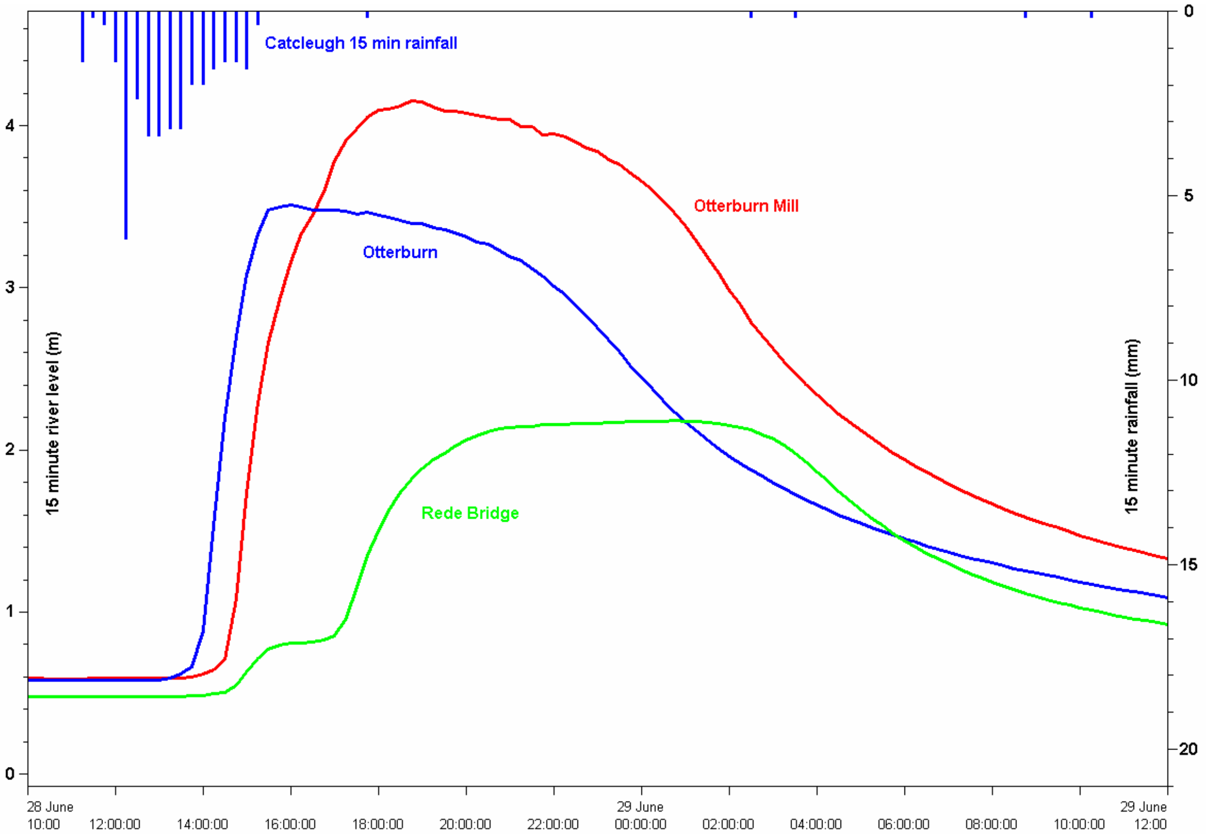

Figure 25: June 28th 2012 river levels in the Rede catchment.

Figure 25 shows that levels in the middle reaches of the Rede rose extremely sharply in response to the rainfall during the morning, increasing by over 2.8m in just two hours. The extract from Table 8 for these sites shows that the resulting peak levels were the highest in a 17 year record at Otterburn Mill and a 13 year record at Otterburn.

Rank	Otterburn Mill	Otterburn
record length (years)	17	13
1	4.154	3.508
2	4.149	3.502
3	4.122	3.49
4	4.119	3.458
5	3.975	3.4
6	3.96	3.372
7	3.926	3.317
8	3.839	3.304
9	3.832	3.259
10	3.813	3.223
11	3.694	3.18
12	3.672	3.025
13	3.58	2.986
14	3.46	
15	3.456	
16	3.297	
17	2.68	
18		

Extract from table 8 showing rank order of AMAX peak stage.

