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Jersey Shoreline Management Plan

Extreme Rainfall Analysis (Appendix J)

Government of Jersey

Project number: 60580871

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Quality information

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Revision History

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1	17 December 2018	Adjustment for revised rainfall data		Mark Davin	Associate
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5	17 December 2019	Minor edits following Jersey Met review		Mark Davin	Associate

Distribution List

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Table of Abbreviations

AEP	Annual Exceedance Probability, the probability of observing an event of equal or greater magnitude in a given year
AMAX	Annual Maximum
ARF	Areal Reduction Factor, a factor applied to point rainfall data to account for variations in rainfall depth across a catchment area
FEH	Flood Estimation Handbook
FORGEX	Focused Rainfall Growth Extension, a method of combining rainfall data from gauging stations to determine rainfall depths in extreme events
FSR	Flood Studies Report
GEV	Generalised Extreme Value, a probability distribution
GL	Generalised Logistic, a probability distribution
GP	Generalised Pareto, a probability distribution
M5	The depth of rainfall in a given duration which is observed, on average, once every five years (1 in 5 year return period)
POT	Points over threshold
RMED	Median annual maximum rainfall depth
TUFLOW	Two-Dimensional flood modelling software

1. Introduction

This report has been produced in consultation with Jersey Met and we would like to acknowledge the technical support and reviews provided by John Searson and Paul Aked. Our thanks also to Jennie Holley and Frank Le Blancq who are responsible for the diligent recording and digitising of much of the rainfall data used in this report, and who along with research and writings on historic rainfall on Jersey provided many of the facts and references used in this study.

1.1 Scope of Works

Jersey Shoreline Climate Resilience Management Plan (Jersey SCRMP) requires an assessment of the risk of flooding across the island. An island-wide pluvial model is required to create surface water flood outlines for the catchment and to refine the flood outlines representative of fluvial flood zones. The proposed approach is to develop simulated rainfall event hyetographs, as documented in this technical note, for input into a two-dimensional hydrodynamic model (TUFLOW).

The proposed approach requires rainfall of a suitable frequency to be developed. Historically, flood frequency was expressed as a 'return period'; the average amount of time which elapsed between two events of a given duration and depth. More recently flood frequency has been expressed in terms of Annual Exceedance probability (AEP), the inverse of the return period. The three modelled rainfall events have return periods of 1 in 30 years (a 3.3% AEP), 1 in 100 years (a 1% AEP) and 1 in 1000 years (0.1% AEP). The AEP is useful in giving the probability of observing an event of a given duration and magnitude in any given year. However, return periods have been used throughout this report for consistency with the Flood Studies Report used in the analysis.

A previous version of this report was published on 29th January 2019 and the analysis has been repeated here following receipt of additional historical rainfall data in September 2019, including an expanded hourly rainfall record for Jersey Airport and Guernsey Airport.

1.2 Background

The Channel Island of Jersey is located 22km to the west of Normandy, France in the English Channel. It is the largest of the Channel Islands, occupying an area of 118km^2 and is heavily urbanised, with approximately 31% of the island considered urbanised, mainly in the south of the island around the capital of St Helier (Figure 1-1).

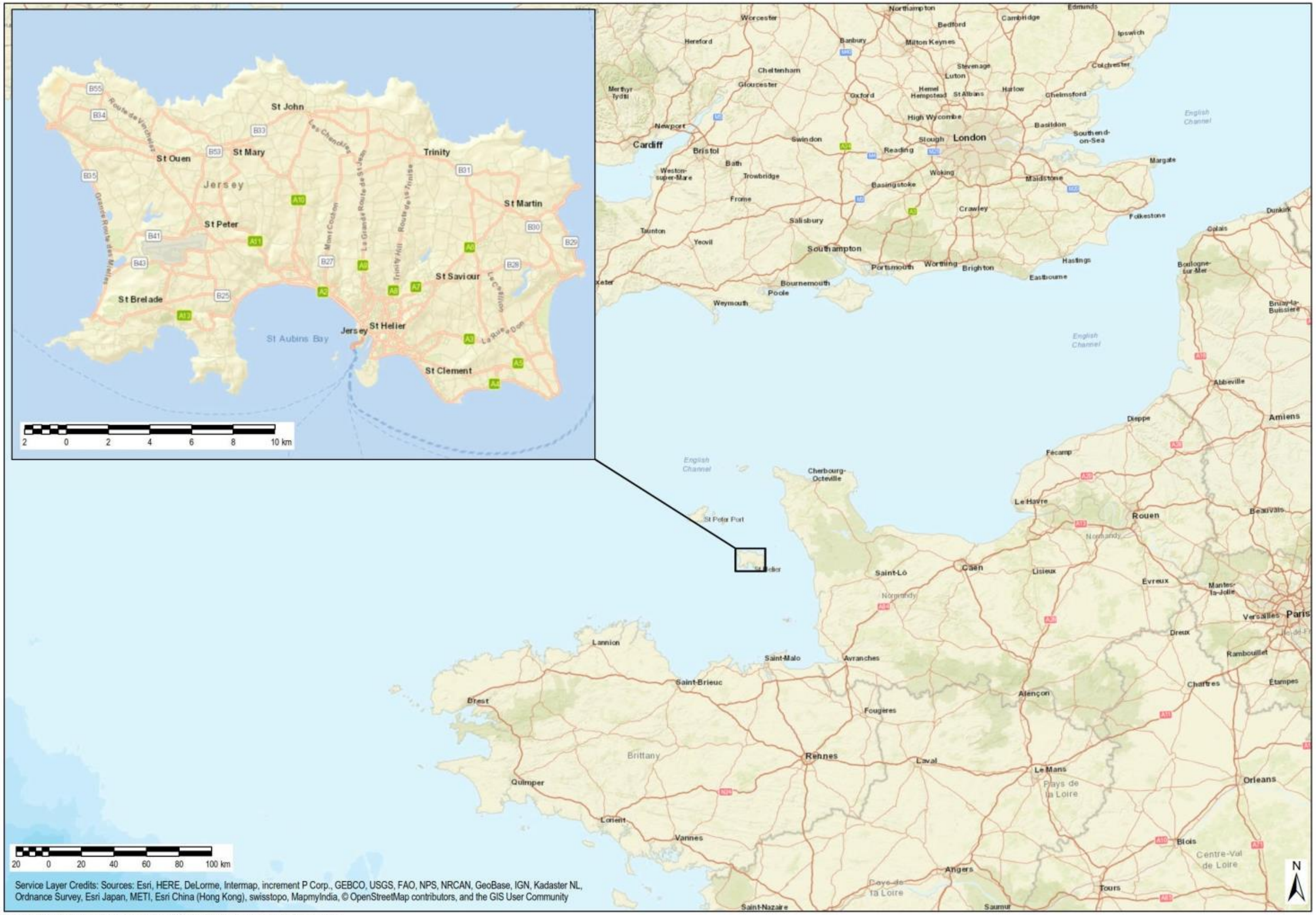

Figure 1-1: Jersey Island Location

1.2.1 Jersey Climate

The climate in Jersey is temperate, with extremes of temperature restricted by the surrounding Atlantic Ocean. Island wide average temperature and rainfall data are presented in Figures 1-2 and 1-3.

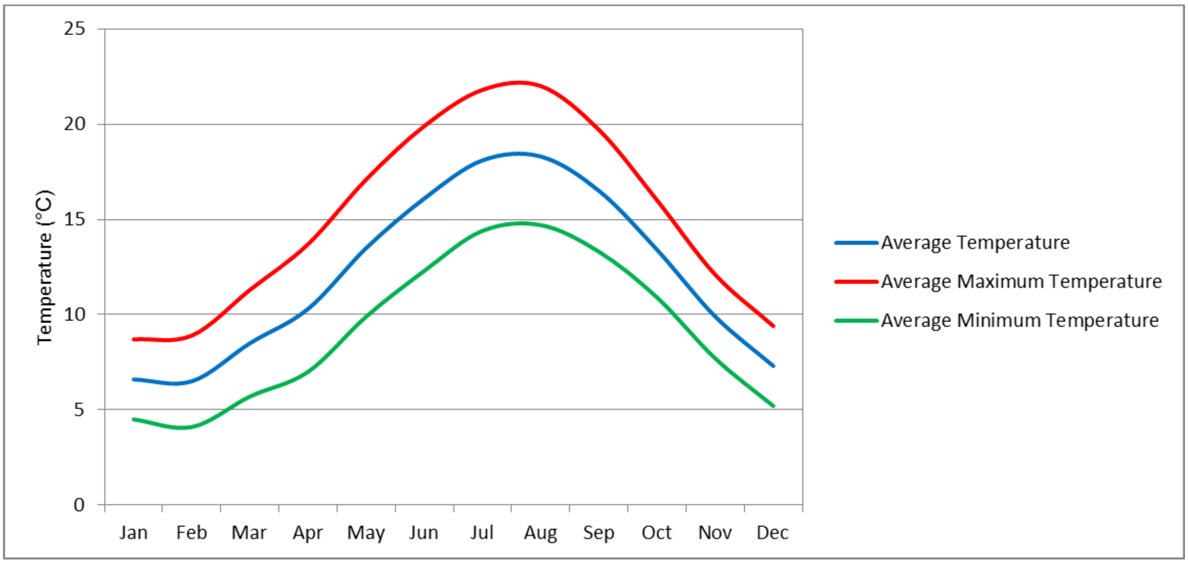

Figure 1-2: Daily Mean, Mean Maximum and Mean Minimum Temperature in Jersey (1981-2010) (Source: Jersey Met)

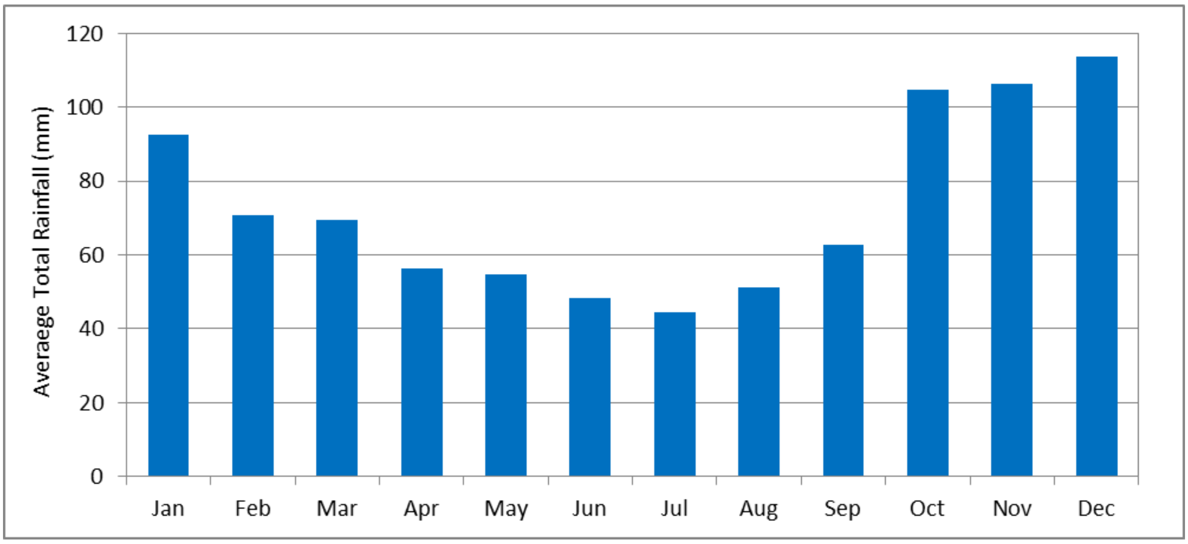

Figure 1-3: Mean Monthly Rainfall Totals for Jersey (1981-2010) (Source: Jersey Met)

Regional variations in rainfall across Jersey are shown in Figure 1-4, an isohyet map for Jersey based on rainfall data from 1971-2000. Average annual rainfall varies from 950mm in the higher areas in the north of the island to 750mm in the extreme west and south.

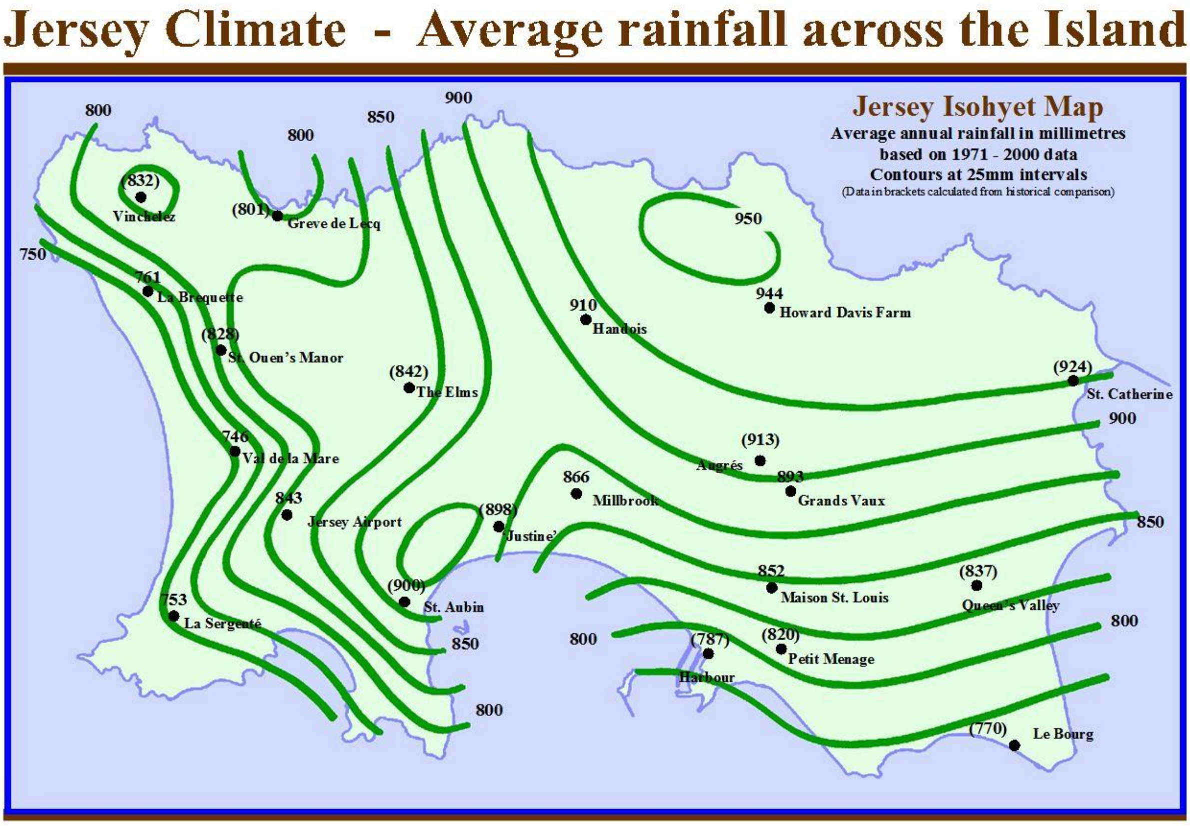

Figure 1-4: Isohyet Map of Jersey [Note: figures in brackets are based on historic data and are not currently recording rainfall][1]

1.2.2 Jersey Geology

The geology of the island mainly comprises granitic igneous rocks with large areas of shale in the west. The soils are dominated by loess with some alluvium and blown sand in the west and south[2].

1.3 Jersey Flooding History

A flood history has been compiled for Jersey based on historical records provided by the States of Jersey, information included in past reports and internet searches (Appendix A). Records have been included of tidal flooding (due to high tides, storm surges and extreme wave action), fluvial flooding (flooding from watercourses when the flow exceeds the channel capacity) and pluvial flooding (surface flooding from extreme rainfall when the capacity of drainage systems, natural and artificial, are exceeded). Appendix A also sets out the source of the information for each event.

Table 1-1 provides a summary of the pluvial and fluvial flooding events only, along with rainfall depths and durations recorded at the hourly rain gauges, where available. A total of 17 events have been identified where pluvial and/or fluvial flooding occurred, of which rainfall data is available for 12 events.

[1] Le Blancq F (2004) (Jersey Met unpublished) "A Jersey Isoheyts Map using 1971 to 2000 Rainfall Data"
[2] Hydrogeological map of Jersey, British Geological Survey, 1992, available at www.bgs.ac.uk/data/maps/map.cfc?method=viewRecord&mapId=11570, accessed October 2018

Table 1-1: Rainfall Details - Pluvial Flood Events

Date	Flooding Extent	Event Rainfall Depths	Rainfall Duration
27 November 2017	Torrential downpours caused flooding. Roads and properties flooded at Beaumont, several inches deep at the bottom of Beaumont Hill. St Peter, St Lawrence and Grand Vaux also flooded	Jersey Airport: total rainfall was 28.7mm, peak of 14.5mm/hr. Less at Maison St Louis Observatory: total of 24.0mm, peak of 6.8mm/hr	10 hours at Jersey Airport, 11 hours at Maison St Louis Observatory
16 September 2017	Flash flooding left roads underwater after torrential rain. St Ouen and St Peter were badly affected, particularly St Peter's Valley. The road between St Ouen and St Peter was closed and roads below Greve de Lecq hill flooded. The area around St Ouen's Manor also flooded.	Jersey Airport: total rainfall was 31.2mm, peak of 14.9mm/hr. Less at Maison St Louis Observatory: 12.2mm in total, 6.6mm/hr peak.	4 hours at Jersey Airport, 4 hours at Maison St Louis Observatory
8-9 February 2016	Storm Imogen flooded roads including Victoria Avenue. Some of this flooding may have been tidal rather than pluvial.	This event straddled the 9am divide between 8 and 9 February. The following rainfall totals are for the entire storm event. Jersey Airport: total rainfall was 19.6mm, peak of 3.2mm/hr. Maison St Louis Observatory total was 23.4mm, peak of 4mm/hr	11 hours at Jersey Airport, 11 hours at Maison St Louis Observatory
12 June 2015	Roads flooded in response to heavy rainfall, some areas having over 28mm.	Jersey Airport: total rainfall was only 17.1mm, peak of 7.8mm/hr. Maison St Louis Observatory: total rainfall was only 12.9mm, peak of 6.2mm/hr. Event not well reflected in available data.	6 hours at Maison St Louis Observatory, 7 hours at Jersey Airport
August 2010	Localised flooding in St Helier	No data – exact date of event is not known	No data – exact date of event is not known
19 to 21 March 2001	Wettest March on record, with 196mm of rain (previous record 152mm in 1912). No property flooding was noted. Surface water ponded northeast of Kempt Tower, St Ouen, near Craniere, and on the site of the demolished Sable D'Or Hotel, the Jersey Scout Association campsite and Netherton Farm.	Jersey Airport recorded 54mm of rain over 19-22 of March. Fell as three separate events with peaks of 6.7, 5.8 and 6.8mm/hr. Maison St Louis Observatory recorded 70.7mm in the same period.	No hourly data from Maison St Louis Observatory. The three rainfall events at Jersey Airport had durations of 10, 5 and 10 hours.
8 to 9 February 2001	Following on from wet autumn and winter below, 63mm of rainfall fell at Maison St Louis Observatory in 48 hours. Pluvial and fluvial flooding affected several locations, including the brook at Rue du Moulin de Tesson, Tesson Mews and Goose Green Marsh. the Montrose Testate at Grand Vaux also flooded along the road at Vallee de Vaux. Landslips also occurred.	Jersey Airport record shows 54mm of rain in 48 hours, falling in two events with peaks of 5.1 and 6.5mm/hr	Two events lasted 11 and 18 hours respectively. No data for Maison St Louis Observatory.
January 2001	Flooding followed very wet autumn – only seven days without rainfall from 1st October to 2nd December 2000. 100mm of rain fell in the last week of December and first week of January at Maison St Louis Observatory, causing Goose Green Marsh to flood, landslips at Rozel and Mont Arthur and flooding of several houses.	Maison St Louis Observatory recorded a total of 181.9mm in January 2001, with 177.5mm recorded at Jersey Airport. This was the third wettest January on record (1894 to 2018).	During the last week in December and first week in January there were four significant rainfall events with durations of 16, 13, 8 and 9 hours

31 October 1985	Flooding in the east of Jersey due to intense storm. This was a localised event and caused flooding to 18 properties and to roads in Georgetown, St Clement , St Clement's Gardens and Rue de Maupertuis. Flooding may have been exacerbated due to blockage of drains with autumn leaf-fall.	43mm were recorded at Maison St Louis Observatory, 54mm at Longueville and 60mm at Petit Menage (St Saviour), compared with 2.5mm at Jersey Airport.	This event lasted 4 hours
November 1984	Article on 31st October 1985 event also refers to flooding in November 1984 in which the States of Jersey Fire Service received 100-150 phone calls compared with 54 in the1985 event. However, no further information is given and the precise date is not known. Searches have not provided any further information on this flood event.	Jersey Airport noted a maximum of 13mm of rainfall in any one event during this month. No other rain gauge data is available.	The duration cannot be confirmed as the precise date of this event is not known.
5 June 1983	Severe thunderstorm with hail in the north and northwest of Jersey. Flooding occurred around Greve de Lecq. Little or no rainfall occurred in the east of the Island.	53.3mm recorded at St John's Rectory, 28mm in total at Jersey Airport, with a peak of 20.5mm/hr	2 hours at Jersey Airport (no data for Maison St Louis Observatory)
31 May 1983	Severe rainstorm in the west of the island. Flooding occurred in St Aubin, St Peter's Valley and Greve de Lecq.	43.3mm of rainfall recorded in 2 hours at Jersey Airport with 25mm arriving in six minutes. A daily total of 52.2mm was recorded at St Peter's Rectory	2 hours at Jersey Airport (no data for Maison St Louis Observatory)
10 June 1982	Severe storm in the east of the Island. St Saviour, Georgetown, Rozel, St Catherine, St Martin, La Ville Bree and St Helier experienced flooding.	55.4mm of rainfall recorded over 24 hours at Maison St Louis. The return period of this event was estimated at the time as 1 in 400 years.	54.0mm record at Maison St Louis in one hour (no data available for Jersey Airport)
25 September 1981	A severe storm in the east of the island caused flooding at St Saviour, St Clements, Georgetown, St Martin and St Helier.	Over 24 hours: 64.2mm at Maison St Louis 25.9mm at Jersey Airport. 65.5mm at Grands Vaux 19.6mm at Val de la Mare 58.5mm at Augres 38.2mm at Millbrook 36mnm at Handois	50mm recorded at Maison St Louis in one hour (no hourly data for any other gauges)
1950s	A localised flash flood in the Mourier Valley area followed intense localised rainfall. The channel of the Douet de la Mer stream was reconfigured in the lower part of the valley.	No information available, the precise date of this event is not known.	No information available
28 December 1839	Very wet winter conditions followed by heavy rainfall on the 28 December with flooding on Bath Street, Town Mills, St Peter's Valley and other areas.	No information available	No information available
3 to 4 January 1650	Heavy rain followed a very wet winter and fell on saturated soils. Flooding and landslips appear to have been widespread, including flooding of properties.	No information available	No information available

The rainfall event data associated with events during 2005, 2016 and 2017 show that the rainfall depths recorded at the rain gauges at Jersey Airport and Maison St Louis Observatory can differ significantly for a single event. This demonstrates the extremely localised nature of some of the extreme rainfall events which result in flooding in Jersey. The details in Table 1-1 also demonstrate the importance of antecedent conditions: flooding occurred in 1650, 1839 and in January, February and March 2001 were in part due to rainfall following a very wet winter. Individual rainfall event totals in the January 2001 event were not large but flooding occurred because soils were already saturated. In contrast, the summer storms in May and June 1983, June 2015 and September 2017 caused flooding due to high intensity rainfall events which could have exceeded the infiltration capacity of the soils, since soils were less likely to be saturated at this time of year.

2. Rainfall Data

2.1 Data Availability

Rainfall data provided by Jersey Water, Jersey Met and Meteo-France used in this study is summarised in Table 2-1 and the locations referenced are shown in Figures 2-1 and 2-2.

Table 2-1: Rain Gauge Summary

Source	Name	Location	Data Type	Length of Record
Jersey Met	Jersey Airport (station ID 03895)	Lat 49º12'32.1''N, Long 02º11'34.92''W, (Altitude: 84m*)	Hourly Rainfall Data	1983-2018 (36 years)
	Maison St Louis Observatory (station ID 03896)	Lat 49º11'29.32''N , Long 02º05'37.3''W- (Altitude: 54m*)	Hourly Rainfall Data	2004-2017 (14 years)
	Maison St Louis Observatory (station ID 03896)	Lat 49º11'29.32''N , Long 02º05'37.3''W- (Altitude: 54m*)	Daily Rainfall Data	1894-2018 (124 years)
	Maison St Louis Observatory (station ID 03896)	Lat 49º11'29.32''N , Long 02º05'37.3''W- (Altitude: 54m*)	Monthly Rainfall Data	1894-2018 (124 years)
Guernsey Met	Guernsey Airport (station ID 03894)	Lat 49°26'20.3"N, Long 02°36'05.6"W, (Altitude: 101m*)	Hourly Rainfall Data	1982-2018 (37 years)
Jersey Water	Historic Rainfall Records	Not fully identified	Monthly Rainfall Totals	1865-2018 (153 years)
	Handois	See Figure 2-2	Daily Rainfall Totals	1995-2018 (23 years)
	Millbrook	See Figure 2-2	Daily Rainfall Totals	1995-2018 (23 years)
	Augres	See Figure 2-2	Daily Rainfall Totals	1995-2018 (23 years)
	Val de la Mare	See Figure 2-2	Daily Rainfall Totals	1995-2018 (23 years)
	Grands Vaux	See Figure 2-2	Daily Rainfall Totals	1995-2018 (23 years)
	Queen's Valley	See Figure 2-2	Daily Rainfall Totals	1995-2018 (23 years)
	Greve de Lecq	See Figure 2-2	Daily Rainfall Totals	1995-2018 (23 years)
	St Catherine	See Figure 2-2	Daily Rainfall Totals	1995-2018 (23 years)

Meteo-France	Dinard	See Figure 2-1	AMAX[3] Series	1971-2016, with missing data in 1980, 1985, 1986, 1988-1990 (40 years in total)
	Feins SA	See Figure 2-1	AMAX Series	2006-2016 (11 years)
	Pontorson	See Figure 2-1	AMAX Series	1998-2016, 2002 missing (18 years)
	Quintenic	See Figure 2-1	AMAX Series	2000-2016, 2010 missing (16 years)
	Saint-Cast-Le-Guildo	See Figure 2-1	AMAX Series	2004-2016 (13 years)
	Pte De La Hague	See Figure 2-1	AMAX Series	1996-2017, 2011 missing (20 years)
	Gonneville	See Figure 2-1	AMAX Series	1982-1983, 1984-1987 and 1996 – 2016 (23 years in total)
	Sainte-Marie-Du-Mont Brecourt	See Figure 2-1	AMAX Series	1998-2016, 2010 missing (18 years)
	Valognes	See Figure 2-1	AMAX Series	1992-2016 (25 years)

* Above Mean Sea Level (AMSL)

[3] AMAX = Maximum recorded rainfall for a given duration in a given hydrological year (1 October to 30 September).

