Jersey Shoreline Management Plan

Extreme Rainfall Flood Modelling Report Analysis (Appendix J)

Government of Jersey

Project number: 60580871

May 2019

Project number: 60580871

Quality information

Prepared by	Checked by	Verified by	Approved by
Sarah Waite Consultant Hydrologist Helen Harfoot Principal Hydrologist	Debbie Hay-Smith Principal Hydrologist	Debbie Hay-Smith Principal Hydrologist	Mark Davin Associate

Revision History

Revision	Revision date	Details	Authorized	Name	Position
1	17 December 2018	Adjustment for revised rainfall data		Mark Davin	Associate
2	29 January 2019	Minor edits		Mark Davin	Associate
3	April 2019	Final	April 2019	Mark Davin	Associate
4	May 2019	Revised Final (study naming and formatting changes only)	June 2019	Tara-Leigh McVey	Regional Director

Distribution List

# Hard Copies	PDF Required	Association / Company Name
0	1	Jamie Mason (Government of Jersey)
0	1	John Searson (Jersey Met)

Prepared for:

Government of Jersey

Prepared by:

AECOM Infrastructure & Environment UK Limited
Midpoint, Alencon Link
Basingstoke
Hampshire RG21 7PP
United Kingdom

T: +44(0)1256 310200
aecom.com

Table of Contents

Figures

Tables

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
TUFLOW	2- D flood modelling software

J. Extreme Rainfall Flood Modelling Report Analysis

J.1 Introduction

J.1.1 Scope of Works

Jersey Shoreline Management Plan (Jersey SMP) 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.

J.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 J-1).

