ONGOING ANALYSIS AND INTERPRETATION OF COASTAL MONITORING DATA

Definition of Heavy / Prolonged Rainfall Events

Geotechnical Interpretative Report

January 2010

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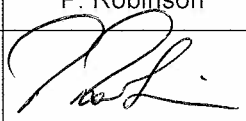
B	Final			
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EXECUTIVE SUMMARY

Mouchel were appointed by Scarborough Borough Council (SBC) to undertake an ongoing monitoring programme at a number of sites along the length of the North Yorkshire coast from Staithes in the north to Speeton in the south. Coastal settlements included in the analysis are located at Runswick Bay, Whitby West Cliff, Scalby Ness, Scarborough North and South Bay, Knipe Point, Killerby, Filey Town & Brigg and Filey Flat Cliffs. Coastal monitoring equipment has been installed at these locations within the Borough and regular inclinometer and piezometer readings are recorded by Mouchel. At each assessment, Mouchel advise SBC of changes in the site condition, stabilisation of site conditions, areas showing no changes in comparison to the previous assessment, changes in the level of risk, any recommended actions of SBC and any changes to the ongoing monitoring regime.

The basis of the recommended monitoring regime for each of the sites (Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL*) followed that already in place at the sites of interest. Departures from this were evident where remedial works had not been undertaken at a site, where there were significant 'gaps' in monitoring data from a site and following periods of heavy and prolonged rainfall. Following a period of heavy / prolonged rainfall it was recommended to carry out monitoring one week after the end of the rainfall event and at monthly intervals thereafter for three months. The designation of '*significant movement*' was proposed, however full quantification of the parameters for 'significant rainfall' was beyond the scope of previous studies. The definition of '*significant rainfall*' has been developed through analysis of rainfall data records (made available by the EA and SBC) and quantified within the context of the effects of such an event on the present monitoring regime frequency.

Rainfall data records covering the period 1995/8 to 2008/9 have been made available to Mouchel Ltd by SBC and the Environment Agency (EA). The data has been supplied from weather stations located throughout the region in particular at Loftus, Fylingdales, Whitby School, Scarborough and Knipe Point, Mulgrave Castle and Ruswarp. In addition to this, limited rainfall data has been provided by the EA for a selection of the above sites and Filey School for part of 2009.

Records provided by SBC have been reviewed to provide an in-sight into prevailing failure mechanisms and slope behaviour at the specific sites under investigation. There would appear to be little information detailing actual dates and any detailed history of individual slope failures themselves along this stretch of coastline although the mechanisms of slope behaviour and failures are well understood. Therefore, a definition of heavy / prolonged rainfall events has been investigated in terms of determining statistically derived values of daily rainfall per month for the period 1995/8 to 2008/9.

From a review of historical rainfall data between 1995/8 and 2008/9, it is evident that numerous exceedances of the average daily rainfall per month have occurred during this period. There are no records available to link known or observed ground movements to such past rainfall events where the average daily values have been exceeded. Therefore this report has identified limiting values of rainfall in terms of how much rainfall, within a 24 hour period, can occur before advising that site inspections should be undertaken.

When reviewing the rainfall data, the 75th percentile has been calculated as a threshold value. This shows that 75% of daily rainfall is below this value and the remaining 25% of rainfall exceeds this amount.

The 75th percentile of daily rainfall values per month has been determined from data collected from a weather station at Whitby School, for Runswick Village and Whitby West Cliff varies between a minimum of **3.20mm** rainfall per day (for the month of May) and a maximum value of **5.90mm** rainfall per day (for August).

For Scalby Ness, Scarborough, Filey Town and Flat Cliffs, the 75th percentile of daily rainfall values determined from Scarborough weather station varies between a minimum of **3.60mm** rainfall per day (for March and May) and a maximum value of **5.90mm** rainfall per day (July and October). Values of the 75th percentile of daily rainfall for the whole year are presented below in Table 1 and 2 for the respective weather stations.

Table 1. 75th Percentile values for Whitby Rainfall Data

75th Percentile Daily Rainfall/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
(mm)	4.4	3.4	3.6	4.4	3.2	4.6	5.2	5.3	3.8	4.4	4.2	3.9

Table 2. 75th Percentile values for Scarborough Rainfall Data

75th Percentile Daily Rainfall/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
(mm)	3.9	4.0	3.6	4.9	3.6	5.7	5.9	4.5	4.6	5.9	4.2	3.9

The 75th percentile of daily rainfall values have also been determined from Filey School weather station data for part of 2009 only. The values vary between a minimum of **0.04mm** rainfall per day (for March) and a maximum value of **0.10mm** rainfall per day (October and November). The data collected from Filey School is very limited, in so

much as data for six months of 2009 have been made available for analysis, compared to up to fifteen years of data retrieved from other weather stations. As a consequence of this, derived values of 75th percentile from Filey compare unfavourably with those derived from Whitby and Scarborough weather stations. Therefore this data has not been applied to Filey Town and Flat Cliffs, instead the data from Scarborough weather station has been applied to these sites. Values of the 75th percentile of daily rainfall for part of the year 2009 are presented below in Table 3.

Table 3. 75th Percentile values for Filey School Rainfall Data

75th Percentile Daily Rainfall/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
(mm)	No Data	No Data	0.04	0.06	No Data	0.07	0.07	No Data	No Data	0.10	0.10	No Data

In the event that the 75th percentile of daily rainfall values are exceeded, it is recommended that walk-over surveys of the site in question are carried out as soon as practicable (taking into account high continuous rainfall scenarios indicated below) and any evidence of ground movements is recorded and monitored on a regular basis.

In order to account for periods of high, continuous rainfall of >75%, it is proposed to allow a 5 day delay in going out on site to cater for additional days of rainfall at >75 percentile. If rainfall continues at >75% for more than 5 days then, either additional site visits will be required after a further 5 days from the first recorded day of >75% or, continuous walk-over surveys should be considered for the sites.

This report has identified limiting values of rainfall in terms of how much rainfall, within a 24 hour period, can occur before advising that site inspections should be undertaken.

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Appendices

1 Introduction

1.1 Terms of Reference

This report is to be read in conjunction with the following Mouchel reports:

Analysis and Interpretation of Coastal Monitoring Data, 721228/001/GR/002/FINAL, March 2009

Ongoing Analysis and Interpretation of Coastal Monitoring Data, Condition Survey Report 721229/001/CSR/002/FINAL, July 2009

Ongoing Analysis and Interpretation of Coastal Monitoring Data, Feasibility Study into the Replacement of Damaged Monitoring Equipment, 721229/017/GIR/002/FINAL, September 2009

Ongoing Analysis and Interpretation of Coastal Monitoring Data, Initial Review of Full Suite Monitoring 721229/002/GIR/002/FINAL, October 2009

Ongoing Analysis and Interpretation of Coastal Monitoring Data, Initial Review of Restricted Suite Monitoring 721229/002/GIR/003/FINAL, October 2009

Ongoing Analysis and Interpretation of Coastal Monitoring Data, Second Review of Restricted Suite Monitoring 721229/002/GIR/004/FINAL, October 2009

Ongoing Analysis and Interpretation of Coastal Monitoring Data, Third Review of Restricted Suite Monitoring 721229/002/GIR/005/FINAL, November 2009

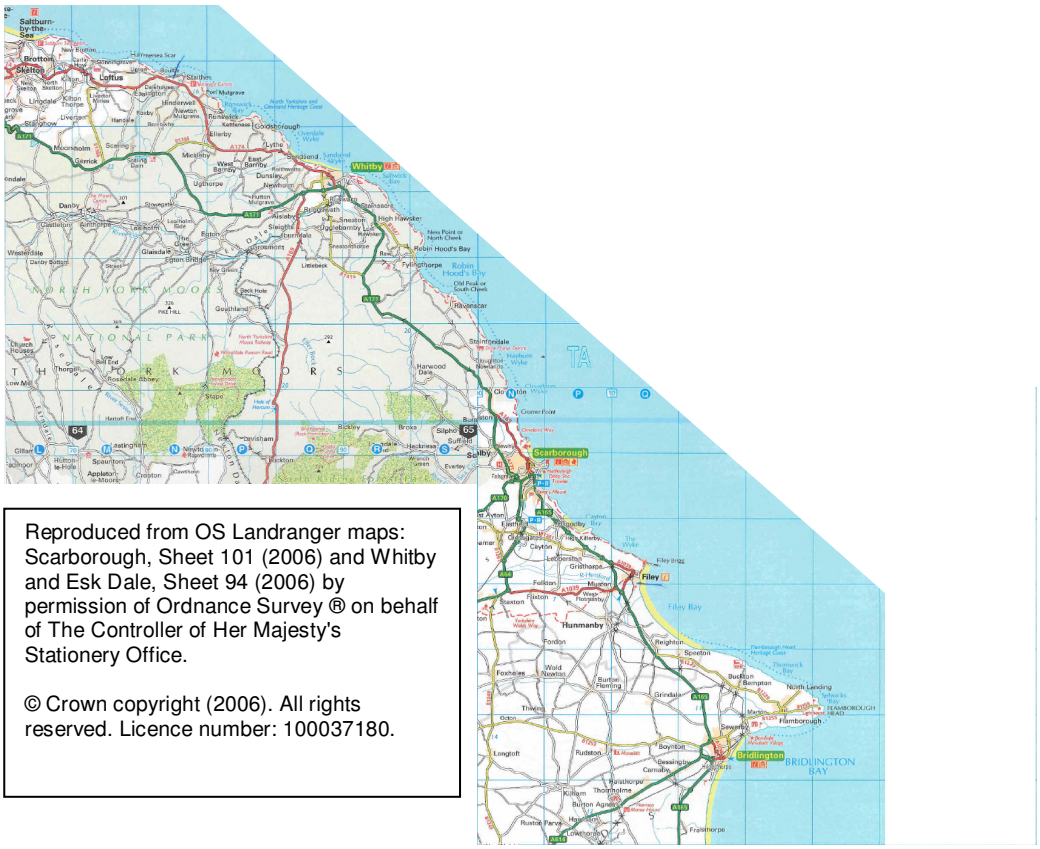
Ongoing Analysis and Interpretation of Coastal Monitoring Data, Fourth Review of Restricted Suite Monitoring 721229/002/GIR/006/FINAL, December 2009

The publications detailed above recommend a regime of monitoring and a programme of replacing damaged installations, the current conditions of existing geotechnical instrumentation (slip indicators, inclinometers, piezometers and recession points) and a commentary on the results of monitoring data so far collected from sites that come under the jurisdiction of Scarborough Borough Council (SBC).

1.2 Previous Studies

The findings of this report are based upon the on-going recording of rainfall data from several weather stations and borehole instrumentation installed at sites along the North Yorkshire coastline (Figure 1). Weather stations from which data has been collected stretch from Loftus in the north to Scarborough in the south. In addition to this data, rainfall monitoring is currently being undertaken at Knipe Point. This work is being carried out by Halcrow on behalf of The National Trust as part of a wider scoped investigation into the problems occurring at this promontory. The findings of this progressive investigation have not been made available, as yet. Data from Loftus weather station has been included within the report (Appendix C and D) although due to its distance to the nearest site (Runswick Village), it is considered the data has little relevance to the project and hence has not been used for analysis. Rainfall data from weather stations at Ruswarp and Fylingdales has been omitted from detailed analysis due to their locations. Ruswarp, while in close proximity to Whitby, lies in a deep valley and the resulting rainfall records does not reflect that from Whitby. Fylingdales is located on exposed high moor land which records much higher levels of rainfall and hence, recorded rainfall is not indicative of that which has been recorded at Whitby. A location plan of the weather stations is presented in Appendix A.

Figure 1. Scheme Location



2 Rainfall Conditions

2.1 Rainfall Data

Rainfall data records have been made available to Mouchel by SBC and the Environment Agency. Data supplied is referenced to stations throughout the region in particular at Loftus, Fylingdales, Whitby School, Scarborough, Filey School, Mulgrave Castle, Ruswarp and Knipe Point. Within Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL,* reference was made to 'periods of heavy and / or prolonged rainfall' in terms of considering such an event with respect to their effects upon slope stability.

This subject has been refined through analysis of rainfall data records made available by the Environment Agency and SBC and the definition of such an event has been quantified within the context of the effects of such an event on the present monitoring regime frequency.

Seasonal rainfall data has been processed and presented in graphical format to illustrate the Mean seasonal rainfall for Spring / Summer periods (April – September) and Autumn / Winter (October – March) for 1995/8 to 2006, 2007 and 2008. This format follows that presented to Mouchel by SBC for the data from Scarborough and Knipe Point weather stations. Monthly rainfall values have been similarly presented for minimum, maximum and mean values for the period 1995/8 – 2006 with a comparison of data from 2007 and 2008. Data provided by SBC for Scarborough has a similar presentation with the inclusion of limited data from 2009 for Knipe Point site. Data provided for Filey School has not been presented graphically due to the very limited data set available.

From a review of historical daily rainfall data between 1995/8 and 2008/9, it is evident that numerous exceedances of the average daily rainfall per month have occurred during this period. There are no records available to link known or observed ground movements to such past rainfall events where the average daily values have been exceeded. Therefore this report has identified limiting values of rainfall in terms of how much rainfall, within a 24 hour period, can occur before advising that site inspections should be undertaken.

When reviewing the rainfall data, the 75th percentile has been calculated and used as the cut-off (threshold) value of daily rainfall. This has been used as a threshold value as it gives an upper limit of statistically derived normal values and above this value an exceedance occurs. The 75th percentile shows that 75% of daily rainfall falls below this value and the remaining 25% of daily rainfall exceeds this amount.

A percentile is the value of a variable below which a certain percentage of observations fall. For a set of measurements arranged in order of magnitude, the 75th percentile is the value that has 75% of the measurements below it and (100-75%) above it. The 75th percentile is also referred to as the 3rd Quartile.

In general,

- A percentile greater than 75 is considered *above normal*
- A percentile between 25 and 75 is considered *normal* (median)
- A percentile less than 25 is considered *below normal*

A comparison of groundwater level data retrieved from functioning boreholes installed at the sites with historic rainfall data from specified weather stations has been carried out. Ground water data retrieved from piezometers has, in most cases, been inconclusive due to the discontinuous format of the data and general lack of piezometer data retrieved from sites.

In the event that daily rainfall values exceed the 75th percentile, it is recommended that walk-over surveys of the site in question are carried out as soon as practicable and any evidence of ground movements is recorded and monitored on a regular basis.

This report has identified limiting values of rainfall in terms of how much rainfall, within a 24 hour period, can occur before advising that site inspections should be undertaken.

There are difficulties in being able to gather rainfall information in real time, or of being notified of an event of heavy and / or prolonged rainfall, defining how much rain has fallen within a set period (24 hours), determining whether this amount of rain has exceeded the 75th percentile, identifying the effect of this upon certain sites and reacting in a timely manner in order to predict whether the rainfall event has or will have a detrimental effect upon slope stability at any section of the North Yorkshire coast. These issues need to be addressed in a 'suitable response' manner in order to determine an appropriate plan of action.

Rainfall data used in this study has been supplied by SBC and the EA and covers the period 1995/8 to 2008/9. This data provides the daily sum of rainfall recorded from 00:00 hrs over a 24 hour period, in several circumstances there are substantial gaps in this data (i.e. no data for 2000-2001). 'Preliminary' data for January to September 2009 was provided by the EA in November 2009, this data has, at the time of writing, now been quality assured. There remains the potential problem of being able to gather up-to-date data immediately and quantifying the amount of rainfall as either exceeding or not exceeding the 75th percentile.

Enquires have been made of the EA as to how quickly rainfall data can be made available for analysis, where weather stations are on a telemetry system this data can be e-mailed the following day.

Rainfall gauges at Whitby School, Loftus and Fylingdales are operated by the Met. Office and the EA. It is not possible for data from these to be supplied in a timescale suitable for the purposes of this report (i.e. next day delivery). In the opinion of the E.A., as these are storage gauges there would be at least a month lag in receiving preliminary data and longer for quality assured data.

Mulgrave Castle storage gauge (daily data) and Ruswarp tipping bucket gauge (15-minute, hourly or daily data) operated by the E.A. are not on a telemetry system. Preliminary data would be available within 5 weeks and quality assured data has up to a 2 month lag.

Filey and Scarborough tipping bucket gauges (15 minute, hourly or daily data) are on a telemetry system operated by the EA. Preliminary data are available for the previous day, or potentially in real-time if an alarm or telemetry dial-up is set up. Quality assured data can be made available with up to a 2 month lag as a worst case. The QA process depends on comparison with the whole month's data from a storage check gauge, which is only collected early the next month.

The possibility of providing rainfall data from the telemetry gauges is a service that the EA do not routinely offer. However, potential options are:

- EA are supplied with critical rainfall thresholds and set automatic alarms on their telemetry system for when these are exceeded. This would alert EA's monitoring and forecasting duty officer to issue SBC with a warning that heavy rainfall had recently occurred,

- EA supply SBC with as feed to their telemetry system which they could dial up to obtain the data directly.

Either arrangement would need to be discussed and organised through the EA and SBC to ensure the correct requirements are achievable.

However, several weather stations located around the North Yorkshire coast area are able to provide 'preliminary' rainfall data which is readily available from various websites e.g. http: www.greatweather.co.uk. Although the data is not officially verified by The Met Office or EA, data from such origins is useful in providing more immediately available 'preliminary' rainfall data as a guide to whether the 75th percentile has been exceeded and thus whether walk-over surveys are required to be undertaken.

3 Runswick Bay

3.1 Site Location and Description

Runswick Bay is situated on the north east coast of England some 16 km north west of Whitby town at NGR NZ 800 160. It is formed between the headlands of Caldron Cliff to the north and Kettleness to the south and comprises a deeply indented sandy bay approximately 2 km in length. The bay is backed mostly by cliffs and steep glacial till coastal slopes. The village of Runswick Bay is developed within the general valley formed by the Runswick and Nettledale Becks. The village straddles the boundary between the glacial till slopes which occupy most of the bay and the Jurassic shale and sandstone cliffs to the north. Most of the village is founded on weathered shale but properties to the southern edge and the access road (Runswick Bank) and car parks are founded on glacial till landslide debris. The village is fronted by four separate sea defences, of varying age and construction, which stretch from Runswick Beck north of Caldron Cliff around to Nettledale Beck to the south.

Figure 2. Site Location - Runswick Bay

3.2 Rainfall Conditions

The rainfall data presented in Appendix C and D is based upon rainfall records provided by the EA and SBC. The data represents daily rainfall recorded between January 1998 and October / December 2008 by a Casella rainfall logging system located at Mulgrave Castle and Whitby School, North Yorkshire. Presentation of the rainfall data has followed a similar format to that of Scarborough Borough Council's which has been made available to Mouchel. Limited data for 2009 has also been made available at the time of writing this report.

A comparison of rainfall data from Mulgrave Castle and Whitby School weather stations has been made to give an indication of rainfall affecting Runswick Bay. Mulgrave Castle is situated 8 miles south – south east and Whitby School is located 9 miles south east of Runswick Village. Data from Ruswarp has not been utilised as it is considered to lie too far inland, than the two weather stations being used, to reflect climatic conditions prevailing at Runswick Bay.

The overall pattern of rainfall recorded from the two stations is broadly similar for the period covered between January 1998 and 2008 although there are noticeable differences in the amounts of rainfall recorded (in mm). A comparison of Spring / Summer rainfall from Mulgrave and Whitby showed differences in rainfall varied between 48mm and 148mm for the period 1998 to 2008; the greater rainfall being attributed to Mulgrave Castle weather station.

3.2.1 Monthly Rainfall Data

The general trend in monthly rainfall from 1998 to 2008 illustrates a similar pattern at both weather stations of alternating high and low rainfall (per month) recorded throughout this designated period.

The mean monthly recorded rainfall at Whitby is not as high as that recorded at Mulgrave Castle emphasising the fact that greater rainfall experienced at Mulgrave is due to the exposed location of this weather station.

In general, differences between the two weather stations mean monthly rainfall in the region of between 2.3mm and 21mm were noted for January and November, respectively with the greatest difference reflected in November's rainfall figures. Also, the maximum rainfall recorded from the two stations was experienced at Mulgrave Castle where 181.7mm were recorded for the month of November; the next highest rainfall being in June (170.1mm) also at Mulgrave Castle.

Incomplete data up to September 2009 has been made available for Whitby and hence a meaningful monthly comparison for the year 2009 cannot be made. However, an analysis of this limited data show that monthly rainfall is lower than the preceding average monthly period (1998-2008) except for February 2009 where rainfall was 26% higher and July 2009 where rainfall was 46% higher.

Monthly data from Mulgrave Castle has been made available up to May 2009. A comparison of this data with the average monthly period for 1998-2008 shows that monthly rainfall for 2009 is lower except for February 2009 which is 26% higher.

Monthly rainfall results are presented in Appendix C.

Table 4. Monthly Rainfall at Mulgrave Castle

Month	Mulgrave Castle Average (1995-2006) mm	Mulgrave Castle	
		mm	% of average
Apr. 2008	76.8	109.7	42.8%
May 2008	48.4	16.0	-66.9%
Jun. 2008	74.9	82.1	9.6%
Jul. 2008	64.1	127.1	98.3%
Aug. 2008	97.1	109.3	12.6%
Sept. 2008	67.0	68.3	1.9%

Table 5. Monthly Rainfall at Whitby School

Month	Whitby School Average (1995-2006) mm	Whitby School	
		mm	% of average
Apr. 2008	58.5	67.7	15.7%
May 2008	45.4	17.4	-61.7%
Jun. 2008	57.6	54.1	-6.1%
Jul. 2008	47.1	97.2	106.4%
Aug. 2008	81.8	86.7	6.0%
Sept. 2008	47.1	76.0	61.4%

Table 6. Combined Monthly Rainfall for Whitby School / Mulgrave Castle

Month	Combined Average (1995-2006) mm	Combined	
		mm	% of average
Apr. 2008	68.78	88.7	29.0%
May 2008	47.0	16.7	-64.5%
Jun. 2008	66.81	68.1	1.93%
Jul. 2008	68.13	112.2	64.7%
Aug. 2008	90.0	98.0	8.9%
Sept. 2008	57.69	72.2	25.2%

3.2.2 Seasonal Rainfall Data

The seasonal trend of rainfall for Mulgrave Castle can be seen as one of increasing rainfall from 1998 onwards. The mean seasonal Spring/Summer rainfall for 2007 rose by 10.7% on the preceding period of 1998-2006 and a further increase was experienced in the following year 2008 of 34.5%. A similar picture of increasing average rainfall can be viewed from data for Autumn / Winter 2007-2008 where this data was 8.5% higher than the period 1998-2006. However, for Autumn / Winter 2008-2009 mean rainfall was recorded as 22.2% lower in comparison to the same period of 1998-2006.