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Figure 2-1: Rain Gauge Locations in Jersey, Guernsey and France

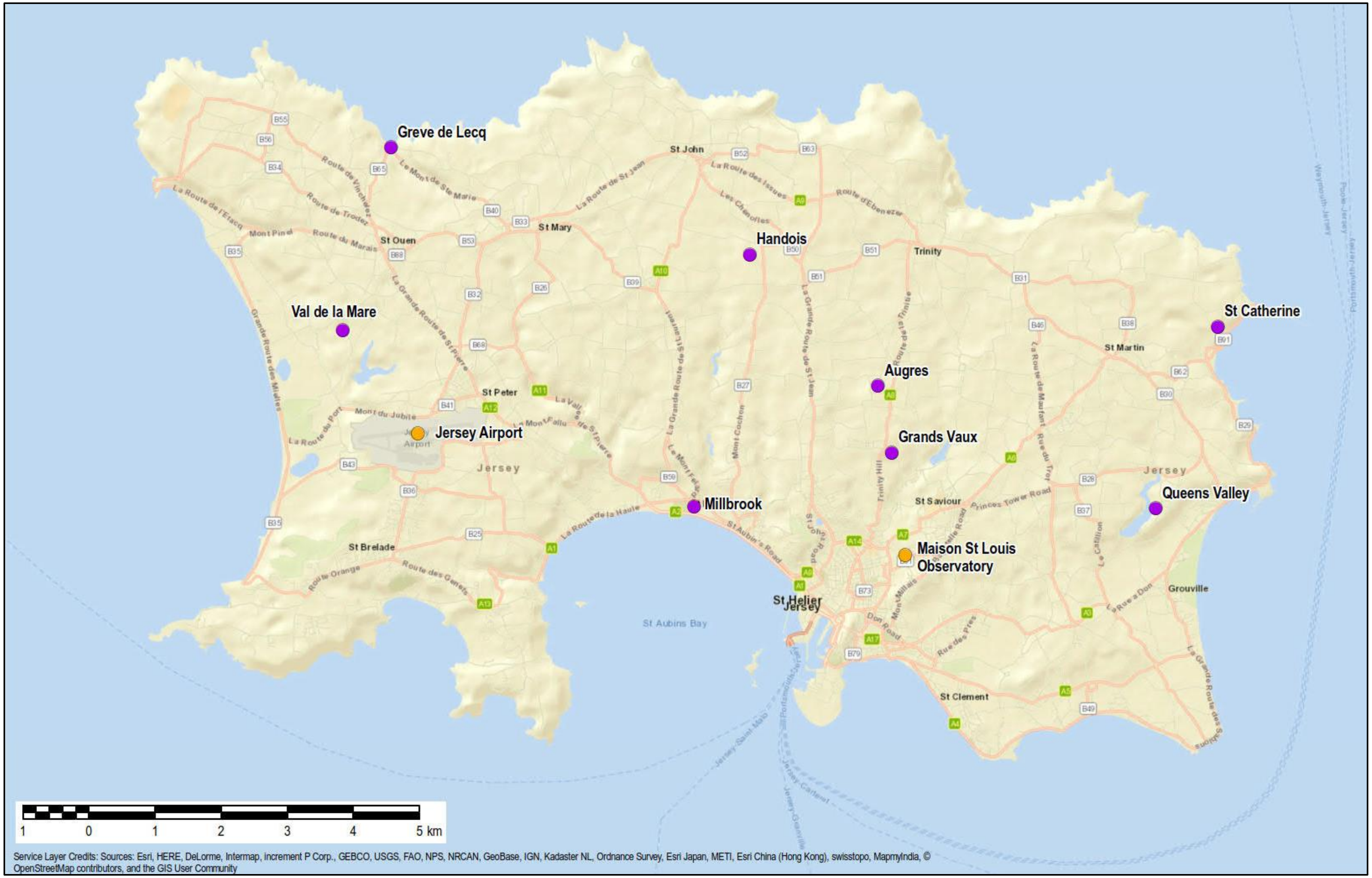

Figure 2-2: Rain Gauge Locations in Jersey. Hourly rain gauges(gold), daily rain gauges (purple)

2.2 Data Quality

2.2.1 Hourly Rainfall Records

The hourly rainfall datasets from Jersey Airport, Maison St Louis Observatory and Guernsey Airport are continuous with very little missing data. At Maison St Louis Observatory 17% of the data for the 2017 hydrological year is missing and this hydrological year has therefore been excluded from the annual maxima (AMAX) analysis. The hydrological year runs from 1 October to 30 September and is named for the year in which it starts, i.e. the 2017 hydrological year runs from 1 October 2017 to 30 September 2018. Hydrological years are used in the statistical analysis of rainfall data to ensure that rainfall events over the winter period, when prolonged rainfall and flooding are more likely, is contained within a single hydrological year rather than being divided between two calendar years.

Butler *et al* (1985)[4] analysed hourly data recorded between 1951 and 1982 at Jersey Airport and between 1940 and 1943 and 1947 and 1983 at Maison St Louis Observatory. From discussions with Jersey Met, this data is not currently available, having not yet been digitised.

Comparison of cumulative rainfall totals at Jersey Airport and Maison St Louis Observatory for dates where both datasets are present reveals similar rainfall patterns at both sites (Figure 2-3). Over the fourteen-year period, Maison St Louis Observatory records slightly more rainfall, 13,328mm of rain compared with 12,748mm at Jersey Airport.

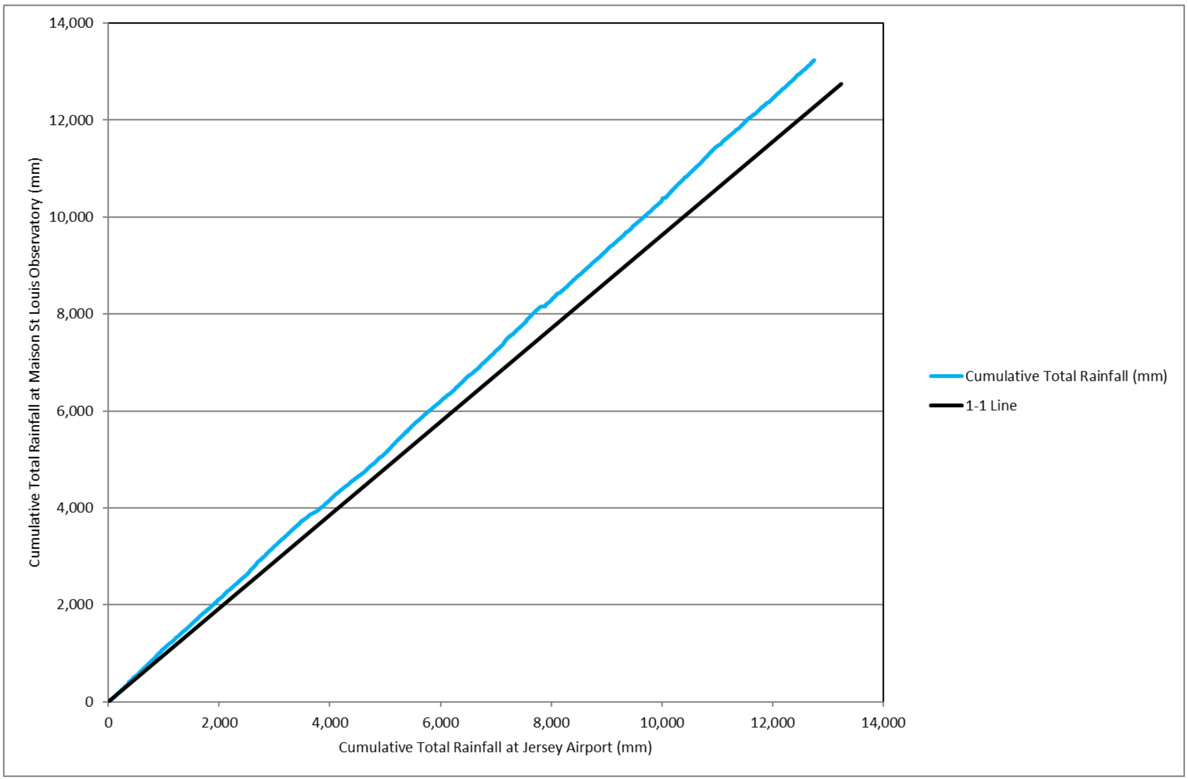

Figure 2-3: Rainfall Comparison – Cumulative Rainfall Totals at Maison St Louis Observatory and Jersey Airport (2004-2018)

Hourly rainfall data has also been provided for Guernsey Airport. The island of Guernsey lies 27km to the north west of Jersey (Figure 2-1) and is thus likely to experience similar rainfall patterns. The overlap between the available data for Jersey and Guernsey Airports is greater than the overlap between Jersey Airport and Maison St Louis Observatory and the available data have been used to produce the double mass plot in Figure 2-4. This figure shows that patterns of rainfall at Jersey and Guernsey are very similar, although Jersey Airport received slightly more rainfall over the comparison period (31,130mm) compared with Guernsey Airport (30,299mm).

[4] Butler, A.P., Grundy, J.D., May, B.R. (1985) An analysis of extreme rainfall events observed in Jersey, Meteorological Magazine, 114.

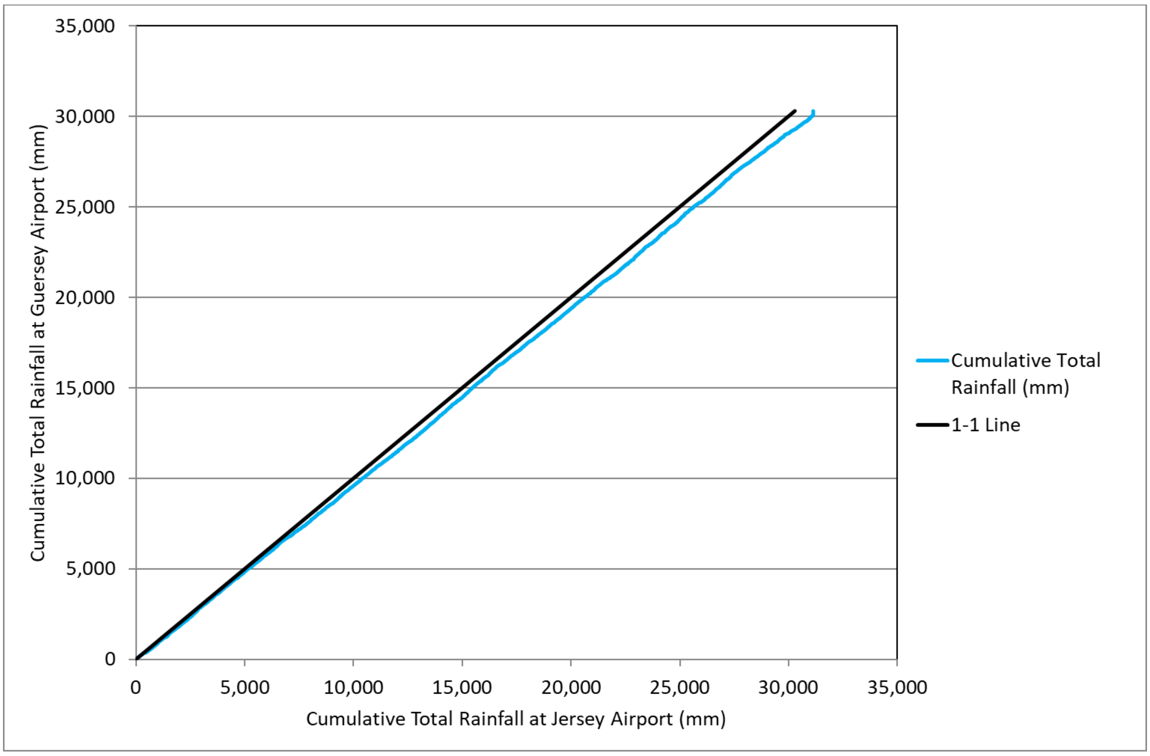

Figure 2-4: Rainfall Comparison – Cumulative Rainfall Totals at Jersey Airport and Guernsey Airport (1983-2019)

2.2.2.1 AMAX Series

Annual maxima, or AMAX series for Jersey Airport, Maison St Louis Observatory and Guernsey Airport have been developed for each hydrological year (1 October to 30 September) for which there is sufficient data. The AMAX values have been calculated for a rolling period of 1, 2, 4, 6, 10, 12 and 24 hours with a further calculation of annual maximum rainfall per day (9am to 9am) to allow comparison with rainfall totals recorded at other daily rain gauges in Jersey. The resulting AMAX series are shown graphically in Figure 2-5 and Appendix B. Note that the 1982 AMAX value for Jersey Airport is based on an incomplete hydrological year (hourly data are only available from 1 January 1983, whereas the 1982 hydrological year starts on 1 October 1982). However, the 1982 AMAX value reflects the intense storm which occurred on 31 May 1983 and discussions with Jersey Met confirm that this event was extreme and memorable and that, from their knowledge, the 2 hour rainfall total was not exceeded in the remainder of the 1982 hydrological year for which we have no data. On this basis, the 2 hour rainfall depth recorded on 31 May 1983 has been accepted as the 2 hour duration 1982 AMAX value.

Since the 6 hour duration rainfall recorded for the 31 May 1983 event is larger than the AMAX2 (the second largest AMAX value when all AMAX values are ranked from largest to smallest, Figure B3 in Appendix B), it is considered likely that the 6 hour duration rainfall depth was also not exceeded in the period 1 October 1982 to 31 December 1982 and this even is therefore accepted as the 6 hour duration 1982 AMAX value.

There is less certainty about the 31 May 1983 12 hour duration rainfall depth being the 1982 AMAX (Figure B5 in Appendix B). Since the value is within the range of other AMAX values it is possible that it could have been exceeded in the period 1 October 1982 to 31 December 1982. However, given the lack of data and the rainfall depths recorded within the 2 hour and 6 hour durations, it is considered sufficiently likely that the 12 hour rainfall depth recorded for the 31 May 1983 event will be the 12 hour 1982 AMAX.

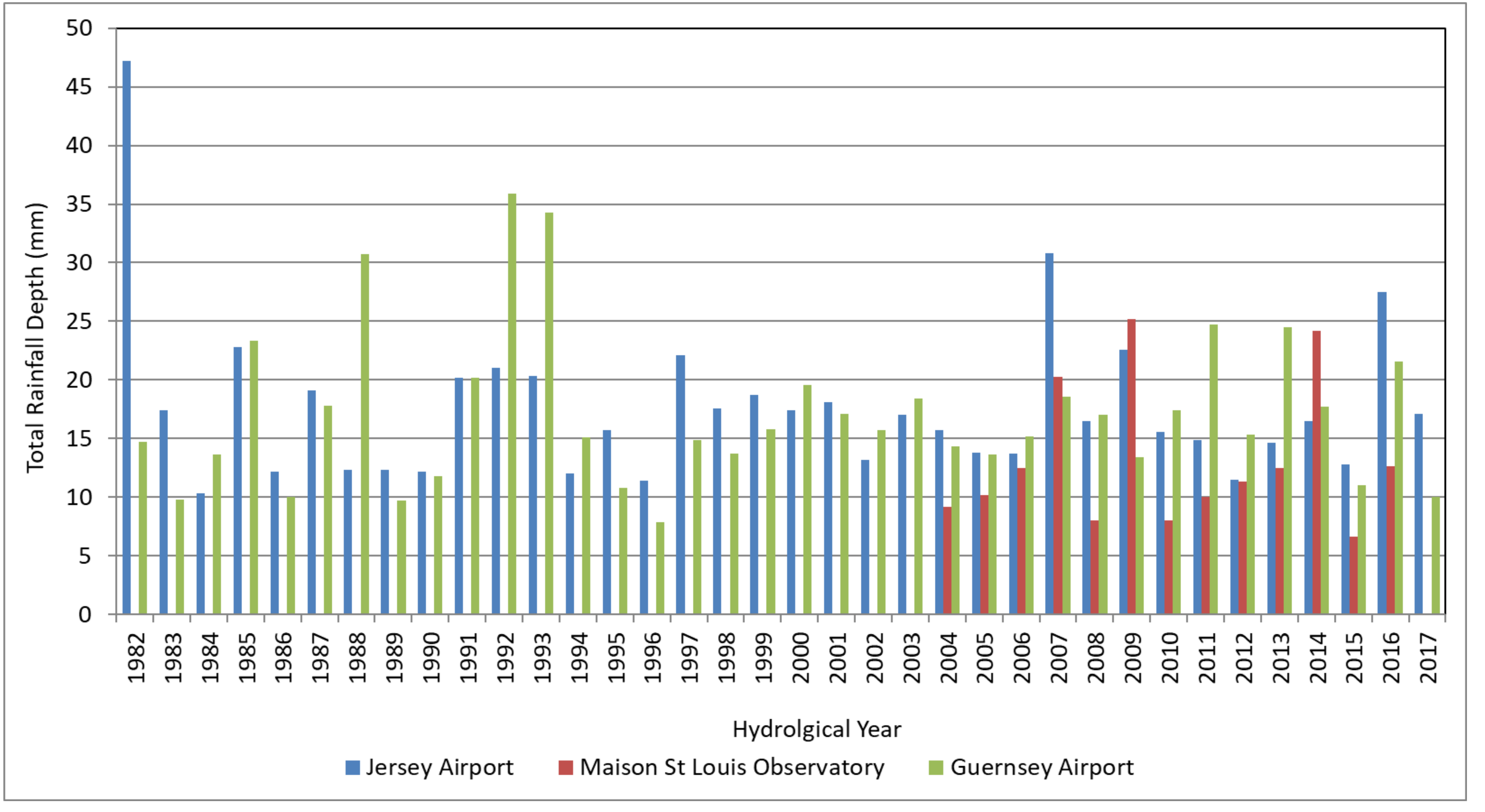

Figure 2-5: 2 Hour Duration AMAX Series for hourly Rain Gauges in Jersey and Guernsey

2.2.2 Daily Rainfall Records

Hourly rainfall records at sites shown in Figure 2-2 have been used to derive a daily (9am to 9am) rainfall AMAX series. The datasets were only complete for all gauges for the period 1995-2000 and there was considered insufficient data for any of these gauges for the period of 2001-2005. The data records at Handois and Augres are complete from 2005 onwards but the records from the other daily gauges still have too many missing data days to allow for their use in analysis.

Figure 2-6 shows the extent of the usable AMAX record from the daily gauges alongside the daily (9am to 9am) AMAX series developed from the daily Maison St Louis Observatory data and the hourly Jersey Airport data. There is little overlap between the records but the dataset overall shows broad agreement in terms of the range of daily AMAX seen at the various gauges. On this basis, it appears that daily AMAX rainfall values do not suggest a significant trend in the distribution of extreme daily rainfall depths across the island.

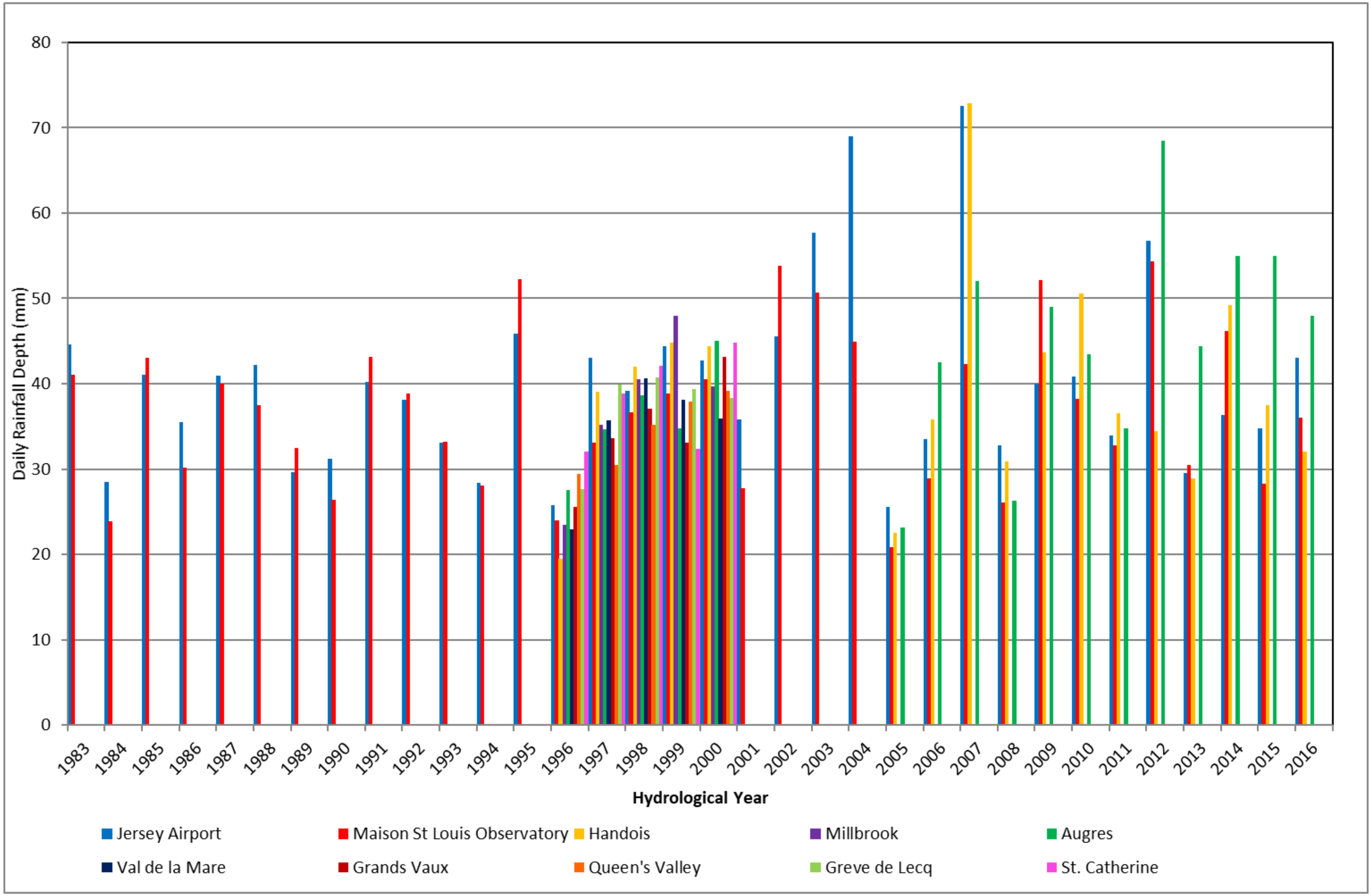

Figure 2-6: Daily AMAX (9am-9am) Rainfall Totals (mm) at Jersey Rain Gauges (1983-2016)

2.2.3 Long Term Monthly Rainfall Records

The two long-term rainfall data series provided by Jersey Water and Jersey Met contain monthly rainfall totals. Some of this data needs to be treated with caution since there are concerns about the accuracy in some years, as described in the written notes from Jersey Met reproduced in Appendix C. The cumulative totals of monthly rainfall seen at the two gauges from 1865 to 2018 are very similar (Figure 2-7) showing that the two records contain similar data and there is no significant difference in long-term rainfall totals between the two records.

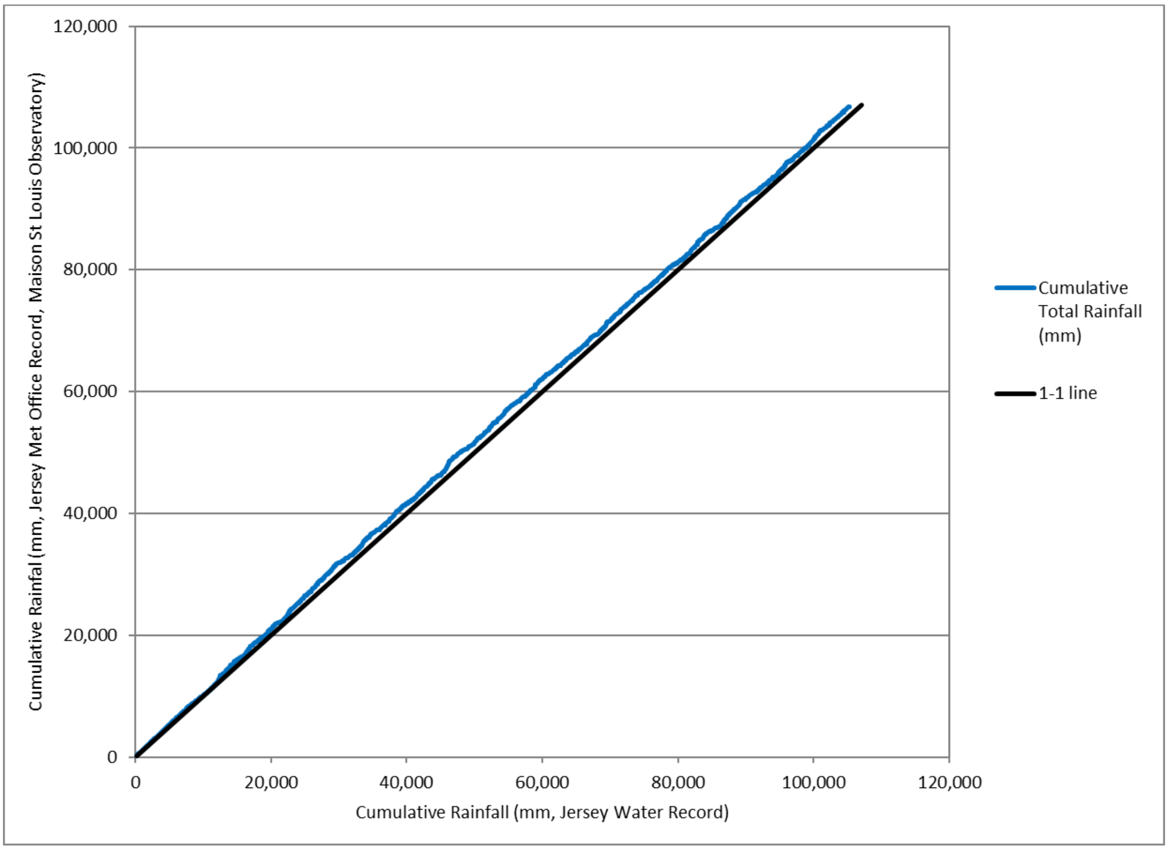

Figure 2-7: Rainfall Comparison – Cumulative Rainfall Totals for Jersey Water and Jersey Met Long Term Records (1865-2018)

The long-term datasets are of insufficient resolution to be useful in analysis of pluvial flooding events which typically involve storms lasting hours rather than days. However, examination of the long-term trend shows a gradual increase in average annual rainfall in Jersey over the record period (Figure 2-8). This creates an additional source of uncertainty in estimating extreme rainfall because the current analysis, as with all current statistical analysis processes, assumes stationarity, which may not be the case if there is a trend of increasing rainfall.