June 2012 event highlighted in **red**, September 2008 event highlighted in **orange**

Levels in the downstream reach of the Rede rose to a flat peak in the early evening of the 28th, which was maintained for over five hours. The pattern of levels in the downstream section of the River Rede was significantly different to those upstream. This difference can be explained predominantly by the difference in run off response within the catchment and also by the lower amounts of rainfall recorded.

5.2.2 River Browney

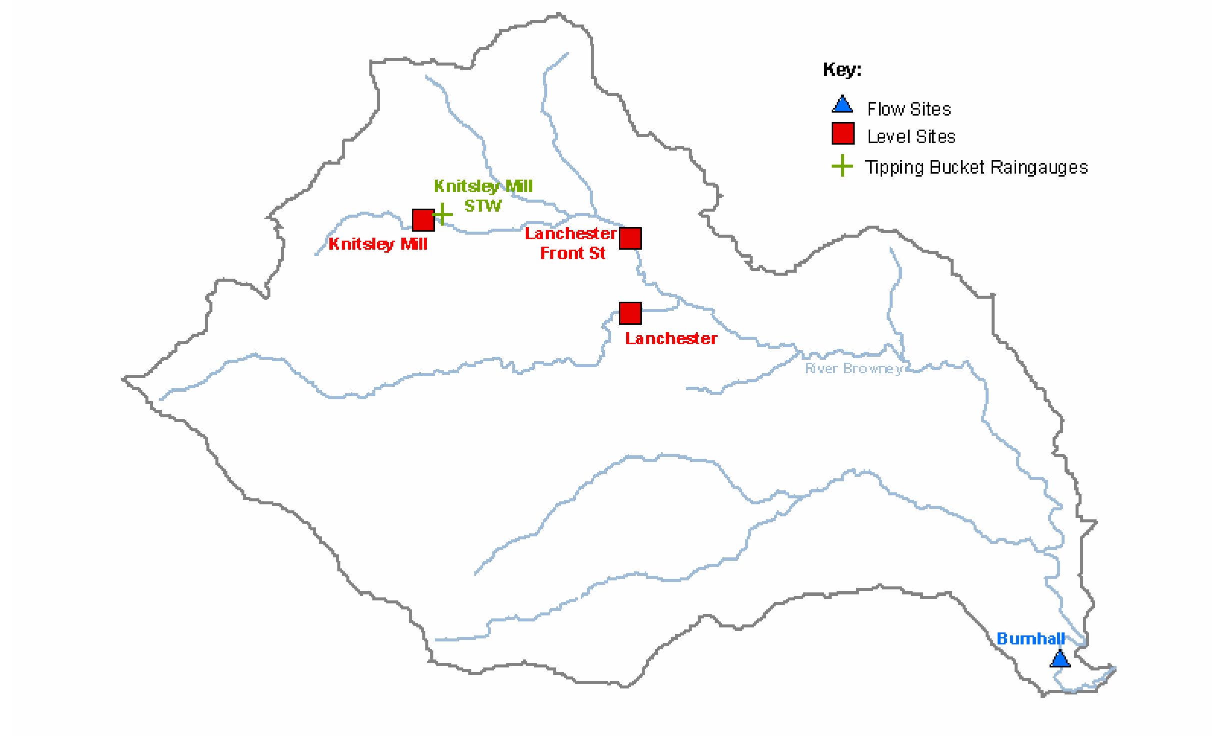

Figure 26: Browney catchment map

The River Browney is a tributary of the middle section of the River Wear which joins the Wear just downstream of Sunderland Bridge. There is one flow gauging station at Burn Hall in the lower catchment and a level site in the upper Browney at Lanchester, together with two level sites on the Smallhope Burn in the headwaters.

Rainfall

The rain started in the upper catchment at 1445 GMT and had virtually ended 90 minutes later. There were two main bursts of rain separated by a 30 minute lull, which are reflected in the record from the level sites at Knitsley and Lanchester. Both of these sites demonstrate an initial rapid rate of rise followed by a slight levelling off before the levels rose again.