The seasonal rainfall trend at Whitby for 2007 shows a decrease against the Spring / Summer mean for 1998-2006 of 6.6%, this then increases in 2008 by 9%, illustrating that 2007 was drier than the preceding eight year mean and the succeeding year. Data for 2009 is incomplete and a comparison has not been undertaken. Similar to the Spring / Summer mean for 1998-2006, the Autumn / Winter rainfall figures show a decrease in the following year's mean rainfall by 22.5% from 472mm to 366mm. In the succeeding year (2008) a further decrease of 35.2% in precipitation is evident.

Seasonal rainfall results are presented in Appendix D.

Table 7. Seasonal Rainfall at Mulgrave Castle

Season(s)	Mulgrave Castle Spring / Summer (April-September)		Mulgrave Castle Autumn / Winter (October-March)	
	mm	% of Average	mm	% of Average
1995-2006 (Average)	405.3	N/A	400.0	N/A
2007	450	10.7%	-	-
2007-2008	-	-	433.9	8.5%
2008	546.7	34.5%	-	-
2008-2009	-	-	311.1	-22.2%
2009	91.9*	-77.4%*	-	-

** Incomplete Data Set*

Table 8. Seasonal Rainfall at Whitby School

Season(s)	Whitby School Spring / Summer (April-September)		Whitby School Autumn / Winter (October-March)	
	mm	% of Average	mm	% of Average
1995-2006 (Average)	366.0	N/A	472.5	N/A
2007	341.7	-6.6%	-	-
2007-2008	-	-	366.4	-22.5%
2008	399.1	9.0%	-	-
2008-2009	-	-	306.1	-35.2%
2009	72.1*	-80.3%*	-	-

** Incomplete Data Set*

3.2.3 Daily Rainfall

Monthly rainfall data for each specific year have been refined to give average daily totals per month and these results have been used to determine an average daily rainfall per month over the period data has been available (i.e. 1998 to 2008/9 for Whitby School and Mulgrave Castle). Daily average rainfall data from the two weather stations has been combined to give an average of the two stations.

The 75th percentile for daily rainfall per month has been determined to provide 'benchmark' values against which to measure current and future amounts of daily rainfall. Where the 75th percentile daily rainfall is exceeded by a daily rainfall event then an action of walk-over surveys and inspections of the sites in question is recommended to determine whether any adverse effects are apparent from such a rainfall occurrence.

It is proposed to allow a 5 day delay in going out on site to cater for additional days of rainfall at >75 % percentile. If rainfall continues at > 75% for more days then either additional site visits will be required after a further 5 days or, continuous walk-over surveys should be considered for the sites.

The difficulty lies in being able to gather rainfall information in real time, determining how much rain has fallen within a set period (24 hours), identifying whether this amount of rain has exceeded the 75th percentile and reacting in a timely manner in order to predict whether the rainfall event has or will have a detrimental effect upon slope stability at any section of the North Yorkshire coast. Where rainfall data is not readily available on an immediate basis (the day after basis) from government agencies, an alternative source can be offered from local, amateur run weather stations (i.e. Eddsfield airfield weather station) to provide 'provisional' rainfall data. Such data can be of use to provide a general pattern of rainfall on which to determine whether the 75th percentile has been exceeded and walkover surveys are required, or not.

Average daily rainfall data are presented in Appendix E.

3.3 Groundwater Conditions

Historical groundwater data has not been made available for the area around Runswick Village, although limited piezometric data is available in Report No. 89. This data relates to a ground investigation undertaken in August 1998, with piezometric details covering the period 18th August to 15th October 1998. Piezometric data from these boreholes varies in nature from artesian conditions (BH02 and 03) and reducing groundwater levels (BH01). These boreholes no longer exist.

Current groundwater readings provided from existing inclinometers, installed within piles, present at the site were recorded in June and July 2009. Groundwater levels within these inclinometers varied by a maximum of 70mm between the two sets of readings. There is no evidence to suggest that the instruments are affected by tidal influences however, as the instruments are located in concrete piles and they are not designed to record groundwater levels, one would conclude that readings may not accurately reflect the groundwater regime at this site.

3.4 Conclusions

A review of historical rainfall data between 1998 and 2008/9 has shown that for 2008 deviation from the mean of between -66.9% and +106.4% has occurred. There are no records available to link any observed or known ground movements to such past rainfall events where the average daily values have been exceeded. Therefore this report has identified limiting values of rainfall in terms of how much rainfall, within a 24 hour period, can occur before site inspections should be undertaken.

When reviewing the rainfall data, the 75th percentile has been calculated and used as the cut-off value. This shows that 75% of rainfall is below this value and the remaining 25% of rainfall exceeds this amount.

The 75th percentile of daily rainfall values per month has been determined from data from the weather station at Whitby School. For Runswick Village these values vary between a minimum of **3.20mm** rainfall per day (for the month of May) and a maximum value of **5.90mm** rainfall per day (for August).

The 75th percentile values for the whole year are presented below in Table 8.

Table 9. 75th Percentile values for Whitby Rainfall Data

75th Percentile Daily Rainfall/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
(mm)	4.4	3.4	3.6	4.4	3.2	4.6	5.2	5.3	3.8	4.4	4.2	3.9

In the event that these daily rainfall values are exceeded, it is recommended that walk-over surveys of the site are carried out as soon as practicable and any evidence of ground movements is recorded and monitored on a regular basis.

This report has identified limiting values of rainfall in terms of how much rainfall, within a 24 hour period, can occur before advising that site inspections should be undertaken.

Future failures within the glacial till slopes are most likely to be shallow and caused by excessive water entrainment. If such failures were to occur then adverse loading of the partially rotated lower landslide blocks would occur resulting in increased loading of the piles. This mechanism could be controlled by slope betterment works and improved surface drainage systems to take groundwater away and prevent excess water pressure build-up.

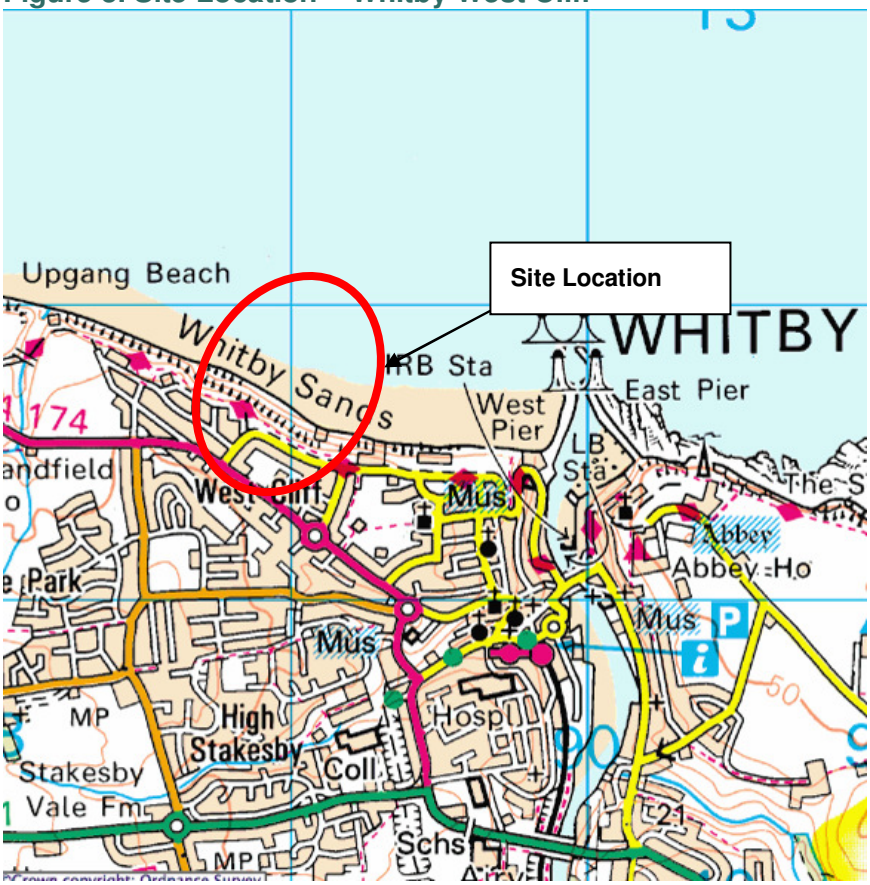
4 Whitby West Cliff

4.1 Site Location and Description

Whitby is located on the north east coast of England approximately 30 miles south of the industrial town of Middlesbrough and 20 miles north of Scarborough. West Cliff is part of a long stretch of exposed cliffs running west-east forming protected soft, glacial till cliffs to the west of Whitby harbour and, further west towards Sandsend the coastline is formed of unprotected soft, glacial till cliffs.

The West Cliff site is bounded by The Spa complex to the east and the Cliff Lift towards the west. The natural slope morphology of the protected cliffs has been modified by several phases of slope stabilisation works which included drainage and slope re-profiling that has been undertaken since the 1960's. The slopes attain a height of up to 40-45 metres at slope angles of 25 to 35 degrees. Set back approximately 10 metres from the crest of the slopes is a main road (North Terrace) and beyond this are large terraced, residential and commercial properties. The faces of the slopes are criss-crossed by pedestrian footpaths, which give public access from the top of the cliffs to the beach below, low retaining walls, gabion walls and relict slip failure scars. At the base of the slopes is a sea wall with a promenade, forming a sea defence, with a wide sandy beach foreshore.

Figure 3. Site Location – Whitby West Cliff



4.2 Rainfall Conditions

The rainfall data presented in Appendix C and D is based upon rainfall records provided by the EA and SBC. The data represents daily rainfall recorded between January 1998 and October / December 2008 by Casella rainfall logging systems located at Mulgrave Castle and Whitby School in North Yorkshire. Limited rainfall data for 2009 has also been made available at the time of writing this report.

4.2.1 Monthly Rainfall Data

The general trend in monthly rainfall from 1998 to 2008 illustrates a similar pattern at both weather stations of alternating high and low rainfall (per month) recorded throughout this designated period.

The mean monthly recorded rainfall at Whitby is not as high as that recorded at Mulgrave Castle emphasising the fact that greater rainfall experienced at Mulgrave is due to the exposed location of this weather station.

In general, differences between the two weather stations mean monthly rainfall in the region of between 2.3mm and 21mm were noted for January and November, respectively with the greatest difference reflected in November's rainfall figures. Also, the maximum rainfall recorded from the two stations was experienced at Mulgrave Castle where 181.7mm were recorded for the month of November; the next highest rainfall being in June (170.1mm) also at Mulgrave Castle.

Incomplete data up to September 2009 has been made available for Whitby and hence a meaningful monthly comparison for the year 2009 cannot be made. However, an analysis of this limited data show that monthly rainfall is lower than the preceding average monthly period (1998-2008) except for February 2009 where rainfall was 26% higher and July 2009 where rainfall was 46% higher.

Monthly data from Mulgrave Castle has been made available up to May 2009. A comparison of this data with the average monthly period for 1998-2008 shows that monthly rainfall for 2009 is lower except for February 2009 which is 26% higher.

Monthly rainfall results are presented in Appendix C.

Table 10. Monthly Rainfall at Mulgrave Castle

Month	Mulgrave Castle Average (1995-2006) mm	Mulgrave Castle	
		mm	% of average
Apr. 2008	76.8	109.7	42.8%
May 2008	48.4	16.0	-66.9%
Jun. 2008	74.9	82.1	9.6%
Jul. 2008	64.1	127.1	98.3%
Aug. 2008	97.1	109.3	12.6%
Sept. 2008	67.0	68.3	1.9%

Table 11. Monthly Rainfall at Whitby School

Month	Whitby School Average (1995-2006) mm	Whitby School	
		mm	% of average
Apr. 2008	58.5	67.7	15.7%
May 2008	45.4	17.4	-61.7%
Jun. 2008	57.6	54.1	-6.1%
Jul. 2008	47.1	97.2	106.4%
Aug. 2008	81.8	86.7	6.0%
Sept. 2008	47.1	76.0	61.4%

4.2.2 Seasonal Rainfall Data

The seasonal trend of rainfall for Mulgrave Castle can be seen as one of increasing rainfall from 1998 onwards. The mean seasonal Spring/Summer rainfall for 2007 rose by 10.7% on the preceding period of 1998-2006 and a further increase was experienced in the following year 2008 of 34.5%. A similar picture of increasing average rainfall can be viewed from data for Autumn / Winter 2007-2008 where this data was 8.5% higher than the period 1998-2006. However, for Autumn / Winter 2008-2009 mean rainfall was recorded as 22.2% lower in comparison to the same period of 1998-2006.

The seasonal rainfall trend at Whitby for 2007 shows a decrease against the Spring / Summer mean for 1998-2006 of 6.6%, this then increases in 2008 by 9%, illustrating that 2007 was drier than the preceding eight year mean and the succeeding year. Data for 2009 is incomplete and a comparison has not been undertaken. Similar to the Spring / Summer mean for 1998-2006, the Autumn / Winter rainfall figures show a decrease in the following year's mean rainfall by 22.5% from 472mm to 366mm. In the succeeding year (2008) a further decrease of 35.2% in precipitation is evident.

Seasonal rainfall results are presented in Appendix D.

Table 12. Seasonal Rainfall at Mulgrave Castle

Season(s)	Mulgrave Castle Spring / Summer (April-September)		Mulgrave Castle Autumn / Winter (October-March)	
	mm	% of Average	mm	% of Average
1995-2006 (Average)	405.3	N/A	400.0	N/A
2007	450	11%	-	-
2007-2008	-	-	433.9	-31.3%
2008	546.7	34.9%	-	-
2008-2009	-	-	311.1	-50.8%
2009	91.9*	-77.3%	-	-

** Incomplete Data Set*

Table 13. Seasonal Rainfall at Whitby School

Season(s)	Whitby School Spring / Summer (April-September)		Whitby School Autumn / Winter (October-March)	
	mm	% of Average	mm	% of Average
1995-2006 (Average)	357.2	N/A	324.5	N/A
2007	341.7	-4.4%	-	-
2007-2008	-	-	366.4	12.9%
2008	339.1	11.7%	-	-
2008-2009	-	-	306.1	-5.7%
2009	72.1*	-79.8%*	-	-

- *Incomplete Data Set*

4.2.3 Daily Rainfall Data

Monthly rainfall data for each specific year have been refined to give average daily totals per month and these results have been used to determine an average daily rainfall per month over the period data has been available (i.e. 1998 to 2008/9 for Whitby School and Mulgrave Castle). Daily average rainfall data from the two weather stations has been combined to give an average of the two stations.

The 75th percentile for daily rainfall per month has been determined to provide 'benchmark' values against which to measure current and future amounts of daily rainfall. Where the 75th percentile daily rainfall is exceeded by a daily rainfall event then an action of walk-over surveys and inspections of the sites in question is recommended to determine whether any adverse effects are apparent from such a rainfall occurrence.

It is proposed to allow a 5 day delay in going out on site to cater for additional days of rainfall at >75 % percentile. If rainfall continues at > 75% for more days then either additional site visits will be required after a further 5 days or, continuous walk-over surveys should be considered for the sites.

The difficulty lies in being able to gather rainfall information in real time, determining how much rain has fallen within a set period (24 hours), identifying whether this amount of rain has exceeded the 75th percentile and reacting in a timely manner in order to predict whether the rainfall event has or will have a detrimental effect upon slope stability at any section of the North Yorkshire coast.

Average daily rainfall data are presented in Appendix E.

4.3 Groundwater Conditions

Historical groundwater data has been made available for the area around BH2 in reports made available by SBC. A ground investigation carried out in 2000 involved the installation of 2 no. piezometers (BH1 and BH3) and an inclinometer (BH2). Water levels recorded in BH1 show consistently low values around 18.50m bgl which relates to a level approximately one-third slope height below crest level. The piezometer was installed into a layer of sand and gravel which outcrops on the slope face. Therefore the low groundwater values are consistent with the hydrostatic pressure expected from an unconfined stratum. The high groundwater levels of BH3 would appear to reflect the high porewater pressures generated from the suspected sandstone strata in which the slip indicator/standpipe is located at 26.00m bgl. A piezometer installed at 19.50m depth also recorded high groundwater levels within BH3. The readings, taken over an eleven day period, following installation recorded groundwater levels between 1.22m and 0.05m bgl.

The readings in BH2 seem to reflect the hydrostatic regime prevailing at that time within the glacial till and may be influenced by the fluvio-glacial horizon which is directly underlying the piezometer tip from 21.50m to 23.10m depth. The observed groundwater level readings may have been subjected to the influence of defective drains, artificially affecting the results. Further readings have been made available for analysis from BH2 between June and November 2009. The readings illustrate groundwater varying from 6.13m to 7.73m bgl. over this period and are influenced by the effects of the tidal regime. Piezometric Groundwater Data Graphs are presented in Appendix F.

4.4 Conclusions

From a review of historical rainfall data between 1998 and 2008/9, it is evident that numerous exceedances of the average daily rainfall per month have occurred over this period. There are no records available to link any observed or known ground movements to such past rainfall events where the average daily values have been exceeded. Therefore this report has identified limiting values of rainfall in terms of how much rainfall, within a 24 hour period, can occur before site inspections should be undertaken.

When reviewing the rainfall data, the 75th percentile has been calculated and used as the cut-off value. This shows that 75% of rainfall is below this value and the remaining 25% of rainfall exceeds this amount.

The 75th percentile of daily rainfall values per month has been determined from data from the weather station at Whitby School. For Whitby West Cliff these

values vary between a minimum of **3.20mm** rainfall per day (for the month of May) and a maximum value of **5.90mm** rainfall per day (for August).

The 75th percentile values for the whole year are presented below in Table 13.

Table 14. 75th Percentile values for Whitby Rainfall Data

75th Percentile Daily Rainfall/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
(mm)	4.4	3.4	3.6	4.4	3.2	4.6	5.2	5.3	3.8	4.4	4.2	3.9

In the event that these daily rainfall values are exceeded, it is recommended that walk-over surveys of the site are carried out as soon as practicable and any evidence of ground movements is recorded and monitored on a regular basis.

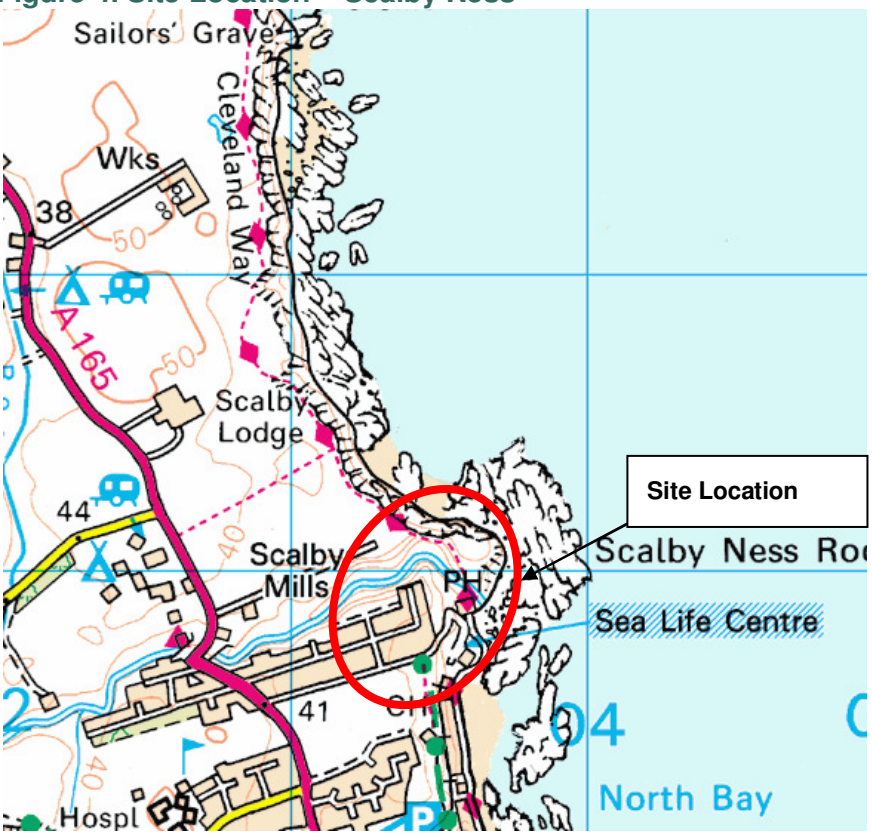
Future failures within the glacial till slopes are most likely to be shallow and caused by excessive water entrainment. If such failures were to occur then adverse loading of the sea wall would occur resulting in increased loading and possible failure of this structure. This mechanism could be controlled by slope betterment works and improved surface drainage systems to take groundwater away and prevent excess water pressure build-up.

5 Scalby Ness

5.1 Site Location and Description

Scalby Ness forms a broad promontory to the north of Scarborough North Bay, approximately 3 km north of Scarborough. The headland is incised by Scalby Beck which acts as an overflow from the River Derwent when in flood. The beck flows in an east-north easterly direction through Scalby, where at Scalby Mills it changes direction sharply through 90 degrees to flow south easterly at Scalby Ness and outfalls to the sea between Scalby Ness headland and the Sea Life Centre. A housing development was constructed during the 1970's and 1980's on land forming a plateau approximately 25-30 m above the beck at Scalby Ness. Over-steepened glacial till cliffs are present on the north west and north east sides of the development, falling down towards the beck. The beck contributes to toe erosion of these slopes and is a contributing factor of the mechanism of slope instability. Scalby Mills Road bounds the southern edge of the north east slopes. This road was constructed to give access to the Sea Life Centre on the coast. Part of the works involved re-profiling slopes with toe protection offered by rock outcrops at Scalby Beck and emplaced toe protection around the Sea Life Centre.