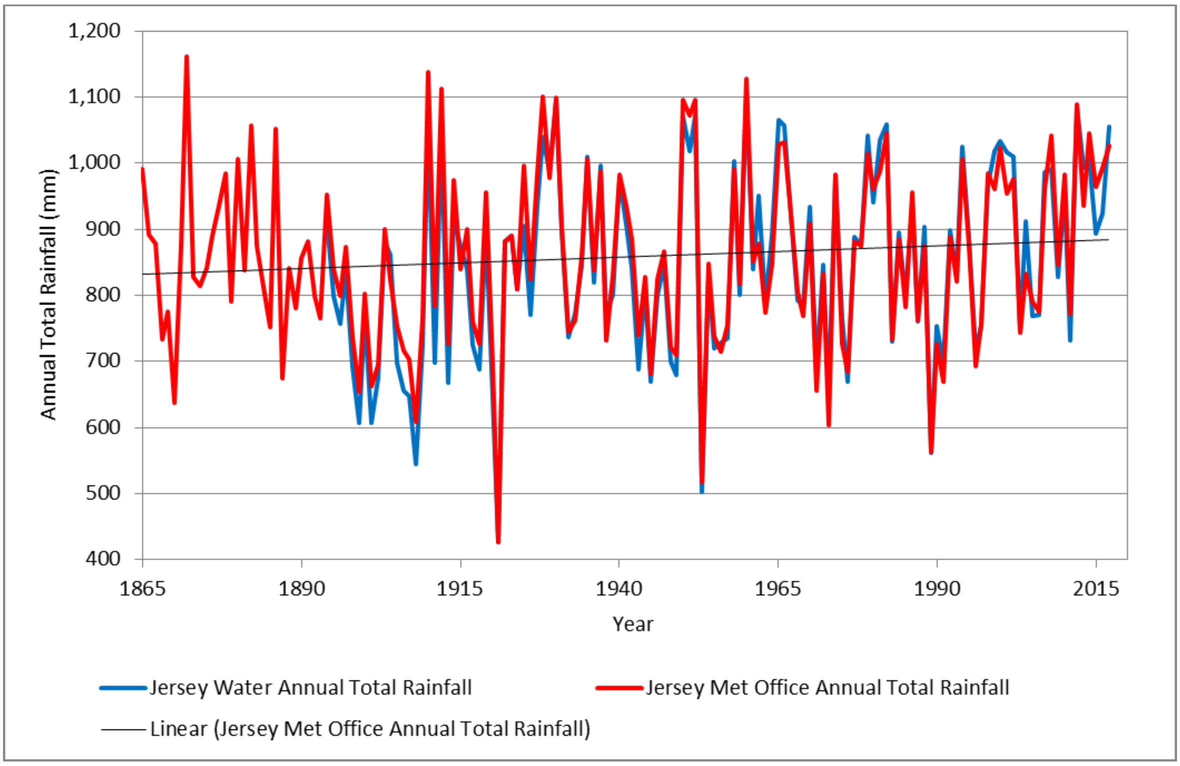

Figure 2-8: Annual Rainfall Long Term Trend

2.2.4 Meteo-France Data

Meteo-France is the French national meteorological service responsible for weather monitoring and forecast. Meteo-France provides design rainfall depths and AMAX series for durations of 6, 15 and 30 minutes, 1, 2, 3, and 6 hours and 1, 2, 3, 4, 6 and 10 days. AMAX series have been provided for two areas closest to Jersey: Gonneville and Dinard (Figure 2-1). The Gonneville area record contains 86 AMAX points from four stations (Gonneville, Valognes, Ste Marie Du Mont Brecourt and Pte de la Hague) all within a 35.5km radius. The Dinard record contains 98 AMAX data points from Dinard, Saint Cast le Guido, Quintenic, Pontorson and Feins SA, which are all located in a 45.9km radius.

The record length for the French rain gauges are relatively short, between 11 and 40 years, with the longest record at Dinard being nearly twice the length of the next longest record (Gonneville, see Table 2-1). This is important because the Dinard record shows some differences in rainfall distribution compared with the other records. However, the Dinard record is not excluded as it is the longest dataset available and is therefore considered to offer a more complete picture of rainfall distribution across the region. The shorter datasets will be biased due to the limited time period included in the sample. The France AMAX series are presented graphically in Figure 2-9 and in Appendix B. The AMAX series from the rain gauges in France have been provided for rainfall events of 2, 6 and 12 hour duration.

The AMAX series shows broad agreement between raingauge locations. The datasets do show some extreme events such as the 80.2mm event at Dinard in 2000 and the 45.6mm event at Feins in 2006, which are not replicated at other gauges, however this simply confirms the findings from the Jersey flood history in which high intensity storms can occur in localised areas.

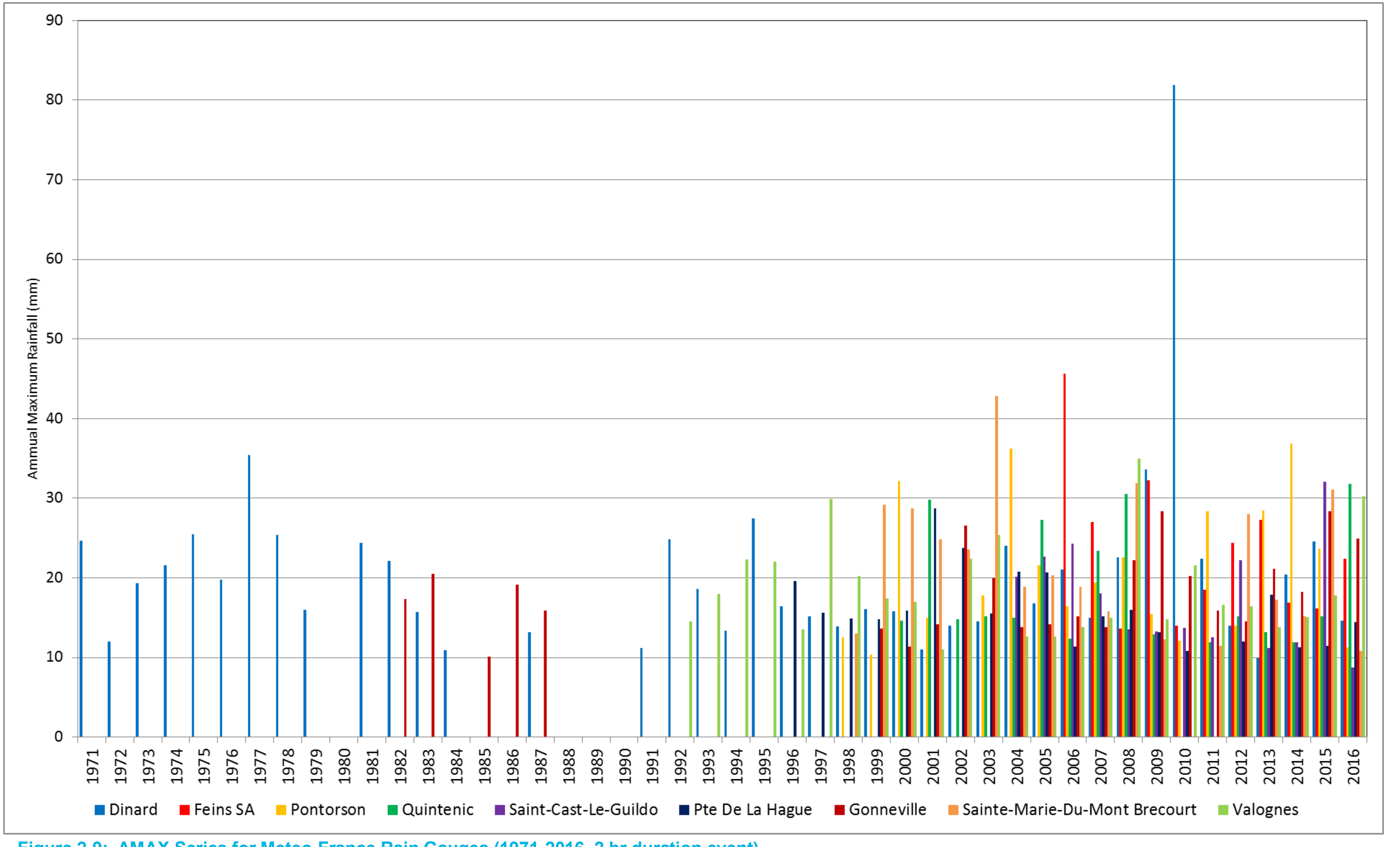

Figure 2-9: AMAX Series for Meteo-France Rain Gauges (1971-2016, 2 hr duration event)

The ranges of values in the AMAX series have been reviewed in order to determine whether it is appropriate to use the AMAX series from the rain gauges in France to inform extreme rainfall estimates for Jersey. Table 2-2 shows the variation in AMAX series for all gauges and all durations. The relatively low sea temperatures in summer compared to ground temperatures in continental France is thought to moderate rainfall intensity in Jersey. However, the majority of the rain gauges report similar minimum and median AMAX values, which suggests that the French data can be used to inform rainfall estimates for Jersey.

Table 2-2: Variation in AMAX Values Recorded at all Rain Gauges

Gauge	Record Length (years)	Minimum AMAX (mm)			Maximum AMAX (mm)			Median AMAX Value (RMED) (mm)		
		2hr	6hr	12hr	2hr	6hr	12hr	2hr	6hr	12hr
Jersey Airport	36	10	16	22	47	68	71	17	24	33
Maison St Louis Observatory	13	10	17	23	37	43	50	16	24	32
Guernsey Airport	37	8	15	18	36	44	48	16	26	33
Dinard	40	10	14	19	82	108	109	18	26	29
Feins	11	14	18	23	46	48	48	22	27	32
Pontorson	18	10	17	19	37	56	72	19	26	30
Quintenic	16	12	15	17	32	44	76	15	26	30
Saint Cast Le Guildo	13	9	13	17	32	33	38	14	24	31
Pte de la Hauge	20	11	16	19	29	36	45	15	23	29
Gonneville	18	10	14	17	28	49	57	17	26	34
Sainte Marie Du Mont Brecourt	18	11	16	21	43	57	61	20	27	35
Valognes	25	11	18	22	35	51	56	17	27	35

A further check on the similarity between the AMAX datasets for Jersey and French rain gauges has been carried out by comparing the L-moments (L-skew and L-kurtosis) based on the methodology outlined in the FEH. The datasets were analysed using Jersey AMAX data only (i.e. Jersey Airport and Maison St Louis Observatory), for the complete AMAX dataset including Guernsey and France, and lastly for the complete AMAX dataset, excluding the Dinard AMAX series. Dinard was excluded because this series appears to have a significantly different probability distribution compared to the records from other stations. The record at Dinard is longer than the AMAX records from the other French stations, resulting in additional weight given to this station when calculating the pooled skewness and kurtosis of the all stations AMAX dataset. Thus, when the AMAX series at Dinard is added to the pooled dataset, the resulting L-moments plotting position lies well above the probability distribution curves (Figure 2-10). This suggests that rainfall conditions at Dinard may be different from that of Jersey and the other French rain gauges, or that there may be an issue with the data quality at Dinard. A review of the AMAX 2 hour duration rainfall timeseries at Dinard suggests that there is similar probability of observing a rainfall event between 15 and 25mm, whilst other rainfall datasets reflect a more limited range around the mean AMAX value.

In view of this, growth curves which include the Dinard data may not be representative of flood frequency growth curves in Jersey and the rainfall timeseries from Dinard data has therefore been excluded from the analysis in Section 4.

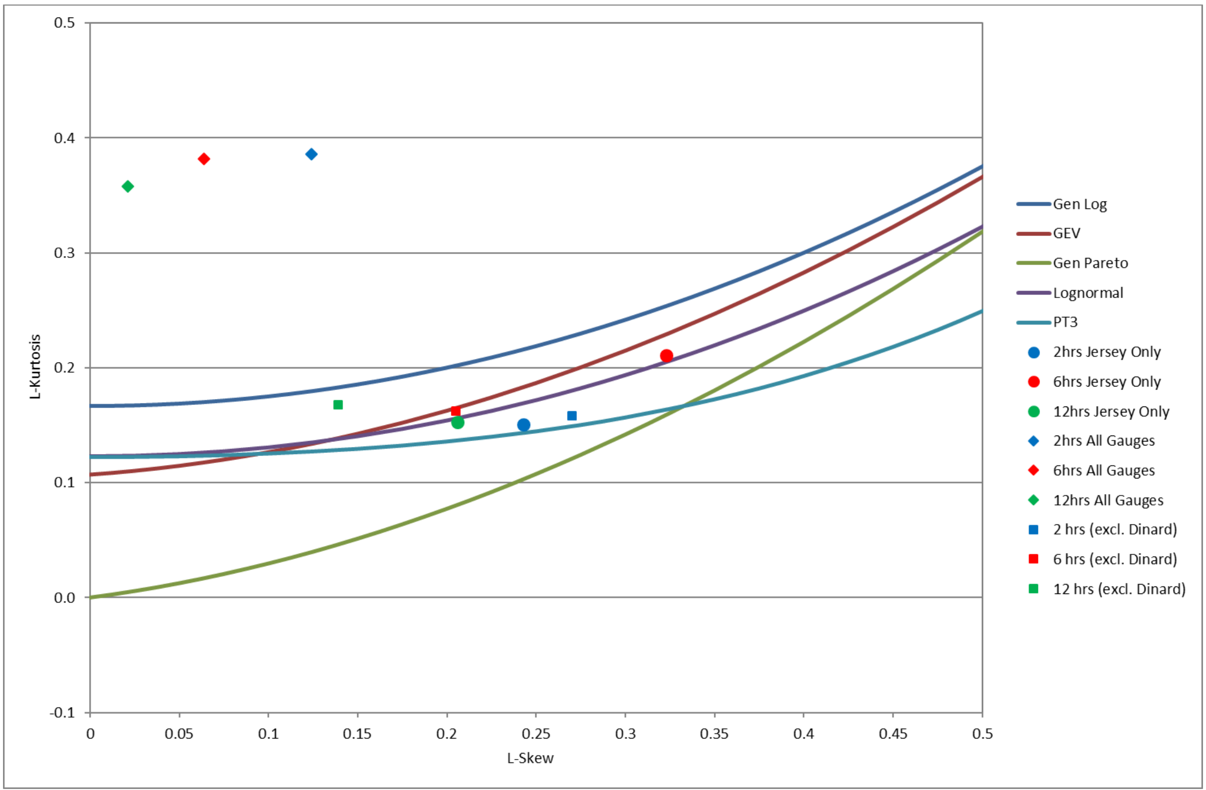

Figure 2-10: L-moments Plotting Positions for Various Groupings of Rainfall AMAX Data.

2.3 Summary

The hourly, daily and AMAX series available for gauging stations in Jersey, Guernsey and north western France have been analysed for consistency and trends. This reveals that localised extreme events with short duration and high intensity can occur across the region. The gauges generally show good agreement, despite some records being short, with the exception of the record at Dinard which has been excluded on the basis of low similarity of statistical distribution compared to that observed at all the other stations.

The rainfall data have been used as described in the following sections to derive modelled hyetographs for use in pluvial flood modelling. The hourly data at Jersey Airport and Maison St Louis Observatory have been used to determine the number and seasonality of significant rainfall events affecting Jersey over the period of record. The AMAX data forms the basis of rainfall growth curves to derive the depth of rainfall for events with various annual exceedance probabilities.

3. Methodology

3.1 Overview

The proposed approach for the high-level pluvial and fluvial modelling pluvial flooding of Jersey is to develop simulated rainfall hyetographs for input into a two- dimensional flood hydrodynamic model (TUFLOW). The FEH depth-duration-frequency model is the current standard of practice for estimating rainfall depths in the UK, but unfortunately, the method does not extend to Jersey. The precursor to the FEH, the Flood Studies Report (FSR, 1976) used generalised methods for calculating rainfall depths. These methods were based on broad scale data and regressions based on rainfall data. These methods were extended to Jersey by Butler *et al* (1985) and were found to be valid based on the data then available.

Extreme rainfall depths have therefore been derived based on two approaches: the FSR method and a statistical analysis of AMAX distributions (similar to those undertaken in the FEH) which relies on analysis of existing rainfall data only. The outputs of the two approaches have been compared to allow selection of the most appropriate peak rainfall depth to form the basis of the modelled hyetographs. This section outlines the methods used, whilst the analysis is presented in Section 4.

3.2 The Flood Studies Report

The Flood Studies Report (FSR) was published in 1975 and utilised rainfall records from across the UK to produce a standardised method for estimating rainfall depth for a given return period event. The FSR method requires only an outline of catchment geography and uses the ratio between rainfall depths in certain rainfall events, together with tabulated growth curves, to derive a modelled rainfall depth in events with return periods of between 0.5 and 10,000 years. Note that in the FSR, the return period of the rainfall events is not quite the same as the return period of a resulting flood event due to the effect of antecedent conditions in determining flood extents. The FSR identifies the corresponding rainfall return period event for each flood return period and it is the flood return period event that has been used throughout this report.

The first stage of the FSR method is to calculate the critical design storm duration. In this case the duration of the modelled events has been chosen based on analysis of the rainfall data and an understanding of the flood causing mechanisms in Jersey and is set at 2, 6 and 12 hours.

The second stage of the FSR is to estimate rainfall depths for the M5 event for each duration. The M5 event is given as the mean of upper two quartiles of the ordered AMAX series for rainfall events of each duration. The FSR allows for modelling of the M5 rainfall depth based on the average annual rainfall and the ratio of the rainfall depths during M5 events with a 1 hour and 2 day duration. However, the M5 rainfall depth has been calculated for Jersey for each modelled duration based on the existing AMAX data, as set out in Volume 2 of the FSR.

The M5 index variable is then multiplied by tabulated growth factors to give rainfall depths during more extreme events. Since the M5 rainfall depth for each modelled storm duration is known, the FSR method simplifies to using the tabulated FSR growth factors to derive estimated rainfall depths for the specified flood return periods. The FSR's tabulated growth factors allow estimation of total rainfall depths for events up to the 1 in 10,000 year flood event and are based on statistical analysis of rain gauge data from across the UK, as set out in Volume 2 of the FSR. The FSR provides separate growth curve tables for England and Wales and for Scotland and Northern Ireland; the tables for England and Wales have been used for the modelling of rainfall in Jersey and are given in Section 4.

3.3 Statistical Analysis

Although the FSR does produce modelled rainfall depths for given return periods, it is based on less data and is regionalised, and therefore of coarse scale. FSR rainfall depth estimation was superseded by the Flood Estimation Handbook (FEH) depth-duration-frequency model in 1999 and updated in 2013. However, it is not possible to use the full FEH rainfall frequency estimation as its spatial extent does not include Jersey.

Standard extreme value statistical analysis methods outlined in FEH Volume 2 can still be applied to the available rainfall data to provide localised growth curves, giving rainfall depths for different durations and frequencies, which can then be compared with the FSR outputs.

Statistical analysis of rainfall data relies on the analysis of annual maximum rainfall collected in AMAX series and the use of the median AMAX value RMED. The AMAX series for each gauge are plotted on a reduced variate (Gumbel) scale according to the Gringorten plotting position (ref. Section 8.3, FEH Volume 2). In this method, the AMAX rainfall is standardised by division by the RMED and plotted on the y-axis against the Gumbel reduced variate on the x-axis. Plotting data on the reduced variate scale allows the return period to be derived and probability distributions to be fitted. The Gringorten plotting positions are calculated separately at all points for all gauging stations and then plotted on the same graph. Aggregating the AMAX series together in this way assists in development of the growth curve where records are short.

The FEH rainfall frequency estimation method does not assume rainfall growth curves follow any particular frequency distribution, as this has a large effect on the estimation of rainfalls with long return period and could cause contradictions between growth curves of different durations. With the luxury of a close spatial network of rain gauges and many thousands of station-years of data, the FEH rainfall frequency model was able to develop an empirical method (FORGEX) to generate growth curves for any given location, that followed the data, rather than assuming the data follows any particular frequency distribution. However, such a method requires plentiful data and could not be employed for this study.

Volume 3 of the FEH sets out a method for selecting the most appropriate probability distribution for AMAX flow data and this has been applied to the rainfall data in this analysis. The preferred distribution is chosen based on L-moments analysis (skew and kurtosis), which when plotted on a graph also shows the trends in five probability distributions (Generalised Logistic (GL), Generalised Extreme Value (GEV), Generalised Pareto (GP), Log Normal (LN) and Pearson Type 3 (PT3). The most appropriate distribution is chosen according to where the data skew and kurtosis values plot in comparison to the probability distribution lines, with the closest line considered to best represent the data. Worldwide, the GEV distribution is commonly used for rainfall frequency analysis and this is used by Meteo-France.

3.4 Areal Reduction

Both the FSR and the FEH recognise that the modelled extreme rainfall depths estimated from the growth curves are based on analysis of point rainfall, i.e. rainfall at specific gauges. In practice, the rainfall seen at the gauge will not be replicated over the entire catchment. An areal reduction factor (ARF) is applied to the modelled total rainfall depth when deriving the catchment wide hyetograph in order to allow for this. The same method is followed in both the FSR and FEH where the ARF value used depends on the duration of the event and the catchment area. The values of ARF calculated for the modelled storm durations are set out in Table 3-1.

Table 3-1: ARF Values Applied to Event Hyetographs

Storm Duration (hours)	ARF Value
2	0.840
6	0.897
12	0.922

The ARF is applied to total rainfall before the rainfall is distributed according to the relevant seasonal hyetograph shape.

3.5 Hyetograph Shape

Both FSR and FEH apply the same method for distributing rainfall across a hyetograph. A symmetrical hyetograph shape is assumed, and the rainfall is distributed such that winter storm profiles are broader and flatter than summer storm profiles which have a higher peak rainfall intensity. The rainfall is distributed in accordance to a formula given in FEH Volume 2, Section 4.2, page 14.

Winter storm profiles are recommended for rural areas or where winter flooding is more common, while summer storm profiles have higher peak rainfall density and are recommended for urban areas and for areas where summer flooding is more common. Review of the flooding history for Jersey shows that flooding in response to intense rainfall events can occur throughout the year. A greater proportion of 2 and 6 hour AMAX values occur in summer rather than in winter (Section 4.2.2) while flooding in the 12 hour (lowest intensity) event is more likely when soils are saturated in winter. In view of this, the summer profile will be applied to the 2 and 6 hour events and the winter profile will be applied to the 12 hour event.

4. Analysis

4.1.1 Peaks Over Threshold (POT) Analysis

The hourly datasets for Jersey Airport and Maison St Louis Observatory were analysed to extract all rainfall events during which consecutive hours contained measurable rainfall and the total rainfall depth during the event was at least 10mm. This rainfall threshold was selected to exclude the smaller events but ensure a sufficient number of independent events were selected to characterise the rainfall in Jersey. The number of events with at least 10mm of rainfall is shown in Figure 4-1 for each hydrological year for which a complete dataset is available. The number of such events varies between 8 and 31, with an average of 19 at Jersey Airport and 22 at Maison St Louis Observatory. Note that the available datasets for both stations is short and the average number of events in the existing data may differ from the true long-term average at these sites.

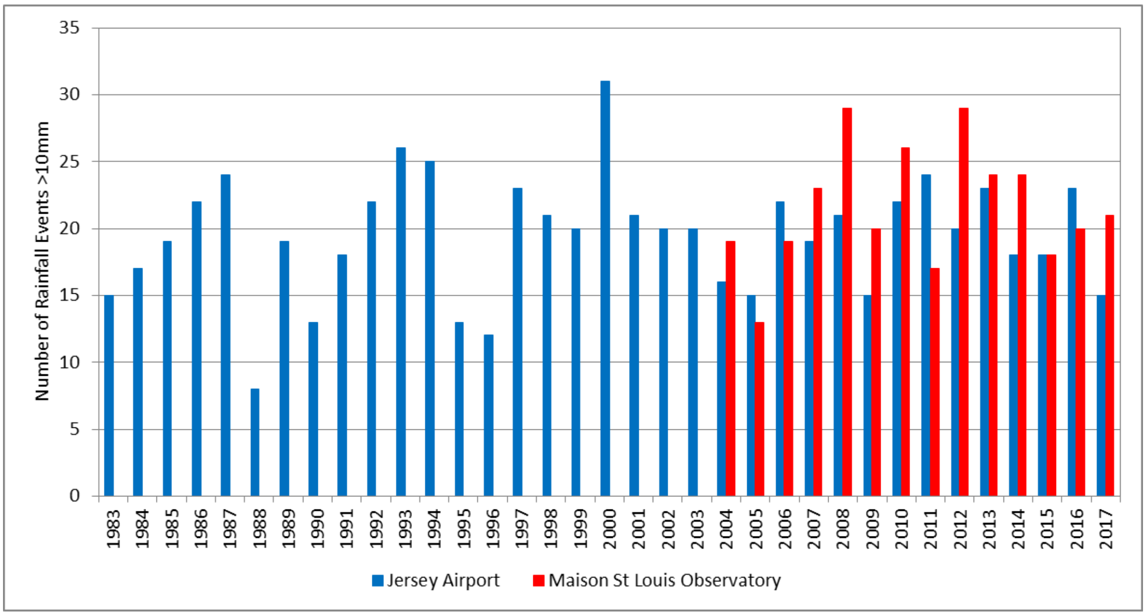

Figure 4-1: Number of Rainfall Events ≥10mm Total Rainfall Depth at Jersey Airport and Maison St Louis Observatory (1994-2016)

4.1.2 Event Duration

In the derivation of rainfall depth-duration-frequency growth curves, each rainfall duration is treated separately. Flood mechanisms that result in pluvial and fluvial flooding typically result from different durations of rainfall, with pluvial flooding from intense, short-duration rainfall and fluvial flooding from longer-duration rainfall with lower intensity. A review of the flood history proved inconclusive in defining critical durations and thus the rainfall time-series was analysed in order to understand the frequency of occurrence of rainfall of differing durations. Rainfall events greater than 10mm were analysed to determine the range of duration of significant rainfall events seen in Jersey. The results are shown in Table 4-1.

Table 4-1: Variation in Rainfall Event Duration for Events >10mm

	Jersey Airport	Maison St Louis Observatory
Number	694	309
Maximum Duration (hrs)	31	30
Minimum Duration (hrs)	1	1
Mean Duration (hrs)	9.9	8.6
Median Duration (hrs)	9	8
25th Percentile Duration (hrs)	7	5
75th percentile Duration (hrs)	12	11
90th percentile Duration (hrs)	16	14
10th percentile Duration (hrs)	5	4

In view of the results in Table 4-1 and the limited information from the flood history (Table 1-1), the rainfall durations chosen for the modelled hyetographs for Jersey are 2, 6 and 12 hours. The 6 and 12 hour durations are close to the 25th and 75th percentile duration values at Jersey Airport and at Maison St Louis Observatory, ensuring that the majority of the event durations seen at both sites will be included within the range of modelled durations. A duration of 2 hours corresponds to the observed duration of the extreme rainfall events which caused flooding in 1983 (see Appendix A and Table 1-1), ensuring that the intense events which caused pluvial flooding in the past are also considered in this study.