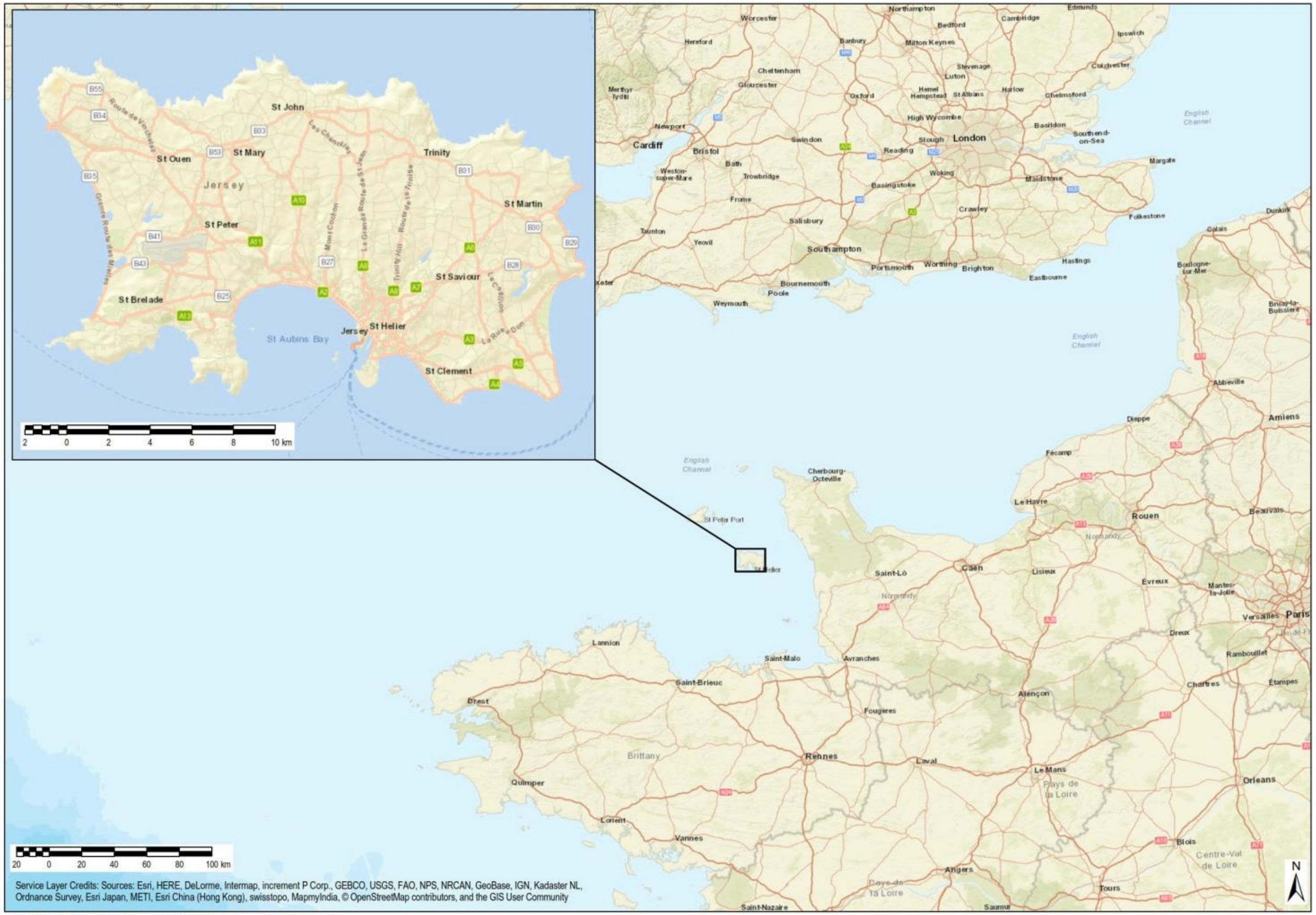

Figure J-1: Jersey Island Location

J.1.2.1 Jersey Climate

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

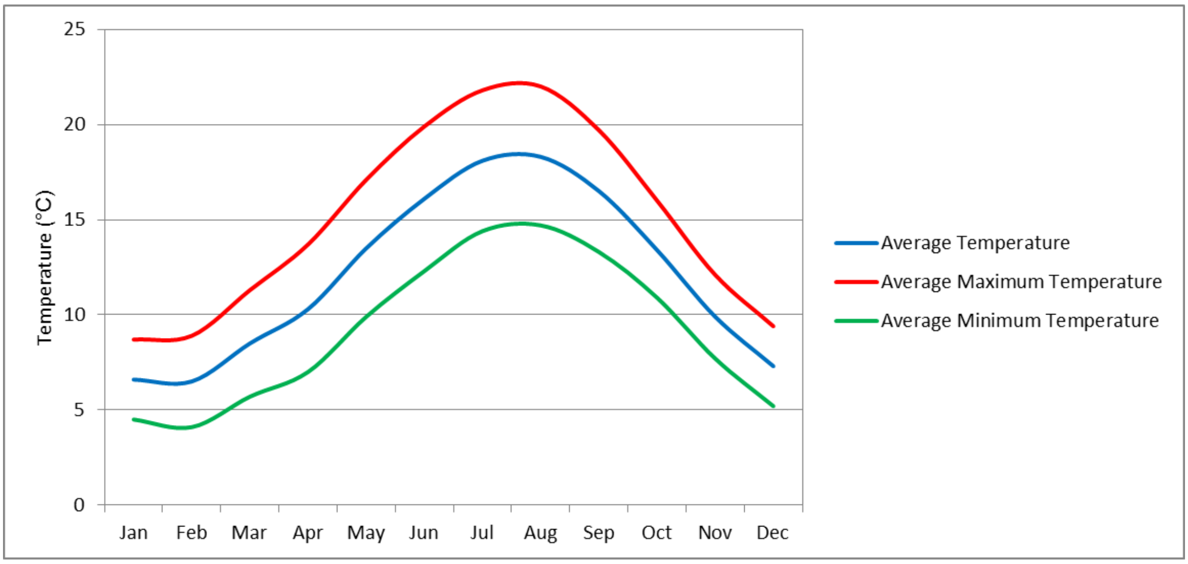

Figure J-2: Daily Mean, Mean Maximum and Mean Minimum Temperature on Jersey (1981-2010) (Source: Jersey Met)

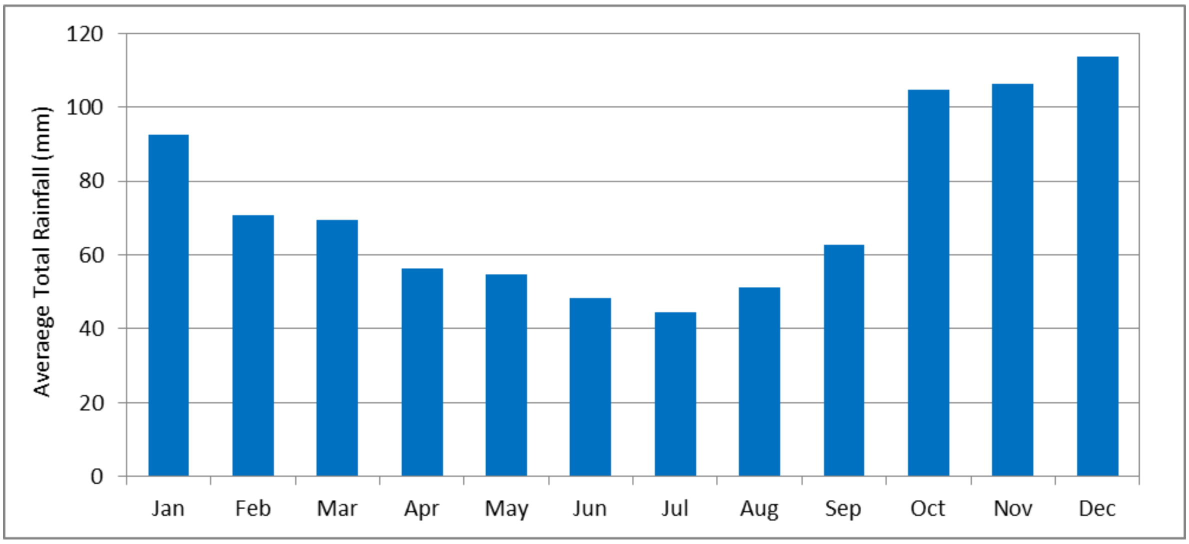

Figure J-3: Mean Monthly Rainfall Totals for Jersey (1981-2010) (Source: Jersey Met)

Regional variations in rainfall across Jersey are shown in Figure J-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.

J.1.2.1.1 Maison St Louis Observatory

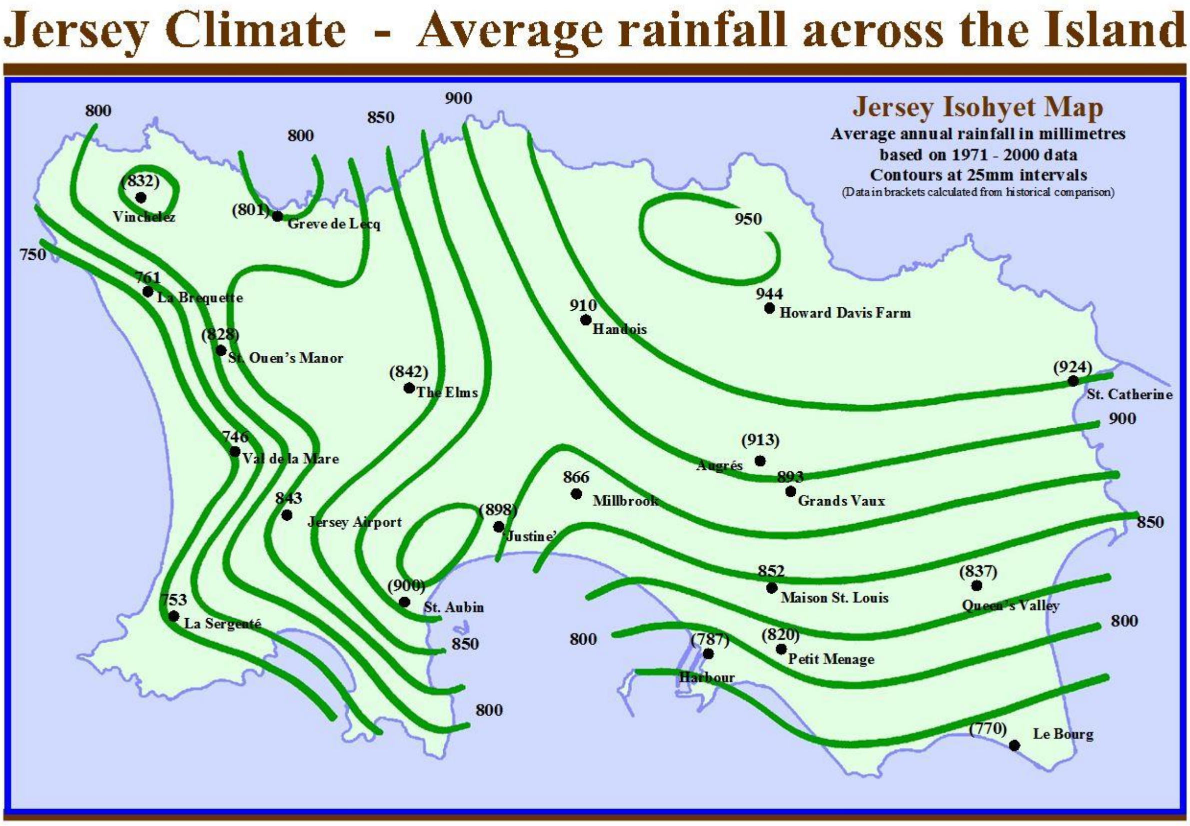

Figure J-4: Isohyet Map of Jersey [Note: figures in brackets are based on historic data and are not currently recording rainfall] (Source: Jersey Met)

J.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[1].