Figure 4. Site Location – Scalby Ness



5.2 Rainfall Conditions

The rainfall data presented in Appendix C and D has been provided by the EA and SBC. The data represents daily rainfall recorded between January 1995 and October / December 2008 by a Casella rainfall logging system located at Scarborough, North Yorkshire. Limited data for 2009 has also been made available at the time of writing this report.

5.2.1 Monthly Rainfall Data

The mean monthly recorded rainfall at Scarborough illustrates a period of higher mean rainfall occurring between June and December from 1995 to 2009.

Rainfall recorded at Scarborough illustrates a notable difference in the monthly rainfall total for July 2009. Monthly rainfall for 2009 has so far been lower than the mean monthly rainfall (1995-2009) except in February and July 2009. February and July were wetter than average with 52mm and 109mm rainfall, representing an increase of 8.3% and 113%, respectively. Rainfall from March to June 2009 was lower than average ranging between -5 and -52% less and August was also drier than average with -61% less rainfall and at Knipe Point, rainfall was -68% less.

Table 15. Monthly Rainfall at Scarborough

Month	Scarborough Average (1995-2006) mm	Scarborough	
		mm	% of average
Mar. 2009	47.5	23.3	-51%
Apr. 2009	63.3	36.0	-43%
May 2009	48.2	45.8	-5%
Jun. 2009	75.1	41.9	-44%
Jul. 2009	51.2	109.2	113%
Aug. 2009	78.3	30.9	-61%

Table 16. Monthly Rainfall at Knipe Point

Month	Scarborough Average (1995-2006) mm	Knipe Point	
		mm	% of average
Mar. 2009	47.5	29.2	-39%
Apr. 2009	63.3	30.2	-52%
May 2009	48.2	40.6	-16%
Jun. 2009	75.1	35.8	-52%
Jul. 2009	51.2	78.8	54%
Aug. 2009	78.3	25.4*	-68%

5.2.2 Seasonal Rainfall Data

Seasonally, the Summer period of 2009 has been drier than the 1995-2006 average. Up to the end of September, 292mm of rainfall had been recorded in comparison with 366mm for the mean 1995-2006 value. These figures reverse the trend of increased mean rainfall from previous Summer periods 1995-2006, 2007 and 2008 where increases of 13% and 16% have been recorded. Autumn / Winter rainfall values recorded against a mean value of 363 (for 1995-2006) have followed a trend of decreasing rainfall of -3% and -19% for 2007-2008 and 2008-2009, respectively.

Table 17. Seasonal Rainfall at Scarborough

Season(s)	Scarborough Spring / Summer (April-September)		Scarborough Autumn / Winter (October-March)	
	mm	% of Average	mm	% of Average
1995-2006 (Average)	365.8	N/A	363.0	N/A
2007	412.0	13%	-	-
2007-2008	-	-	353.1	-3%
2008	423.4	16%	-	-
2008-2009	-	-	294.8	-19%
2009	292.4*	-20%	-	-

** Incomplete Data Set*

5.2.3 Daily Rainfall Data

Monthly rainfall data for each specific year have been refined to give average daily totals per month and these results have been used to determine an average daily rainfall per month over the period data has been made available (i.e. 1995 to 2008/9 for Scarborough).

The 75th percentile for daily rainfall per month has been determined to provide 'benchmark' values against which to measure current and future amounts of daily rainfall. Where the 75th percentile daily rainfall is exceeded by a daily rainfall event then an action of walk-over surveys and inspections of the sites in question is recommended to determine whether any adverse effects are apparent from such a rainfall occurrence.

It is proposed to allow a 5 day delay in going out on site to cater for additional days of rainfall at >75 % percentile. If rainfall continues at > 75% for more days then either additional site visits will be required after a further 5 days or, continuous walk-over surveys should be considered for the sites.

The difficulty lies in being able to gather rainfall information in real time, determining how much rain has fallen within a set period (24 hours), identifying whether this amount of rain has exceeded the 75th percentile and reacting in a timely manner in order to predict whether the rainfall event has or will have a detrimental effect upon slope stability at any section of the North Yorkshire coast.

Average daily rainfall data are presented in Appendix E.

5.3 Groundwater Conditions

Groundwater monitoring of piezometers installed at the site has been carried out since 2004. The data has illustrated the presence of perched groundwater within the glacial tills at varying depths across the site, above a lower groundwater table. Following periods of heavy or sustained rainfall a rise in the water table has been reflected in raised water levels in piezometers. Since installation in 2004, instruments DP1 to 6 recorded maximum groundwater levels on 31st January 2008. These readings coincide with a rainfall event of nine days earlier when 20.2mm of rainfall was recorded on 21st January 2008. In addition to this, maximum water level readings from DP9 were recorded in September 2004 ten days after 15.7mm rainfall, in November 2004 six days after 7.5mm rainfall and in November 2006 eight days after 15.7mm rainfall. Following each event of rainfall, the resulting rise in groundwater levels is reflected within the piezometers on site and thus the potential for possible slope failures due to increased porewater pressures can be evaluated. Piezometric Groundwater Data Graphs are presented in Appendix F.

5.4 Conclusions

From a review of historical rainfall data between 1995 and 2008/9, it is evident that numerous exceedances of the average daily rainfall per month have occurred during this period; several have been detailed above. There are no records available to link known or observed ground movements to such past rainfall events where the average daily values have been exceeded. Therefore this report has identified limiting values of rainfall in terms of how much rainfall, within a 24 hour period, can occur before site inspections should be undertaken.

When reviewing the rainfall data, the 75th percentile has been calculated as the cut-off value. This shows that 75% of rainfall is below this value and the remaining 25% of rainfall exceeds this amount.

For Scalby Ness, the 75th percentile of daily rainfall values determined from data recorded at a Scarborough weather station varies between a minimum of

3.60mm rainfall per day (for March and May) and a maximum value of **5.90mm** rainfall per day (July and October). The values for the whole year are presented below in Table 17.

Table 18. 75th Percentile values for Scarborough Rainfall Data

75th Percentile Daily Rainfall/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
(mm)	3.9	4.0	3.6	4.9	3.6	5.7	5.9	4.5	4.6	5.9	4.2	3.9

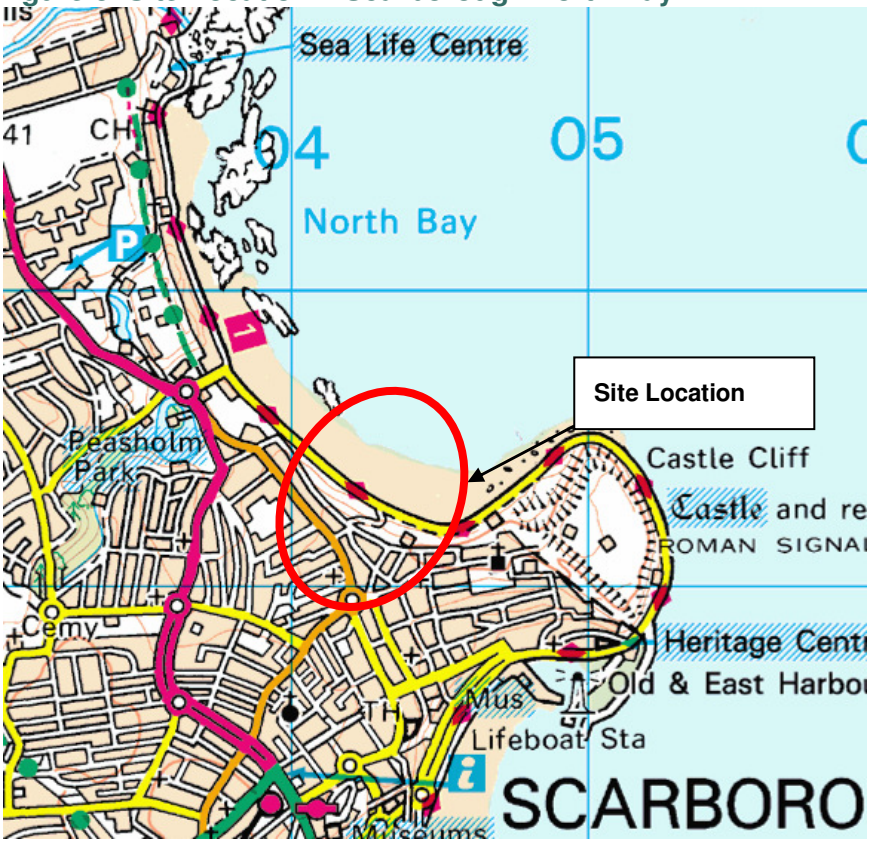
In the event that these daily rainfall values are exceeded, it is recommended that walk-over surveys of the site are carried out as soon as practicable and any evidence of ground movements is recorded and monitored on a regular basis.

6 Scarborough North Bay

6.1 Site Location and Description

North Bay is one of two bays either side of a headland around which the town of Scarborough has developed on the north east coast of Yorkshire. North Bay extends from Castle Cliff northwards to Scalby Ness. The site is known as The Holms, an area of sloping, open parkland between the Castle above and Royal Albert Drive (Marine Drive) along the coast. The parkland consists of open grassed areas with groups of semi-mature trees and shrubs and, meandering tarmac footpaths which increase in steepness from the sea front leading up to the south western flanks of Castle Headland. Discrete rock outcrops are clearly visible across the slopes.

Figure 5. Site Location – Scarborough North Bay



6.2 Rainfall Conditions

The rainfall data presented in Appendix C and D has been provided by the EA and SBC. The data represents daily rainfall recorded between January 1995 and October / December 2008 by a Casella rainfall logging system located at Scarborough, North Yorkshire. Limited data for 2009 has also been made available at the time of writing this report.

6.2.1 Monthly Rainfall Data

The mean monthly recorded rainfall at Scarborough illustrates a period of higher mean rainfall occurring between June and December from 1995 to 2009.

Rainfall recorded at Scarborough illustrates a notable difference in the monthly rainfall total for July 2009. Monthly rainfall for 2009 has so far been lower than the mean monthly rainfall (1995-2009) except in February and July 2009. February and July were wetter than average with 52mm and 109mm rainfall, representing an increase of 8.3% and 113%, respectively. Rainfall from March to June 2009 was lower than average ranging between -5 and -52% less and August was also drier than average with -61% less rainfall and at Knipe Point, rainfall was -68% less.

Table 19. Monthly Rainfall at Scarborough

Month	Scarborough Average (1995-2006) mm	Scarborough	
		mm	% of average
Mar. 2009	47.5	23.3	-51%
Apr. 2009	63.3	36.0	-43%
May 2009	48.2	45.8	-5%
Jun. 2009	75.1	41.9	-44%
Jul. 2009	51.2	109.2	113%
Aug. 2009	78.3	30.9	-61%

6.2.2 Seasonal Rainfall Data

Seasonally, the Summer period of 2009 has been drier than the 1995-2006 average. Up to the end of September, 292mm of rainfall had been recorded in comparison with 366mm for the mean 1995-2006 value. These figures reverse the trend of increased mean rainfall from previous Summer periods 1995-2006, 2007 and 2008 where increases of 13% and 16% have been recorded. Autumn / Winter rainfall values recorded against a mean value of 363 (for 1995-2006) have followed a trend of decreasing rainfall of -3% and -19% for 2007-2008 and 2008-2009, respectively.

Table 20. Seasonal Rainfall at Scarborough

Season(s)	Scarborough Spring / Summer (April-September)		Scarborough Autumn / Winter (October-March)	
	mm	% of Average	mm	% of Average
1995-2006 (Average)	405.3	N/A	631.7	N/A
2007	450	11%	-	-
2007-2008	-	-	433.9	-31.3%
2008	546.7	34.9%	-	-
2008-2009	-	-	311.1	-50.8%
2009	91.9*	-77.3%	-	-

** Incomplete Data Set*

6.2.3 Daily Rainfall Data

Monthly rainfall data for each specific year have been refined to give average daily totals per month and these results have been used to determine an average daily rainfall per month over the period data has been made available (i.e. 1995 to 2008/9 for Scarborough).

The 75th percentile for daily rainfall per month has been determined to provide 'benchmark' values against which to measure current and future amounts of daily rainfall. Where the 75th percentile daily rainfall is exceeded by a daily rainfall event then an action of walk-over surveys and inspections of the sites in question is recommended to determine whether any adverse effects are apparent from such a rainfall occurrence.

It is proposed to allow a 5 day delay in going out on site to cater for additional days of rainfall at >75 % percentile. If rainfall continues at > 75% for more days then either additional site visits will be required after a further 5 days or, continuous walk-over surveys should be considered for the sites.

The difficulty lies in being able to gather rainfall information in real time, determining how much rain has fallen within a set period (24 hours), identifying whether this amount of rain has exceeded the 75th percentile and reacting in a timely manner in order to predict whether the rainfall event has or will have a detrimental effect upon slope stability at any section of the North Yorkshire coast.

Average daily rainfall data are presented in Appendix E.

6.3 Groundwater Conditions

Groundwater monitoring data from borehole instruments across the site is limited to results from mid-late 1997 to late 2000. The results pre-date remedial works under taken at The Holms landslide area and the succeeding coastal defence improvement works. The available piezometer data effectively shows a steady-state condition of the water tables targeted by piezometers. Groundwater data retrieved from the recent monitoring regime is of little use as the piezometers are no longer functioning correctly due to ground movements. The ground movements have caused shearing of tubes and any water level results gathered do not reflect a groundwater level originally recorded and targeted when the instruments were first installed. Hence, a comparison of groundwater data with rainfall records has not been undertaken. Piezometric Groundwater Data Graphs are presented in Appendix F.

6.4 Conclusions

From a review of historical rainfall data between 1995 and 2008/9, it is evident that numerous exceedances of the average daily rainfall per month have occurred during this period. There are no records available to link known or observed ground movements to such past rainfall events where the average daily values have been exceeded. Therefore this report has identified limiting values of rainfall in terms of how much rainfall, within a 24 hour period, can occur before site inspections should be undertaken.

When reviewing the rainfall data, the 75th percentile has been calculated as the cut-off value. This shows that 75% of rainfall is below this value and the remaining 25% of rainfall exceeds this amount.

For Scarborough North Bay, the 75th percentile of daily rainfall values determined from data recorded at a Scarborough weather station varies between a minimum of **3.60mm** rainfall per day (for March and May) and a maximum value of **5.90mm** rainfall per day (July and October). The values for the whole year are presented below in Table 20.

Table 21. 75th Percentile values for Scarborough Rainfall Data

75th Percentile Daily Rainfall/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
(mm)	3.9	4.0	3.6	4.9	3.6	5.7	5.9	4.5	4.6	5.9	4.2	3.9

In the event that these daily rainfall values are exceeded, it is recommended that walk-over surveys of the site are carried out as soon as practicable and any evidence of ground movements is recorded and monitored on a regular basis.

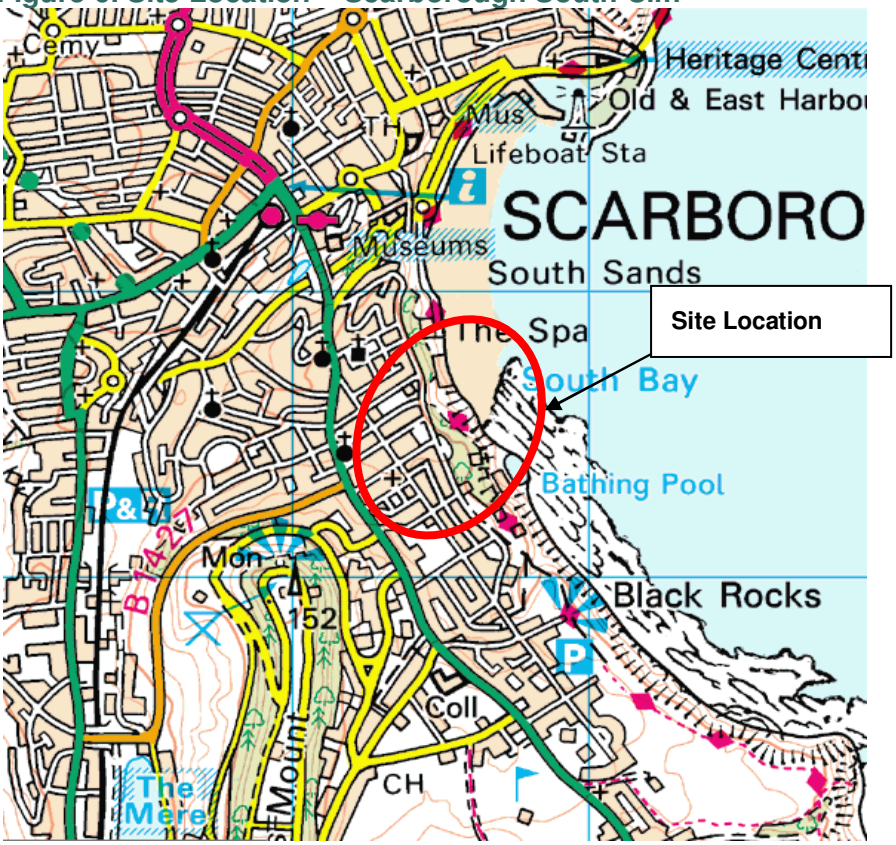
Future failures within the glacial till slopes are most likely to be shallow (although these can trigger deeper seated failures), caused by excessive water entrainment. If such failures were to occur, adverse loading of the sea wall could result in increased loading and possible failure of this structure. This mechanism of potential failure could be controlled by slope betterment works and improved surface drainage systems to take groundwater away and prevent excess water pressure build-up.

7 Scarborough South Cliff

7.1 Site Location and Description

Scarborough is a popular sea-side resort located on the north east coast of England. The South Cliff occupies the southern bay of Scarborough town with a gently sweeping coastline from the northern promontory of Castle Hill to the Black Rocks some 2km southwards. The South Cliff site comprises a variety of landscaped gardens stretching from north to south in the following order: Spa Chalet Cliff, Spa Cliff, Prince of Wales Cliff, South Cliff Gardens, Rose Gardens, South Bay Pool Cliff, Holbeck Gardens, Holbeck Cliff and Wheatcroft Cliff. The cliff top is a gently undulating plateau surface with a road, Esplanade Crescent, running parallel to the cliff line. Large houses and hotels line the landward side of the road, set-back generally 30metres, but up to 100metres in places, from the cliff edge.

Figure 6. Site Location – Scarborough South Cliff



7.2 Rainfall Conditions

The rainfall data presented in Appendix C and D has been provided by the EA and SBC. The data represents daily rainfall recorded between January 1995 and October / December 2008 by a Casella rainfall logging system located at Scarborough, North Yorkshire. Limited data for 2009 has also been made available at the time of writing this report.

7.2.1 Monthly Rainfall Data

The mean monthly recorded rainfall at Scarborough illustrates a period of higher mean rainfall occurring between June and December from 1995 to 2009.

Rainfall recorded at Scarborough illustrates a notable difference in the monthly rainfall total for July 2009. Monthly rainfall for 2009 has so far been lower than the mean monthly rainfall (1995-2009) except in February and July 2009. February and July were wetter than average with 52mm and 109mm rainfall, representing an increase of 8.3% and 113%, respectively. Rainfall from March to June 2009 was lower than average ranging between -5 and -52% less and August was also drier than average with -61% less rainfall and at Knipe Point, rainfall was -68% less.

Table 22. Monthly Rainfall at Scarborough

Month	Scarborough Average (1995-2006) mm	Scarborough	
		mm	% of average
Mar. 2009	47.5	23.3	-51%
Apr. 2009	63.3	36.0	-43%
May 2009	48.2	45.8	-5%
Jun. 2009	75.1	41.9	-44%
Jul. 2009	51.2	109.2	113%
Aug. 2009	78.3	30.9	-61%

7.2.2 Seasonal Rainfall Data

Seasonally, the Summer period of 2009 has been drier than the 1995-2006 average. Up to the end of September, 292mm of rainfall had been recorded in comparison with 366mm for the mean 1995-2006 value. These figures reverse the trend of increased mean rainfall from previous Summer periods 1995-2006, 2007 and 2008 where increases of 13% and 16% have been recorded. Autumn / Winter rainfall values recorded against a mean value of 363 (for 1995-2006) have followed a trend of decreasing rainfall of -3% and -19% for 2007-2008 and 2008-2009, respectively.

Table 23. Seasonal Rainfall at Scarborough

Season(s)	Scarborough Spring / Summer (April-September)		Scarborough Autumn / Winter (October-March)	
	mm	% of Average	mm	% of Average
1995-2006 (Average)	405.3	N/A	631.7	N/A
2007	450	11%	-	-
2007-2008	-	-	433.9	-31.3%
2008	546.7	34.9%	-	-
2008-2009	-	-	311.1	-50.8%
2009	91.9*	-77.3%	-	-

** Incomplete Data Set*

7.2.3 Daily Rainfall Data

Monthly rainfall data for each specific year have been refined to give average daily totals per month and these results have been used to determine an average daily rainfall per month over the period data has been available (i.e. 1995 to 2008/9 for Scarborough).

The 75th percentile for daily rainfall per month has been determined to provide 'benchmark' values against which to measure current and future amounts of daily rainfall. Where the 75th percentile daily rainfall is exceeded by a daily rainfall event then an action of walk-over surveys and inspections of the sites in question is recommended to determine whether any adverse effects are apparent from such a rainfall occurrence.

It is proposed to allow a 5 day delay in going out on site to cater for additional days of rainfall at >75 % percentile. If rainfall continues at > 75% for more days then either additional site visits will be required after a further 5 days or, continuous walk-over surveys should be considered for the sites.

The difficulty lies in being able to gather rainfall information in real time, determining how much rain has fallen within a set period (24 hours), identifying whether this amount of rain has exceeded the 75th percentile and reacting in a timely manner in order to predict whether the rainfall event has or will have a detrimental effect upon slope stability at any section of the North Yorkshire coast.

Average daily rainfall data are presented in Appendix E.