The Knitsley TBR rainfall return periods in the extract from Table 4 below are not as extreme as those in Tyneside. Similarly, Table 4 shows that the TBR at Tunstall, which is located to the west of Crook in the upper Wear catchment, also experienced very intense short duration rainfall. The record at the Knitsley TBR probably reflects the southernmost limit of the intense storms located in the Crook area between 1600 GMT and 1630 GMT shown in the radar image Figure 6.

28 June event (peak intensities)		Wear Knitsley
mm rainfall		
	30 min	16.8
	1 hour	19.2
	75 mins	27.2
	1.5 hours	33.6
	2 hour	33.8
return period		
	30 min	15
	1 hour	10
	75 mins	25
	1.5 hours	43
	2 hour	30
% of LTA June rainfall		
	30 min	30%
	1 hour	34%
	75 mins	48%
	1.5 hours	60%
	2 hour	60%

Extract from Table 4 showing rainfall analysis in the Browney Catchment

River Levels

Figure 26 shows how river levels in the upper catchment responded rapidly to the rainfall within 15 minutes of it being recorded.

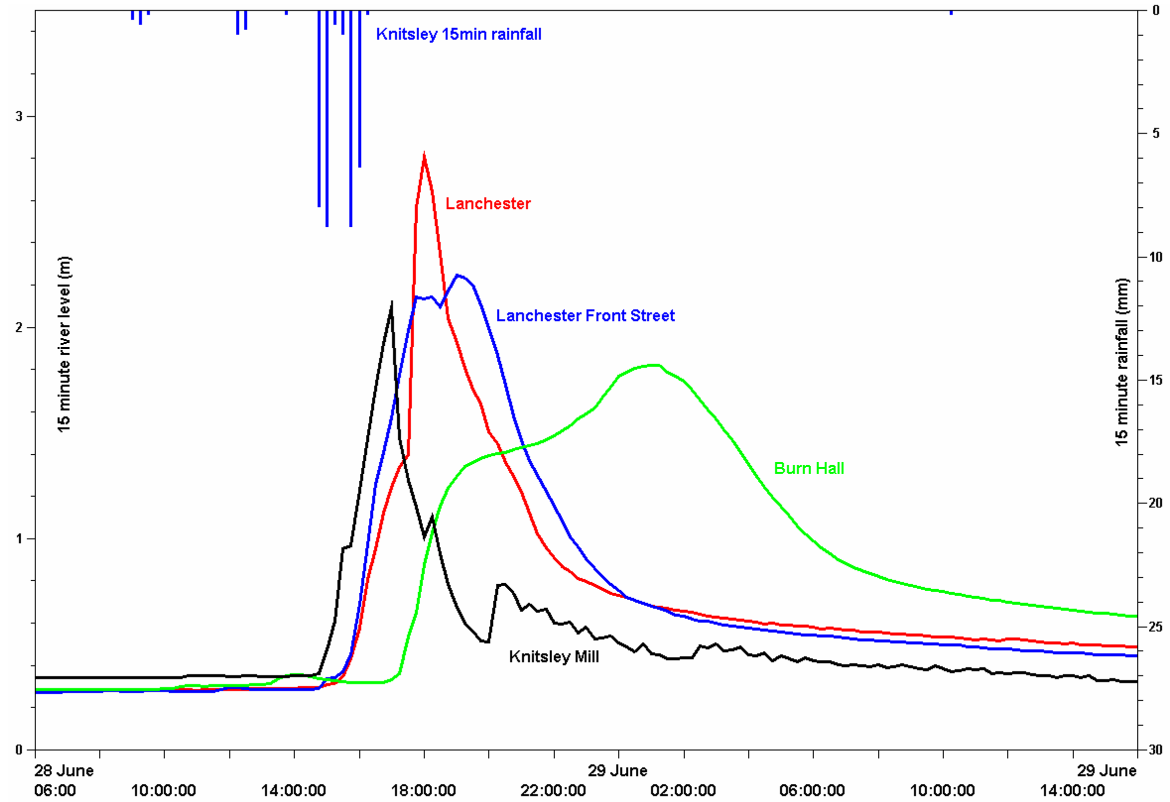

Figure 26: Rainfall and river response in the Browney catchment between June 28th & 29th 2012.