J.1.3 Jersey Flooding History

A flood history has been compiled for Jersey based on historical records provided by the Government 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). A summary of the pluvial and fluvial flooding events only are reproduced in Table J-1 along with a summary of the rainfall depths and durations recorded at the hourly rain gauges where available. A total of 13 events have been identified where pluvial and/or fluvial flooding occurred, for which rainfall data is available for 11 events.

[1] 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 J-1: Rainfall Details - Pluvial Flood Events

Date	Flooding Extent	Rainfall Depths	Rainfall Duration
27th November 2017	Torrential downpours cause flooding. Roads and properties flooded at Beaumont, several inches deep at the bottom of Beaumont Hill. Also flooding in St Peter, St Lawrence and Grand Vaux.	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
16th September 2017	Flash flooding in Jersey. Roads left underwater after torrential rain. St Ouen and St Peter 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
8th-9th February 2016	Storm Imogen floods roads including Victoria Avenue. Some of this flooding may have been tidal rather than pluvial.	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
12th June 2015	Roads flooding in response to heavy rainfall, some areas having over 28mm.	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 (no data for Jersey Airport)
19th to 21st March 2001	Wettest March on record, with 196mm of rain (previous record 152mm in 1912). No property flooding noted. Surface water ponding northeast of Kemp Tower, near La 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.	Maison St Louis Observatory. The three rainfall events at Jersey Airport had durations of 10, 5 and 10 hours.
8th to 9th 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 Mews and Goose Green Marsh. Also flooding at the Montrose Testate at Grand Vaux along the road at Vallee de Vaux. Additional 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).	No useful information available
31st 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 Garden 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 Merage, 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 fire brigade received 100-150 phone callscompared with 54 in the1985 event. However, no further information is provided 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.	No information available
5th June 1983	Another 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	Two hours at Jersey Airport (no data for Maison St Louis Observatory)

Date	Flooding Extent	Rainfall Depths	Rainfall Duration
31st 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 two hours at Jersey Airport with 25mm arriving in six minutes. A daily total of 52.2mm was recorded at St Peter's Rectory	Two hours at Jersey Airport (no data for Maison St Louis Observatory)
28th 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.	No information available	No information available
3rd to 4th 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. This demonstrates the extremely localised nature of some of the extreme rainfall events which result in flooding in Jersey. The details in Table J-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.

J.2 Rainfall Data

J.2.1 Data Availability

Rainfall data provided by Jersey Water, Jersey Met and Météo-France used in this study is summarised in Table J-2 and the locations referenced are shown in Figure J-5 and Figure J-6.

Table J-2: Rainfall 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	1983-2003 & 2015-2017 (23 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	1983-December 2004 (21 years)
Jersey Water	Historic Rainfall Records	Not fully identified	Monthly Rainfall Totals	1865-2018 (153 years)
	Handois	See Figure J-6	Daily Rainfall Totals	1995-2018 (23 years)
	Millbrook	See Figure J-6	Daily Rainfall Totals	1995-2018 (23 years)
	Augres	See Figure J-6	Daily Rainfall Totals	1995-2018 (23 years)
	Val de la Mare	See Figure J-6	Daily Rainfall Totals	1995-2018 (23 years)
	Grands Vaux	See Figure J-6	Daily Rainfall Totals	1995-2018 (23 years)
	Queen's Valley	See Figure J-6	Daily Rainfall Totals	1995-2018 (23 years)
	Greve de Lecq	See Figure J-6	Daily Rainfall Totals	1995-2018 (23 years)
	St Catherine	See Figure J-6	Daily Rainfall Totals	1995-2018 (23 years)
Météo-France	Dinard	See Figure J-5	AMAX[2] Series	1971-2016, with missing data in 1980, 1985, 1986, 1988-1990 (40 years in total)
	Feins SA	See Figure J-5	AMAX Series	2006-2016 (11 years)
	Pontorson	See Figure J-5	AMAX Series	1998-2016, 2002 missing (18 years)
	Quintenic	See Figure J-5	AMAX Series	2000-2016, 2010 missing (16 years)
	Saint-Cast-Le-Guildo	See Figure J-5	AMAX Series	2004-2016 (13 years)
	Pte De La Hague	See Figure J-5	AMAX Series	1996-2017, 2011 missing (20 years)
	Gonneville	See Figure J-5	AMAX Series	1982-1983, 1984-1987 and 1996 – 2016 (23 years in total)
	Sainte-Marie-Du-Mont Brecourt	See Figure J-5	AMAX Series	1998-2016, 2010 missing (18 years)
	Valognes	See Figure J-5	AMAX Series	1992-2016 (25 years)

** Above Mean Sea Level (AMSL)*

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

Other daily rainfall data are available from Jersey Airport and Maison St Louis Observatory but has not been used in this analysis and is therefore not included in Table J-2.