7.3 Groundwater Conditions

Long term groundwater monitoring has been intermittently carried out in boreholes across this site, generally from the date of instrument installation to the present day covering the period 1995 to 2009. The data has illustrated the presence of perched groundwater within the glacial tills at varying depths across the site, above a lower groundwater table. Following periods of heavy or sustained rainfall a rise in the watertable has been reflected in raised water levels in piezometers across the site. Such occurrences are detailed as follows:-

BH1 recorded maximum groundwater level on 3rd September 2009. There was no evidence of heavy rainfall prior to this date other than 13.2mm rainfall recorded on 2nd September 2009.

E4 recorded maximum groundwater level on 16th August 2002 following 62.1mm rainfall on 9th August 2002 and 50.5mm rainfall on 1st August 2002.

BH4 recorded maximum groundwater level on 15th July 2009 following 19.7mm rainfall on 6th July 2009 and 9.6mm rainfall on 11th July 2009.

Peak groundwater levels from G1 were recorded on

These readings coincide with a rainfall event of nine days earlier when 20.2mm of rainfall was recorded on 21st January 2008. In addition to this, maximum water level readings from DP9 were recorded in September 2004 ten days after 15.7mm rainfall, in November 2004 six days after 7.5mm rainfall and in November 2006 eight days after 15.7mm rainfall. Following each event of rainfall, the resulting rise in groundwater levels is reflected within the piezometers on site and thus the potential for possible slope failures due to increased porewater pressures can be evaluated. Piezometric Groundwater Data Graphs are presented in Appendix F.

7.4 Conclusions

From a review of historical rainfall data between 1995 and 2008/9, it is evident that numerous exceedances of the average daily rainfall per month have occurred during this period; several have been detailed above. There are no records available to link known or observed ground movements to such past rainfall events where the average daily values have been exceeded. Therefore this report has identified limiting values of rainfall in terms of how much rainfall, within a 24 hour period, can occur before site inspections should be undertaken.

When reviewing the rainfall data, the 75th percentile has been calculated as the cut-off value. This shows that 75% of rainfall is below this value and the remaining 25% of rainfall exceeds this amount.

For Scarborough South Cliff, the 75th percentile of daily rainfall values determined from data recorded at a Scarborough weather station varies between a minimum of **3.60mm** rainfall per day (for March and May) and a maximum value of **5.90mm** rainfall per day (July and October). The values for the whole year are presented below in Table 23.

Table 24. 75th Percentile values for Scarborough Rainfall Data

75th Percentile Daily Rainfall/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
(mm)	3.9	4.0	3.6	4.9	3.6	5.7	5.9	4.5	4.6	5.9	4.2	3.9

In the event that these daily rainfall values are exceeded, it is recommended that walk-over surveys of the site are carried out as soon as practicable and any evidence of ground movements is recorded and monitored on a regular basis.

Future failures within the glacial till slopes are most likely to be shallow (although these can trigger deeper seated failures), caused by excessive water entrainment. If such failures were to occur, adverse loading of the sea wall could result in increased loading and possible failure of this structure. This mechanism of potential failure could be controlled by slope betterment works and improved surface drainage systems to take groundwater away and prevent excess water pressure build-up.

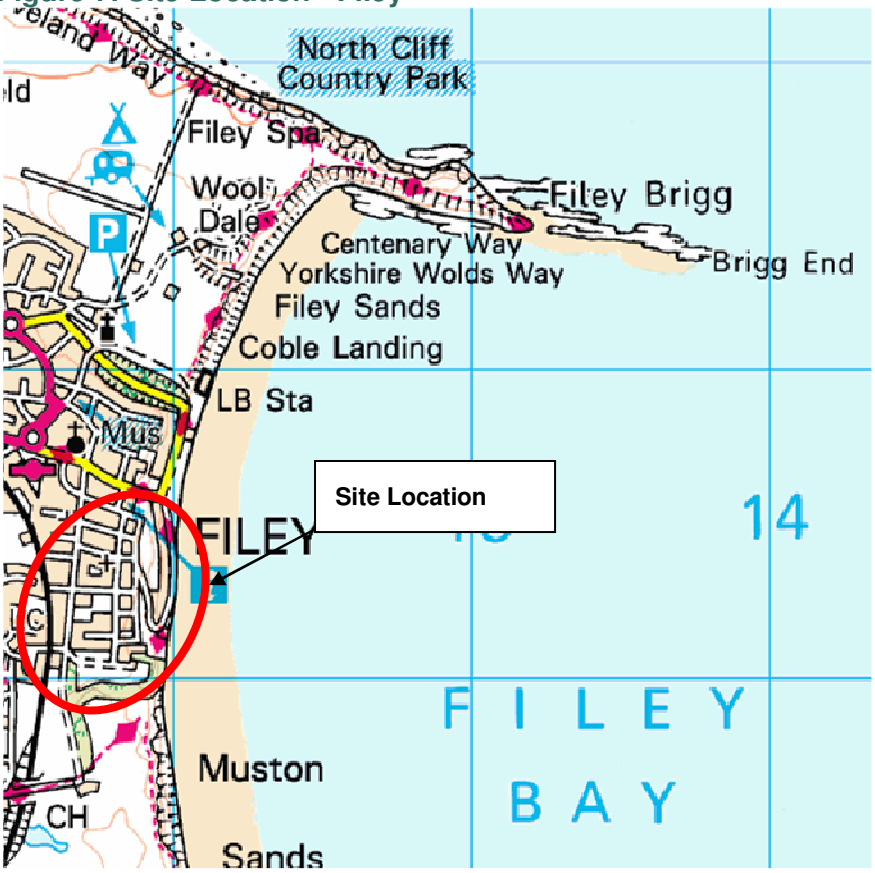
8 Filey Town

8.1 Site Location and Description

The site is located to the south and east of Filey town centre, a popular holiday resort, on the north east coast of England.

Martin's Ravine is a steep sided valley to the south of Filey, through which a footpath leads, sloping downwards from a car park to the southern end of Royal Parade and the sea. Royal Parade is a flat esplanade along the sea front extending from the south at the base of Martin's Ravine, northwards to where The Crescent approaches from above, and continues north towards Filey town centre and Church Ravine. To the rear of Royal Parade is a line of small chalets behind which is a steep slope rising up to a level grassed area (Glen Gardens). The northern edge of this area is bounded by Crescent Hill which leads off The Crescent, from the top of the recreation grounds, and winds down to join Royal Parade. A number of footpaths criss-cross the slopes allowing pedestrian access from the cliff top to the beaches below.

Figure 7. Site Location - Filey



8.2 Rainfall Conditions

The rainfall data presented in Appendix C and D has been provided by the EA and SBC. The data represents daily rainfall recorded between January 1995 and October / December 2008 by a Casella rainfall logging system located at Scarborough, North Yorkshire. Limited data for 2009 has also been made available at the time of writing this report.

8.2.1 Monthly Rainfall Data

The mean monthly recorded rainfall at Scarborough illustrates a period of higher mean rainfall occurring between June and December from 1995 to 2009.

Rainfall recorded at Scarborough illustrates a notable difference in the monthly rainfall total for July 2009. Monthly rainfall for 2009 has so far been lower than the mean monthly rainfall (1995-2009) except in February and July 2009. February and July were wetter than average with 52mm and 109mm rainfall, representing an increase of 8.3% and 113%, respectively. Rainfall from March to June 2009 was lower than average ranging between -5 and -52% less and August was also drier than average with -61% less rainfall and at Knipe Point, rainfall was -68% less.

Table 25. Monthly Rainfall at Scarborough

Month	Scarborough Average (1995-2006) mm	Scarborough	
		mm	% of average
Mar. 2009	47.5	23.3	-51%
Apr. 2009	63.3	36.0	-43%
May 2009	48.2	45.8	-5%
Jun. 2009	75.1	41.9	-44%
Jul. 2009	51.2	109.2	113%
Aug. 2009	78.3	30.9	-61%

8.2.2 Seasonal Rainfall Data

Seasonally, the Summer period of 2009 has been drier than the 1995-2006 average. Up to the end of September, 292mm of rainfall had been recorded in comparison with 366mm for the mean 1995-2006 value. These figures reverse the trend of increased mean rainfall from previous Summer periods 1995-2006, 2007 and 2008 where increases of 13% and 16% have been recorded. Autumn / Winter rainfall values recorded against a mean value of 363 (for 1995-2006) have followed a trend of decreasing rainfall of -3% and -19% for 2007-2008 and 2008-2009, respectively.

Table 26. Seasonal Rainfall at Scarborough

Season(s)	Scarborough Spring / Summer (April-September)		Scarborough Autumn / Winter (October-March)	
	mm	% of Average	mm	% of Average
1995-2006 (Average)	405.3	N/A	631.7	N/A
2007	450	11%	-	-
2007-2008	-	-	433.9	-31.3%
2008	546.7	34.9%	-	-
2008-2009	-	-	311.1	-50.8%
2009	91.9*	-77.3%	-	-

** Incomplete Data Set*

8.2.3 Daily Rainfall Data

Monthly rainfall data for each specific year have been refined to give average daily totals per month and these results have been used to determine an average daily rainfall per month over the period data has been available (i.e. 1995 to 2008/9 for Scarborough).

The 75th percentile for daily rainfall per month has been determined to provide 'benchmark' values against which to measure current and future amounts of daily rainfall. Where the 75th percentile daily rainfall is exceeded by a daily rainfall event then an action of walk-over surveys and inspections of the sites in question is recommended to determine whether any adverse effects are apparent from such a rainfall occurrence.

It is proposed to allow a 5 day delay in going out on site to cater for additional days of rainfall at >75 % percentile. If rainfall continues at > 75% for more days then either additional site visits will be required after a further 5 days or, continuous walk-over surveys should be considered for the sites.

The difficulty lies in being able to gather rainfall information in real time, determining how much rain has fallen within a set period (24 hours), identifying whether this amount of rain has exceeded the 75th percentile and reacting in a timely manner in order to predict whether the rainfall event has or will have a detrimental effect upon slope stability at any section of the North Yorkshire coast.

Average daily rainfall data are presented in Appendix E.

8.3 Groundwater Conditions

Groundwater readings were taken during and after site works from July to early October 2008. The readings recorded during this period showed little, if any, fluctuation in ground water levels indicating a static water regime at this site. Follow-on readings taken in June and July 2009 show no variation to the pattern of steady-state groundwater levels previously indicated. Piezometric Groundwater Data Graphs are presented in Appendix F.

8.4 Conclusions

From a review of historical rainfall data between 1995 and 2008/9, it is evident that numerous exceedances of the average daily rainfall per month have occurred during this period. There are no records available to link known or observed ground movements to such past rainfall events where the average daily values have been exceeded. Therefore this report has identified limiting values of rainfall in terms of how much rainfall, within a 24 hour period, can occur before site inspections should be undertaken.

When reviewing the rainfall data, the 75th percentile has been calculated as the cut-off value. This shows that 75% of rainfall is below this value and the remaining 25% of rainfall exceeds this amount.

For Filey, the 75th percentile of daily rainfall values determined from data recorded at a Scarborough weather station varies between a minimum of **3.60mm** rainfall per day (for March and May) and a maximum value of **5.90mm** rainfall per day (July and October). The values for the whole year are presented below in Table 26.

Table 27. 75th Percentile values for Scarborough Rainfall Data

75th Percentile Daily Rainfall/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
(mm)	3.9	4.0	3.6	4.9	3.6	5.7	5.9	4.5	4.6	5.9	4.2	3.9

In the event that these daily rainfall values are exceeded, it is recommended that walk-over surveys of the site are carried out as soon as practicable and any evidence of ground movements is recorded and monitored on a regular basis.

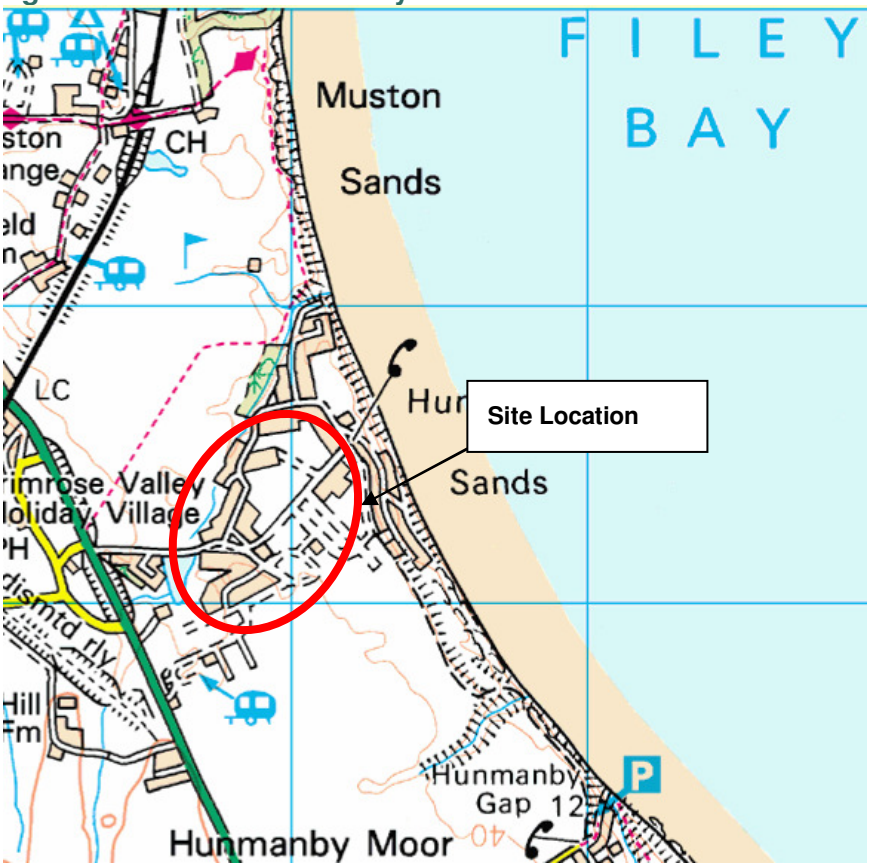
Future failures within the glacial till slopes of Filey are most likely to be shallow, caused by excessive water entrainment and possible groundwater run-off. This mechanism of potential failure could be controlled by slope betterment works and improved surface drainage systems to take groundwater away and prevent excess water pressure build-up.

9 Filey Flat Cliffs

9.1 Site Location and Description

Filey Flat Cliffs is situated near Primrose Valley Holiday Park, 2 km south of Filey town centre on the north east coast of England. The site comprises steep unprotected coastal slopes of glacial till on which holiday homes and static caravans have been constructed with narrow tarmac access roads. The site is bounded to the north, west and south by the holiday park and to the east by the cliffs.

Figure 8. Site Location – Filey Flat Cliffs



9.2 Rainfall Conditions

The rainfall data presented in Appendix C and D has been provided by the EA and SBC. The data represents daily rainfall recorded between January 1995 and October / December 2008 by a Casella rainfall logging system located at Scarborough, North Yorkshire. Limited data for 2009 has also been made available at the time of writing this report.

9.2.1 Monthly Rainfall Data

The mean monthly recorded rainfall at Scarborough illustrates a period of higher mean rainfall occurring between June and December from 1995 to 2009.

Rainfall recorded at Scarborough illustrates a notable difference in the monthly rainfall total for July 2009. Monthly rainfall for 2009 has so far been lower than the mean monthly rainfall (1995-2009) except in February and July 2009. February and July were wetter than average with 52mm and 109mm rainfall, representing an increase of 8.3% and 113%, respectively. Rainfall from March to June 2009 was lower than average ranging between -5 and -52% less and August was also drier than average with -61% less rainfall and at Knipe Point, rainfall was -68% less.

Table 28. Monthly Rainfall at Scarborough

Month	Scarborough Average (1995-2006) mm	Scarborough	
		mm	% of average
Mar. 2009	47.5	23.3	-51%
Apr. 2009	63.3	36.0	-43%
May 2009	48.2	45.8	-5%
Jun. 2009	75.1	41.9	-44%
Jul. 2009	51.2	109.2	113%
Aug. 2009	78.3	30.9	-61%

9.2.2 Seasonal Rainfall Data

Seasonally, the Summer period of 2009 has been drier than the 1995-2006 average. Up to the end of September, 292mm of rainfall had been recorded in comparison with 366mm for the mean 1995-2006 value. These figures reverse the trend of increased mean rainfall from previous Summer periods 1995-2006, 2007 and 2008 where increases of 13% and 16% have been recorded. Autumn / Winter rainfall values recorded against a mean value of 363 (for 1995-2006) have followed a trend of decreasing rainfall of -3% and -19% for 2007-2008 and 2008-2009, respectively.

Table 29. Seasonal Rainfall at Scarborough

Season(s)	Scarborough Spring / Summer (April-September)		Scarborough Autumn / Winter (October-March)	
	mm	% of Average	mm	% of Average
1995-2006 (Average)	405.3	N/A	631.7	N/A
2007	450	11%	-	-
2007-2008	-	-	433.9	-31.3%
2008	546.7	34.9%	-	-
2008-2009	-	-	311.1	-50.8%
2009	91.9*	-77.3%	-	-

** Incomplete Data Set*

9.2.3 Daily Rainfall Data

Monthly rainfall data for each specific year have been refined to give average daily totals per month and these results have been used to determine an average daily rainfall per month over the period data has been available (i.e. 1995 to 2008/9 for Scarborough).

The 75th percentile for daily rainfall per month has been determined to provide 'benchmark' values against which to measure current and future amounts of daily rainfall. Where the 75th percentile daily rainfall is exceeded by a daily rainfall event then an action of walk-over surveys and inspections of the sites in question is recommended to determine whether any adverse effects are apparent from such a rainfall occurrence.

It is proposed to allow a 5 day delay in going out on site to cater for additional days of rainfall at >75 % percentile. If rainfall continues at > 75% for more days then either additional site visits will be required after a further 5 days or, continuous walk-over surveys should be considered for the sites.

The difficulty lies in being able to gather rainfall information in real time, determining how much rain has fallen within a set period (24 hours), identifying whether this amount of rain has exceeded the 75th percentile and reacting in a timely manner in order to predict whether the rainfall event has or will have a detrimental effect upon slope stability at any section of the North Yorkshire coast.

Average daily rainfall data are presented in Appendix E.

9.3 Groundwater Conditions

Groundwater data from the three piezometers has been recorded from March 2001 up to September 2008 and for late 2009. The data illustrates the presence of perched groundwater within the glacial tills lying at various depths across the site, above a lower groundwater table. During periods of heavy or sustained rainfall, a rise in the water table has been reflected in raised water levels within the installed piezometers. Since installation in 2001, borehole D1 recorded maximum groundwater levels on 25th May 2005 and 12th December 2006 when on each occasion, 18.3mm rainfall was recorded over five days. In each instance the daily mean rainfall exceeded the Daily Mean per month on four days out of the five. Two further peaks in groundwater levels were recorded on the 23rd January and 8th July 2008, each occasion was preceded by a period of rainfall of 66.1mm over seven days and 31.7mm over three days, respectively. Following each event of rainfall, the resulting rise in groundwater levels is reflected within the piezometers on site and hence the potential for possible slope failures due to increasing porewater pressures can be evaluated. Piezometric Groundwater Data Graphs are presented in Appendix F.

9.4 Conclusions

From a review of historical rainfall data between 1995 and 2008/9, it is evident that numerous exceedances of the average daily rainfall per month have occurred during this period; several have been detailed above. There are no records available to link known or observed ground movements to such past rainfall events where the average daily values have been exceeded. Therefore this report has identified limiting values of rainfall in terms of how much rainfall, within a 24 hour period, can occur before site inspections should be undertaken.

When reviewing the rainfall data, the 75th percentile has been calculated as the cut-off value. This shows that 75% of rainfall is below this value and the remaining 25% of rainfall exceeds this amount.

For Filey Flat Cliffs, the 75th percentile of daily rainfall values determined from data recorded at a Scarborough weather station varies between a minimum of **3.60mm** rainfall per day (for March and May) and a maximum value of **5.90mm** rainfall per day (July and October). The values for the whole year are presented below in Table 29.

Table 30. 75th Percentile values for Scarborough Rainfall Data

75th Percentile Daily Rainfall/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
(mm)	3.9	4.0	3.6	4.9	3.6	5.7	5.9	4.5	4.6	5.9	4.2	3.9

In the event that these daily rainfall values are exceeded, it is recommended that walk-over surveys of the site are carried out as soon as practicable and any evidence of ground movements is recorded and monitored on a regular basis.

References

Anderton R, et al (1979) A Dynamic Stratigraphy of the British Isles, Chapter 17. George Allen & Unwin.

British Geological Survey (BGS) 1:50,000 Scale, Solid and Drift (Sheet 34 Guisborough)

British Geological Survey (BGS) 1:50,000 Scale, Solid and Drift (Sheet 35 Whitby).

British Geological Survey (BGS) 1:50,000 Scale, Solid and Drift (Sheet 44 Scalby)

British Geological Survey (BGS) 1:50,000 Scale, Solid and Drift (Sheet 54 Scarborough)

BS 1377: (1990) Soils for Civil Engineering Purposes. British Standards Institution.

BS 5930: (1999) Code of Practice for Site Investigations. British Standards Institution.

BS 6031: (1981) Code of Practice for Earthworks. British Standards Institution.

CIRIA Special Publication 149 (1998): A Guide to British Stratigraphic Nomenclature.

Environment Agency, 2006: Underground, Under Threat, Groundwater Protection: Policy and Practice.

Environmental Agency website, "What's in my Backyard"? http:www://216.31.193.171/asp/1_introduction.asp

http: www.eastyorkshire.co.uk/eddsfield/index.htm

http: www.greatweather.co.uk

http: www.metoffice.gov.uk

Lee, E.M. & Jones, D.K.C. (2004) Landslide Risk Assessment – Thomas Telford Ltd.

Mills. (1981) Site investigation report Knipe Point, Cayton Bay, North East Yorkshire, MSc Thesis.

Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL, March 2009.*

Mouchel Report *"Ongoing Analysis and Interpretation of Coastal Monitoring Data*, Condition Survey Report" 721229/001/CSR/02/FINAL, July 2009

Mouchel Report *"Ongoing Analysis and Interpretation of Coastal Monitoring Data*, Feasibility Report into the Replacement of Damaged Monitoring Equipment" 721229/017/GIR/002/FINAL, September 2009

Mouchel Report *"Ongoing Analysis and Interpretation of Coastal Monitoring Data*, Initial Review of Full Suite Monitoring" 721229/002/GIR/002/FINAL, October 2009

Mouchel Report *"Ongoing Analysis and Interpretation of Coastal Monitoring Data*, Initial Review of Restricted Suite Monitoring" 721229/002/GIR/003/FINAL, October 2009

Mouchel Report *"Ongoing Analysis and Interpretation of Coastal Monitoring Data*, Second Review of Restricted Suite Monitoring" 721229/002/GIR/004/FINAL, October 2009

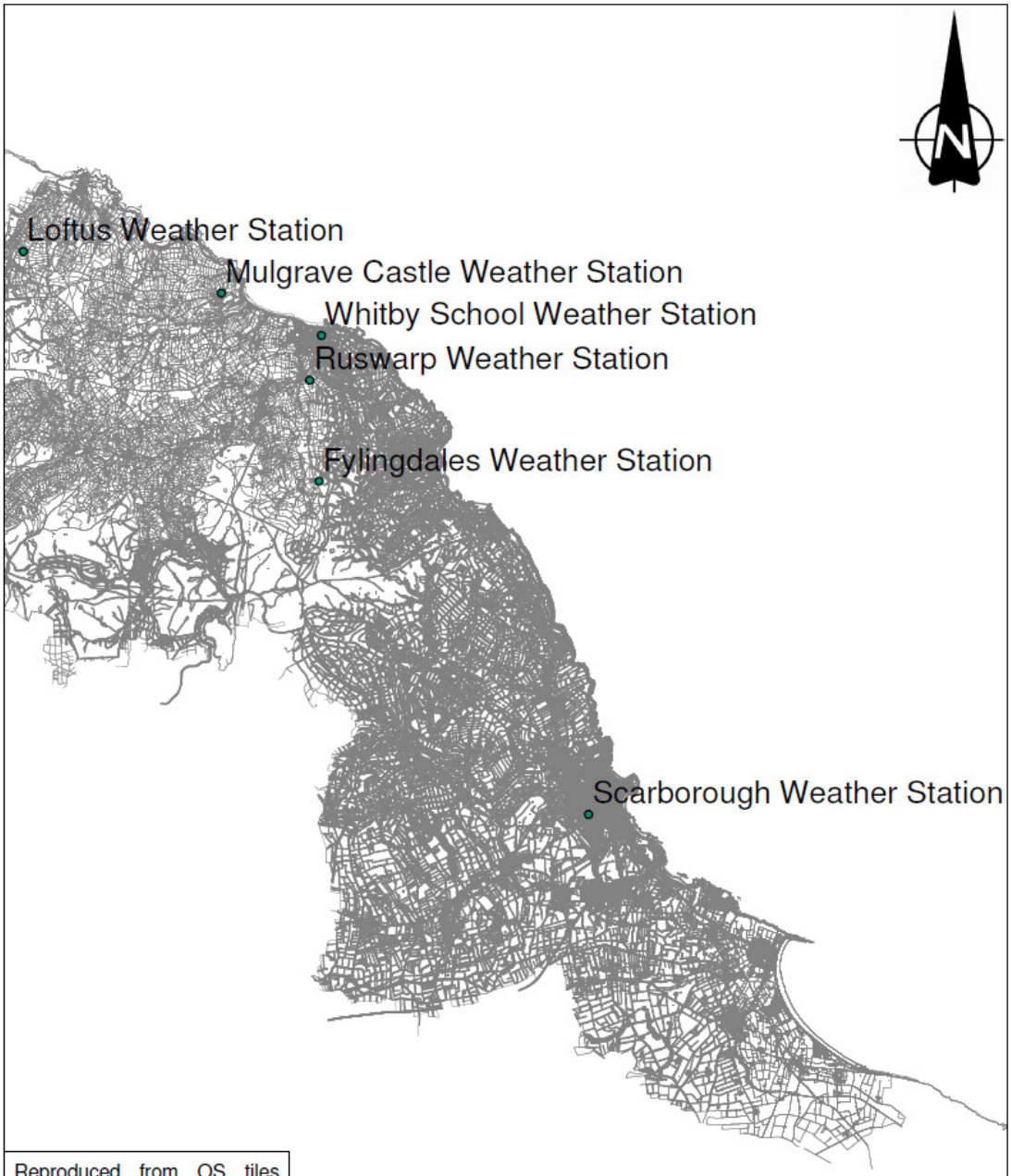
Mouchel Report *"Ongoing Analysis and Interpretation of Coastal Monitoring Data*, Third Review of Restricted Suite Monitoring" 721229/002/GIR/005/FINAL, November 2009

Mouchel Report *"Ongoing Analysis and Interpretation of Coastal Monitoring Data*, Fourth Review of Restricted Suite Monitoring" 721229/002/GIR/006/FINAL, December 2009

Scarborough Borough Council Records.

Spark, B W (1981) Geomorphology - 2nd Edition. Longman.

Appendix A Location of Weather Stations



Location of Weather Stations

Scale: 1:270,000

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Scarborough Borough Council
Analysis and Interpretation of Coastal Monitoring Data

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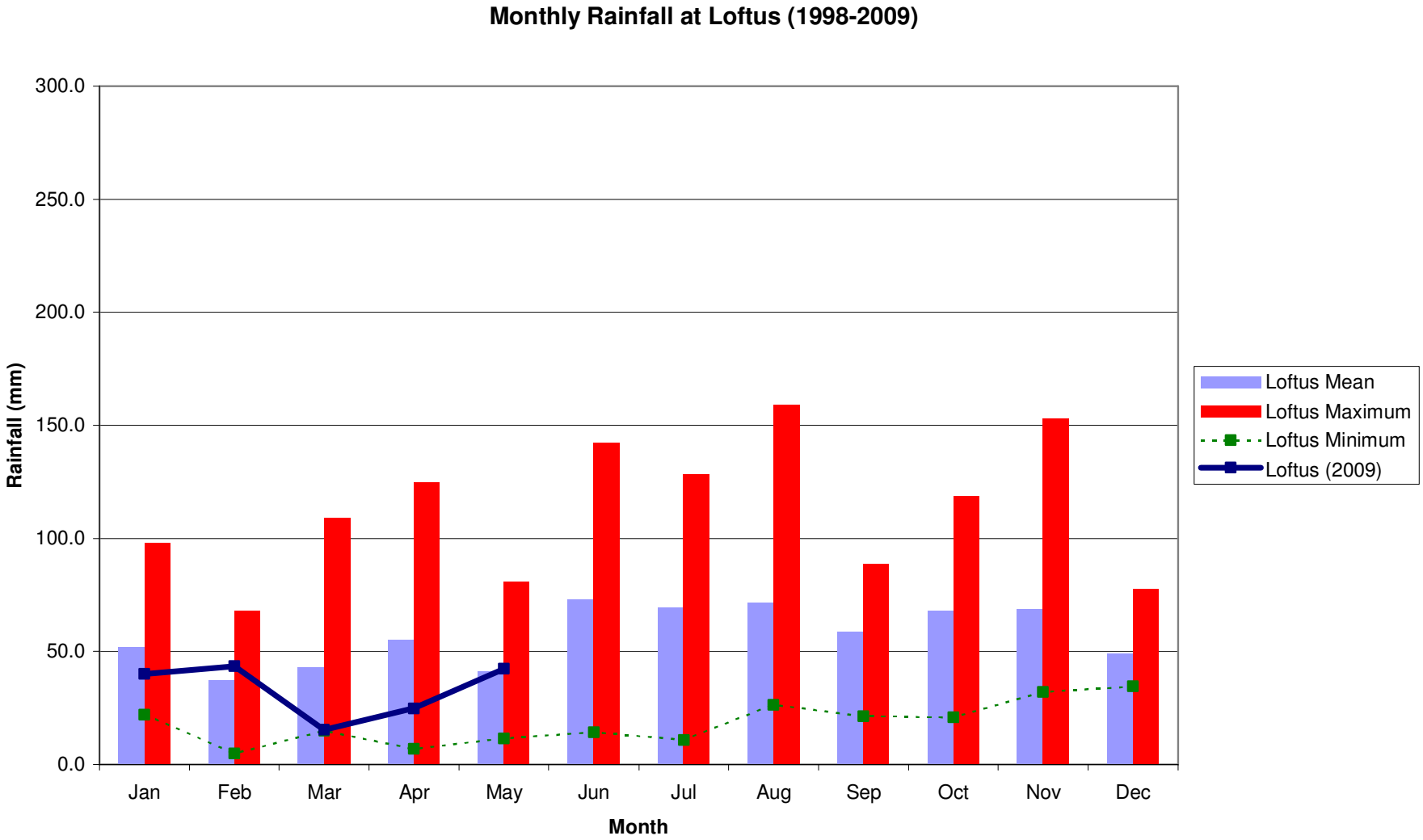
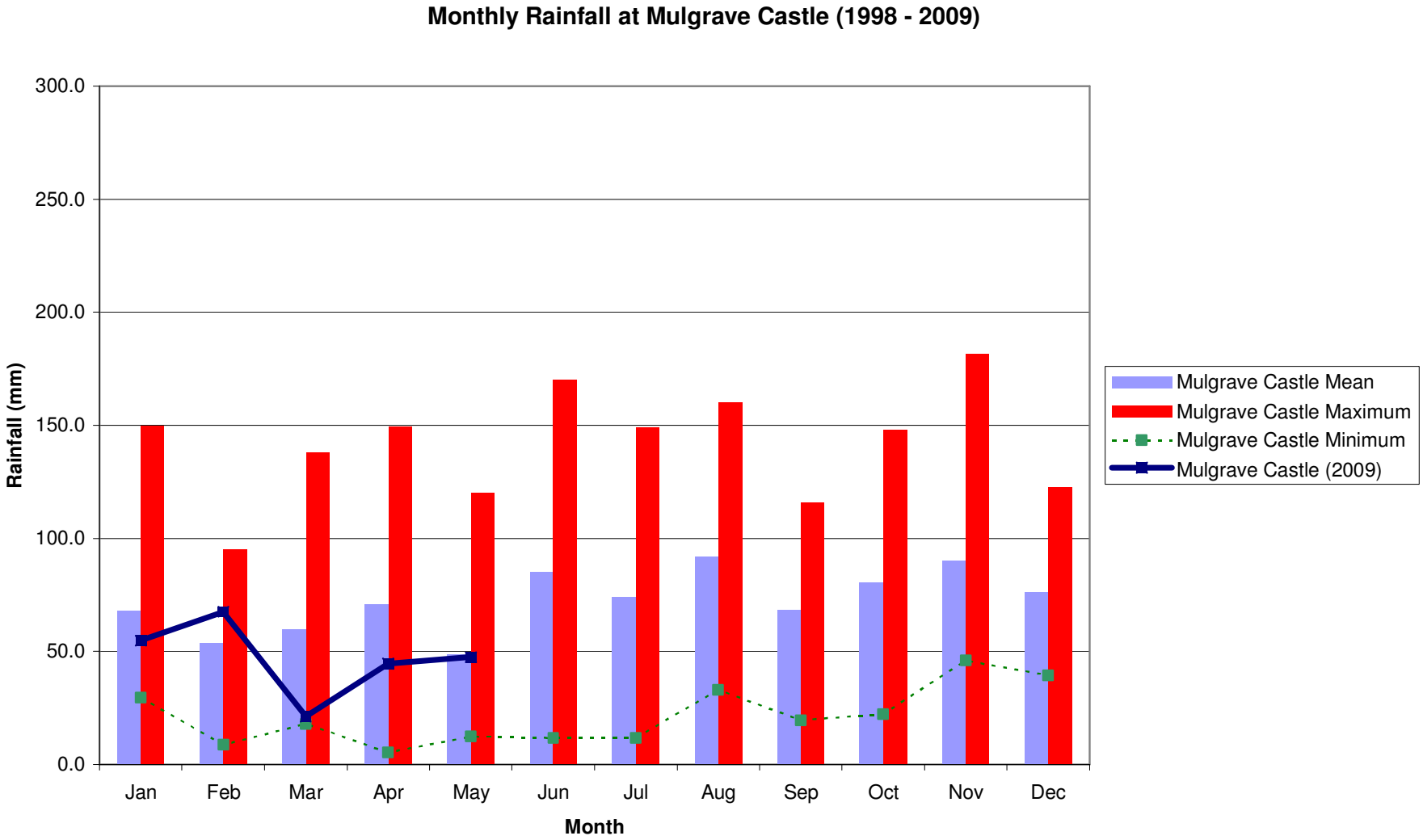
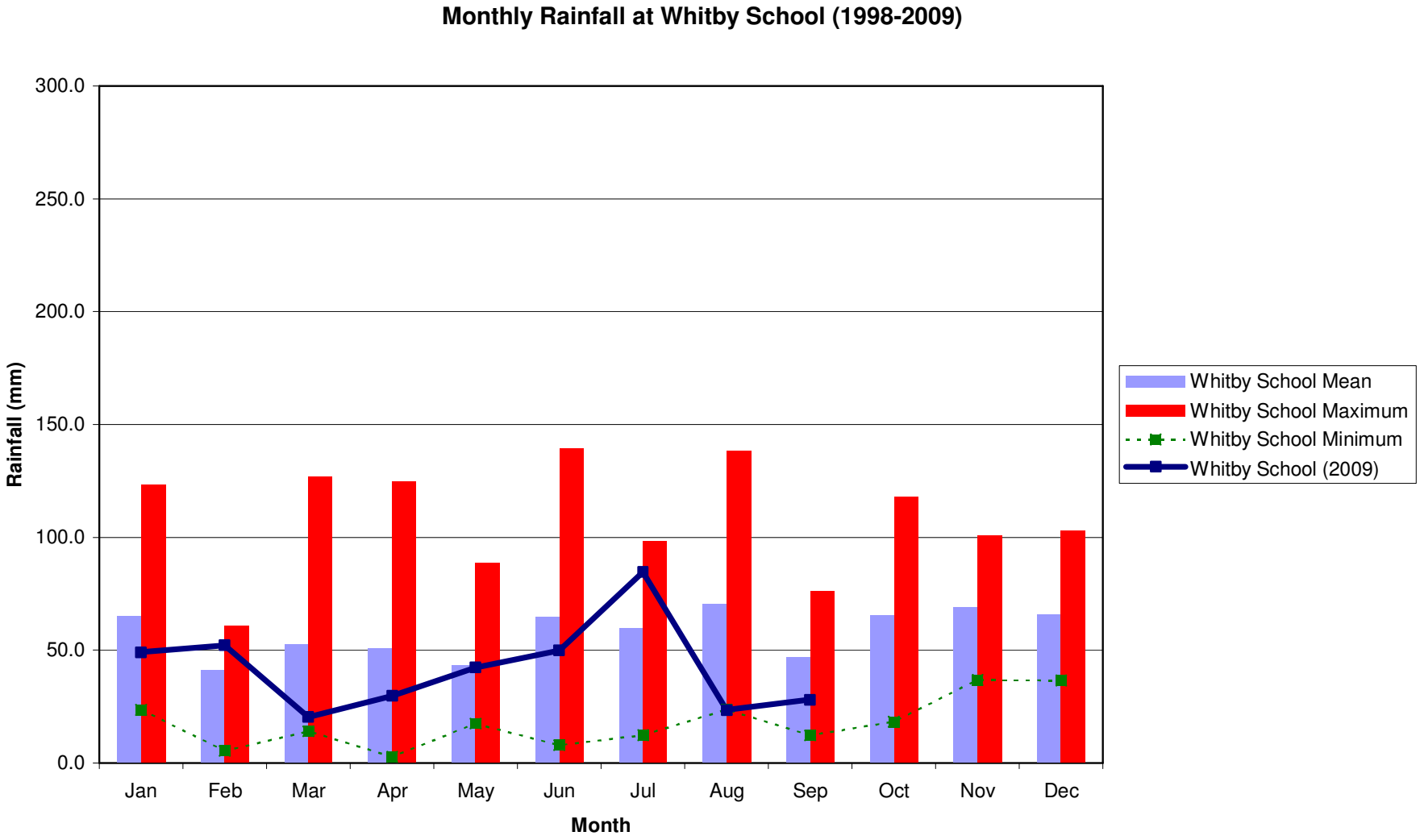
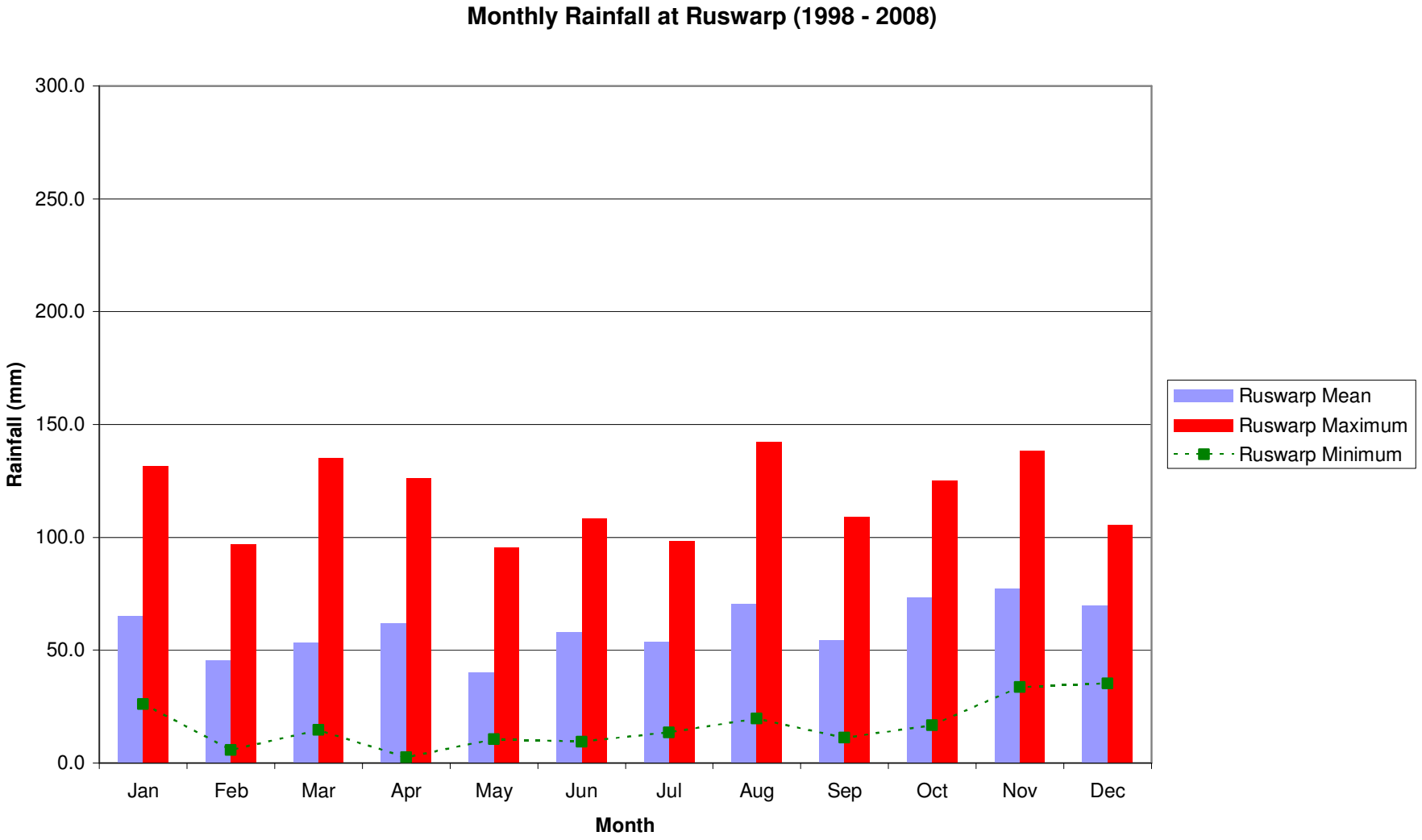
Appendix B Monthly Rainfall Graphs

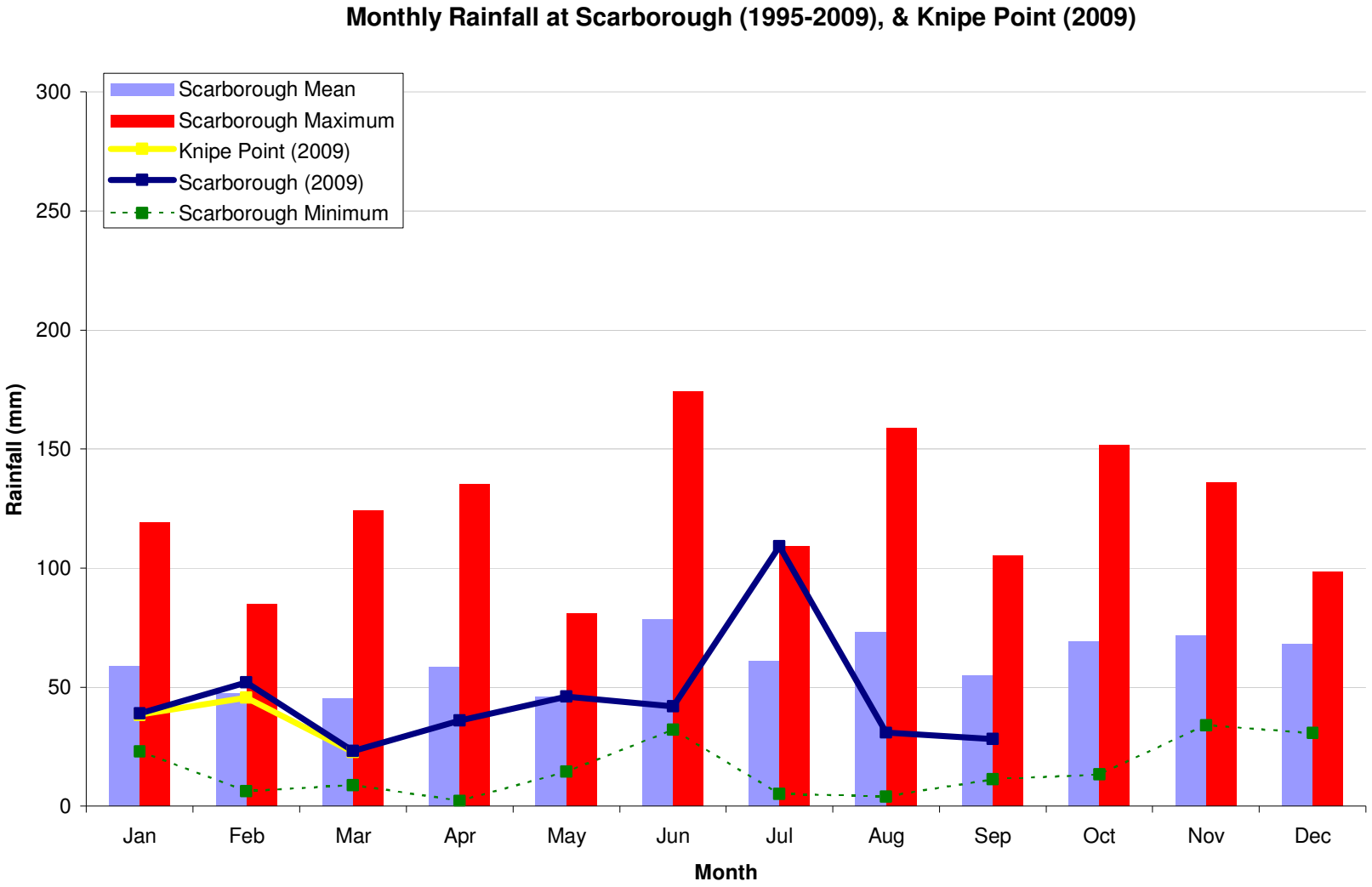
(Data and Graphs for Scarborough & Knipe Point provided by SBC)