4.2 AMAX Analysis

4.2.1 Calculation of the M5 Rainfall Depth

Utilising the pooled (aggregated) AMAX series for Jersey Airport and Maison St Louis Observatory, the M5 rainfall depth (see Section 3.2) has been estimated for the three modelled storm durations: 2, 6 and 12 hours. The results are presented in Table 4-2 below.

Table 4-2: Rainfall Depths in the Modelled 1 in 5 year Return Period Events

Duration (hours)	2	6	12
Rainfall Depth (mm)	23	33	41

4.2.2 AMAX Seasonality

The 2, 6 and 12 hour event AMAX series for Jersey Airport, Maison St Louis Observatory and Guernsey Airport have been combined with the AMAX series from the French rain gauge data. The seasonality of the AMAX series has been assessed to confirm what time of year these events may be most common and if this is different for the different durations. The seasonal plots are provided in Figure 4-2 to 4-4: the location of each point depends on the time of year and the rainfall depth, with larger events (i.e. greater rainfall depth) plotting at greater distance from the origin. The results show a bias towards summer rainfall events with the majority of rainfall events occurring between April and October and with the more extreme rainfall events also occurring in the spring and summer. This same pattern is seen for all three durations, although a greater proportion of annual maximum 12 hour rainfall events occur in the winter compared with the 2 and 6 hour duration events. The 2 hour and 6 hour events will therefore be modelled using a summer hyetograph profile and the 12 hour event will be modelled using the winter hyetograph profile.

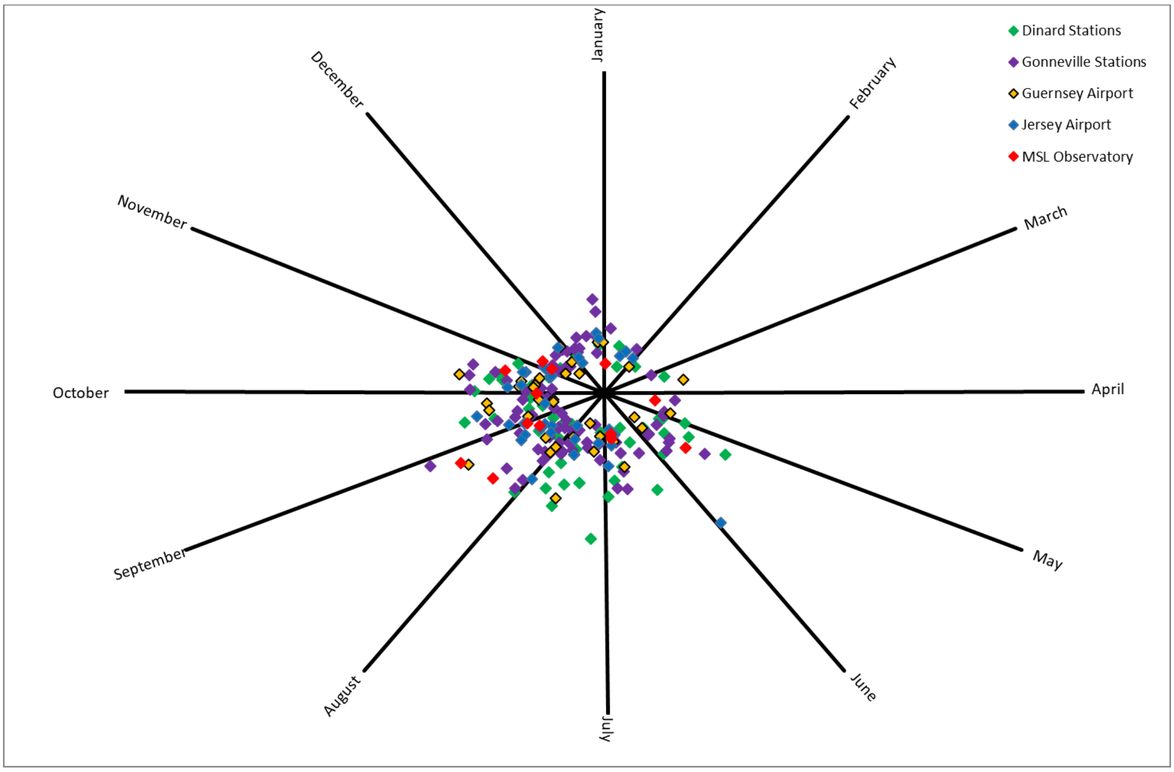

Figure 4-2: Seasonal Plot for 2 hour duration AMAX series

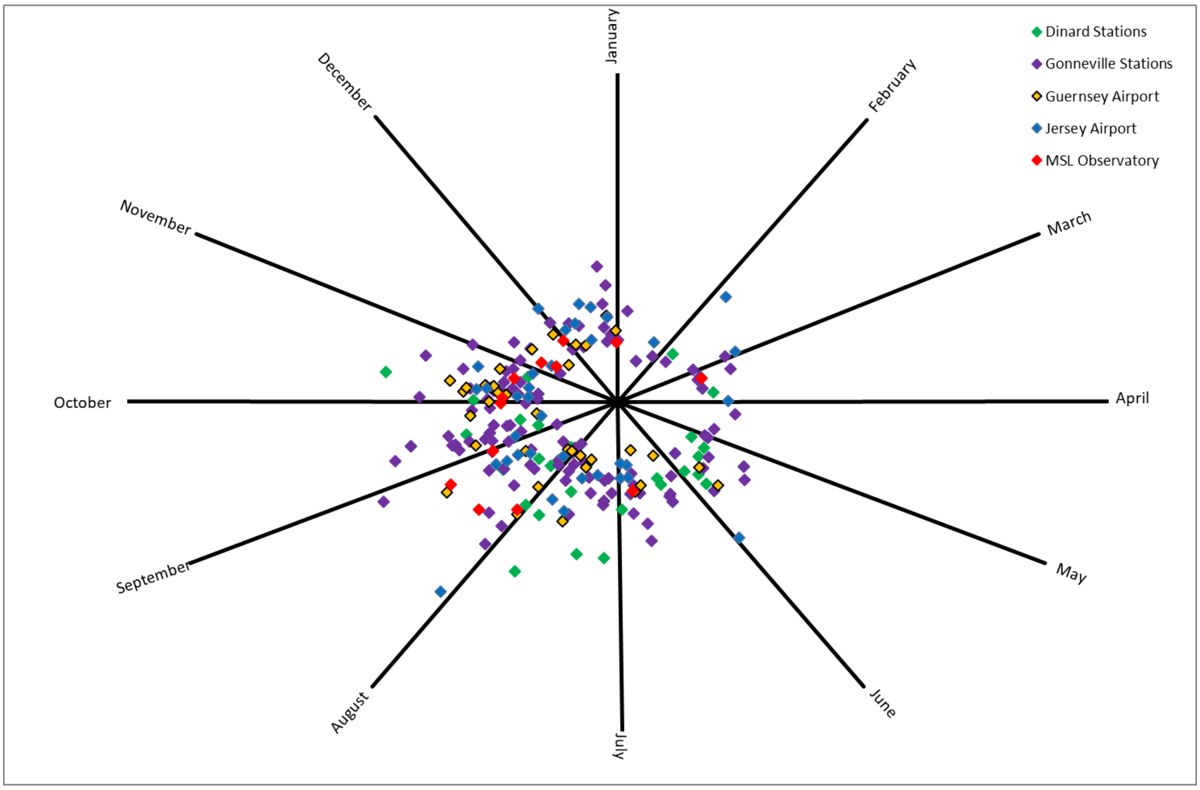

Figure 4-3: Seasonal Plot for 6 hour duration AMAX series

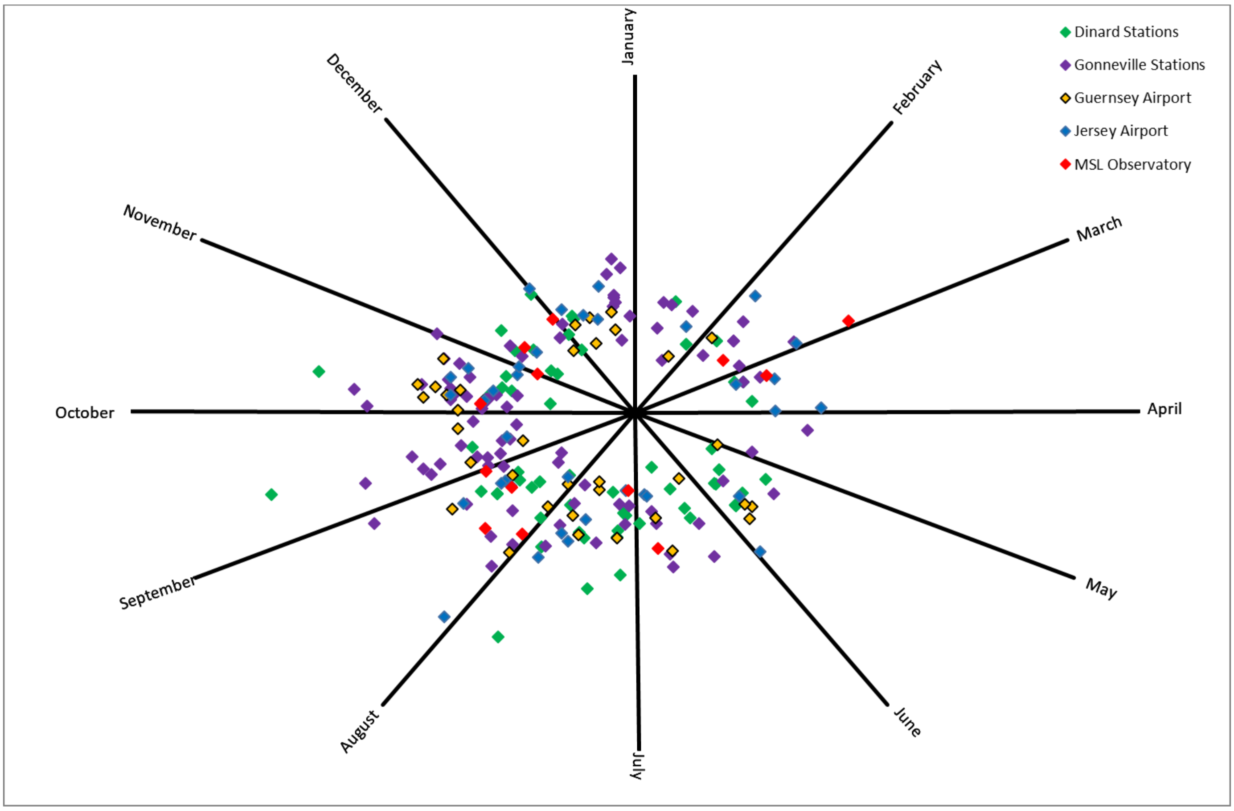

Figure 4-4: Seasonal Plot for 12 hour duration AMAX series

4.2.3 Gumbel Reduced Variate Plotting

The AMAX series for all the rain gauges have been plotted on a Gumbel reduced variate scale. The resulting plots are shown in Figures 4-5 to 4-7. Although the data from the different stations show good agreement for smaller events, there is a significant degree of scatter for the larger events. This reflects the short digitised record length at some stations, e.g. Maison St Louis Observatory. The plotting position assigns a return period based on the length of record, therefore any large rainfall events captured in a short record will be assigned a higher (more frequent) return period than for the same event observed within a longer record. Therefore, the same rainfall event will be assigned a different return period at Jersey Airport compared to Maison St Louis Observatory.

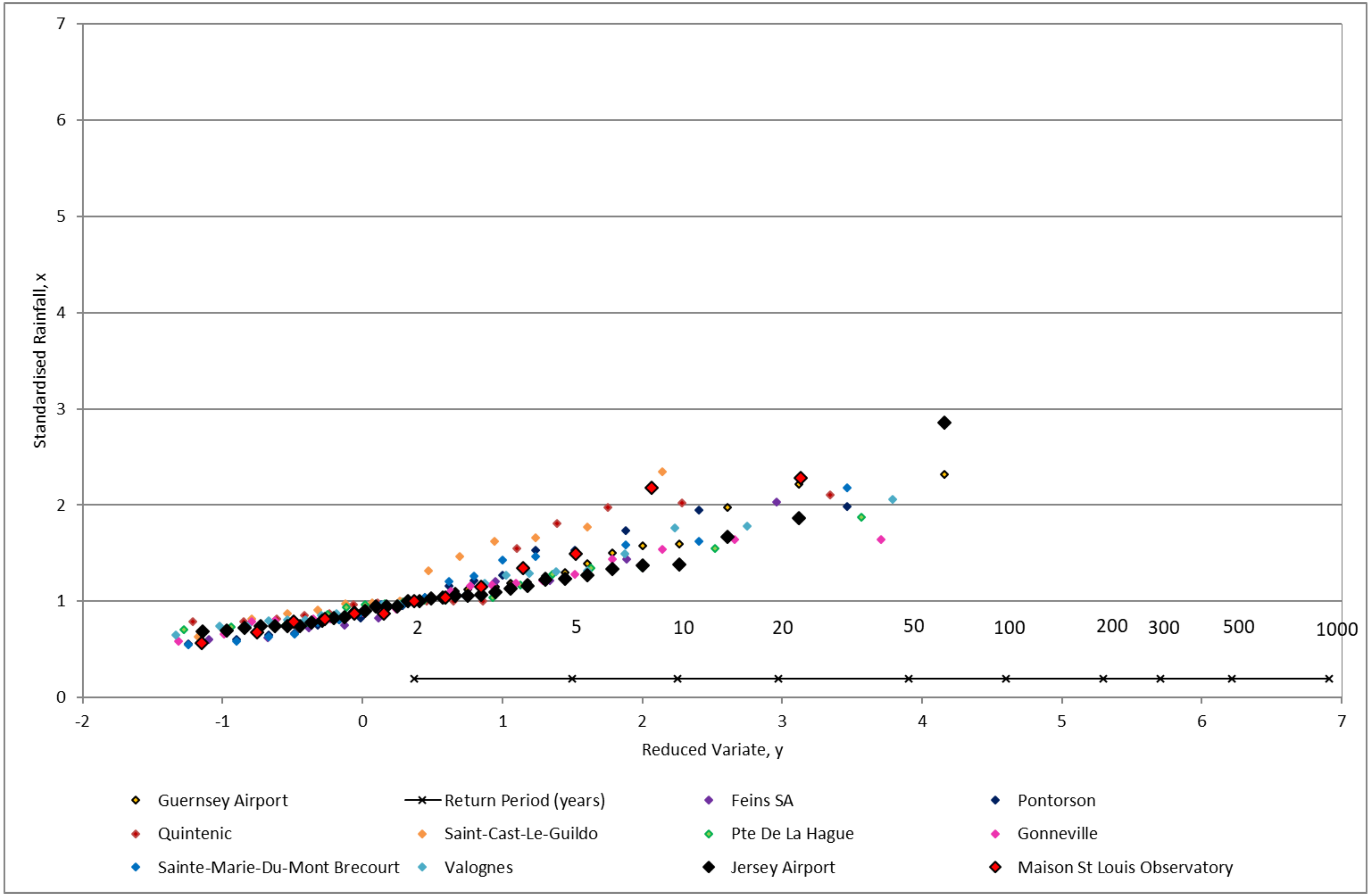

Figure 4-5: Reduced Variate Plot for 2 hour duration AMAX Series (data from Jersey, Guernsey and France)

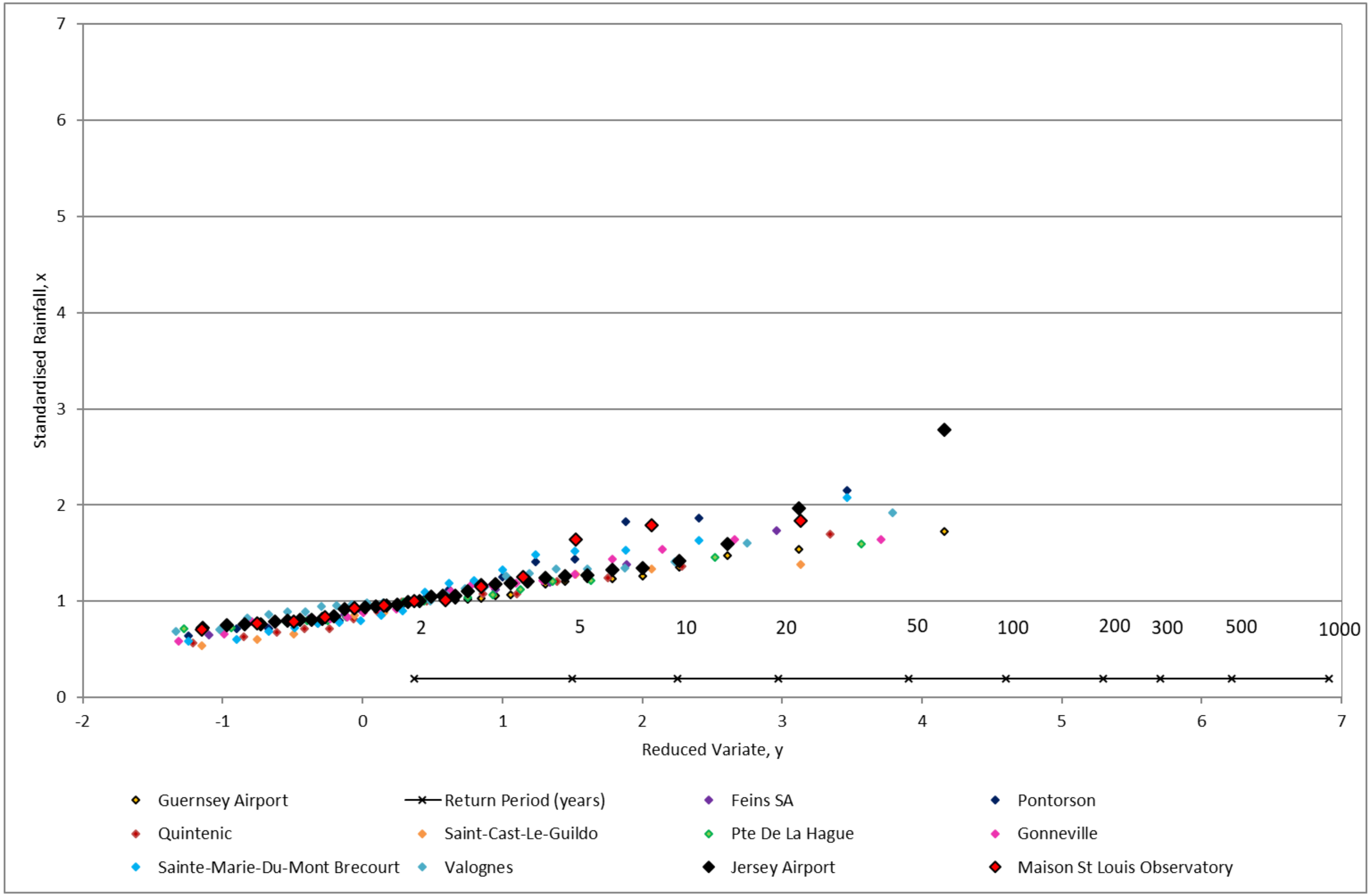

Figure 4-6: Reduced Variate Plot for 6 hour duration AMAX Series (data from Jersey, Guernsey and France)

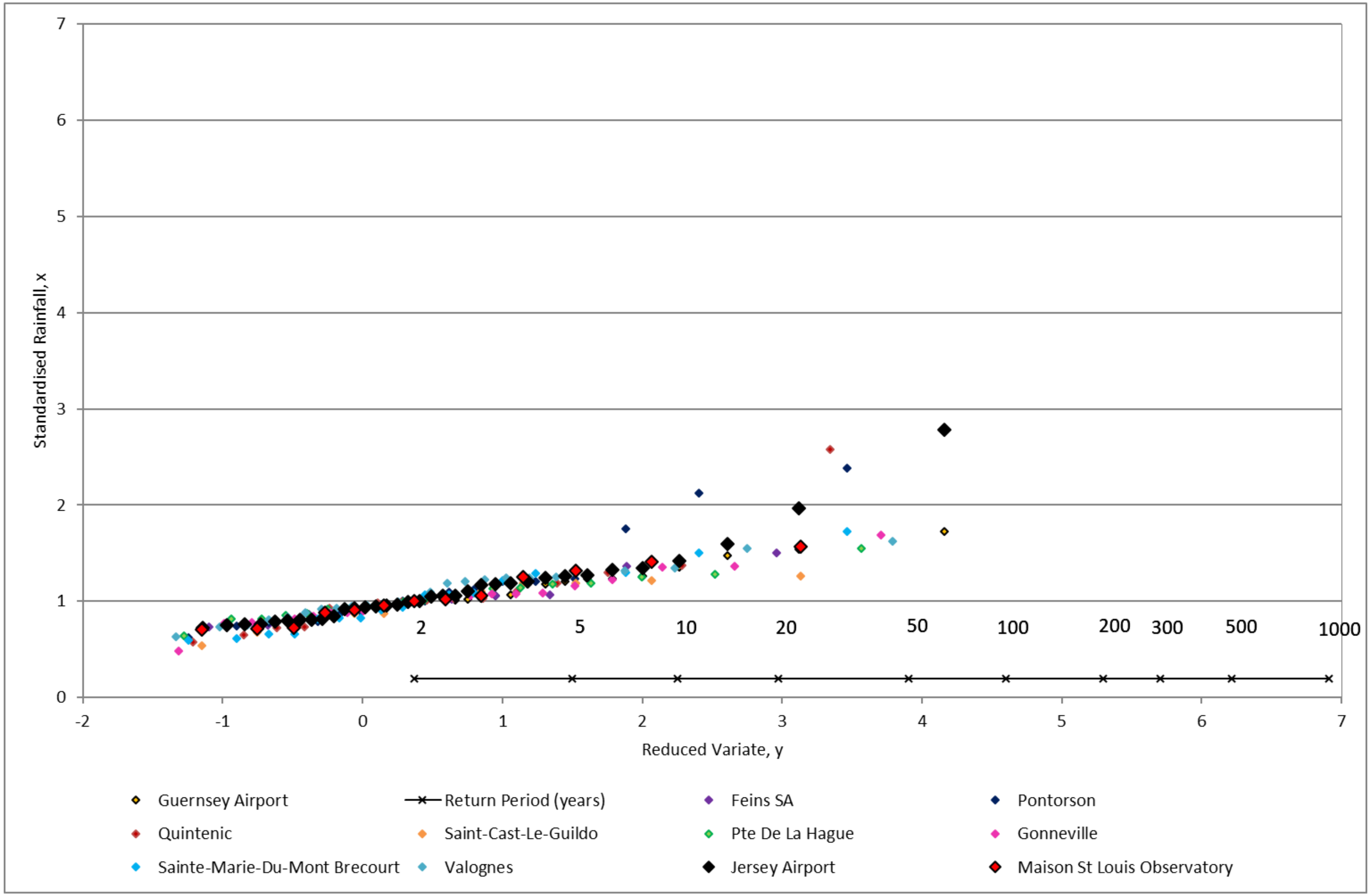

Figure 4-7: Reduced Variate Plot for 12 hour duration AMAX Series (data from Jersey, Guernsey and France)

4.3 Rainfall frequency curve estimation

4.3.1 FSR Method

The FSR method of rainfall frequency estimation involves estimating the M5 rainfall for a specific storm duration, and multiplying that by a regional growth factor to derive the rainfall depth for different flood return periods.

The final modelled rainfall depths based on the FSR (before adjustment for ARF) are shown in Table 4-3.

Table 4-3: Modelled Rainfall Depths (FSR Method)

Storm Return Period Event	Modelled Rainfall Depth (mm)		
	2 hr event	6 hr event	12 hr event
2	17	25	32
5	25	36	44
10	32	44	54
20	36	51	62
30	40	55	67
50	44	61	73
75	47	64	77
100	48	66	79
500	61	84	99
1000	78	106	123

The growth curves are shown on the Gumbel Reduced Variate plots in Figures 4-10 to 4-12 for comparison with existing AMAX data and with the GEV, LN and PT3 growth curves (see Figures 4-8 to 4-13 below).

4.3.2 Statistical Analysis of Rainfall Data

The L-moment plotting position for the Jersey only datasets and the complete dataset (excluding Dinard) suggests that growth curves based on the GEV, LN and PT3 might be appropriate fits to the data (Figure 2-10). The GEV is used by Meteo-France to create growth curves for their rainfall datasets and is considered appropriate for extreme event modelling as it is bounded above. Statistical analysis software “Easyfit[5]” has been used to fit the GEV, LN and PT3 probability distributions to the combined AMAX dataset for all stations. The software produces a value of the variable (in this case rainfall) for a given non-exceedance probability corresponding to the return period of the event (e.g. the 1 in 100 year event is specified using the annual non-exceedance probability of 0.99).

Growth curves have been produced based on the Jersey only AMAX data (Jersey Airport and Maison St Louis Observatory) and for the ‘all stations’ AMAX series which includes the two Jersey stations, Guernsey Airport and the French rain gauges (excluding Dinard). The results are presented in Tables 4-4 to 4-6 and the growth curves are shown in the graphs in Figures 4-8 to 4-11 for comparison with the AMAX data and the FSR curves.

[5] http://www.mathwave.com/articles/generalized_extreme_value_gev_distribution.html

Table 4-4: Modelled Rainfall Depths (2 Hour Duration Event)

Return Period Event	Modelled Rainfall Depth (mm) using Jersey only			Modelled Rainfall Depth (mm) Using All Stations		
	GEV	PT3	LN	GEV	PT3	LN
2	16	16	17	17	17	17
5	21	22	22	23	23	23
10	26	27	26	28	28	28
20	32	32	29	32	32	32
30	35	35	31	36	35	35
50	40	40	34	40	39	39
75	45	43	35	43	42	42
100	48	46	37	46	44	44
500	73	66	44	63	59	58
1000	87	76	48	71	66	64

Table 4-5: Modelled Rainfall Depths (6 Hour Duration Event)

Return Period Event	Modelled Rainfall Depth (mm) using Jersey only			Modelled Rainfall Depth (mm) Using All Stations		
	GEV	PT3	LN	GEV	PT3	LN
2	24	24	25	25	25	25
5	31	31	32	33	33	33
10	37	37	36	38	38	38
20	43	44	40	43	43	43
30	48	48	43	46	46	46
50	54	53	46	50	50	50
75	59	58	48	54	54	53
100	63	62	49	56	56	56
500	91	85	58	70	69	70
1000	107	97	61	77	75	76

Table 4-6: Modelled Rainfall Depths (12 Hour Duration Event)

Return Period Event	Modelled Rainfall Depth (mm) using Jersey only			Modelled Rainfall Depth (mm) Using All Stations		
	GEV	PT3	LN	GEV	PT3	LN
2	32	32	33	32	32	32
5	40	40	40	40	40	40
10	46	46	45	46	46	46
20	51	51	49	51	50	51
30	54	54	51	54	53	54
50	58	59	54	58	56	58
75	62	62	56	61	59	61
100	64	65	58	63	60	63
500	78	79	66	75	70	76
1000	84	87	70	79	74	81

4.3.3 Discussion of Growth Curves

Figures 4-8 to 4-11 present the FSR, GEV, LN and PT3 growth curves together with the AMAX datasets, while Figures 4-12 to 4-14 show the growth curves converted to rainfall depths and plotted alongside the Meteo-France growth curves for the Gonneville and Dinard pooled groups of rain gauges. The curves for each event are presented below with a discussion of the resulting curves for each design duration; 2 hour, 6 hour and 12 hour.