Figure J-5: Rain Gauge Locations on Jersey, Guernsey and France

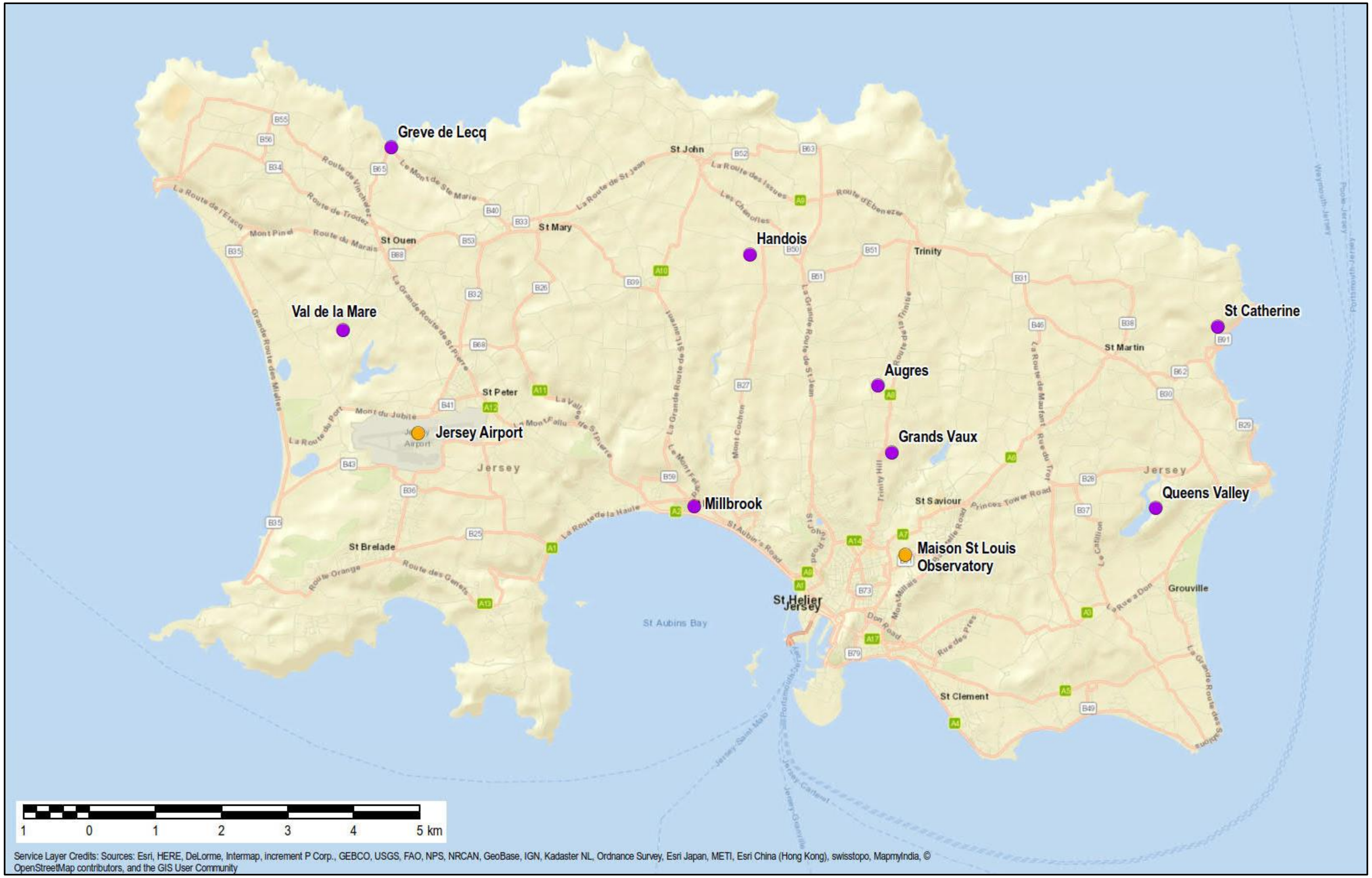

Figure J-6: Rainfall Gauge Locations - Jersey Only

J.2.2 Data Quality

J.2.2.1 Hourly Rainfall Records

The hourly rainfall datasets from Jersey Airport, Maison St Louis Observatory and Guernsey Airport are not continuous with numerous periods of missing data from the digital record. It is understood that much of the missing sub-daily data is available, but only in paper format, having not yet been digitised. Years with more than 5% missing data (Table J-3) were excluded from the annual maxima (AMAX) analysis due to being incomplete.

Butler *et al* (1985)[3] analysed hourly data recorded between 1951 and 1982 at Jersey Airport and between 1940 and 1943 and 1947 and 1982 at Maison St Louis Observatory. From discussions with Jersey Met , this data is not currently available, having not yet been digitised.

Table J-3: Hydrological Years of Hourly Rainfall Data Excluded from Analysis

Rainfall Gauge	Hydrological years excluded (% missing)
Jersey Airport	1983 (47), 1984 (43). 1985 (56). 1986 (35), 1987 (10). 1988 (42), 1989 (38), 1990 (26), 1991 (91), 1992 (91). 1993 (25) 1998 (8), 2000 (9), 2001 (31), 2017 (10)
Maison St Louis Observatory	2017 (17)
Guernsey Airport	1983 (11) 1996 (6), 1998 (9), 2000 (26), 2001 (36), 2002 (9)

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 J-7). Over the three-year period, Maison St Louis Observatory records slightly more rainfall, 3378mm of rain compared with 3168mm at Jersey Airport.

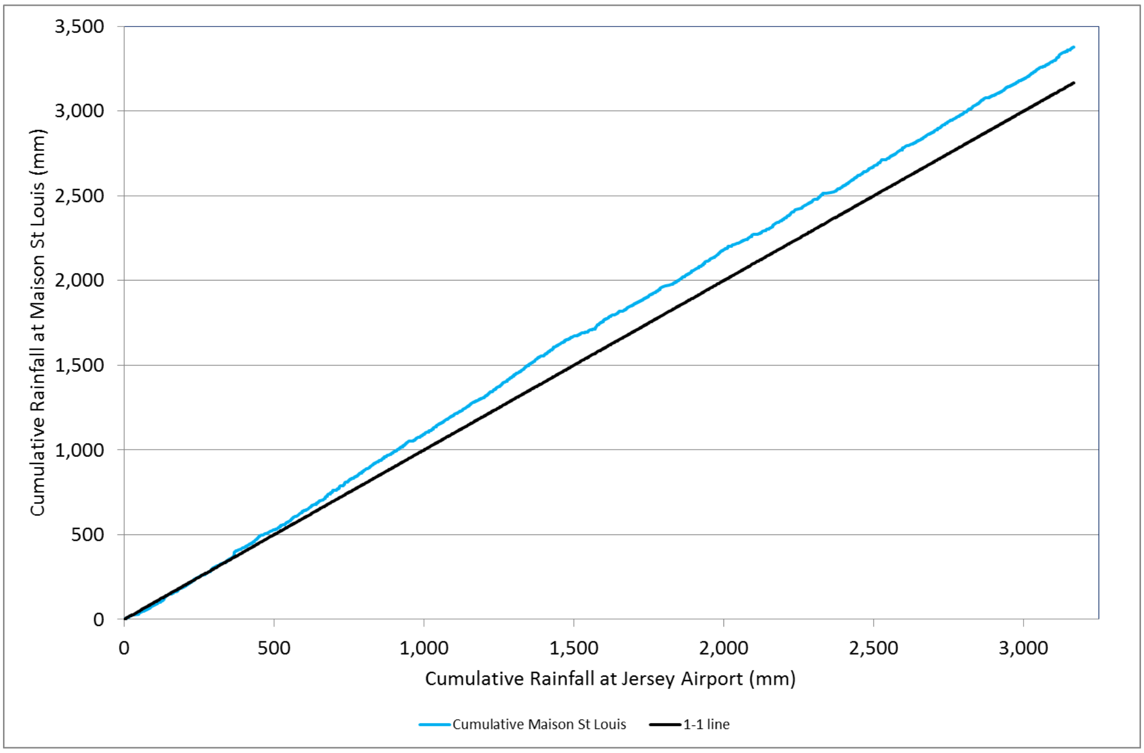

Figure J-7: Rainfall Comparison – Cumulative Rainfall Totals at Maison St Louis Observatory and Jersey Airport (2015-2017)