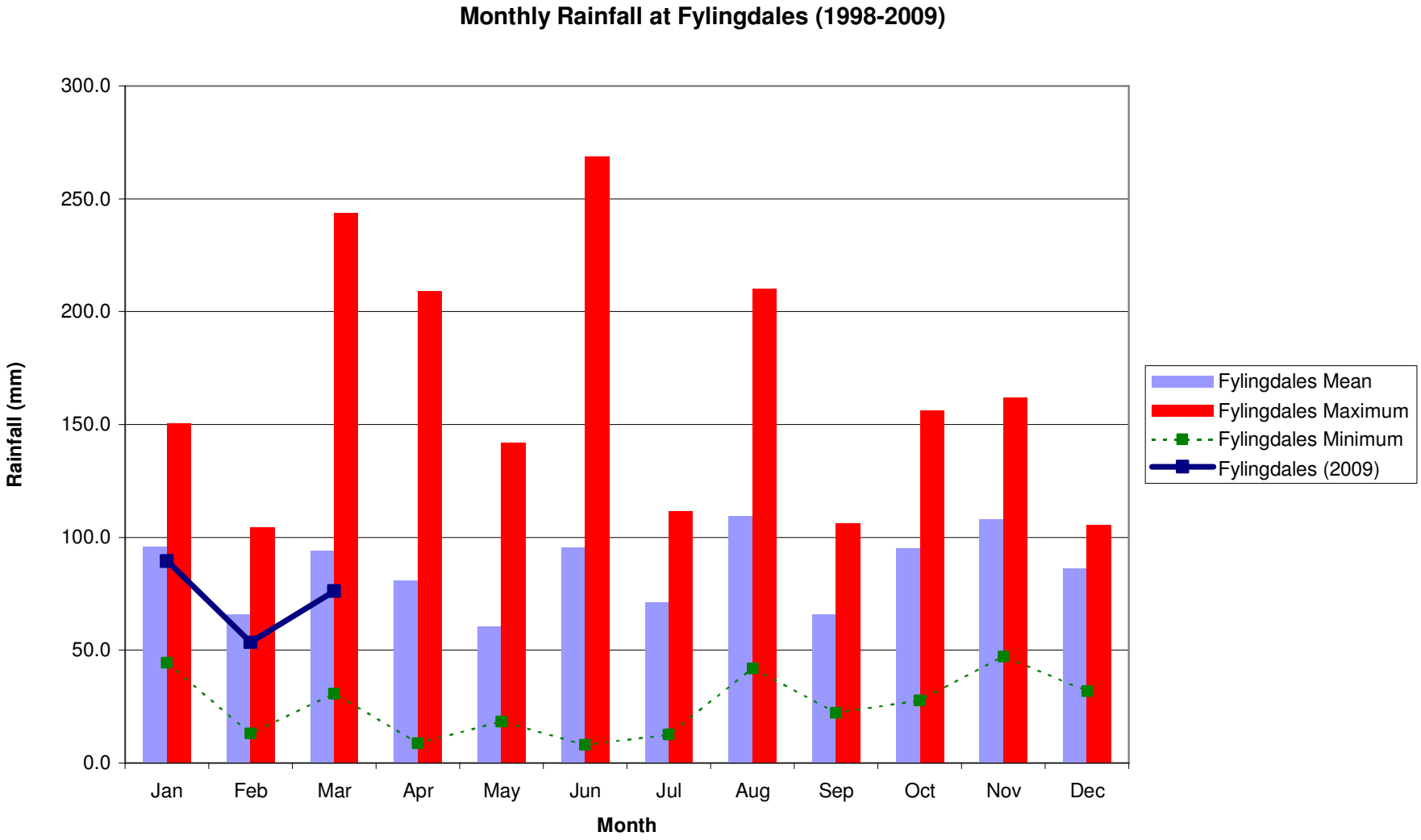

Monthly Rainfall at Loftus (1998-2009)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Rainfall (mm)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Loftus Mean
Loftus Maximum
Loftus Minimum
Loftus (2009)


Monthly Rainfall at Mulgrave Castle (1998 - 2009)
Rainfall (mm)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Mulgrave Castle Mean
Mulgrave Castle Maximum
Mulgrave Castle Minimum
Mulgrave Castle (2009)


Monthly Rainfall at Whitby School (1998-2009)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Rainfall (mm)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Whitby School Mean
Whitby School Maximum
Whitby School Minimum
Whitby School (2009)

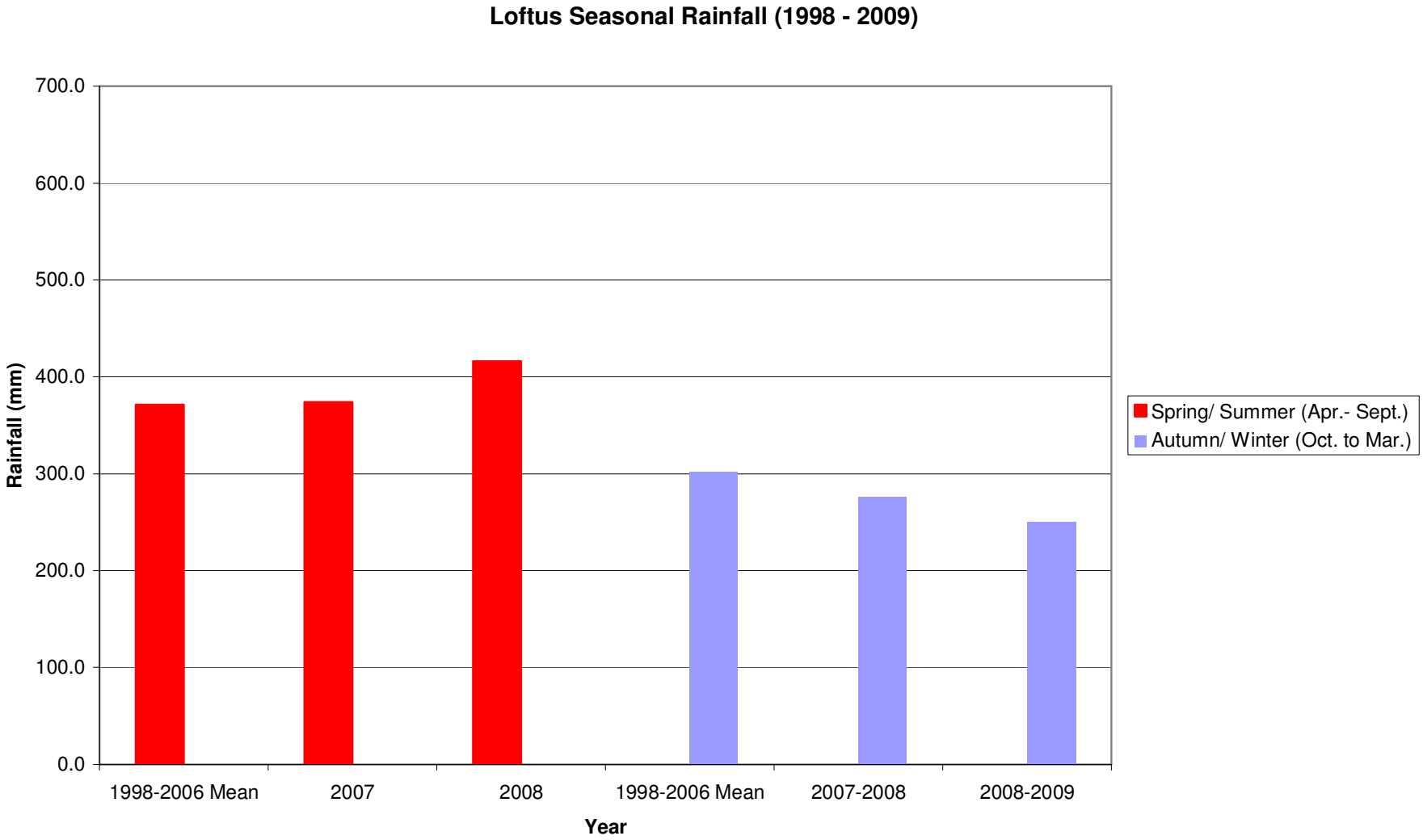

Monthly Rainfall at Ruswarp (1998 - 2008)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Rainfall (mm)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Ruswarp Mean
Ruswarp Maximum
Ruswarp Minimum

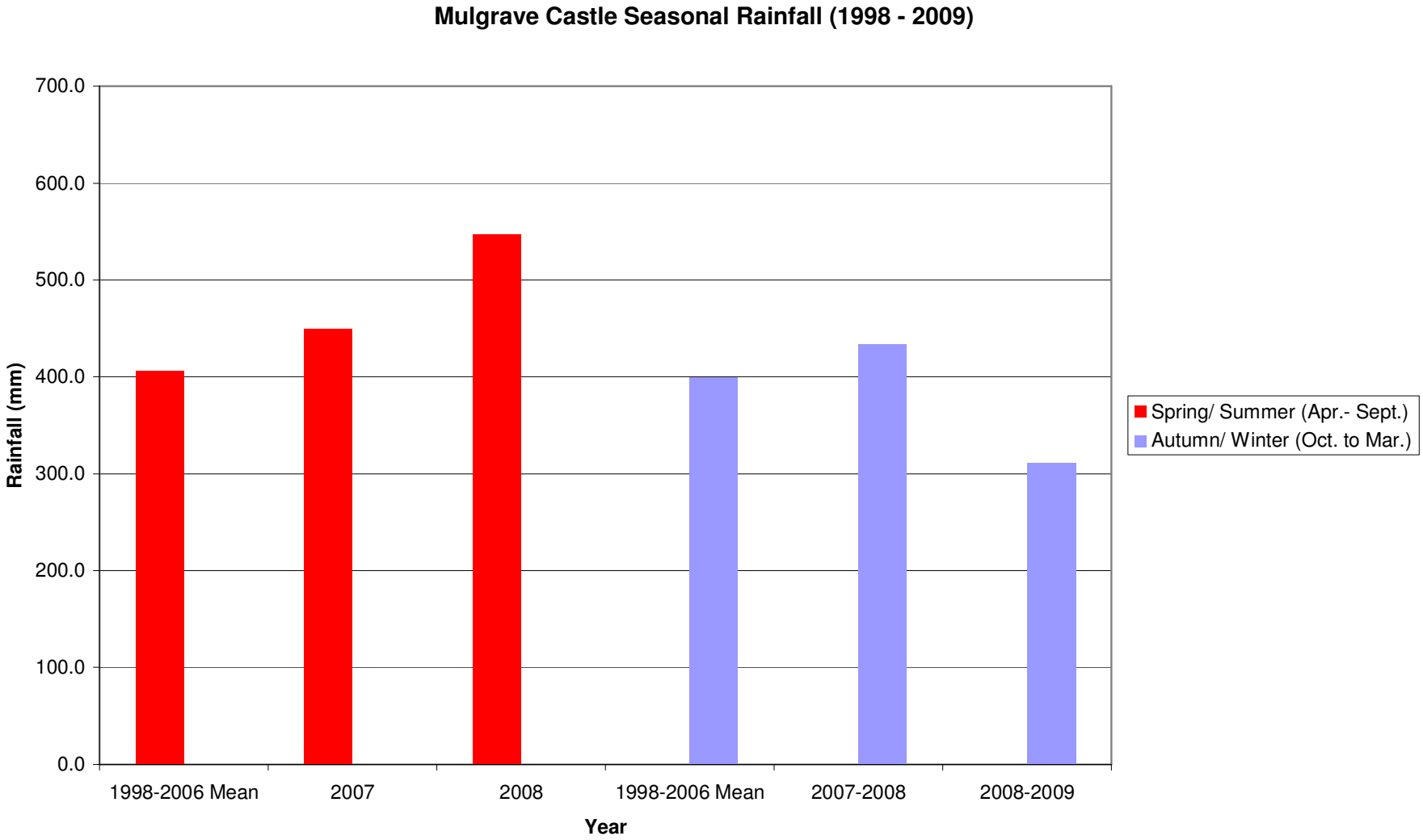

Monthly Rainfall at Scarborough (1995-2009), & Knipe Point (2009)
Scarborough Mean
Scarborough Maximum
Knipe Point (2009)
Scarborough (2009)
Scarborough Minimum
300
250
200
150
100
50
0
Rainfall (mm)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

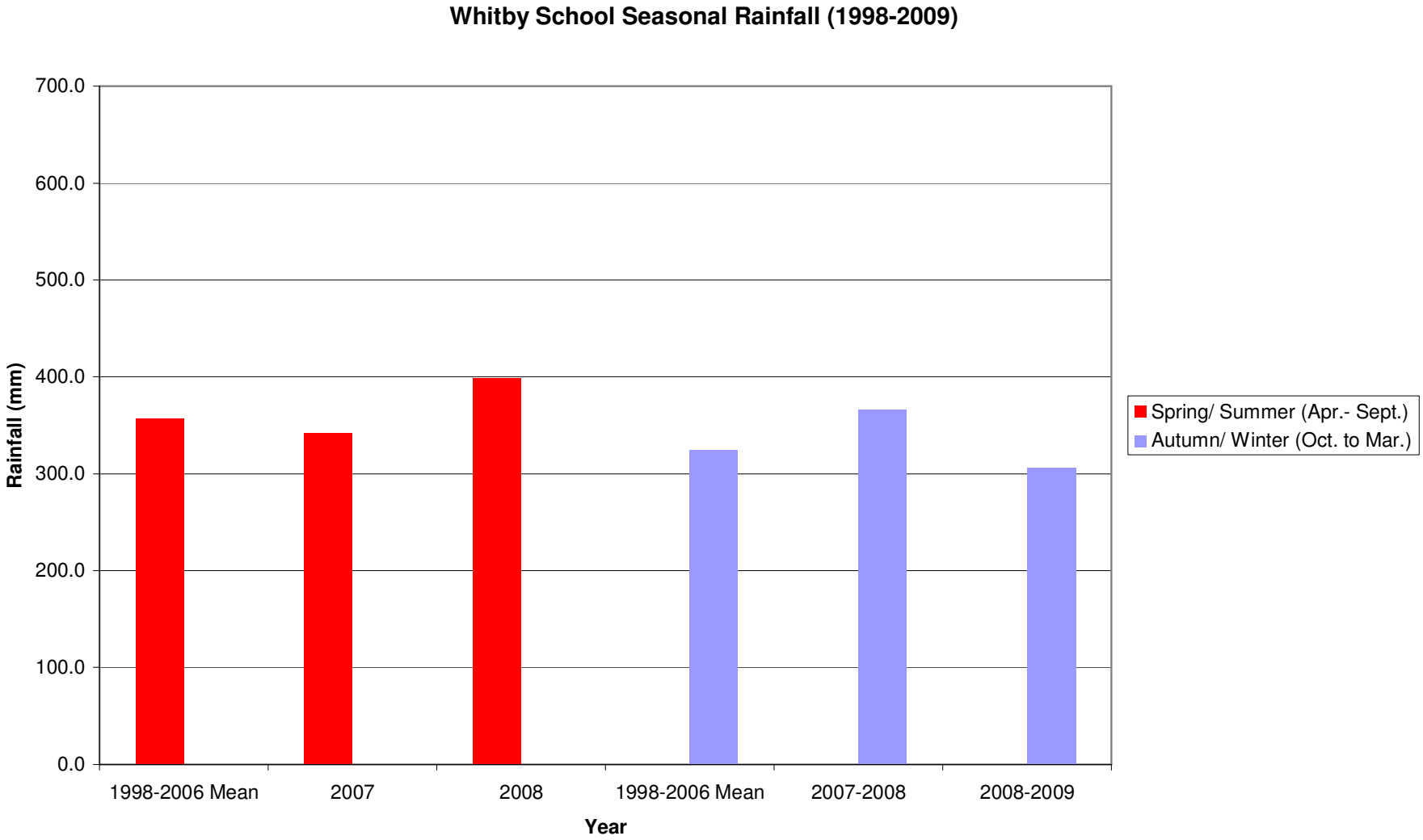

Monthly Rainfall at Fylingdales (1998-2009)
Rainfall (mm)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Fylingdales Mean
Fylingdales Maximum
Fylingdales Minimum
Fylingdales (2009)