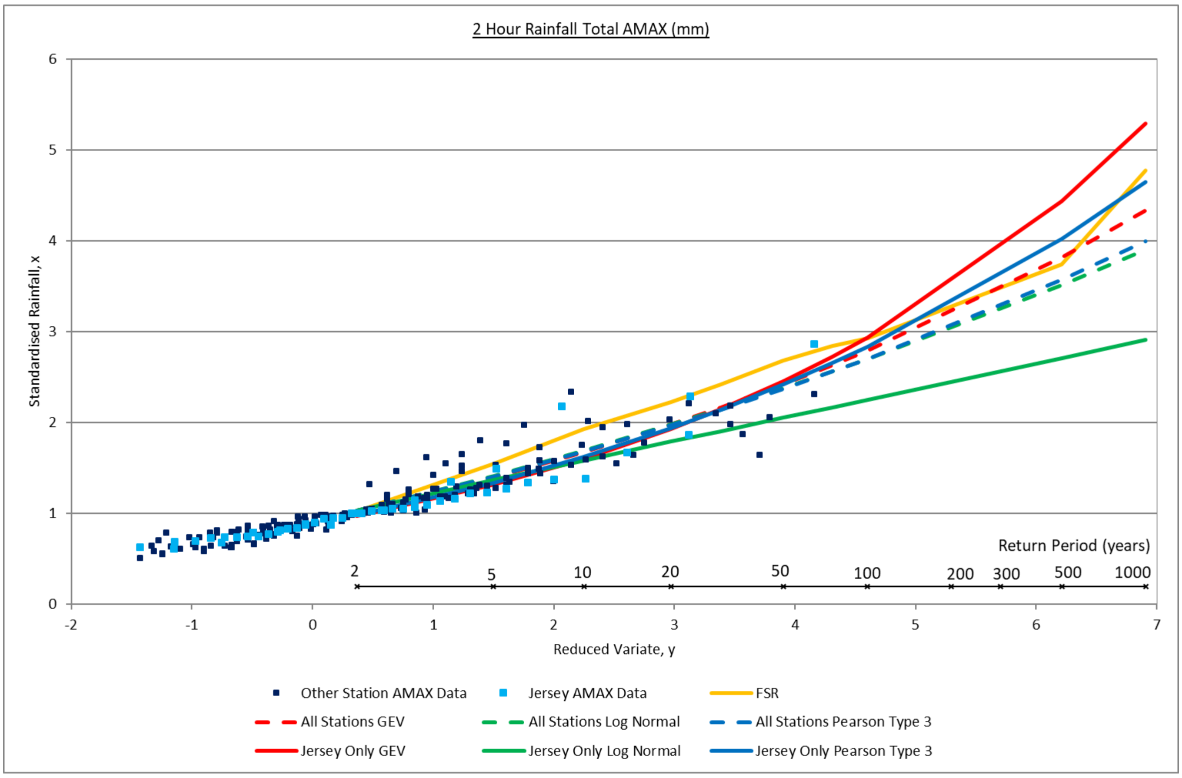

Figure 4-8: Growth Curves with AMAX data: Gumbel Reduced Variable Plot: 2 hour event

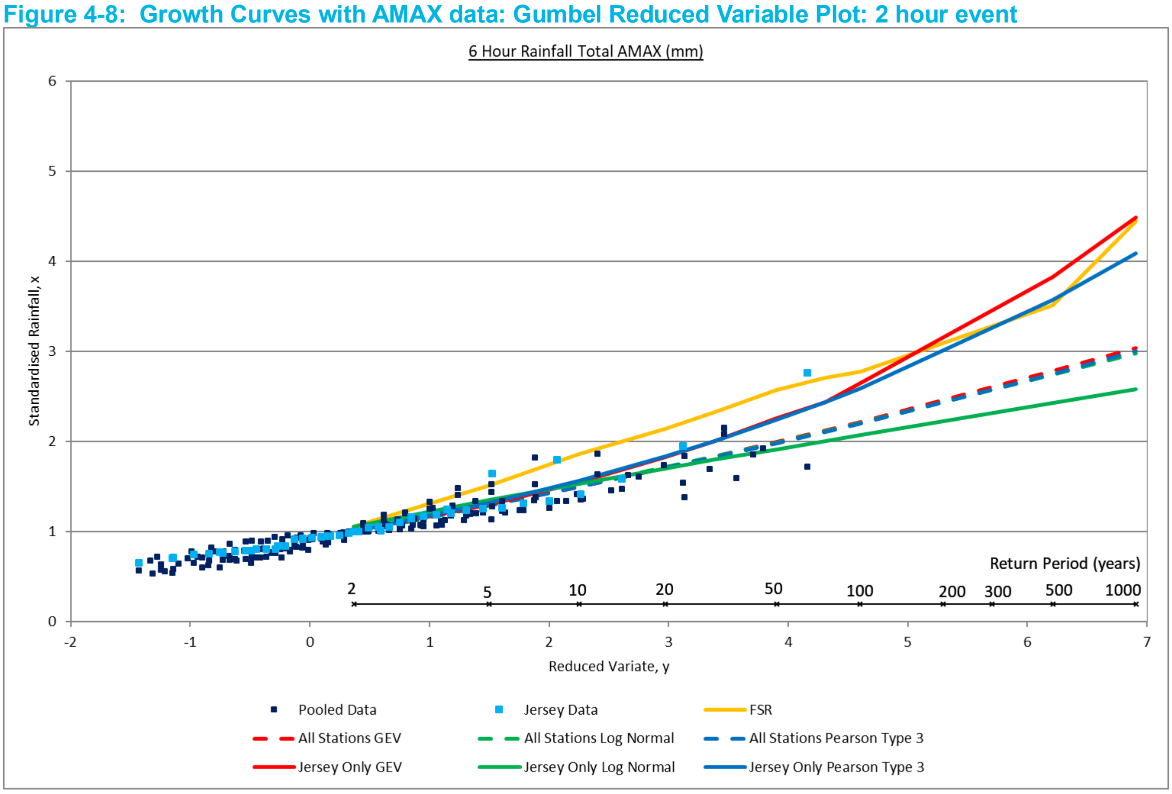

Figure 4-9: Growth Curves with AMAX data: Gumbel Reduced Variable Plot: 6 hour event

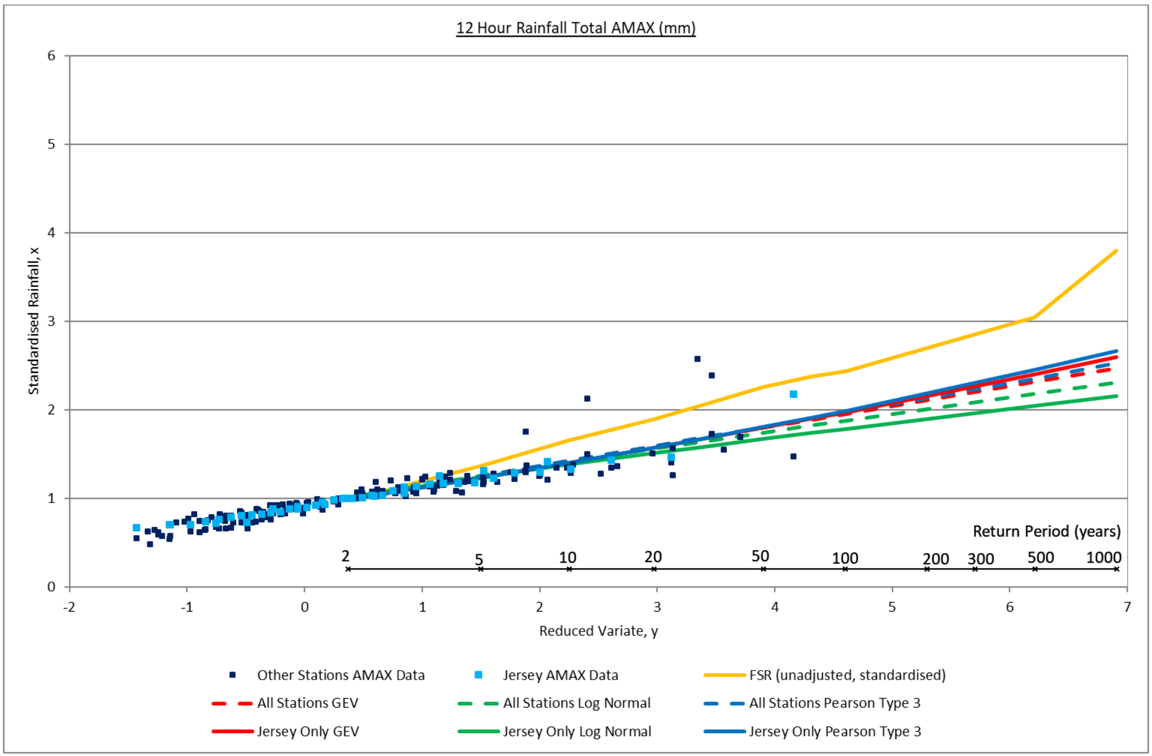

Figure 4-10: Growth Curves with AMAX data: Gumbel Reduced Variable Plot: 12 hour event

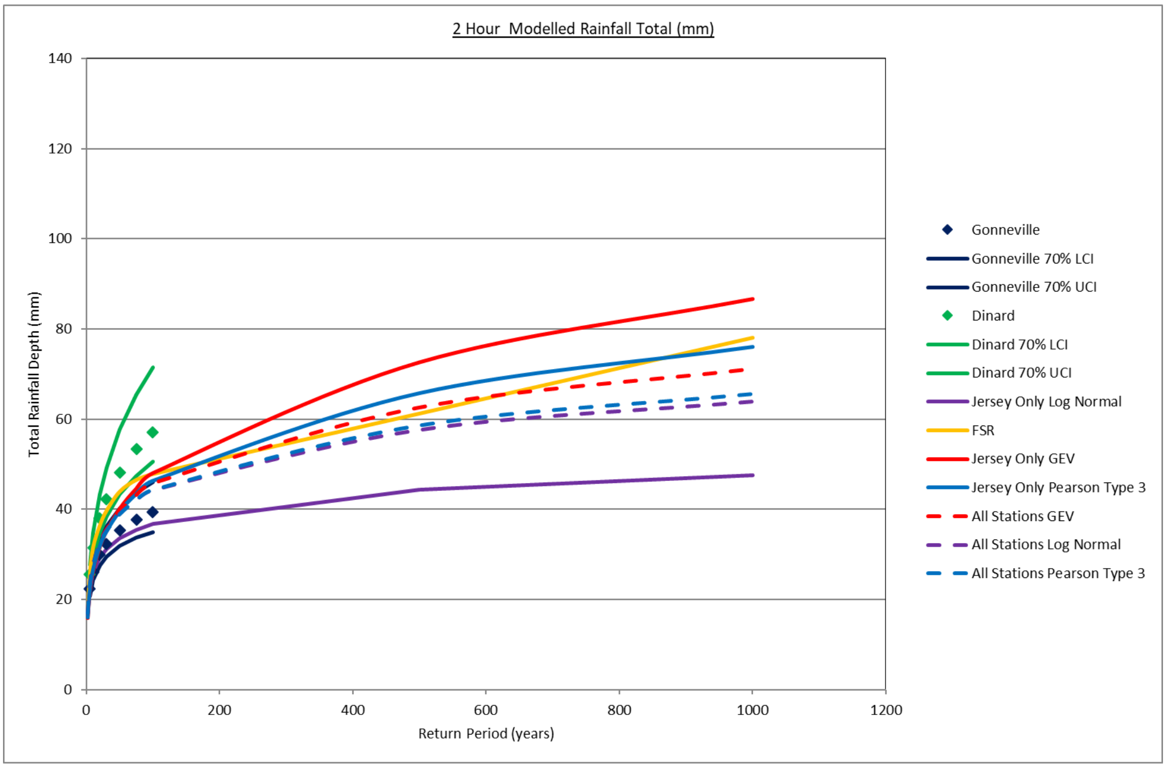

Figure 4-11: Comparison of FSR, GEV, LN, PT3 and Meteo-France Growth Curves (2 hour event)

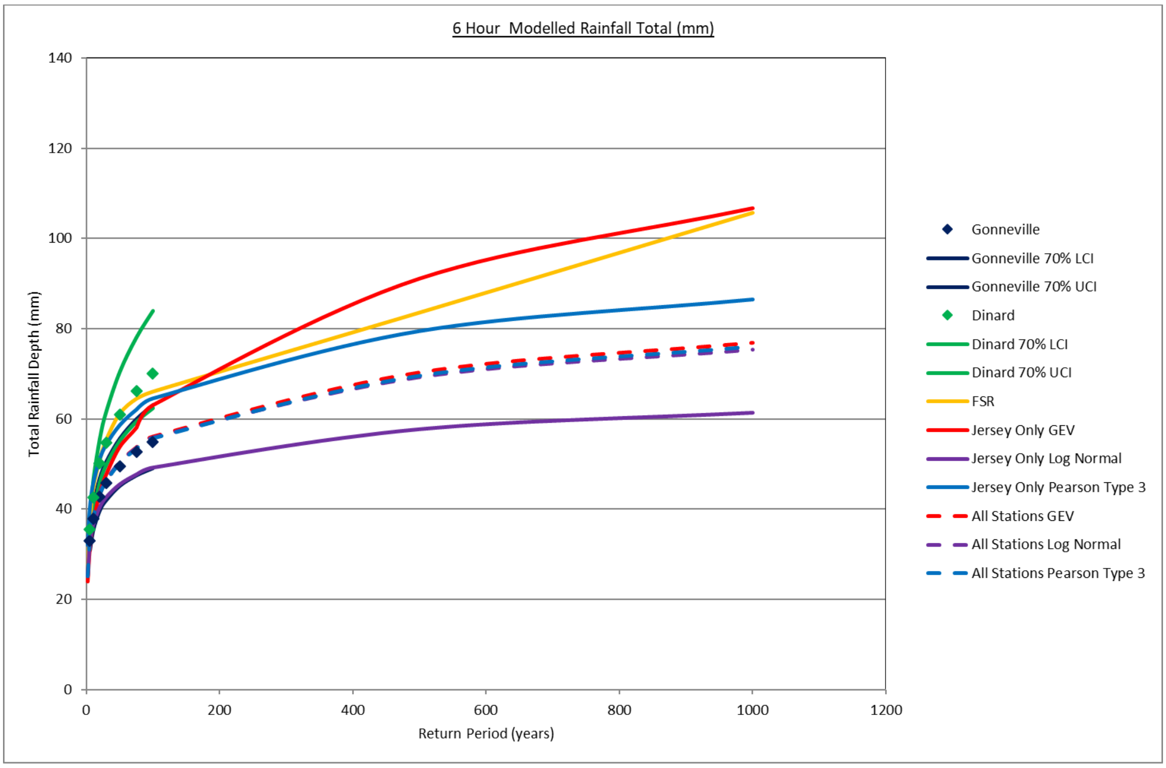

Figure 4-12: Comparison of FSR, GEV, LN, PT3 and Meteo-France Growth Curves (6 hour event)

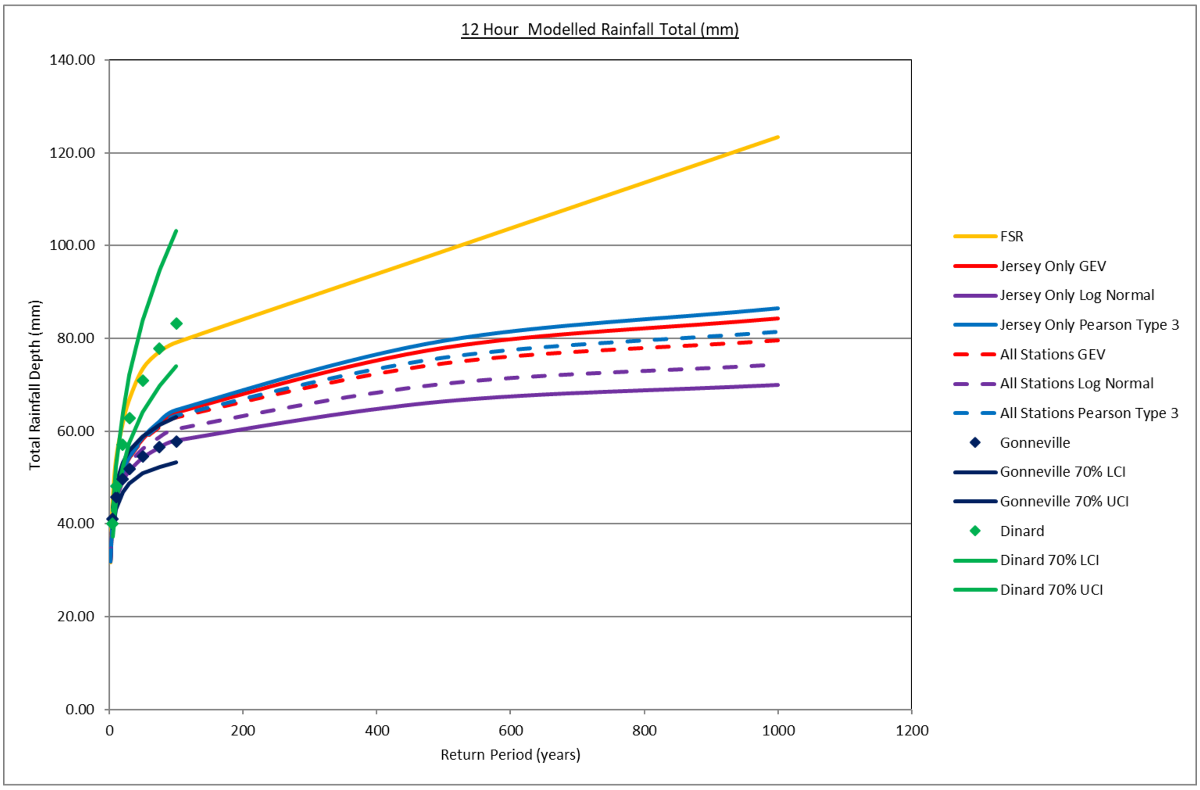

Figure 4-13: Comparison of FSR, GEV, LN, PT3 and Meteo-France Growth Curves (12 hour event)

2 Hour Event

The GEV and PT3 Jersey only growth curves show close agreement up to the 100 year event, deviating thereafter such that the GEV gives rainfall depths 7 and 11mm greater for the two most extreme events (Table 4-4 and Figure 4-8). The LN shows agreement with the GEV and PT3 up to the 10 year event, producing significantly lower rainfall estimates in all other events, up to 28mm lower than the PT3 and 39mm lower than the GEV for the 1000 year event.

The ‘all stations’ dataset results in slightly shallower GEV and PT3 curves and a much steeper LN curve. Again, the GEV and PT3 curve agree closely up to the 100 year event, then diverge, but the degree of divergence is lower with a difference of only 5mm in the 1000 year event. The LN curve is much more similar to the GEV and PT3 curves, agreeing with the PT3 curve for all events and estimating rainfall depths only 7mm lower than the GEV for the 1000 year event.

The 2 hour FSR growth curve predicts higher rainfall totals for lower return period events than any of the statistical distribution curves. However, the Jersey only GEV curve predicts higher rainfall in the 1000 year event and both the GEV and the PT3 Jersey only curves predict higher rainfall in the 500 year event, as does the all stations GEV curve.

Scatter in the AMAX values observed in Figure 4-8 primarily originate from French rain gauges which have short records and for which there is therefore less confidence in the plotting position of these data points. The position on the reduced variate axis is based on the number of points in the record and if these short records contain observations from wetter years, perhaps reflecting a wetter period, then this would artificially steepen the growth curve. In addition, most of these scattered AMAX data points are from the Dinard group of rain gauges, and as previously discussed, the rainfall depth plots (Figures 4-11 to 4-13) indicate the rainfall in Jersey reflects better the rainfall patterns observed at the Gonneville group of rain gauges. Given the longer AMAX series for the rain gauges in Jersey, it is reasonable to have more confidence in the Jersey only growth curves than the all stations growth curves for the 2 hour event.

The Jersey only 2 hour event GEV and PT3 curves are steepened due to the presence of three significant rainfall events in the record: 31 May 1983 (47.2mm) and 25 August 2010 (37mm) and 12 August 2015 (35.3mm). The May 1983 event is from the Jersey Airport record and is known to be extreme, while the two other events are from Maison St Louis which only has a short digitised record. It is possible that these events are less common than the limited dataset would suggest and should plot further to the right on the Gringorton plot. In this case, the Jersey only GEV and PT3 growth curves would be too steep. However, examination of the flood history of Jersey (Table 1-1 and Appendix A) indicate that short duration, high intensity events are fairly common on Jersey, with the following five events recorded in the 1980s:

- September 1981 (50mm in 1 hour at Maison St Louis Observatory);
- June 1982 (54mm in 1 hour at Maison St Louis Observatory);
- May 1983 (43.4mm in 2 hours at Jersey Airport);
- June 1983 (28mm in 2 hours at Jersey Airport);
- October 1985 (43mm in 4 hours at Maison St Louis Observatory).

The inclusion of these events in the record would suggest that the GEV curve for the 2 year event is not too steep, despite predicting the highest extreme rainfall depths of any method of estimation or probability distribution. A comparison of the Jersey only and all stations growth curves with the Meteo-France growth curves and associated 70% confidence intervals (Figure 4-11) indicates that all growth curves, other than the FSR and Jersey only LN curve, produce estimated rainfall depths which fall within the upper confidence intervals calculated for the Gonneville group of rain gauges and the lower confidence interval calculated for the Dinard group of gauges. This suggests that the predicted rainfall depths are consistent with regional rainfall patterns observed in France.

6 Hour Event

As with the 2 hour event, the Jersey only GEV and PT3 growth curves for the 6 hour event produce consistent results in up to the 1 in 100 year event, with divergence thereafter. The PT3 curve predicts rainfall depths 6mm lower in the 500 year event in 10mm lower in the 1000 year event. The LN for the 6 hour event again only agrees with the GEV and PT3 curves in to the 10 year event and then predicts lower rainfall depths, up to 36mm lower than the PT3 and 46mm lower than the GEV in the 1000 year event. The inclusion of the data from the French rainfall gauges produces growth curves which are consistent for all events.

The GEV and PT3 growth curves for the Jersey only data do appear to be biased by a single high rainfall event occurring at Jersey Airport on 3 August 2008 (in the 2007 hydrological year). This event also produces the AMAX rainfall depths for the 2 hour and 12 hour durations, although for both these durations the rainfall totals are less extreme compared to other events of similar duration (Figure 4-14).

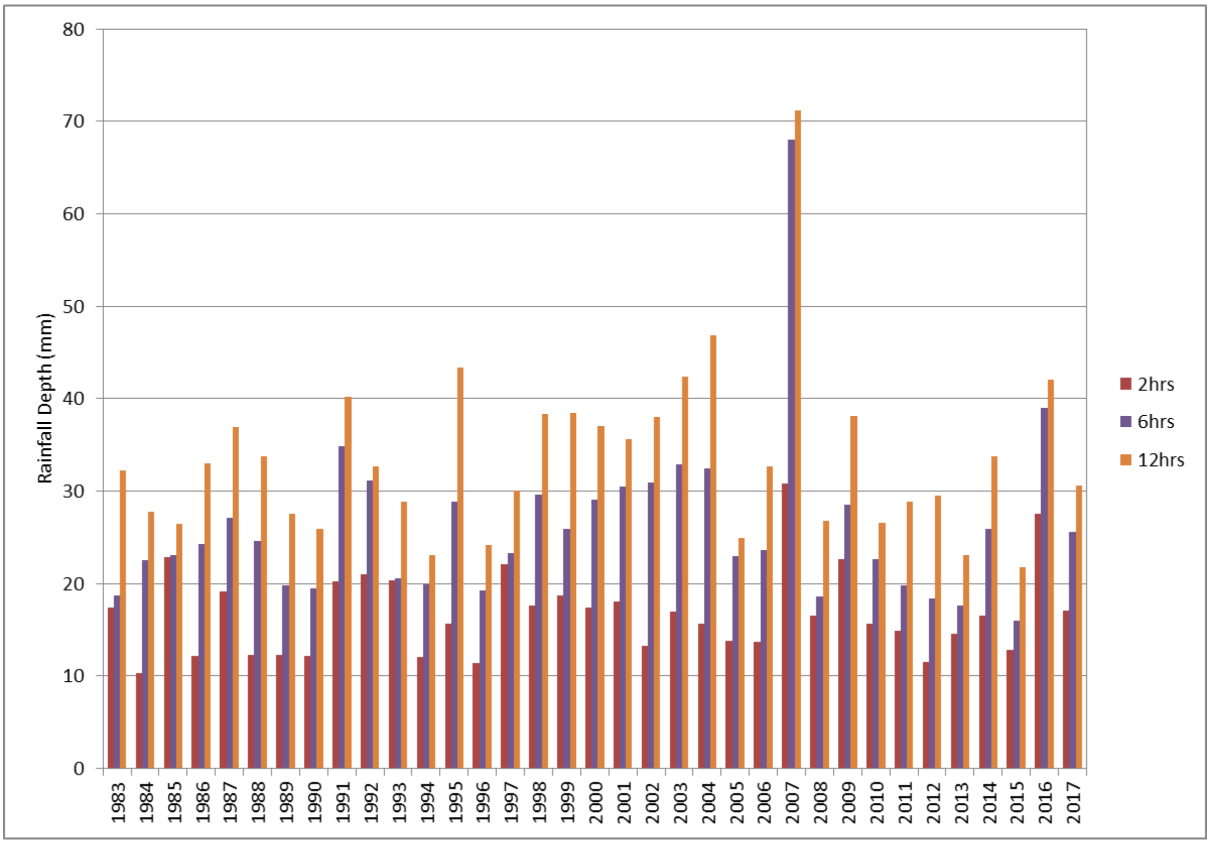

Figure 4-14: AMAX Series for Jersey Airport for 2, 6 and 12 Hour Events

The 2007 event was more extreme in terms of the rainfall depth recorded over 6 hours compared with either that recorded over 2 or 12 hours. The rainfall recorded is 187% of RMED over the 2 hour duration, 218% of RMED over the 12 hour duration, but 280% of RMED over the 6 hour duration. Jersey Met have confirmed[6] that this was a particularly extreme event. Therefore, given a longer record, it is likely this event would plot significantly further to the right, resulting in flatter growth curves for the Jersey only 6 hour duration and making it more consistent with the all stations curves. The influence of this single event on the Jersey only growth curves is noted but we do not want to disregard it.