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

Hourly rainfall data has also been provided for Guernsey Airport. The island of Guernsey lies 27km to the north west of Jersey (Figure J-5) 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, although there are gaps in both records and the comparable data ends in 2004. The available data has been used to produce the double mass plot in Figure J-8 which shows that patterns of rainfall at Jersey and Guernsey are very similar, although Jersey Airport received slightly more rainfall over the comparison period (11,688mm) compared with Guernsey Airport (11,441mm).

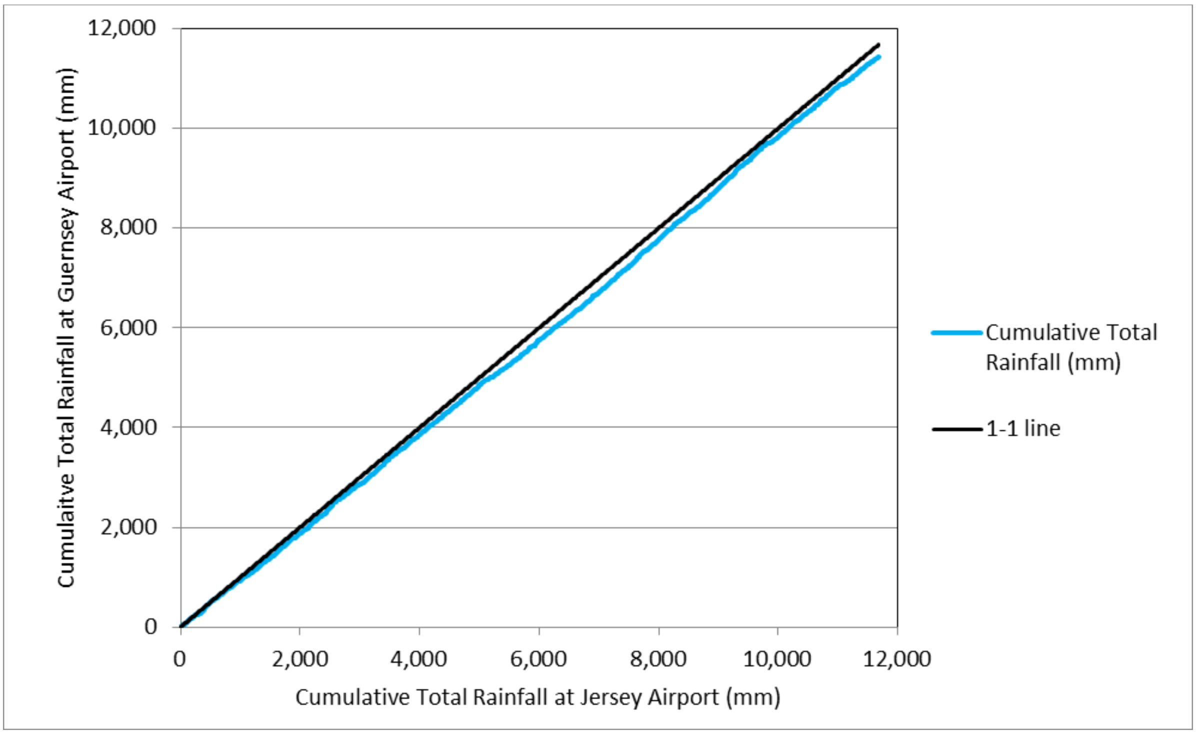

Figure J-8: Rainfall Comparison – Cumulative Rainfall Totals at Jersey Airport and Guernsey Airport (1983-2003)

J.2.2.1.1 AMAX Series

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 rainfall gauges on Jersey.

The results of the AMAX series calculations are shown graphically in Figure J-9 and Appendix B. The two sub-daily gauges on Jersey only overlap by two years, which is insufficient to establish a relationship. Maison St Louis Observatory