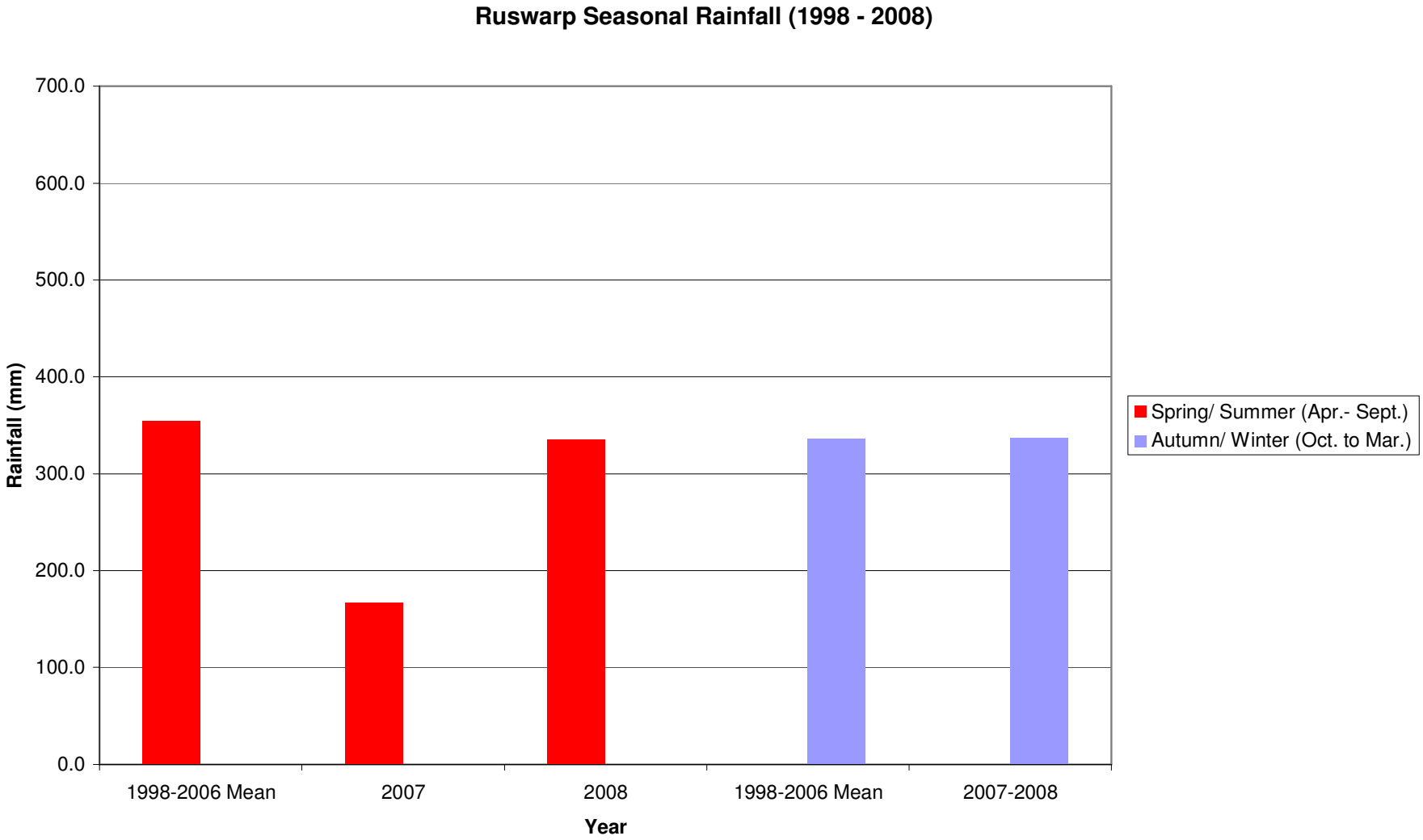
Appendix C Seasonal Rainfall Graphs

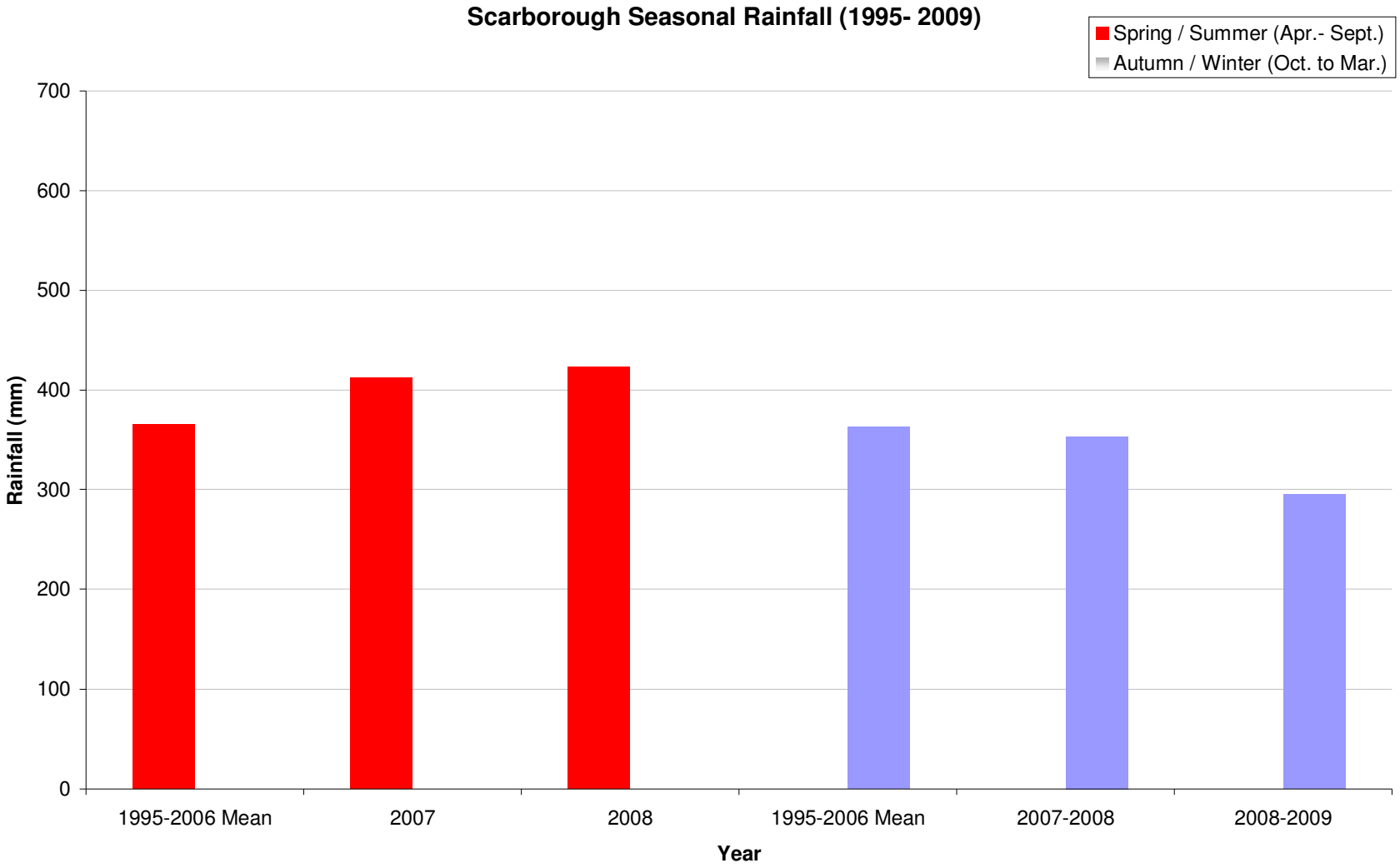
(Data and Graphs for Scarborough & Knipe Point provided by SBC)

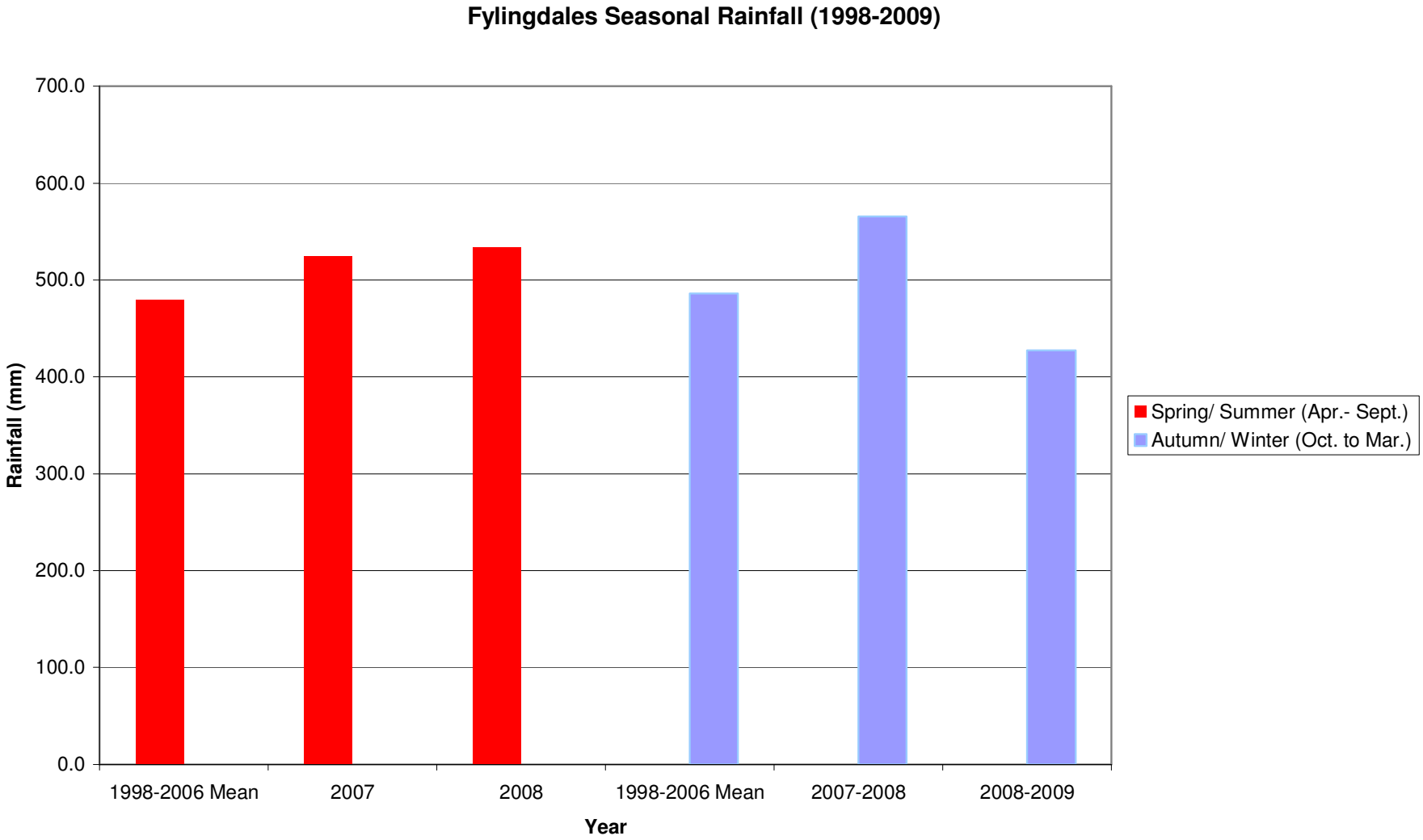

Loftus Seasonal Rainfall (1998 - 2009)
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
Rainfall (mm)
1998-2006 Mean
2007
2008
1998-2006 Mean
2007-2008
2008-2009
Year
Spring/ Summer (Apr.- Sept.)
Autumn/ Winter (Oct. to Mar.)


Mulgrave Castle Seasonal Rainfall (1998 - 2009)
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
Rainfall (mm)
1998-2006 Mean
2007
2008
1998-2006 Mean
2007-2008
2008-2009
Year
Spring/ Summer (Apr.- Sept.)
Autumn/ Winter (Oct. to Mar.)


Whitby School Seasonal Rainfall (1998-2009)
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
Rainfall (mm)
1998-2006 Mean
2007
2008
1998-2006 Mean
2007-2008
2008-2009
Year
Spring/ Summer (Apr.- Sept.)
Autumn/ Winter (Oct. to Mar.)


Ruswarp Seasonal Rainfall (1998 - 2008)
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
Rainfall (mm)
1998-2006 Mean
2007
2008
1998-2006 Mean
2007-2008
Year
Spring/ Summer (Apr.- Sept.)
Autumn/ Winter (Oct. to Mar.)


Scarborough Seasonal Rainfall (1995- 2009)
Spring / Summer (Apr.- Sept.)
Autumn / Winter (Oct. to Mar.)
700
600
500
400
300
200
100
0
Rainfall (mm)
1995-2006 Mean
2007
2008
1995-2006 Mean
2007-2008
2008-2009
Year


Fylingdales Seasonal Rainfall (1998-2009)
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
Rainfall (mm)
1998-2006 Mean
2007
2008
1998-2006 Mean
2007-2008
2008-2009
Year
Spring/ Summer (Apr.- Sept.)
Autumn/ Winter (Oct. to Mar.)

Appendix D Daily Average Rainfall Data

(Based on data provided by SBC)

WHITBY SCHOOL DAILY AVERAGES / MONTH

Year/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	2.57	0.19	1.89	4.16	1.81	3.38	1.33	1.12	1.75	2.33	2.88	1.83
1999	2.68	1.16	4.23	1.56	1.22	2.53	0.41	3.19	1.84	1.86	1.74	1.67
2000	1.45	1.03	0.72	4.21	1.30	2.07	2.65	1.12	3.59	3.73	-	3.02
2001	1.38	3.24	1.60	2.18	0.34	2.37	1.42	2.34	2.86	2.06	1.40	2.04
2002	1.00	2.11	1.27	0.52	1.49	0.97	1.75	4.61	1.09	3.93	3.37	3.43
2003	2.92	0.47	0.47	0.59	1.19	2.36	0.86	0.91	2.36	2.04	1.60	3.22
2004	4.12	1.93	1.17	3.02	0.83	2.72	2.54	4.37	0.41	3.62	1.22	1.22
2005	0.89	1.93	2.05	2.30	1.09	1.22	3.29	2.18	1.61	1.70	2.86	1.63
2006	0.78	1.85	2.47	1.50	2.95	0.26	0.80	2.70	1.92	2.01	2.14	2.39
2007	1.79	2.18	1.08	0.09	1.84	4.65	2.88	0.79	1.14	0.61	2.86	2.16
2008	3.32	1.07	2.27	2.26	0.58	1.80	3.24	2.89	2.53	1.52	2.08	2.56
2009	1.63	1.86	0.67	0.99	1.41	-	-	-	-	-	-	-
TOTAL	**2.04**	**1.58**	**1.66**	**1.95**	**1.34**	**2.21**	**1.92**	**2.38**	**1.92**	**2.31**	**2.22**	**2.29**

MULGRAVE CASTLE DAILY AVERAGES / MONTH

Year/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	-	0.31	2.14	3.82	-	4.84	1.52	-	-	2.68	3.06	2.10
1999	2.75	1.76	4.60	1.49	1.34	3.12	0.39	3.79	2.11	1.82	2.09	1.92
2000	1.42	1.14	0.80	4.98	1.56	2.46	3.14	1.17	3.86	4.11	6.06	3.84
2001	1.30	3.39	1.64	2.67	0.41	-	1.42	2.46	3.30	2.06	1.53	2.16
2002	0.98	2.41	1.28	0.66	1.38	1.25	1.92	4.63	1.23	37.32	3.76	3.32
2003	3.13	0.43	0.60	0.49	1.51	2.75	1.22	1.60	2.77	2.42	2.30	4.09
2004	4.99	3.11	1.55	4.24	1.24	3.96	3.30	5.34	0.65	4.93	1.57	1.31
2005	1.11	2.90	2.98	2.77	1.47	1.19	4.97	3.22	2.35	2.37	3.70	2.33
2006	1.05	1.54	3.07	1.92	4.00	0.39	1.36	3.68	2.26	1.92	2.47	2.37
2007	2.24	2.50	1.37	0.17	2.85	5.67	3.72	1.10	1.49	0.74	3.59	2.01
2008	4.08	1.04	3.07	3.66	0.53	2.74	4.24	3.64	3.42	2.42	-	3.17
2009	1.82	2.41	0.71	1.48	1.58	-	-	-	-	-	-	-
TOTAL	**2.26**	**1.91**	**1.98**	**2.36**	**1.62**	**2.84**	**2.47**	**3.06**	**2.34**	**5.71**	**3.01**	**2.60**

COMBINED WHITBY & MULGRAVE CASTLE DAILY AVERAGES / MONTH

Year/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	2.57	0.50	4.03	7.98	1.81	8.22	2.85	1.12	1.75	5.00	5.94	3.92
1999	5.43	2.93	8.83	3.04	2.56	5.65	0.80	6.98	3.95	3.68	3.83	3.60
2000	2.87	2.17	1.52	9.19	2.86	4.53	5.79	2.29	7.45	7.84	6.06	6.86
2001	2.68	6.63	3.24	4.85	0.75	2.37	2.84	4.80	6.16	4.12	2.93	4.19
2002	1.98	4.53	2.55	1.18	2.87	2.22	3.67	9.25	2.32	41.25	7.13	6.75
2003	6.05	0.90	1.06	1.08	2.70	5.11	2.08	2.50	5.13	4.46	3.90	7.31
2004	9.10	5.03	2.71	7.26	2.07	6.68	5.85	9.71	1.06	8.55	2.80	2.53
2005	1.99	4.83	5.03	5.07	2.56	2.42	8.26	5.40	3.96	4.08	6.56	3.96
2006	1.84	3.40	5.53	3.42	6.95	0.65	2.16	6.38	4.18	3.93	4.61	4.76
2007	4.03	4.68	2.45	0.26	4.70	10.32	6.60	1.88	2.63	1.35	6.44	4.17
2008	7.41	2.11	5.34	5.91	1.11	4.54	7.48	6.53	5.95	3.95	2.08	5.72
2009	3.46	4.27	1.38	2.48	2.99	-	-	-	-	-	-	-
Sub-total	4.12	3.50	3.64	4.31	3.08	4.79	4.40	5.17	4.05	8.02	4.75	4.89
Daily Mean Total	**2.06**	**1.75**	**1.82**	**2.16**	**1.54**	**2.40**	**2.20**	**2.58**	**2.02**	**4.01**	**2.38**	**2.44**

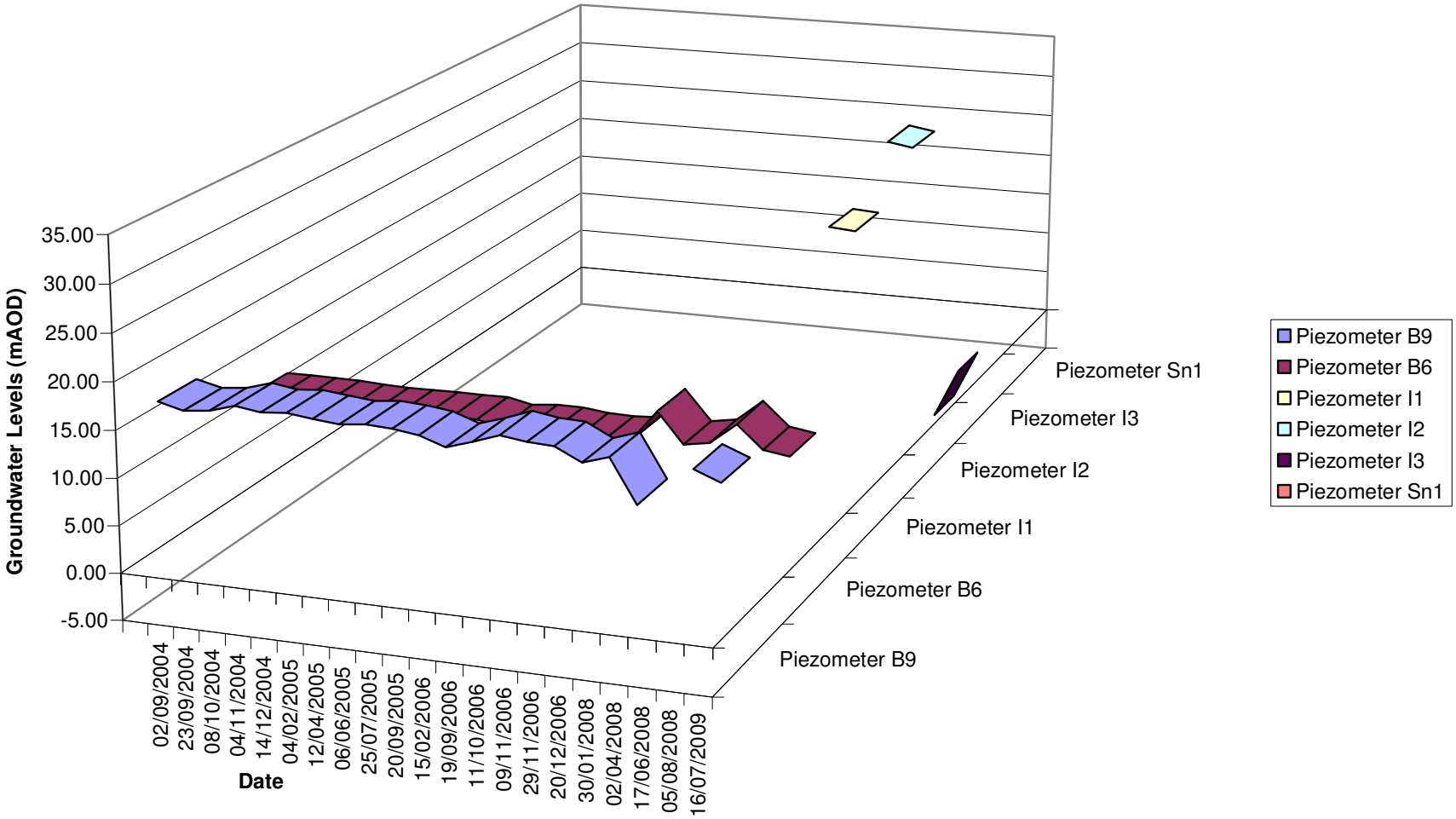
SCARBOROUGH DAILY AVERAGES / MONTH

Year/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1995	2.80	1.95	1.92	0.93	1.35	1.07	0.90	0.14	3.51	0.44	2.48	3.28
1996	1.32	2.21	1.01	0.79	1.37	1.27	1.12	2.28	0.44	1.02	2.97	2.75
1997	0.77	1.58	0.49	0.29	2.06	4.78	1.33	1.81	-	1.28	2.00	3.12
1998	2.82	0.23	2.22	4.40	1.57	3.21	1.82	1.07	1.31	2.96	2.62	1.88
1999	1.88	1.27	4.14	1.28	1.66	2.66	0.17	4.00	2.25	2.07	1.97	2.11
2000	1.41	1.06	0.63	4.52	1.90	3.05	2.61	1.90	3.42	4.78	4.54	2.52
2001	1.34	3.03	1.63	3.30	0.74	2.18	1.47	3.37	3.01	2.14	1.44	1.70
2002	1.05	2.95	1.07	0.84	1.90	1.22	2.30	5.30	0.69	5.06	3.77	2.75
2003	3.44	0.83	0.30	0.79	2.70	3.70	1.41	1.29	1.39	2.52	2.19	2.91
2004	3.97	1.70	1.34	3.93	1.04	2.30	2.98	4.79	0.38	3.27	1.14	1.02
2005	1.03	2.17	2.17	2.16	1.40	2.07	3.30	1.84	2.12	2.17	2.09	1.79
2006	1.03	1.59	2.08	-	-	-	1.10	3.53	-	1.97	1.93	1.60
2007	1.70	2.11	0.76	0.08	1.84	5.81	3.33	0.85	1.83	0.82	2.28	2.26
2008	3.60	0.85	2.02	2.72	0.48	1.86	3.01	3.48	2.56	1.83	2.05	2.14
2009	1.30	1.86	0.78	1.20	1.54	1.40	3.64	1.03	0.94	-	-	-
TOTAL	**1.96**	**1.69**	**1.50**	**1.94**	**1.54**	**2.61**	**2.03**	**2.44**	**1.84**	**2.31**	**2.39**	**2.27**

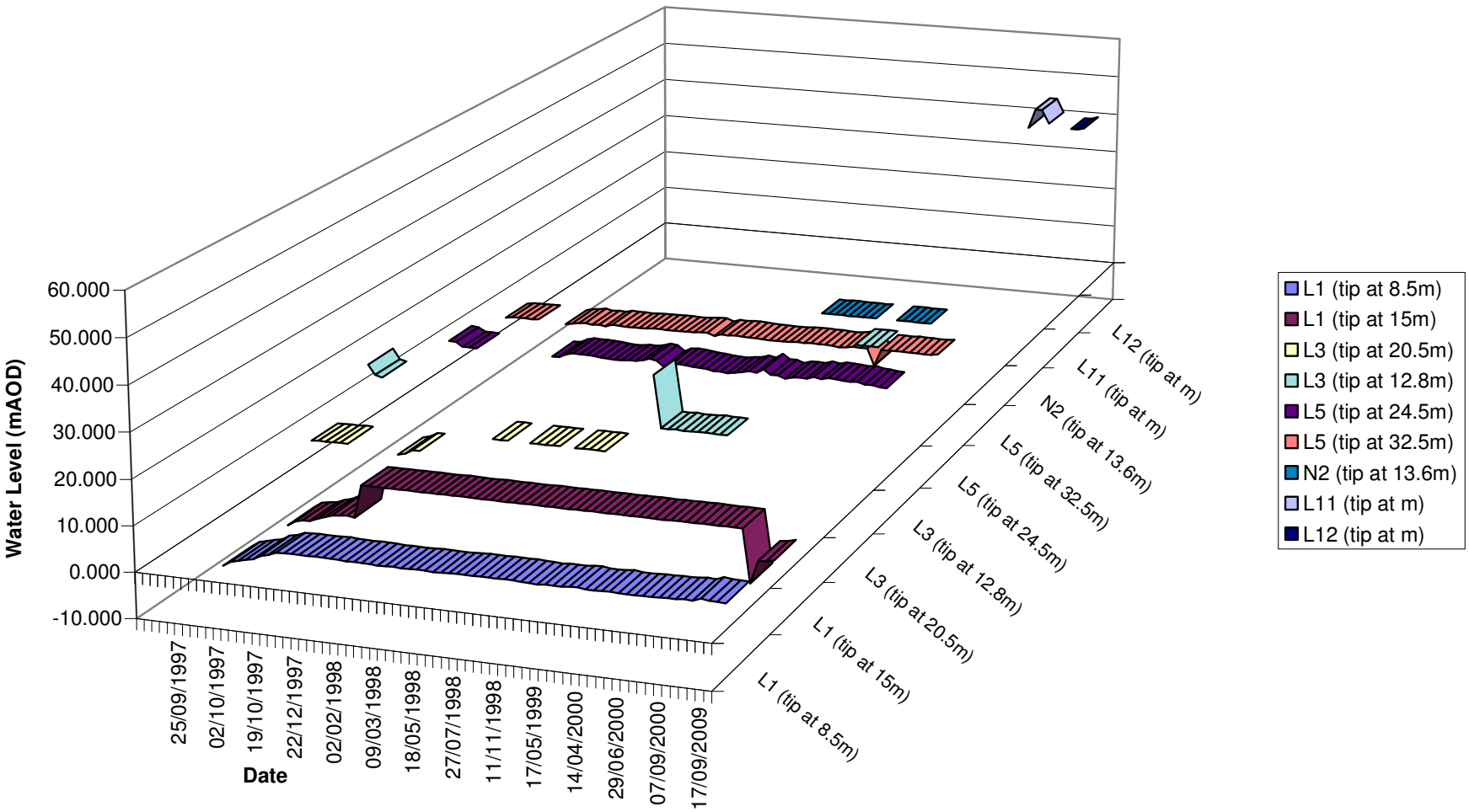
(- = Signifies No Data Available)