The Smallhope Burn at Lanchester rose by almost a metre in an hour and by 1.7m in two hours. Previous rates of rise have been in the order of 0.4m an hour.

	Browney		
Rank	Knitsley Mill	Lanchester	Lanchester Front St
record length (years)	8	27	9
1	2.09	2.806	2.245
2	1.15	2.233	1.722
3	0.882	1.338	1.556
4	0.784	1.251	1.421
5	0.689	1.205	1.338
6	0.593	1.19	1.266
7	0.573	1.154	1.014
8	0.552	1.111	0.877
9		1.094	0.829
10		1.079	
11		1.04	
12		1.04	
13		1.038	
14		1.009	

Extract from table 8 showing rank order of AMAX peak stage.
June 2012 event highlighted in **red**, September 2008 event highlighted in **orange**

The extract from Table 8 shows that the previous highest recorded peaks were exceeded by at least 0.5m in this event, including at Lanchester which has a 27 year record. Given the comparatively low rainfall return period recorded at Knitsley, it is likely that the high levels recorded at both sites at Lanchester were as a response to the 1600 GMT storm cell centred over Crook which may have enhanced the rainfall over the western and northern tributaries.

6. Rates of River Level Rise

Many of the figures in section 5 clearly show some very rapid catchment response to the intensity of the rainfall, despite its relatively short duration. These rates of rise in river levels were unusual for rivers in the north east and particularly for rivers in the middle and lower reaches of catchments.

Figures 27 and 28 compare the rate of rise in various catchments across the affected area with past events which resulted in high levels.

On the Ouseburn, Fgure 27 shows that the rate of rise at Woolsington was similar to that of the June 2000 event, but much more rapid than the two winter events in 2000 and 2008. The near vertical rise recorded at Crag Hall was far more rapid than that of any other event and, as it started from a much lower level, the total rise was much higher.