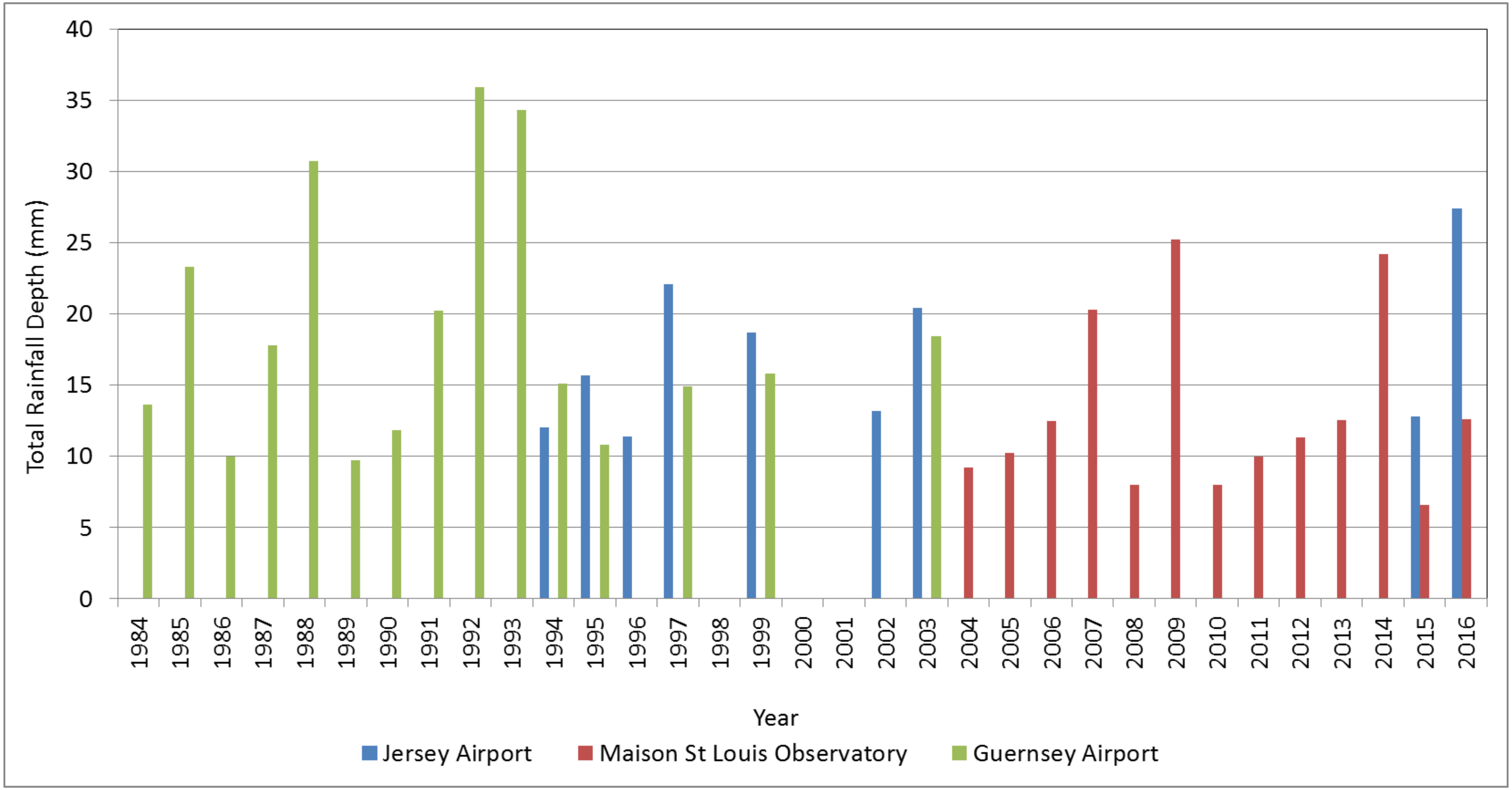

Figure J-9: Two Hour Total AMAX Series for hourly Rainfall Gauges on Jersey and Guernsey

J.2.2.2 Daily Rainfall Records

Hourly rainfall records at sites shown in Figure J-6 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 J-10 shows the extent of the usable AMAX record from the daily gauges alongside the daily (9am to 9am) AMAX series developed from the hourly Jersey Airport and Maison St Louis Observatory data. There is little overlap between the records but the dataset overall shows broad agreement in terms of the range of AMAX seen at the various gauges. On this basis, it does not appear that there are significantly different daily AMAX rainfall totals seen in some areas of the island compared to the others. This supports the use of a single extreme rainfall event profile for use across the island.

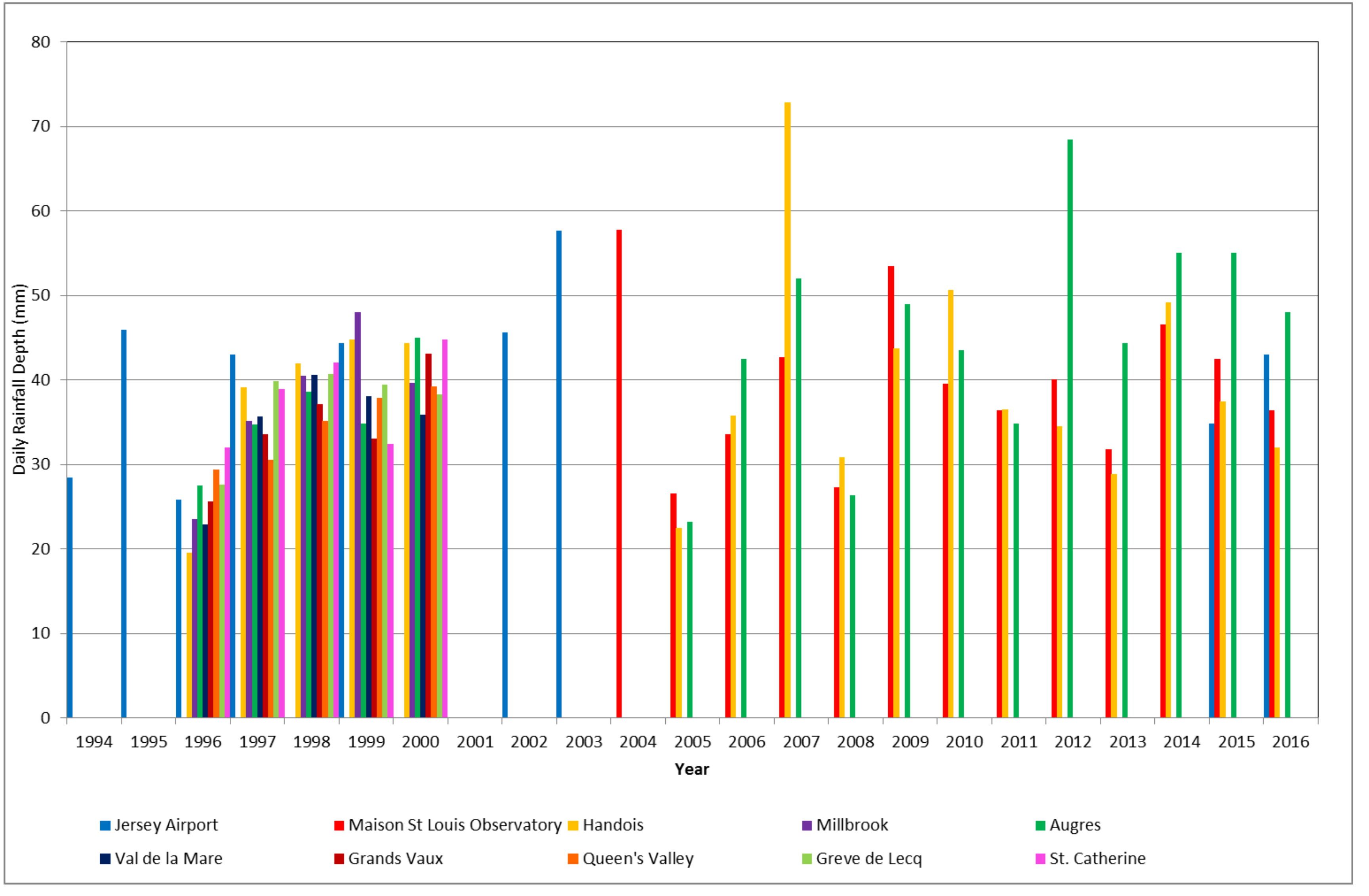

Figure J-10: Annual Maximum (9am-9am) Daily Rainfall Totals (mm) at Jersey Rainfall Gauges (1994-2016)

J.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 J-11) showing that the two records contain similar data and there is no significant difference in long-term rainfall totals between the two records.