The FSR curve estimates the highest rainfall depths compared to all growth curves up to the 100 year event, after which it closely matches the Jersey only PT3 growth curve at the 500 year event and the higher Jersey only GEV growth curve at the 1000 year event. As ever the changing steepness of the FSR growth curve provides a complex relationship between rainfall depth and probability.

The growth curves in Figure 4-12 reveal a greater spread of estimated rainfall depths for the 6 hour duration compared to the 2 hour duration. The LN curves are close to the lower 70% confidence interval for rainfall depths at the Gonneville group of stations, whilst the Jersey only GEV, PT3 and FSR curves all estimate rainfall depths closer to the upper 70% confidence interval for the Gonneville group of stations and the lower 70% confidence interval for the Dinard group of stations. This reflects a change in the relationship between the Jersey and all station growth curves compared with the Meteo-France pooled growth curves when compared to the 2 hour duration curves.

12 Hour Event

The Jersey only GEV and PT3 growth curves are again similar for all events while the flatter LN growth curve estimates lower rainfall depths; up to 17mm lower in the 1000 year event (Table 4-6 and Figure 4-10). Both the Jersey only GEV and PT3 are steeper and estimate slightly higher rainfall depths than the three all stations GEV, PT3 and LN growth curves. The all stations GEV and PT3 growth curves are slightly flatter but still consistent with each other, while the all stations LN curve is slightly steeper than the Jersey only LN growth curve but still

[6] Email from John Searson, Jersey Met to Helen Harfoot (11 November 2019) containing comments on draft report

predicts lower rainfall depths than the GEV and PT3 in all events. The FSR predicts significantly higher rainfall depths for all return periods, with the difference for the 1000 year event being 52mm.

Comparison of the predicted rainfall depths (Figure 4-13) shows that the statistical growth curves all predict rainfall depths which are within the bounds of the 70% confidence intervals for estimated rainfall depths at the Gonneville group of rain gauges. In contrast, the FSR curve estimates rainfall depths which more consistent with the Dinard group of rain gauges.

4.4 Growth Curve Selection

In selecting the final growth curves used to estimate the modelled rainfall depths, the 12 hour event will be considered separately from the 2 and 6 hour durations. Consultation with Jersey Met has confirmed the results of initial pluvial modelling which indicates that although 12 hour duration rainfall events do occur in Jersey they are less likely to result in significant pluvial flooding. This can be attributed to the small and responsive catchments on the island and the lower intensity rainfall associated with a 12 hour duration event. On this basis, the conservative FSR growth curves will be selected for the 12 hour duration rainfall.

Using the FSR curve for the 12 hour duration also avoids inconsistencies in predicted rainfall depth which occur as a result of bounding in the distributions coupled with the very different shaped (flatter) statistical growth curves calculated for this duration. Given that a 6 hour rainfall event must be contained within a 12 hour rainfall event, the 12 hour event rainfall depth must be at least as large as the rainfall depth estimated for the 6 hour rainfall event. However, the results in Table 4-5 and 4-6 show that the GEV and PT3 distributions predict lower rainfall depths in the 12 hour event compared with the 6 hour event for the most extreme storms, which is counterintuitive.

The FSR will not be considered in the selection of the 2 and 6 hour duration growth curves because it is based on older analytical methods and rainfall data from the UK prior to the 1970s. In their 1983 paper, Butler *et al.* concluded that the FSR could be applied to Jersey, despite none of the original rainfall data used in the FSR method being based on rainfall data from the Channel Islands. Given that the hourly rainfall record from Jersey Airport and Maison St Louis Observatory is of sufficient length to derive statistical growth curves and fits the observed data better than the FSR curve, a growth curve based on statistical distributions derived directly from the datasets is preferred for the shorter duration events, which appear to be the origin of much of the pluvial flooding recorded in the flood history.

The flatter LN curves consistently produce the lowest predicted rainfall depths for both the 2 hour and 6 hour events. Rainfall depths estimated for the LN distribution using Jersey only data are lower than rainfall depths previously recorded at Jersey Airport and Maison St Louis Observatory for the 1000 year return period For exampling, using LN curves based on the Jersey only dataset would give a return period of more than 3880 years for the largest 6 hour event recorded at Jersey Airport and 4192 years for the June 1982 event recorded at Maison St Louis Observatory. Given the Jersey Airport is 35 years long and the Maison St Louis Observatory record is 13 years long it is unlikely that rainfall events of this rarity will have been recorded within these relatively short records.

The GEV and PT3 curves produce similar growth curves (Figures 4-11 and 4-12) and in turn similar estimated rainfall depths for events up to around the 100-year return period, with divergence observed at the 500-year and 1000-year return periods. Given the length of the pooled data series for Jersey and the significant extrapolation of data required to obtain the rainfall depths at the 500-year and 1000-year return periods, rainfall depths estimated above the 100 year can be considered highly uncertain. Of the two distributions presented, GEV and PT3, the GEV is preferred for the more conservative rainfall depths estimated at the 500- and 1000-year return periods. Meteo-France also use the GEV distribution, thus the results of this analysis will be consistent with other analyses in the region.

GEV growth curves derived from all stations data (including Jersey, Guernsey and Meteo-France) are flatter than the Jersey only data for the 2 and 6 hour durations, whilst at the 12 hour duration there is almost no difference. This may reflect different underlying rainfall patterns or the effect of a longer-timeseries (Figure 4-13). Using data from Jersey only ensures that the data represents actual rainfall conditions experienced in Jersey with no consideration of any potential effect of ground temperature in continental France on rainfall intensity. There is no consensus of how rainfall may vary between Jersey and continental France, however, as far as the advection of convective cells from France is concerned, one theory is that passage toward the Island over the relatively cool sea has the effect of curtailing the available energy and diminishing rainfall over Jersey. The altitude of the convective process can be critical. Low level convection may become less vigorous, but medium level storms often have sufficient energy to perpetuate high intensity precipitation as they move from France over the Channel Islands, especially when forcing mechanisms for upward motion other than local convection are present. When there is an unstable atmosphere coupled with light winds at the surface and higher up in the atmosphere, sensible heating from the sun on the Island can lead to a difference in temperature of 10 degrees Celsius or more between the land area and surrounding sea. In such cases, local convection, aided by convergence from light sea breezes, can produce slow moving storm cells and significant localised rainfall.

In addition, Jersey Met are in control of the Jersey only data and its quality. They have an unprecedented knowledge of their data having been able to identify anomalous rainfall depths (e.g. notes in Appendix C) and their ready access to up-to-date data would allow this analysis to be more readily updated in future. In addition, and possibly more importantly, the rainfall records from Meteo-France are comparatively short, with the longest record being excluded due to the anomalous distribution of the AMAX series compared to all other Meteo-France rain gauges.

A comparison of the 2 and 6 hour GEV curves reveals a good fit to the gauged rainfall data and consistency between the two curves. The rainfall depths are higher for the 6 hour duration rainfall as we would expect. In conclusion, the 2 hour duration GEV curve will be used to derive the 2 hour duration rainfall depths and the 6 hour GEV curve will be used to derive the 6 hour rainfall depths. As outlined above, the FSR will be used to derive the 12 hour duration rainfall curves.

4.5 Final Growth Curve

Reduced variate plots for the final growth curve at each duration are shown alongside the Jersey only AMAX series in Figures 4-15 to 4-17. These demonstrate a reasonable fit to the data for all three durations. Final growth curves for each duration are presented for comparison with the growth curves of the Dinard and Gonneville groups of rain gauges in Figures 4-18 to 4-20. All three curves fit within either the Gonneville or Dinard 70% confidence intervals, which confirms they are predicting rainfall depths within the bounds of other regional growth curves. The final modelled total rainfall depth in each event is shown in Table 4-7.

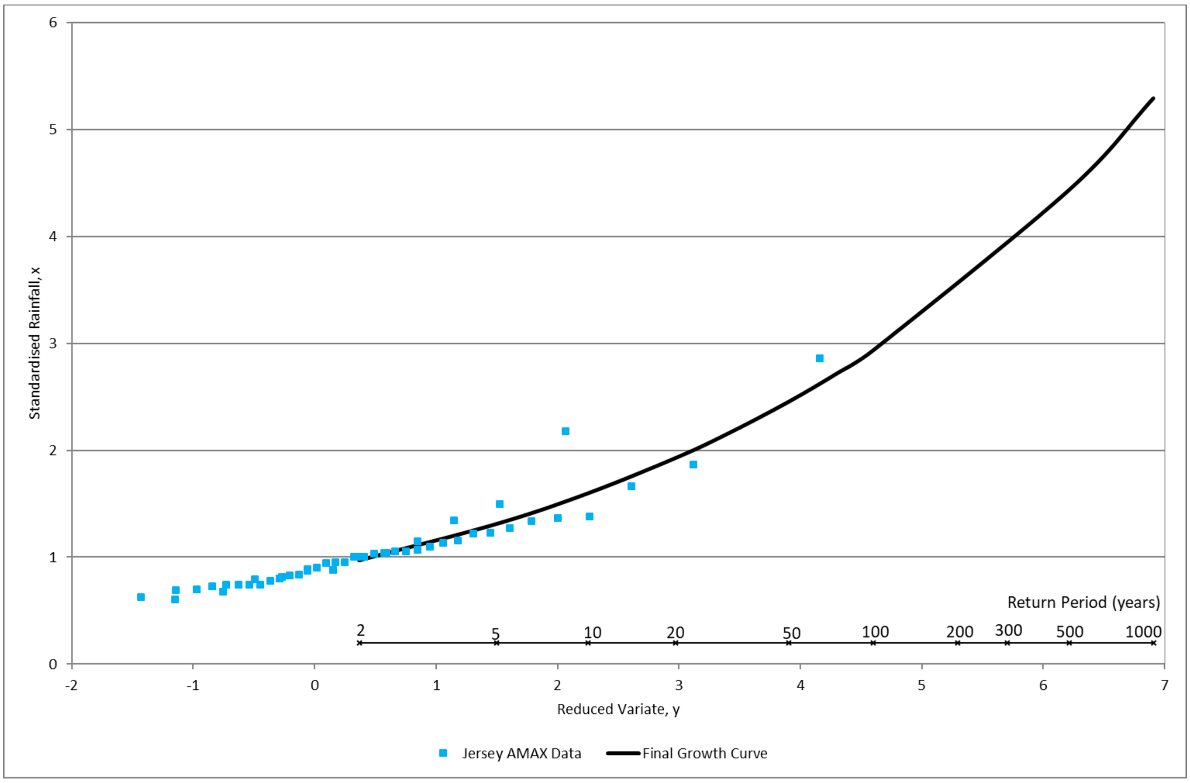

Figure 4-15: Final Growth Curve with Jersey AMAX data: Gumbel Reduced Variable Plot: 2 hour event

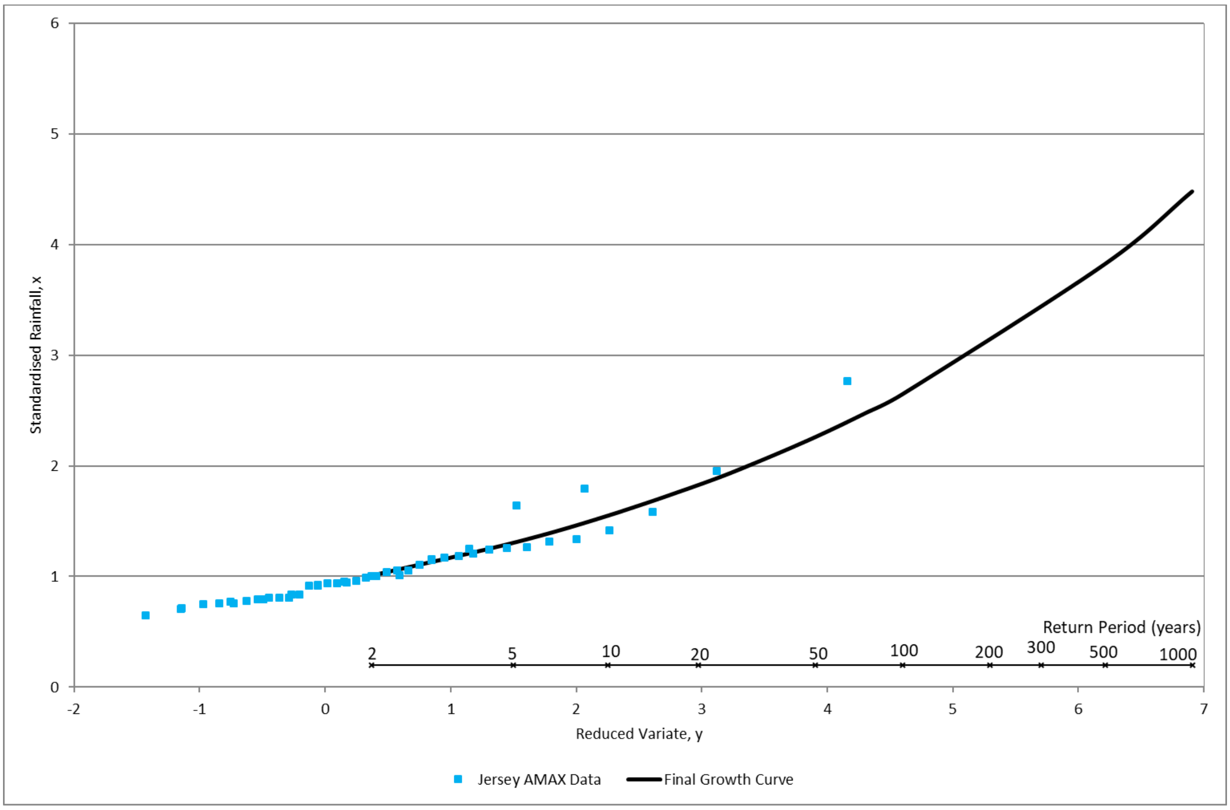

Figure 4-16: Final Growth Curve with Jersey AMAX data: Gumbel Reduced Variable Plot: 6 hour event

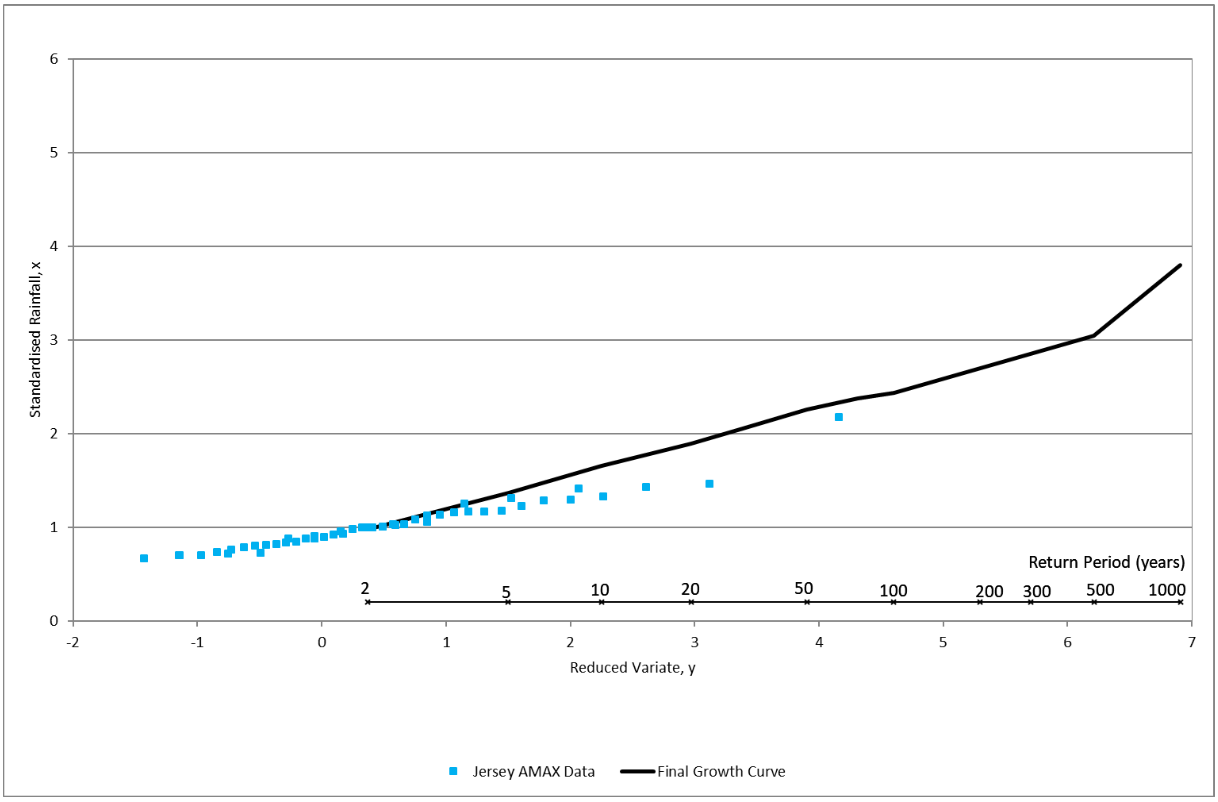

Figure 4-17: Final Growth Curve with Jersey AMAX data: Gumbel Reduced Variable Plot: 12 hour event

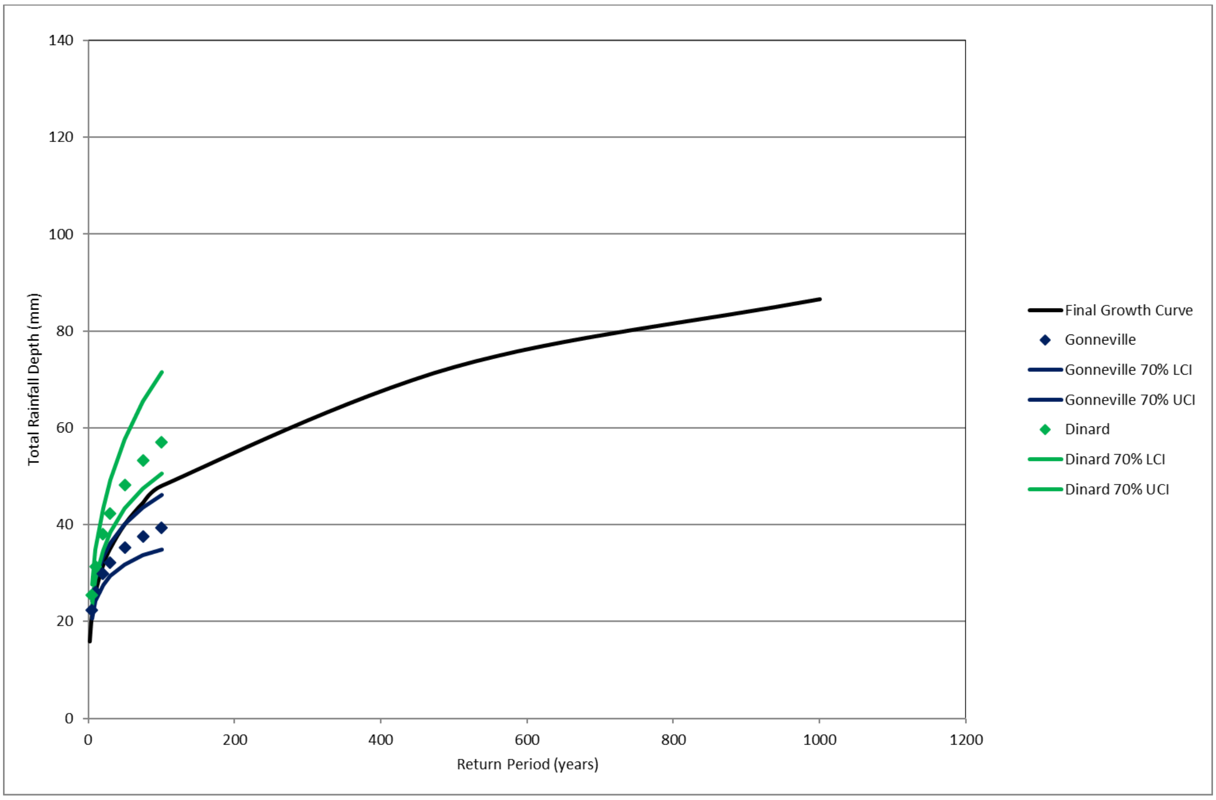

Figure 4-18: Rainfall Depth Plot with Final Growth Curve: 2 hour event

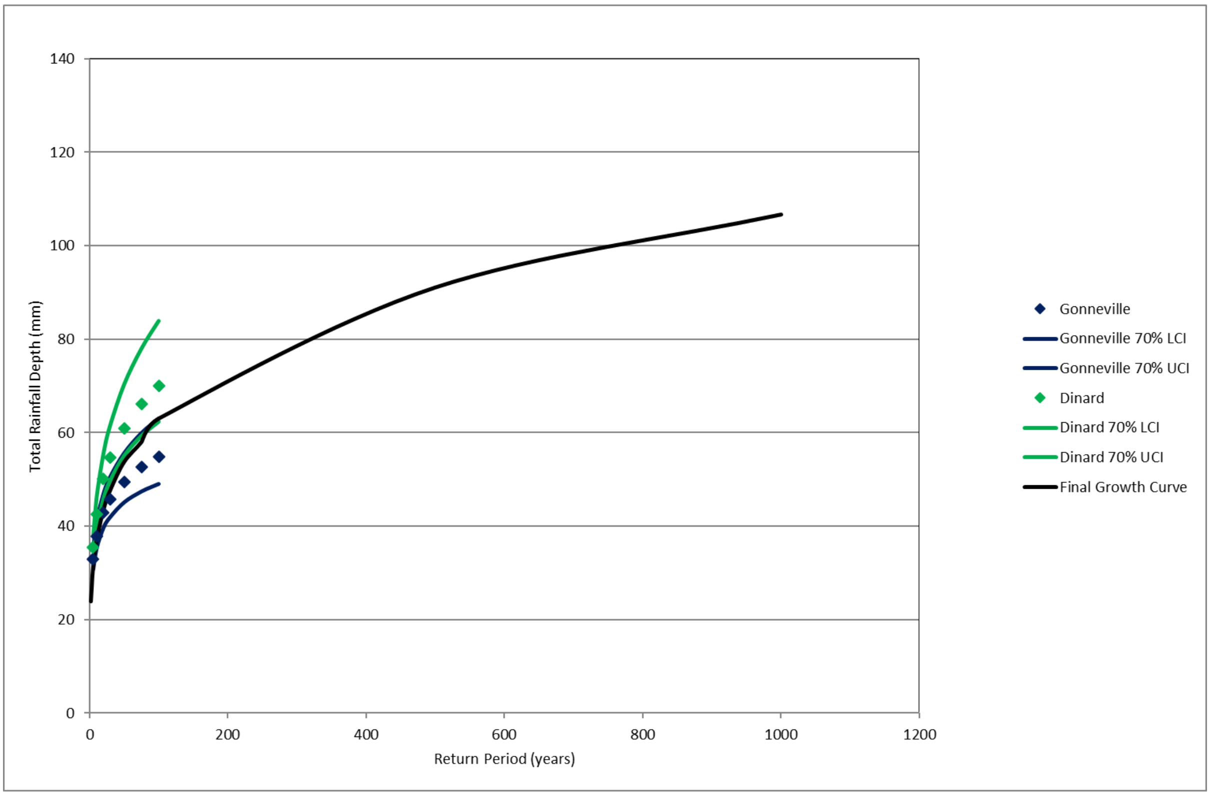

Figure 4-19: Rainfall Depth Plot with Final Growth Curve: 6 hour event

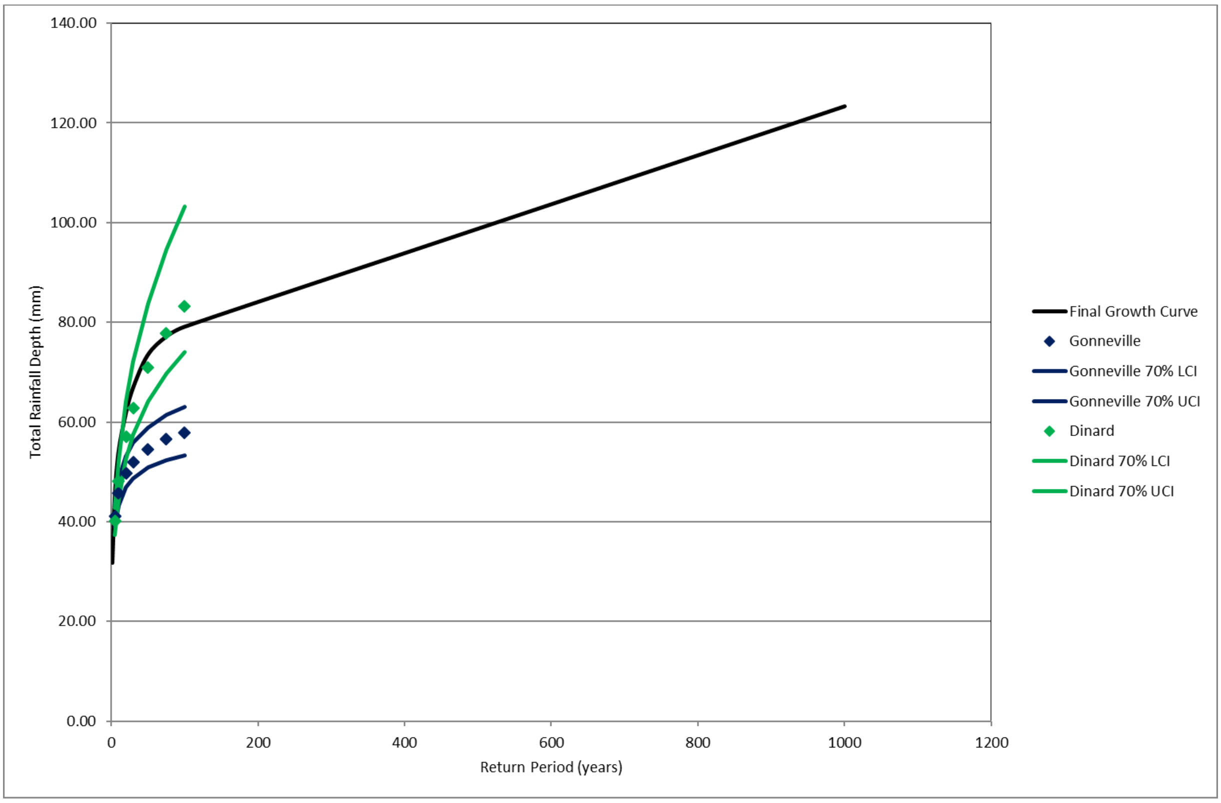

Figure 4-20: Rainfall Depth Plot with Final Growth Curve: 12 hour event

Table 4-7: Modelled Rainfall Depths (Final Growth Curve)

Return Period Event	2 Hour Duration	6 Hour Duration	12 Hour Duration
2	16	24	32
5	21	31	44
10	26	37	54
20	32	43	62
30	35	48	67
50	40	54	73
75	45	59	77
100	48	63	79
500	73	91	99
1000	87	107	123

5. Results and Conclusions

5.1 Hyetograph Calculations

To obtain the final hyetographs, an aerial reduction factor (as outlined in Section 3.4) has been applied to the rainfall totals derived from the final growth curve described in Section 4, and the resulting rainfall depths distributed for summer and winter hyetograph profiles (as appropriate) following the procedure in Section 3.5.