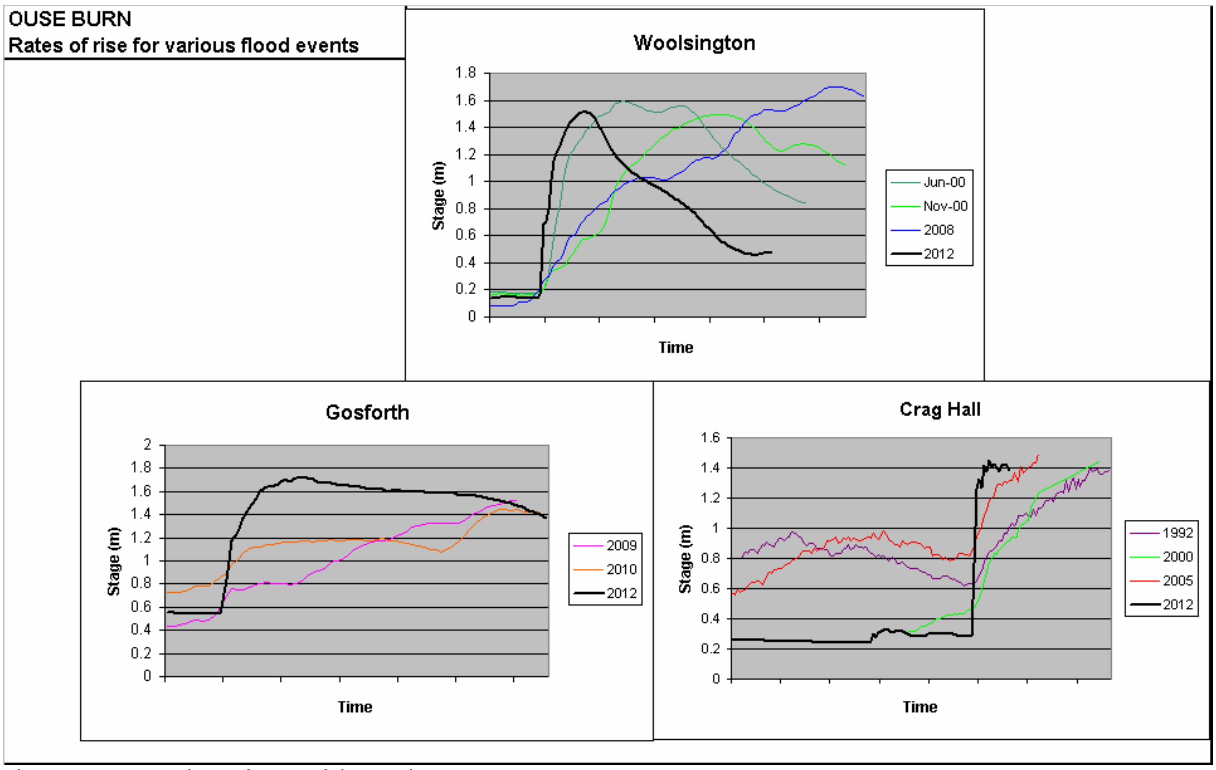

Figure 27: Comparison of rates of rise on the Ouse Burn

Significant rates of rise were not restricted to the urban catchments of Tyneside, as Figure 28 shows.

Unlike the Ouse Burn many of these catchments experienced a much more rapid response in both rise and fall than is normally the case. The level in the River Derwent at both Blackhall Mill and Rowland's Gill peaked and fell in less time than it normally takes the river to peak.

At first glance, the response of the River Tyne at Bywell appears not be unusual. The peak flow was recorded within around six hours of the river beginning to rise and the flow increased by over 300 cumecs, doubling in volume within an hour, but this river response has been noted before. However, in this case the response was driven by a relatively short duration rainfall event of high intensity.

The rapidity of the response provides likely parallels for the surface water runoff and drainage systems. The rapid changes in river levels reflect the fact that although the immediate flush of large volumes of water was generated in a short space of time the total volumes for the event were small and so rivers receded rapidly.

However, at some sites, notably Bywell, the evidence suggests that the widespread nature of the storms as they tracked over Tyneside and the surrounding area produced a large total volume in those locations which drained many smaller systems.

Such remarkable rates of rise have implications on our ability to provide adequate flood warning for those properties at risk in these catchments.