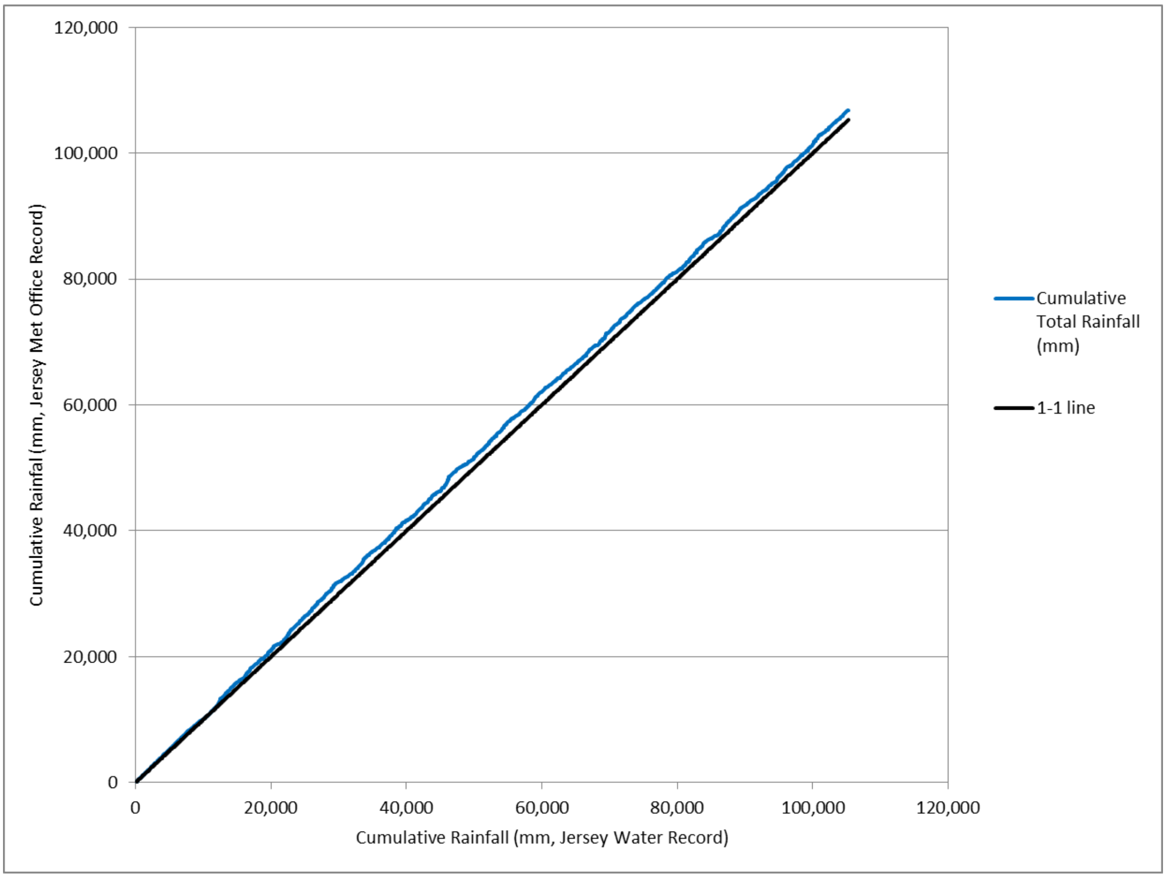

Figure J-11: Rainfall Comparison – Cumulative Rainfall Totals for Jersey Water and Jersey Met Long Term Records (1865-2018)

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 on Jersey over the record period (Figure J-12). 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.

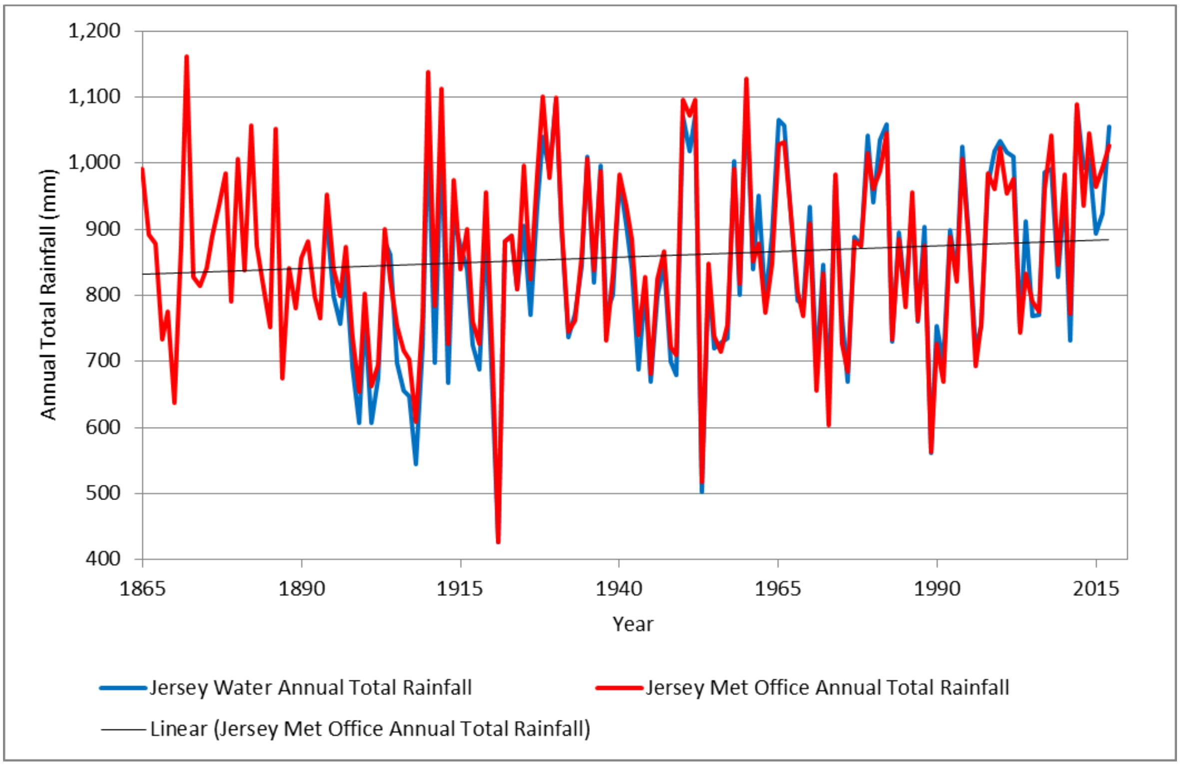

Figure J-12: Annual Rainfall Long Term Trend

J.2.2.4 Météo-France Data

Météo-France is the French national meteorological service responsible for weather monitoring and forecast. Météo-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 J-5). 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 Caste le Guido, Quintenic, Portoson and Fiens SA, which are all located in a 45.9km radius.