The intention is to use the hyetographs as input to a model of fluvial and pluvial flooding. The model will need to consider the capacity of watercourses and urban drainage systems. During smaller events, the rainfall will be accommodated entirely by the drainage system and no flooding is likely. Flooding will start to occur during larger events when drainage systems and watercourses become overwhelmed but a correction to the flood volumes will be needed to correct for that proportion of rainfall which is conveyed without flooding. In this case, the losses have been approximated by assuming that the 1 in 2 year event is entirely accommodated by the drainage system and in watercourses without causing flooding. The 1 in 2 year hyetograph is thus subtracted from all event hyetographs and the remaining rainfall depth is used as an input to the hydraulic model to estimate the extent of fluvial and pluvial flooding.

The final modelled hyetographs for Jersey have been reduced in line with this and are shown in Figures 5-1 to 5-3. Each hyetograph has been distributed over 12 timesteps of 10, 30 or 60 minutes.

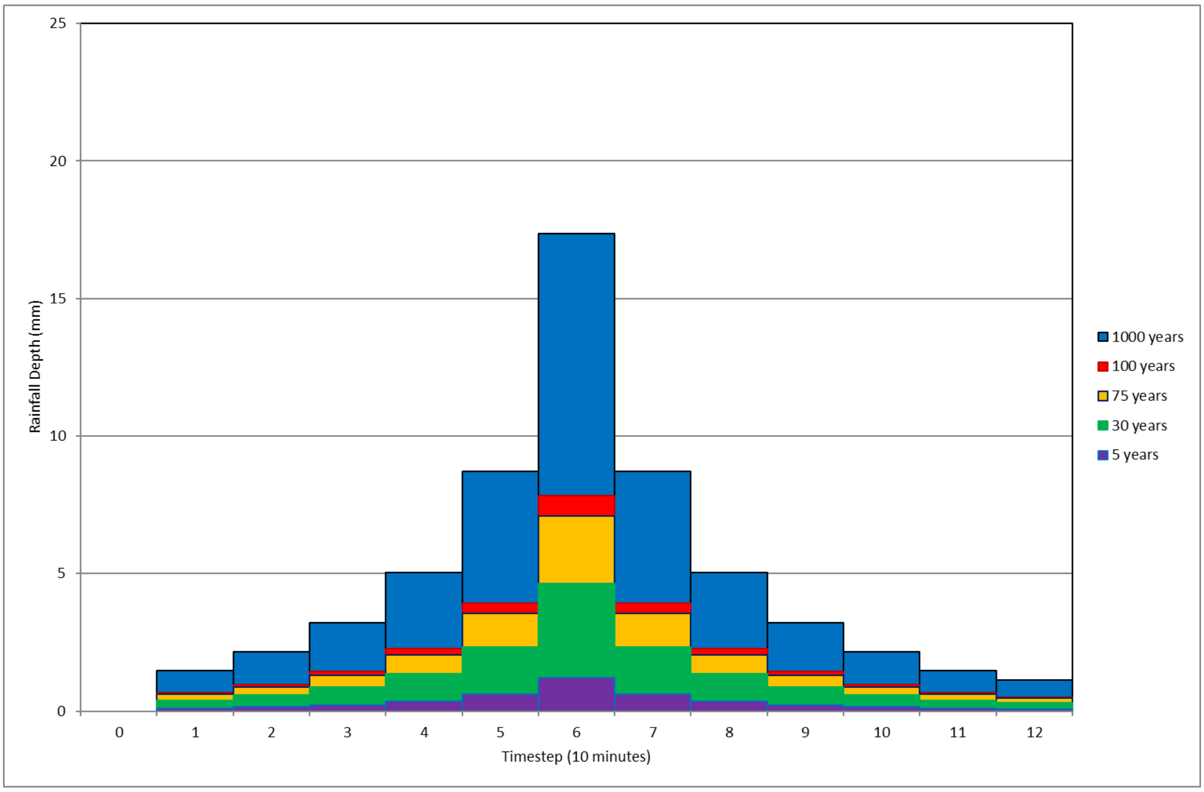

Figure 5-1: Final Modelled Hyetograph for Summer - 2 Hour Event

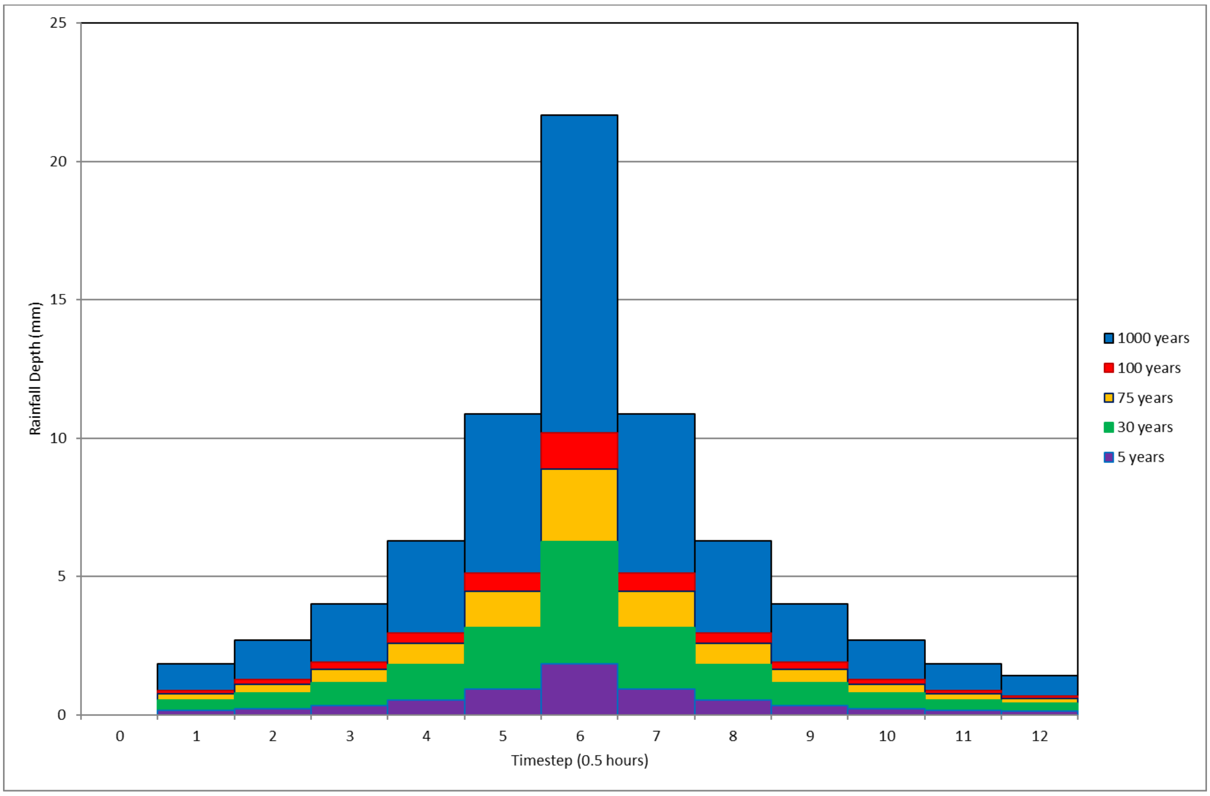

Figure 5-2: Final Modelled Hyetograph for Summer - 6 Hour Event

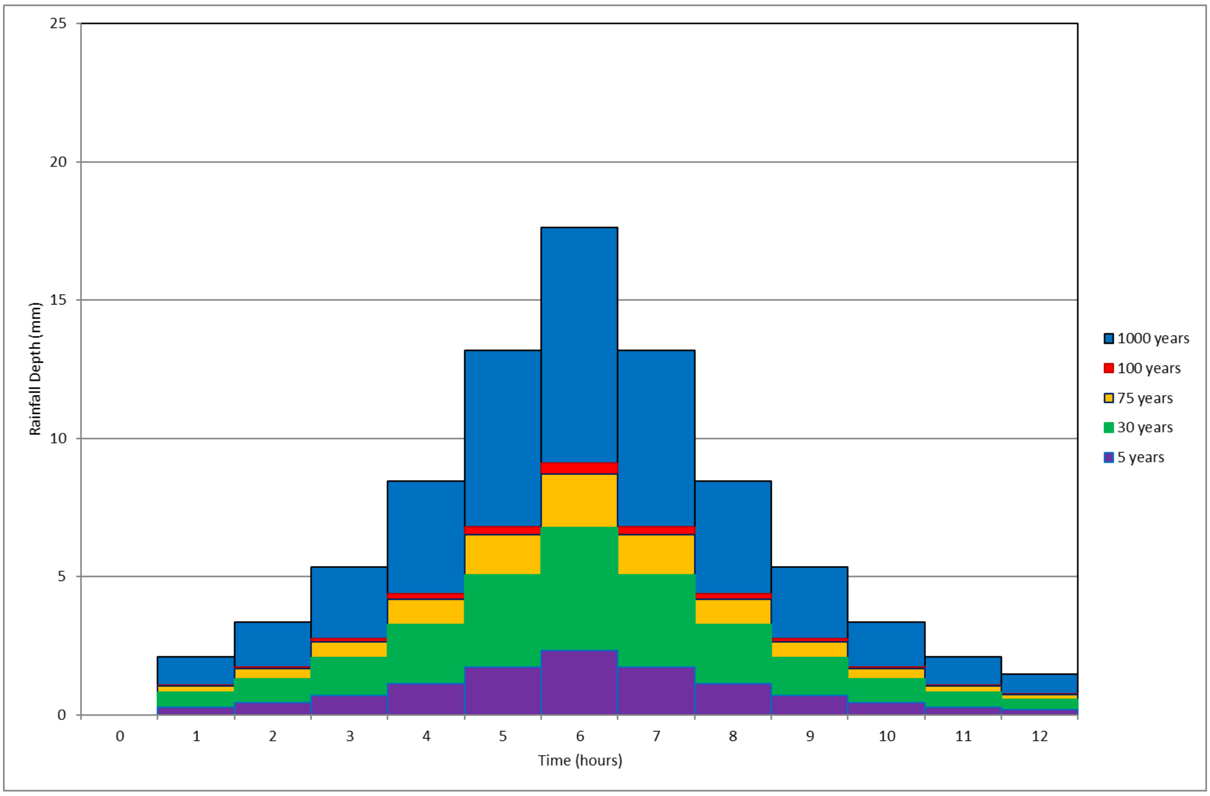

Figure 5-3: Final Modelled Hyetograph for Winter - 12 Hour Event

5.2 Conclusions

Extreme rainfall depths have been estimated for Jersey based on statistical analysis of rainfall data and derivation of growth curves based on the widely used statistical distributions GEV, PT3 and LN. A POT analysis demonstrated that the most appropriate storm durations to model were 2, 6 and 12 hours. This was confirmed by information in the flood history compiled for Jersey which included events of this duration.

Rainfall data obtained from Guernsey and France were analysed and, with the exception of the rain gauge at Dinard in France, found to be sufficiently similar to that of Jersey to allow for a pooled AMAX analysis to extend the Jersey rainfall record. The AMAX series at Dinard was excluded due to it having a statistical distribution significantly different to that of any other rain gauge station. AMAX analysis for the three modelled event durations (2, 6 and 12 hour) suggests a seasonal difference with more high intensity, low duration (2 and 6 hour) events recorded in the spring and summer. The AMAX data were used to produce growth curves according to the Flood Studies Report (FSR) and the probability distributions GEV, LN and PT3 for both the combined series (Jersey, Guernsey and France AMAX) and the Jersey only (Jersey Airport and Maison St Louis Observatory AMAX). The aim was to derive and select a single growth curve based on the AMAX series which could then be used to estimate rainfall depths for a range of return periods at the three selected durations.

There was no consistent level of agreement in the curves produced using the different methods (FSR, GEV, LN or PT3) or dataset (Jersey only or combined AMAX series). Each curve was therefore evaluated to determine which was the most appropriate for predicting extreme rainfall depths. The FSR curve has been used to estimate rainfall depths for the 12 hour duration event as this produced the most conservative estimate of extreme rainfall depth. The statistical growth curves derived for this event were extremely flat, suggesting that there is a lack of extreme 12 hour duration events in the rainfall record. The flood history suggests that most of the pluvial flooding observed in Jersey is associated with short duration, high intensity events and initial modelling confirmed that the 12 hour duration event is associated with significantly less flooding owing to the short response time of the small river catchments in Jersey. The FSR is considered appropriate for modelling this event in view of the uncertainty in the recorded dataset.

Growth curves were derived for the 2 hour and 6 hour events based on statistical distributions GEV, LN and PT3, and rainfall data recorded in Jersey, Guernsey and France. The GEV distribution was selected and the estimated rainfall depths correlated well with the observed rainfall data. GEV also estimated slightly higher rainfall depths than LN and PT3 for most durations which was deemed appropriate as it gave a more realistic estimate of return period for events noted in the rainfall record and flood history. Data from Jersey only was selected in preference to a larger pooled group including data from Guernsey and France for several reasons including the length of the Jersey rainfall record.

The final growth curves calculated for each event have been used to generate predicted rainfall depths for a variety of return periods up to the extreme 1 in 1000 year event. The total rainfall depths have been distributed to produce rainfall hyetographs which can be used in flood risk modelling. A summer hyetograph profile has been applied to the 2 hour and 6 hour events and a winter profile has been applied to the 12 hour event. The modelled hyetographs have been further reduced by subtracting the rainfall depth for the 1 in 2 year return period at each timestep. This represents the assumption that all rainfall in the 1 in 2 year event is conveyed by watercourses or drainage systems and therefore does not contribute to flooding.

5.3 Recommendations for Further Analysis

The analysis set out above is based on datasets of limited duration and primarily from a single point location, Jersey Airport. This makes it more challenging to put historic events into context and less certain when deriving return periods for extreme events. In addition, the analysis is based on hourly rainfall data from two rain gauges on Jersey, there being no rainfall data available at a similar temporal resolution for other locations across the island. The use of two point rain gauges to represent rainfall across the entire island is questionable and may introduce bias into the results and make the results overly sensitive to variations between the records at Maison St Louis Observatory and Jersey Airport. In addition, a single rainfall hyetograph has been derived for the whole Island. This approach may need to change if significant variation in rainfall depth and intensity across the island is identified. Analysis of the existing data suggests that this is not the case but the digitised record from the daily gauges is short and it is not possible to confirm this for certain at present. A review of any additional data available from the daily rain gauges across the island may demonstrate whether this assumption is correct. Consideration should also be given to using the Channel Island Weather radar images, calibrated by local rain gauges, to further understand variations of rainfall depth across the Islands.

Assuming the data is available and appropriate for use, digitising the complete hourly rainfall record at Maison St Louis Observatory would improve the above assessment through the provision of additional information to enhance the hourly record at Jersey Airport.

Given the sensitivity of the results to the occurrence of observed rainfall events, it is also recommended that the above statistical analysis be repeated between every 5 to 10 years depending on the occurrence of extreme rainfall events. This will ensure that the pluvial flood risk for Jersey is based on the best available information.

Appendix A Jersey Flood History Report

Flooding Type	Date	Details	Source
Tidal	3 January 2018	Storm Eleanor caused tidal flooding which closed roads and damaged sea defences. Sections of sea wall collapsed at West Park and Greve De Lecq. Victoria Avenue was closed while Gloucester Street and Five Mile Road also flooded. The tide at St Helier reached 12.01m with maximum wave height of 7.7m (from data buoy 6 miles south of St Brelade)	https://jerseyeveningpost.com/news/2018/01/03/jersey-suffers-coastal-flooding/
Pluvial/Fluvial	27 November 2017	Torrential downpours caused flooding. Roads and properties flooded at Beaumont, several inches deep at the bottom of Beaumont Hill. There was also flooding in St Peter, St Lawrence and Grands Vaux.	https://jerseyeveningpost.com/news/2017/11/27/jersey-hit-by-flooding/
Pluvial/Fluvial	16 September 2017	Flash flooding in Jersey left roads underwater after torrential rain. St Ouen and St Peter were badly affected, particularly St Peter's Valley. The road between St Ouen and St Peter was closed and roads below Greve de Lecq hill flooded. The area around St Ouen's Manor also flooded.	https://jerseyeveningpost.com/news/2017/09/16/jersey-hit-by-flash-flooding/
Pluvial/Fluvial	8 February 2016	Storm Imogen flooded roads including Victoria Avenue	https://www.bbc.co.uk/news/world-europe-jersey-35526934
Pluvial/Fluvial	12 June 2015	Roads flooded in response to heavy rainfall, some areas having over 28mm.	https://jerseyeveningpost.com/news/2015/06/12/st-helier-home-struck-by-lightening-as-thunderstorm-and-heavy-rain-batter-the-island/
Tidal	3 March 2014	High tide (12m) and strong winds combined to cause flooding. Rue Verte at L'Etacq was severely damaged by the high tides. Victoria Avenue was closed.	https://www.bbc.co.uk/news/world-europe-jersey-26390204
Tidal	2 February 2014	Tidal flooding associated with storms. Coastal roads flooded and there was damage to slipways and coastal defences.	https://www.youtube.com/watch?v=tdO18kuP870
Tidal	17 October 2012	High tides caused flooding to various areas, including Beaumont	https://www.youtube.com/watch?v=vPlYf8u5jMs
Pluvial	August 2010	Localised flooding in St Helier. **Jersey Met assigned a 1 in 14 year return period**	Correspondence with States of Jersey project team
Tidal	10 March 2008	"Johanna" Storm caused flooding. Water overtopped flood defences which were breached in four locations. Victoria Avenue was closed at First Tower. Roads flooded in St Aubin, La Haule, Beaumont and The Gunsite. The sea wall was damaged at West Park with flooding onto Victoria Avenue, West Park, Esplanade, Gloucester Street and Seaton Place. Houses and businesses in this area were also flooded. **The report for this event suggests it had a return period of around 20 years.**	https://jerseyeveningpost.com/news/2018/01/02/jersey-facing-biggest-flooding-threat-since-the-storm-of-march-2008/ Jersey Future Hospital Flood Risk Assessment, ARUP, June 2017 https://www.surgewatch.org/events/12/ "The exceptional tide, storm survey and damage on 10 March 2008, as of 1 May 2008." Frank Le Blancq and John Searson, Jersey

			Meteorological Department, May 2008
Pluvial/Fluvial	March 2001	Wettest March on record, with 196mm of rain (previous record 152mm in 1912). 61mm fell over the 19th, 20th and 21st at Maison St Louis Observatory with landslips, although no property flooding was noted. Surface water ponded northeast of Kempt Tower, near Craniere, and on the site of the demolished Sable D'Or Hotel, the Jersey Scout Association campsite and Netherton Farm.	Societe Jersiaise Annual Bulletin for 2002: Record Winter Rainfall in Jersey 2000/2001, Frank Le Blanq and Adrienne Le Maistre, Jersey Meteorological Department (Ann. Bull. Soc. Jersiaise 2002, 28(2), 242-248)
Pluvial/Fluvial	8 to 9 February 2001	Following on from wet autumn and winter below, 63mm of rainfall fell at Maison St Louis Observatory in 48 hours. Pluvial and fluvial flooding affected several locations, including the brook at La Rue du Moulin de Tesson, Tesson Mews and Goose Green Marsh. Flooding also occurred at Montrose Testate at Grand Vaux along the road at Vallee de Vaux. Landslips also occurred.	
Pluvial/Fluvial	January 2001	Flooding followed very wet autumn – only seven days without rainfall from 1st October to 2nd December 2000. 100mm of rain fell at Maison St Louis Observatory in the last week of December and first week of January causing Goose Green marsh to flood, landslips at Rozel and Mont Arthur and flooding of several houses.	
Pluvial/Fluvial	31 October 1985	Flooding in the east of Jersey due to intense storm. This was a localised event – 43mm were recorded at Maison St Louis Observatory, 54mm at Longueville and 60mm at Petit Menage in St Saviour, compared with 2.5mm at Jersey Airport. The event lasted 4 hours and caused flooding to 18 properties and to roads in St George, St Clement, St Clement's Gardens and Rue de Maupertuis. Flooding may have been exacerbated due to blockage of drains with autumn leaf-fall.	Notes and article in Jersey Evening Post on 01/11/1985 – clippings and notes provided by Jersey States
Pluvial/Fluvial	November 1984	Flooding due to storm in November 1984 mentioned and compared with event on 31/12/1985. May be the same event as below but there is insufficient detail to confirm. States of Jersey Fire Service received 100-150 phone calls in November 1984 event compared with 54 in 1985 event.	Notes and article in Jersey Evening Post on 01/11/1985
Tidal	23 November 1984	Severe storm noted for comparison with March 2008 event. Flooding in St Helier.	"The exceptional tide, storm survey and damage on 10 March 2008, as of 1 May 2008." Frank Le Blancq and John Searson, Jersey Meteorological Department, May 2008
Pluvial/Fluvial	5 June 1983	Severe storm in the north and northwest of Jersey. Flooding occurred in Greve de Lecq. Little or no rainfall occurred in the east of the Island. **Return period analysis suggest this may be a 1 in 25 years event.**	Severe Storms in Jersey, 31 May and 5 June 1983, David V Randon, Journal of Meteorology, Vol 8, No 84, 1983 Also: An Analysis of Extreme Rainfalls Observed in Jersey, Butler A.P., Grundy J.D., May B.R., Meteorological Magazine, 114, 1985
Pluvial/Fluvial	31 May 1983	Severe storm in the west of the island. Flooding occurred in St Aubin, St Peters Valley and Greve de Lecq. **Return period analysis suggest this may be a 1 in 25 years event.**	Severe Storms in Jersey, 31 May and 5 June 1983, David V Randon, Journal of Meteorology, Vol 8, No 84, 1983

			Also: An Analysis of Extreme Rainfalls Observed in Jersey, Butler A.P., Grundy J.D., May B.R., Meteorological Magazine, 114, 1985
Pluvial	10 June 1982	Severe storm in the east of the Island. Flooding in St Saviour (Patier Road, Dudley Court, La Fosse âL'Ecrivian, Bagot Manor Court), Georgetown (Victoria Road), Rozel, St Catherine, St Martin, La Ville Bree and St Helier (King Street, Bath Street, Halkett Place, Charing Cross, Bond Street, Seale Street, Green Street, Hotel de la Plage, Esplanade, Beresford Street, de Quetteville Court). Flooding in St Saviour was exacerbated by blocked drains. **Return period analysis suggested that this was a 1 in 400 year event.**	Information provided by Jersey Met., with newspaper clippings from the Jersey Evening Post
Pluvial	25 September 1981	Severe storm in the east of the island. Flooding St Saviour (Fountain Lane, Dudley Court), St Clements (Inner Road, La Blinerie, Grouville Hill, Longueville Road, Bagnor Manor Court, Belvedere Villas), Georgetown (Victoria Road), St Martin and St Helier (Beresford Street, Halkett Place, King Street, Brighton Road, Bond Street, Queen Street, Library Place, Broad Street, Mulcaster Street, Bath Street, Conway Street, Town Mills area, Old Trinity Hill)	Information provided by Jersey Met., with newspaper clippings from the Jersey Evening Post
Pluvial?	July 1969	67.7mm of rainfall recorded at Maison St Louis in 24 hours. No details of any associated flooding available.	Jersey Evening Post, 28 September 1981
Tidal	27 February 1967	Severe storm noted for comparison with March 2008 event. Flooding affected St Helier and was exacerbated by heavy rain.	"The exceptional tide, storm survey and damage on 10 March 2008, as of 1 May 2008." Frank Le Blancq and John Searson, Jersey Meteorological Department, May 2008
Tidal	October 1964	Severe storm noted for comparison with March 2008 event but no further information given. "Jersey's Hurricane" 10 minute wind speed reached hurricane force 12	"The exceptional tide, storm survey and damage on 10 March 2008, as of 1 May 2008." Frank Le Blancq and John Searson, Jersey Meteorological Department, May 2008 Also personal correspondence from Jennie Holley, previously Jersey Met.
Tidal	October 1965	Severe storm noted for comparison with March 2008 event but no further information given.	"The exceptional tide, storm survey and damage on 10 March 2008, as of 1 May 2008." Frank Le Blancq and John Searson, Jersey Meteorological Department, May 2008
Pluvial	1950s	A localised flash flood in the Mourier Valley area followed intense localised rainfall. The channel of the Douet de la Mer stream was reconfigured in the lower part of the valley.	Information from Jennie Holley, previously of Jersey Met.
Pluvial?	August 1931	95.8mm of rainfall recorded at Maison St Louis in 24 hours. No details of any associated flooding available.	Jersey Evening Post, 28 September 1981
Pluvial?	September 1929	67.4mm of rainfall recorded at Maison St Louis in 24 hours. No details of any associated flooding available.	Jersey Evening Post, 28 September 1981

Pluvial?	October 1904	69.4mm of rainfall recorded at Maison St Louis in 24 hours. No details of any associated flooding available.	Jersey Evening Post, 28 September 1981
Pluvial/Fluvial	28 December 1839	Very wet winter conditions followed by heavy rainfall on the 28th December with flooding on Bath Street, Town Mills, St Peter's Valley and other areas.	Societe Jersiaise Annual Bulletin for 2002: Record Winter Rainfall in Jersey 2000/2001, Frank Le Blanq and Adrienne Le Maistre, Jersey Meteorological Department (Ann. Bull. Soc. Jersiaise 2002, 28(2), 242-248)
Pluvial/Fluvial	3 to 4 January 1650	Heavy rain followed a very wet winter and fell on saturated soils. Flooding and landslips appear to have been widespread, including flooding of properties.	
Pluvial/Fluvial	Various – no specific dates of events specified. Some locations are predicted from modelling.	Surface water and sewer flooding occur in the Town Centre of St Helier, St Aubins/ Charing Cross area and the Gunsite near Beaumont SPS. Surface water flooding at St Aubins can occur due to tidal locking of the discharge flap when tide exceeds 6.7m. Flooding near Beaumont SPS occurs due to lack of capacity in the sewer. The following areas are considered to be 'at risk' of foul / combined sewer flooding as during a 1 in 10 year design event: - Fields upstream of Les Ruisseaux SPS - Fields 127 and 134 to the east of St Brelade - La Rue de la Frontiere (upstream of La Frontiere SPS) - La Rue Des Varvots (upstream of La Retraite / La Rue des Varvots SPS) - La Grande Route de St Laurent (various locations) - Various locations in St Lawrence - La Rue de Haut - A1 near La Rue de Trachy in St Helier - Office complex, bowling green and car park off Route es Nouaux in St Helier - Tower Road in St Helier - New St John's Road in St Helier - Claremont Road in St Saviour - Bellozane Valley outside SOJ Offices - La Rue de la Pallotterie in St Saviour - Field 64 to the South of Grouville - Field 260 and 261 in St Clement - La Rue de Fauvic and the B37 in Grouville - Various locations on La Grande Route des Sablons in Grouville - Various locations in St Saviour upstream of Maufant SPS More flooding occurs in the 1 in 30yr event but no new locations are affected. The following areas are considered to be 'at risk' of surface water sewer flooding as during a 1 in 10 year design event: - Wellington Road and Maison St Louis Observatory in St Saviour - Oak Tree Gardens in St Saviour - Pillar Gardens in St Saviour - Princes Tower Road in St Saviour - Plat Douet Road in St Saviour - La Rue le Gros (Trading Estate) in St Saviour - La Grande Route de la Cote (various locations) in St Clement - Le Clos du Rivage in Grouville More flooding affects more locations in St Saviour in the 1 in 30 year event. Baudrette Brook surface water inflow system floods at Belvedere Hill, Plot Douet Road and St Clement's Gardens.	States of Jersey Transport and Technical Services: Jersey DAP Needs Report, July 2012. Prepared by Grontmij. The basis of hydrological analysis is not given.