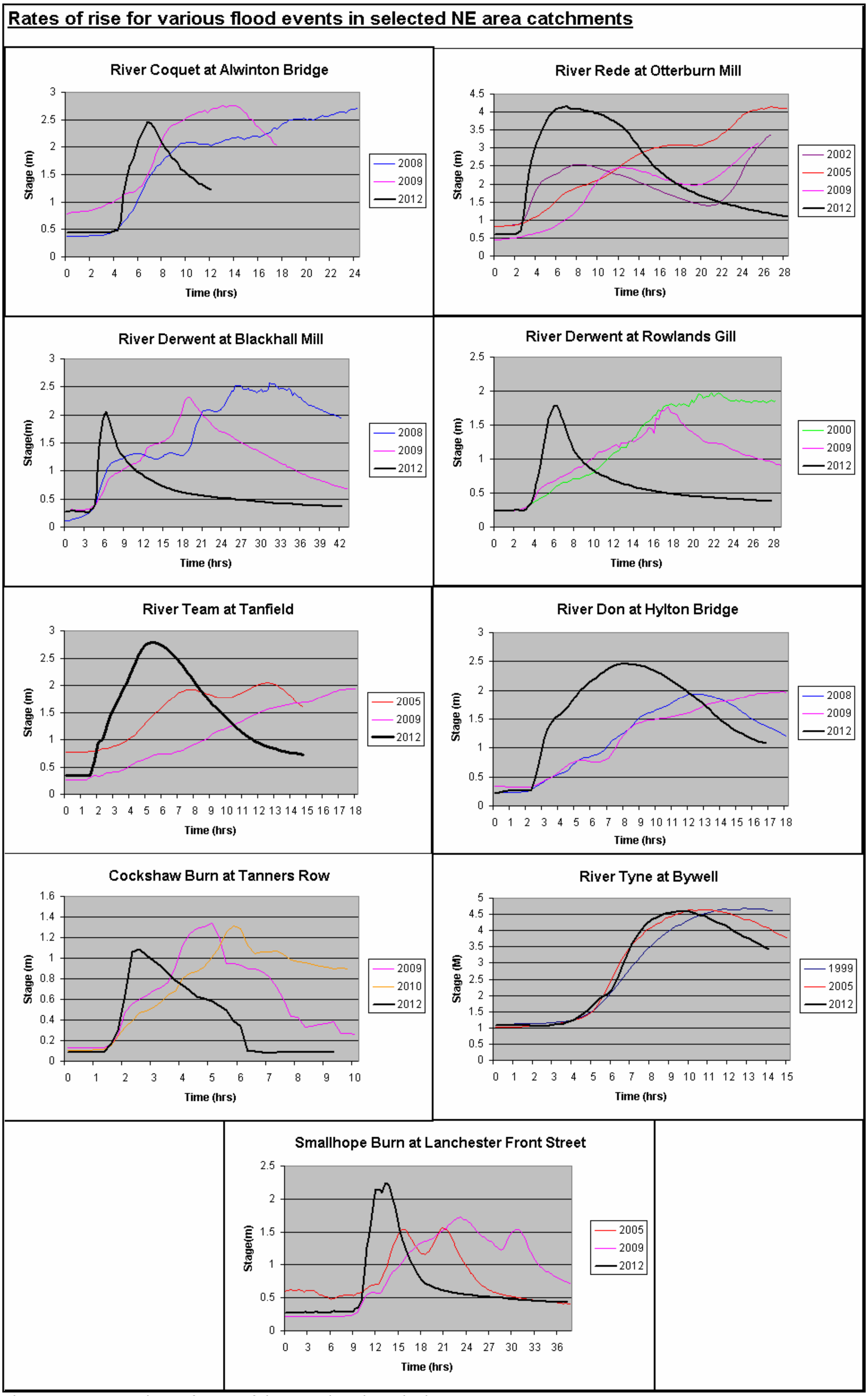

Figure 28: Comparison of rates of rise on other rivers in the NE area

7. Network and Hydrometric Impacts

A good hydrological analysis of a flood event relies very heavily on the availability and quality of the observed hydrometric data. There are two key aspects to the network performance. Firstly, there is the operational performance of the network in real time and the impact this has on our ability to manage the flood event. Secondly, there is the hydrometric performance of the network and its ability to collect data accurately and reliably.

7.1 Operational performance

Management of the event is beyond the scope of this report and will not be covered in detail. It is worth noting that, during the June 2012 event, the telemetry system performed very well, with no significant failures of equipment or communications having an impact on our operations.

- 263 calls were made to telemetry sites.
- 51 calls were made from telemetry sites.
- 45 level, rainfall and plant failure alarms.
- 12 forecast alarms for river levels.
- 105 SMS alarm redirections to duty officers

There were no outstation or sensor failures on the Lower Tyne and no check gaugings were obtained in the NE area during the event.

7.2 Hydrometric performance

The primary interest for this report is the hydrometric performance of the network. That is: the ability of the network to make accurate and continuous measurements throughout the flood event, to provide a complete record for subsequent analysis.

Only one site, Team Valley, had *known* problems recording data during the flood. The site failed to record the flood peak, possibly due to the amount of debris carried into the river by surface water runoff.

8. Further Work Required

There remains a significant amount of data validation and correction of level data at some of the sites such as Team Valley.

Further work is required if the flow return period for the event at Crag Hall is to be calculated as the record is not of sufficient quality to be included in the Hiflows database and flow bypasses the gauge through a sewer interceptor.

9. Acknowledgements

This report has been produced through the combined efforts of the North East Hydrology Team :

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Alex Mason
Richard Maxted
Rachel Merrix
Anne Netherway
Ben Scott

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Rachel Merrix. Hydrology Technical Specialist.