Appendix E Piezometric Groundwater Data Graphs

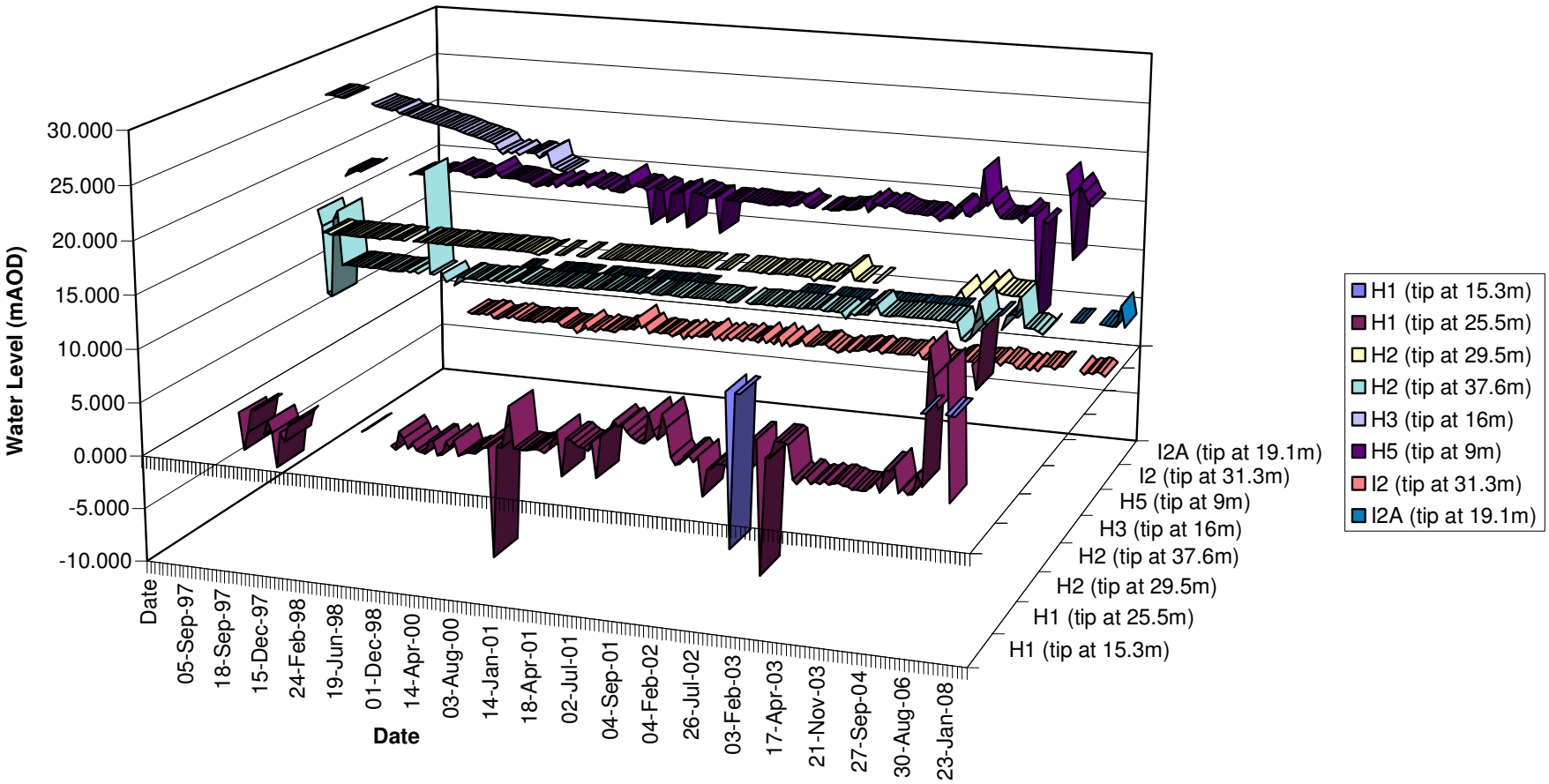
SCALBY NESS GROUNDWATER LEVELS

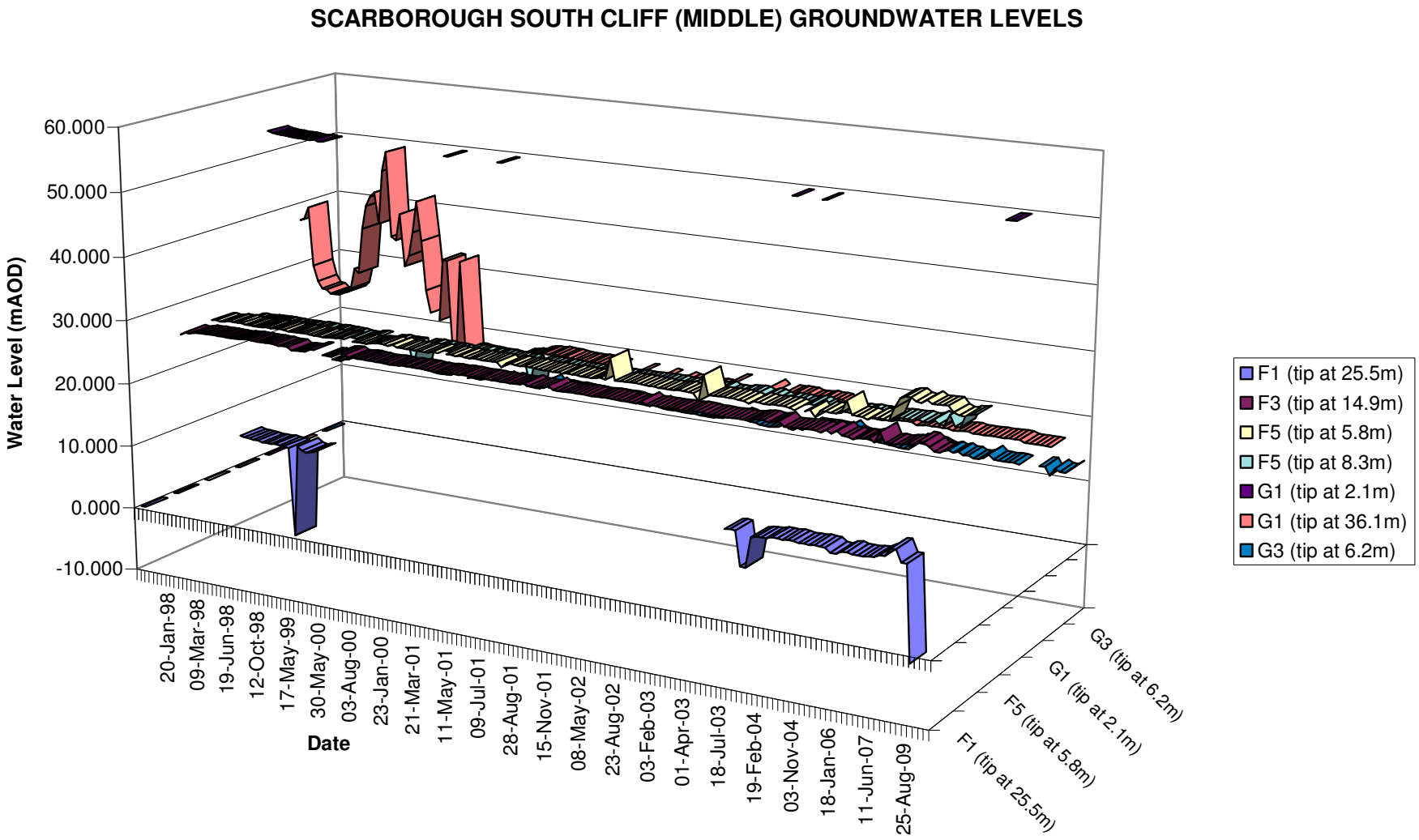


SCARBOROUGH NORTH BAY GROUNDWATER LEVELS

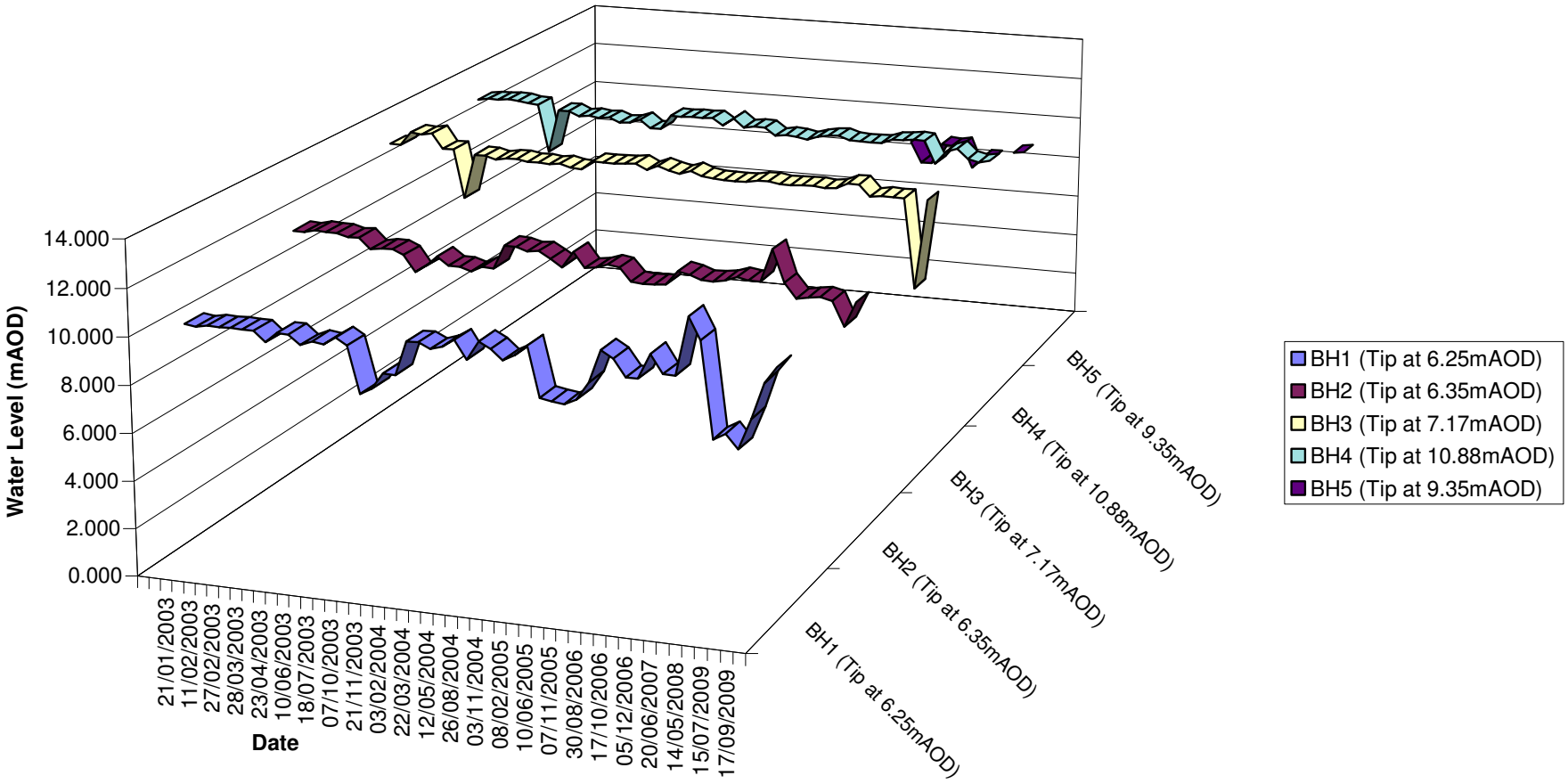


SCARBOROUGH SOUTH CLIFF (NORTH) GROUNDWATER LEVELS

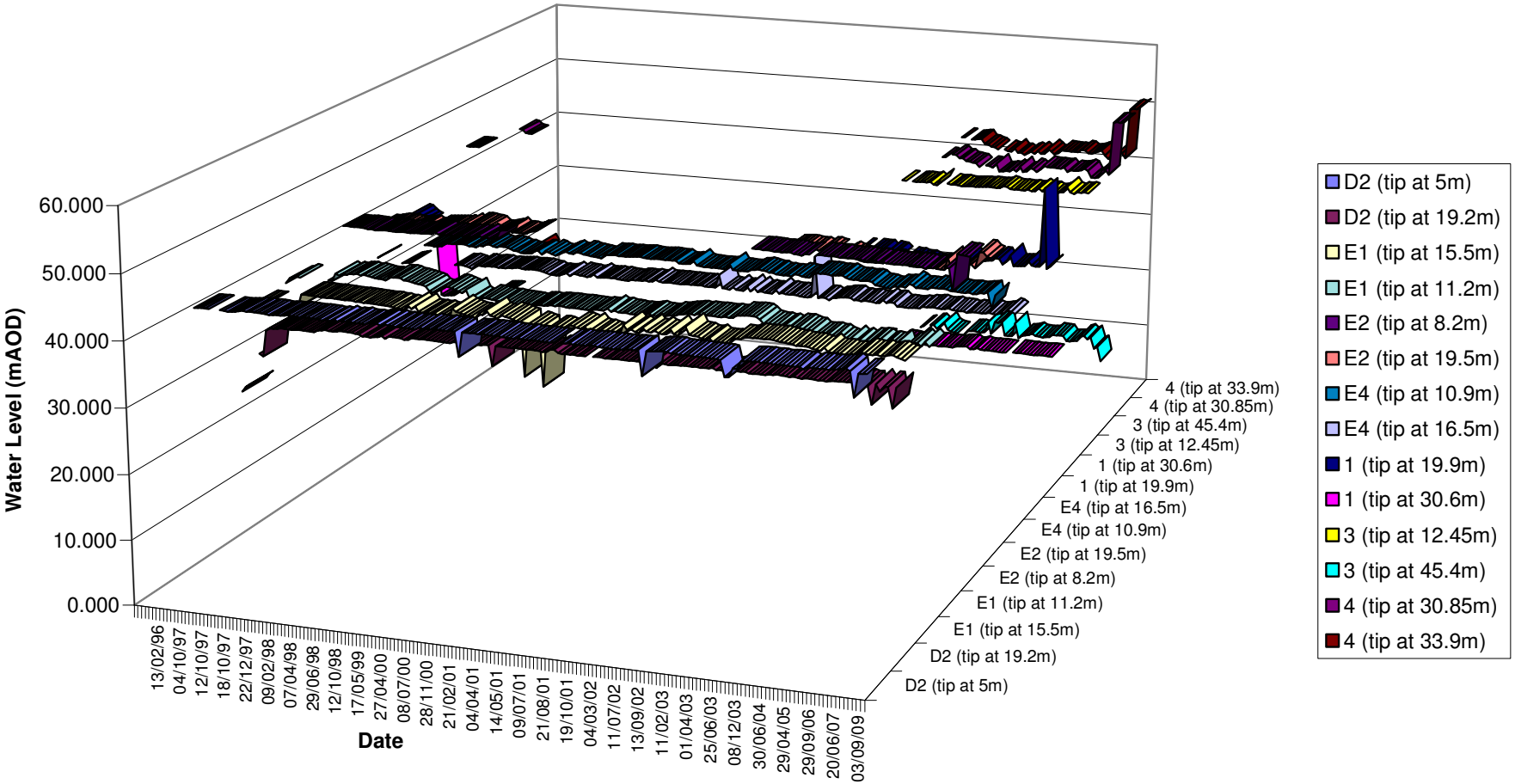



SCARBOROUGH SOUTH CLIFF (MIDDLE) GROUNDWATER LEVELS
Water Level (mAOD)
60.000
50.000
40.000
30.000
20.000
10.000
0.000
-10.000
Date
20-Jan-98
09-Mar-98
19-Jun-98
12-Oct-98
17-May-99
30-May-00
03-Aug-00
23-Jan-00
21-Mar-01
11-May-01
09-Jul-01
28-Aug-01
15-Nov-01
08-May-02
23-Aug-02
03-Feb-03
01-Apr-03
18-Jul-03
19-Feb-04
03-Nov-04
18-Jan-06
11-Jun-07
25-Aug-09
F1 (tip at 25.5m)
F5 (tip at 5.8m)
G1 (tip at 2.1m)
G3 (tip at 6.2m)
F1 (tip at 25.5m)
F3 (tip at 14.9m)
F5 (tip at 5.8m)
F5 (tip at 8.3m)
G1 (tip at 2.1m)
G1 (tip at 36.1m)
G3 (tip at 6.2m)

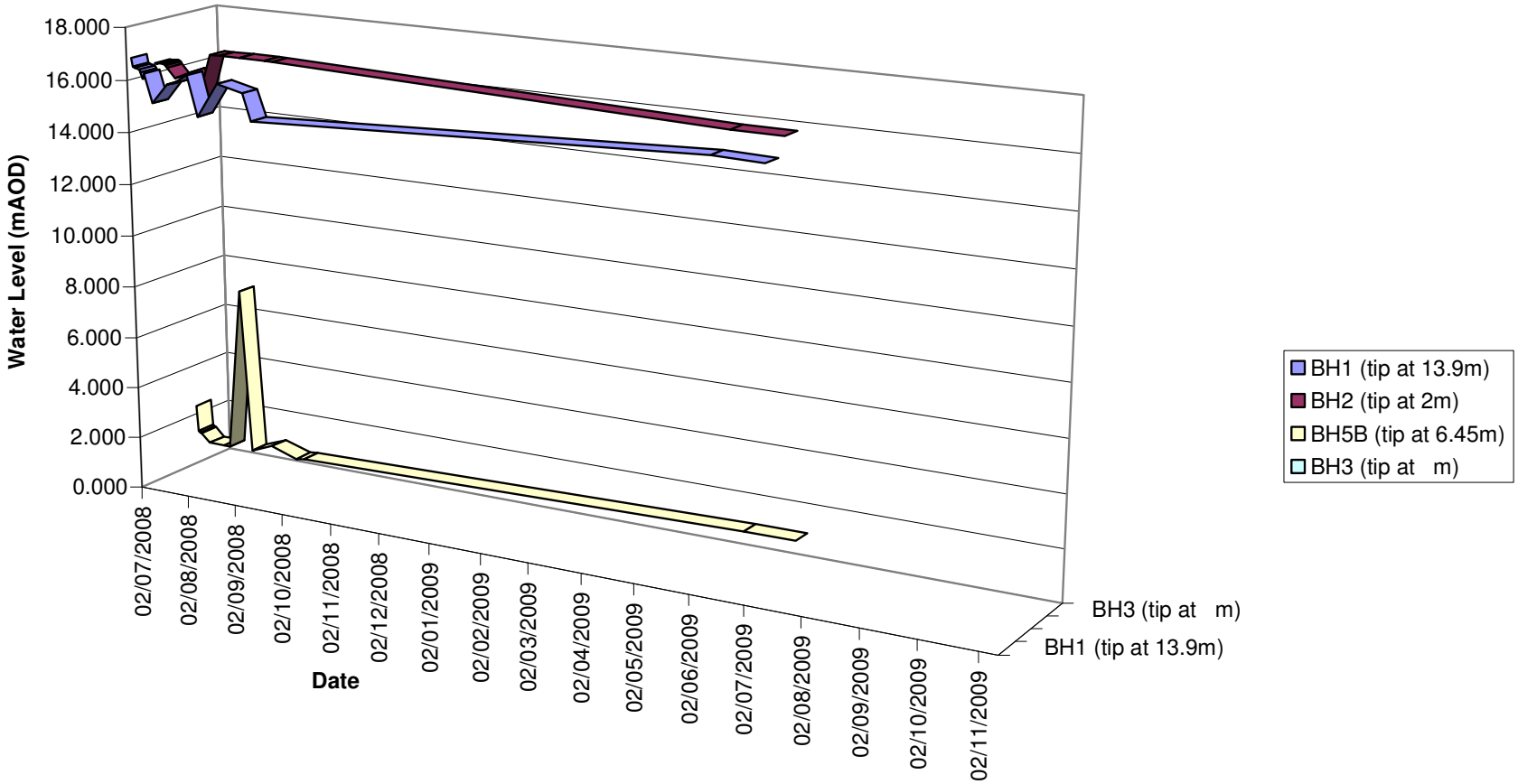
SCARBOROUGH SPA GROUNDWATER LEVELS



SCARBOROUGH SOUTH CLIFF (SOUTH) GROUNDWATER LEVELS



FILEY TOWN GROUNDWATER LEVELS



FILEY FLAT CLIFFS GROUNDWATER LEVELS