Appendix B Plotted AMAX Series for Jersey and Guernsey for differing durations

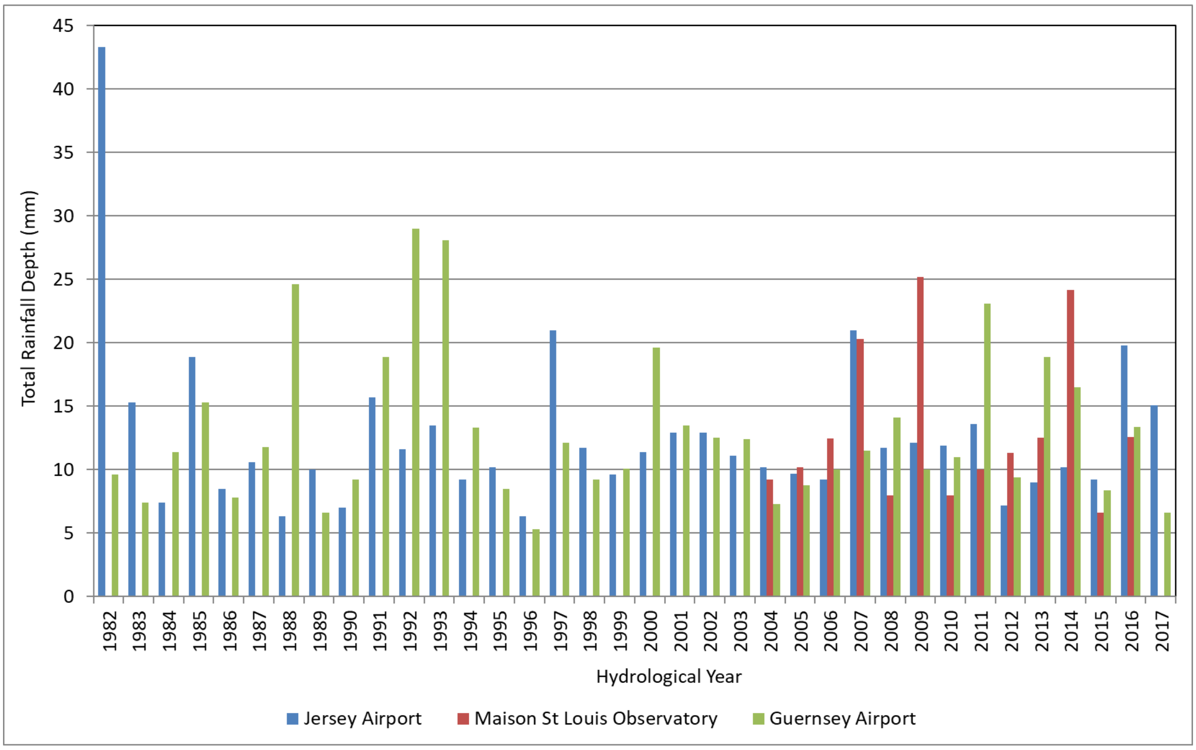

Figure B1: Hourly AMAX Series for sub-daily Rain Gauges in Jersey and Guernsey

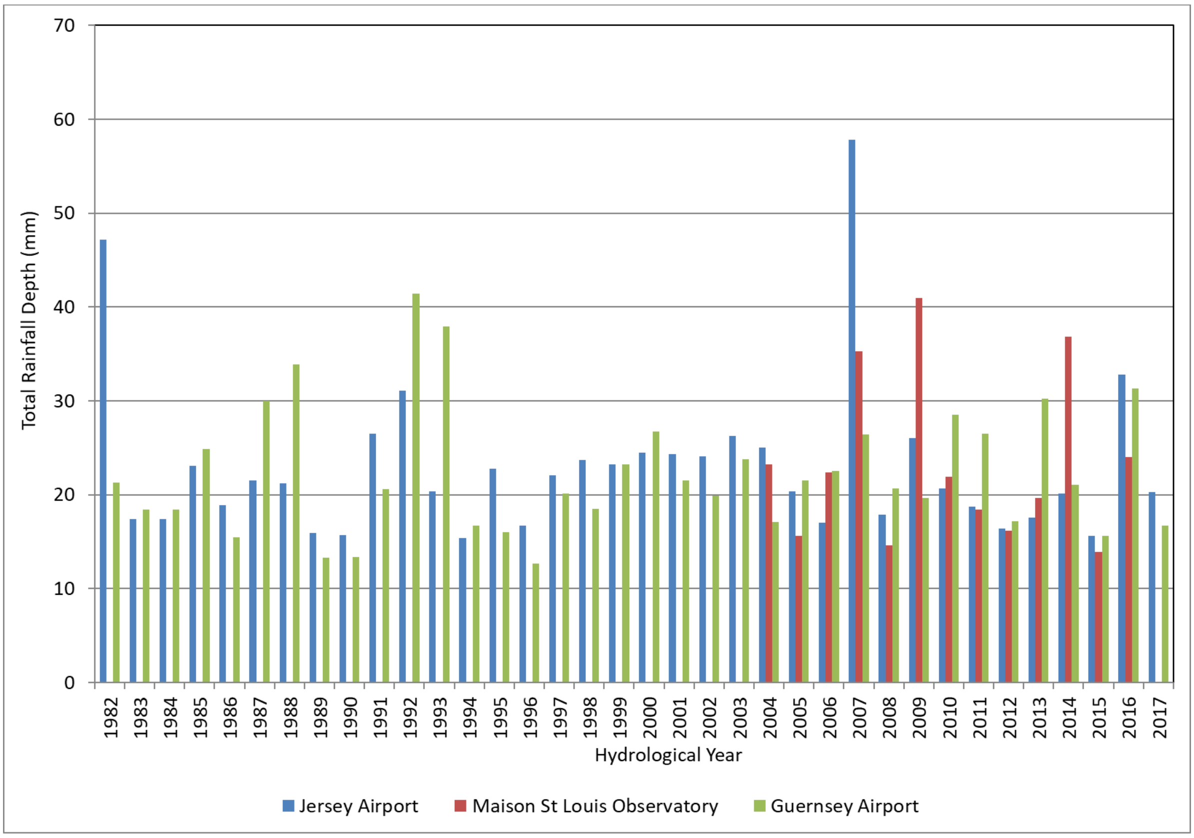

Figure B2: Four Hour Total AMAX Series for sub-daily Rain Gauges in Jersey and Guernsey

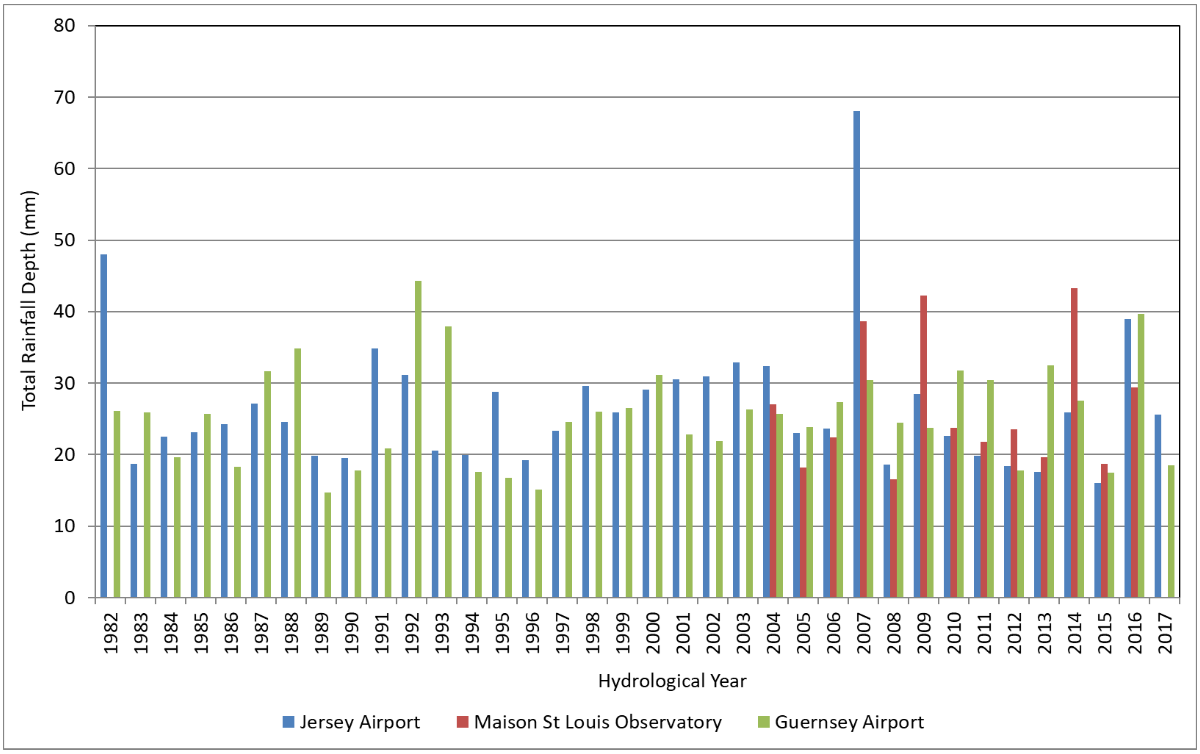

Figure B3: Six Hour Total AMAX Series for sub-daily Rain Gauges in Jersey and Guernsey

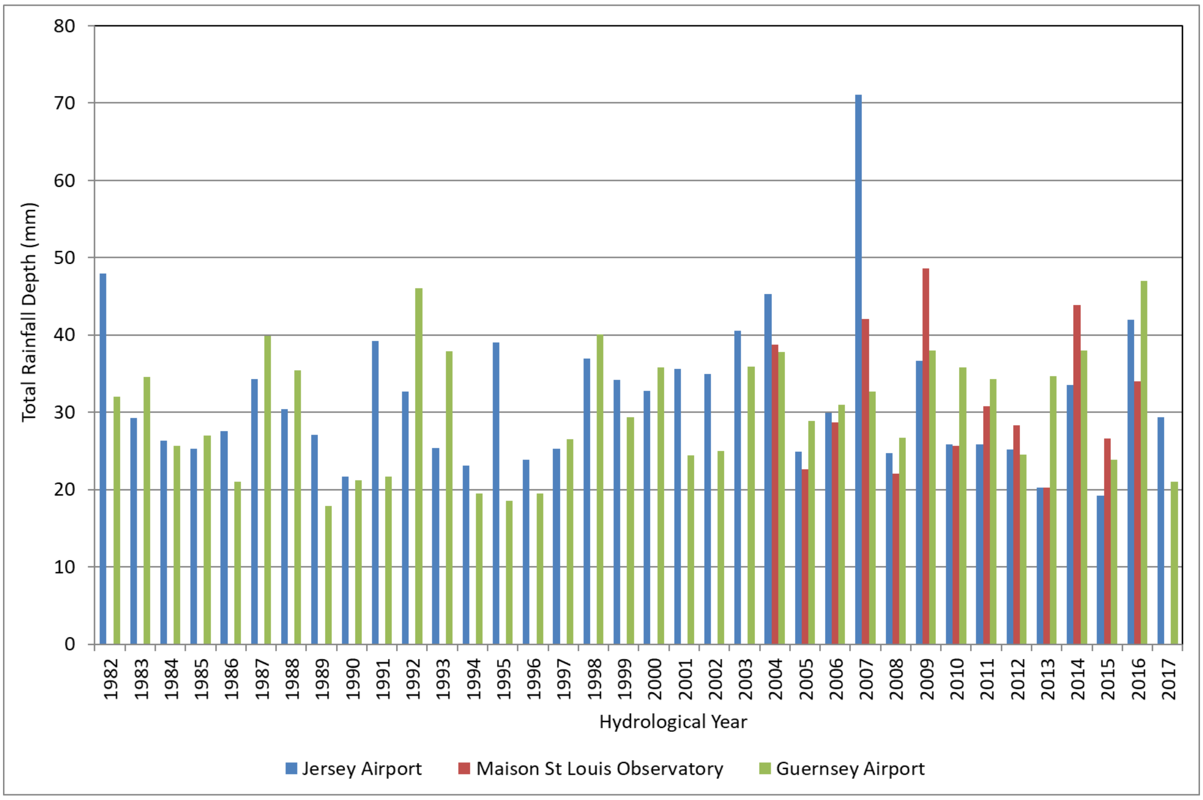

Figure B4: Ten Hour Total AMAX Series for sub-daily Rain Gauges in Jersey and Guernsey

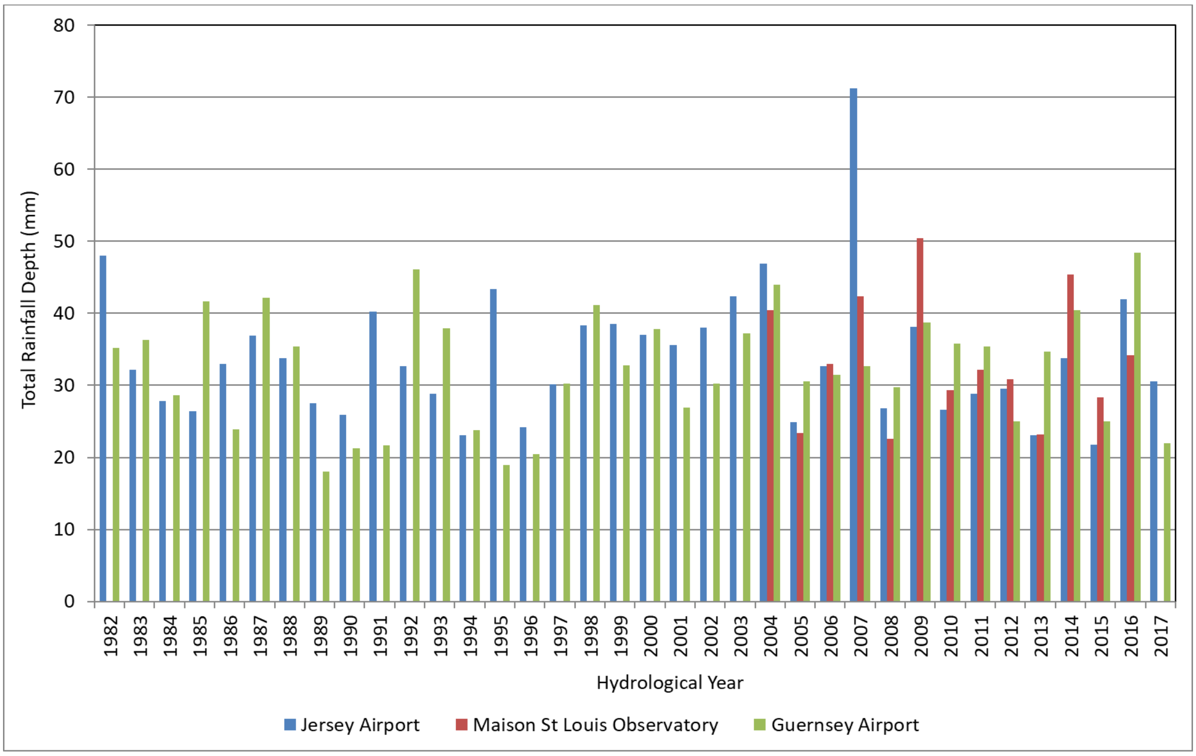

Figure B5: Twelve Hour Total AMAX Series for sub-daily Rain Gauges in Jersey and Guernsey

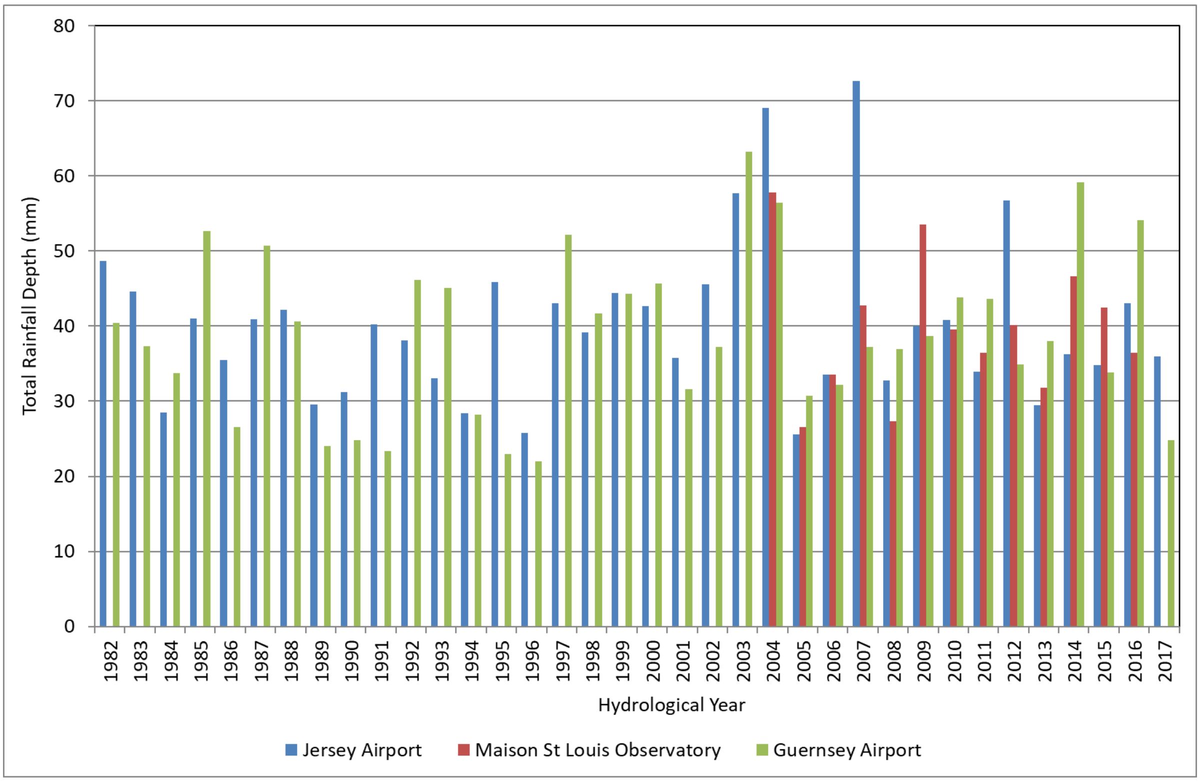

Figure B6: Twenty Four Hour Total AMAX Series for sub-daily Rain Gauges in Jersey and Guernsey

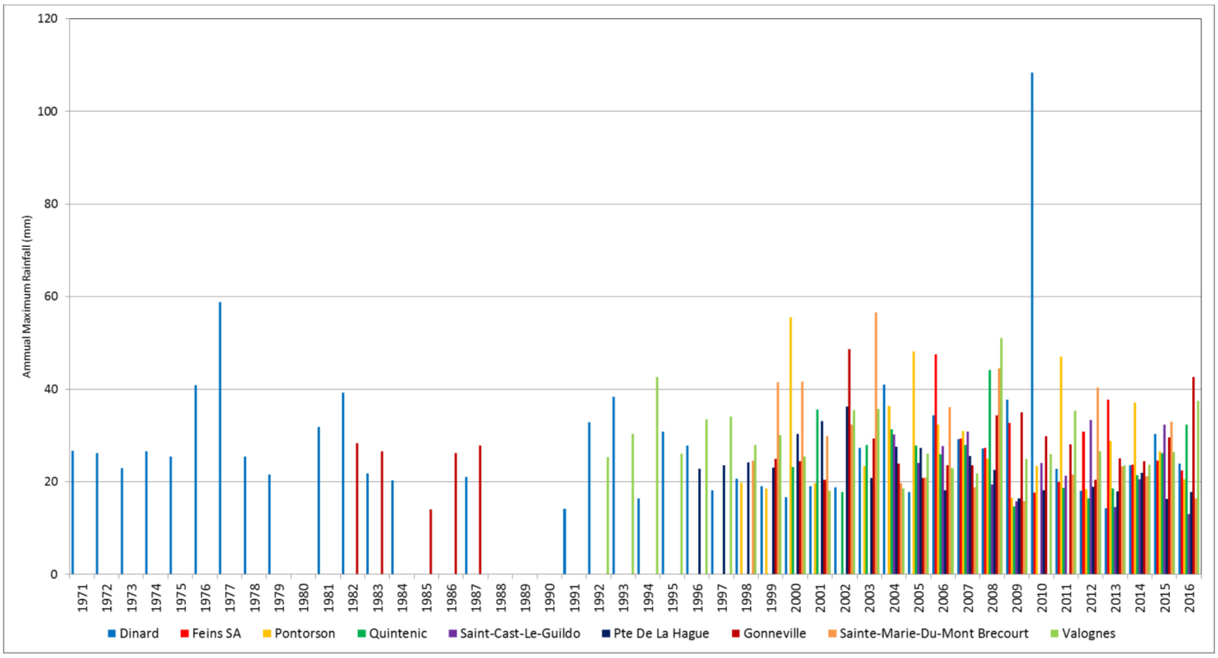

Figure B7: Six Hour Total AMAX Series for Meteo-France Rain Gauges

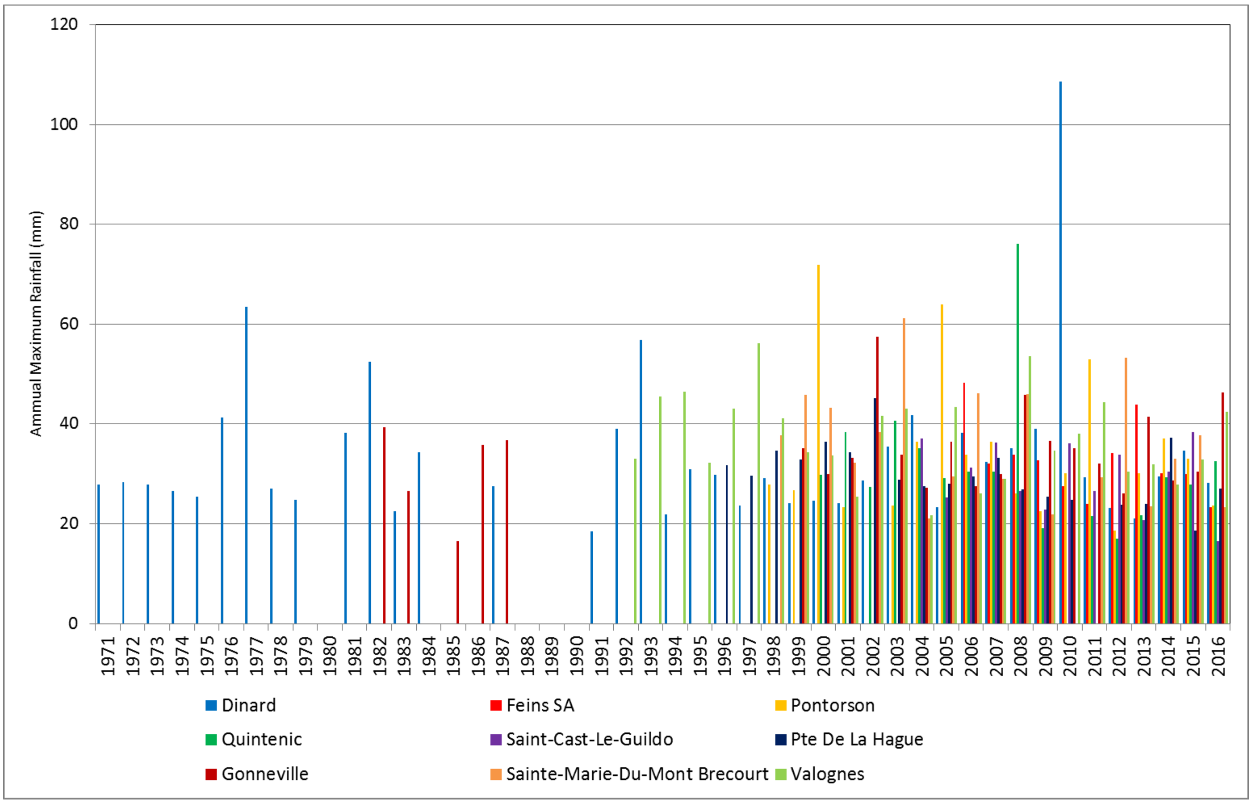

Figure B8: Twelve Hour Total AMAX Series for Meteo-France Rain Gauges

Appendix C Notes on Quality and Availability of Jersey Rainfall Data

Rainfall data has been collected by individuals and organisations in Jersey since at least 1858 with daily records since 1865. One remarkable record has been maintained by the Norman family at La Sergente in St Brelade for over 100 years. The main contributors of longer records and sub daily records are Jersey Met, Jersey Water and the Jesuit Brotherhood. Father Marc Dechevrens, who founded the Shanghai Observatory in 1873 and went on to establish Maison St Louis Observatory, started a daily record of rainfall from 1 January 1894. Daily rainfall charts were introduced to Maison St Louis around 1940 and were continued until 2004 when an automatic weather station was established. At Jersey Airport daily rainfall charts dating back to 1951 are available and continue until 2014. From this date the introduction of a UK Met Office Meteorological Monitoring System (MMS) replaced the paper charts. Butler, Grundy and May (1985)* describes a joint project between Jersey Met and the UK Met Office to digitise the available data hourly up to 1982, in order to calculate return periods for rainfall amounts over various durations. The notes that follow were produced during extraction of data for this project The data was recorded on UK Met Office magnetic tape, but a search of the UK Met Office archives has so far failed to find it. It is hoped that further searches may produce the data so that it can be used in an updated analysis. From 1983 to the present date there is a complete, digitised, hourly record of rainfall for Jersey Airport as well as Guernsey Airport.[7]

[7] Information provided by Jersey Met, by email dated 5th December 2019