The record length for the French rainfall 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 J-2). 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 J-13 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.

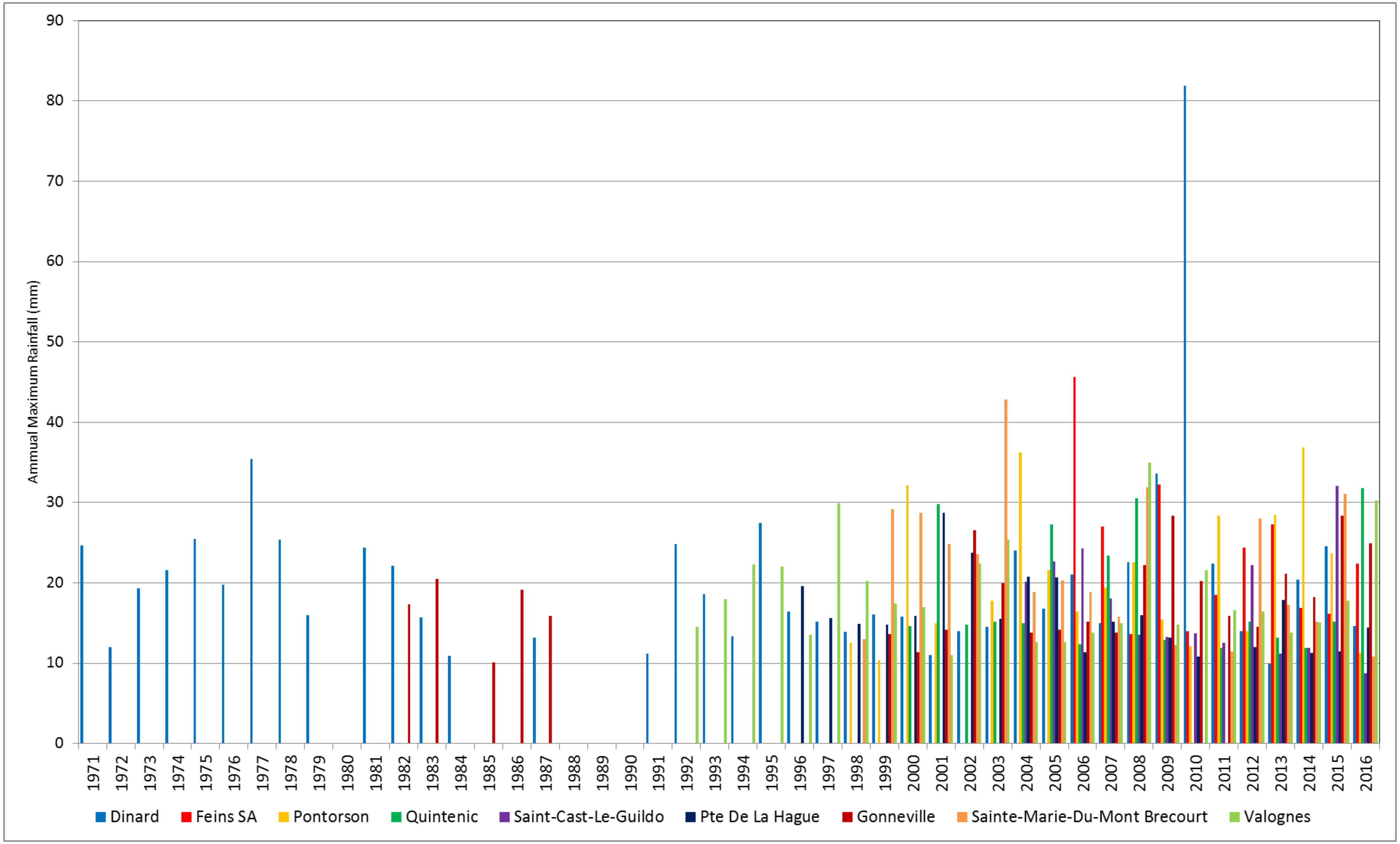

Figure J-13: AMAX Series for French Rainfall Gauges (1971-2016, 2 hr duration event)

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 J-4 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 on 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. A longer time series of hourly data in Jersey is required to improve confidence in the relationship between the maximum AMAX values from France and those expected on the island

Table J-4: Variation in AMAX Values Recorded at all Gauging Stations

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	21	11	18	22	27	39	43	16	26	38
Maison St Louis Observatory	13	10	17	23	37	43	50	16	24	32
Guernsey Airport	17	10	15	18	36	44	46	16	25	30
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

J.2.3 Summary

The hourly, daily and AMAX series available for gauging stations on Jersey, Guernsey and north western France have been analysed for consistency and trends. It reveals that localised extreme events with short duration and high intensity can occur across the region. The gauges generally show good agreement, despite records being short and usually incomplete. The short record length is an important limitation in assessing the magnitude of extreme events since these events are rare and may not be represented in short records. It also increases the uncertainty of the final estimated rainfall depths and makes assigning return periods to individual events particularly difficult.

The data available 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 also form the basis of rainfall growth curves to derive the depth of rainfall for events with various annual exceedance probabilities.

J.3 Methodology

J.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.

J.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 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 gives 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.

J.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 method in 1999, and since updated in 2013. However, we cannot use the FEH rainfall frequency estimation procedure as it 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 close spatial network of rainfall gauges and many thousands of station-years of data, the FEH rainfall frequency model were 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 on the basis of 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 and Pearson Type 3. 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 Météo-France.

J.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 and the ARF depends on both rainfall depth and event duration. 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 J-5.

Table J-5: 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.

J.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 flood are 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.

J.4 Analysis

J.4.1 Peaks Over Threshold (POT) Analysis

The hourly datasets for Jersey Airport and Maison St Louis Observatory were analysed to extract all rainfall events with a total rainfall depth of 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 J-14 for each hydrometric year for which a complete dataset is available. The number of such events varies between 12 and 26, with an average of 18 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.

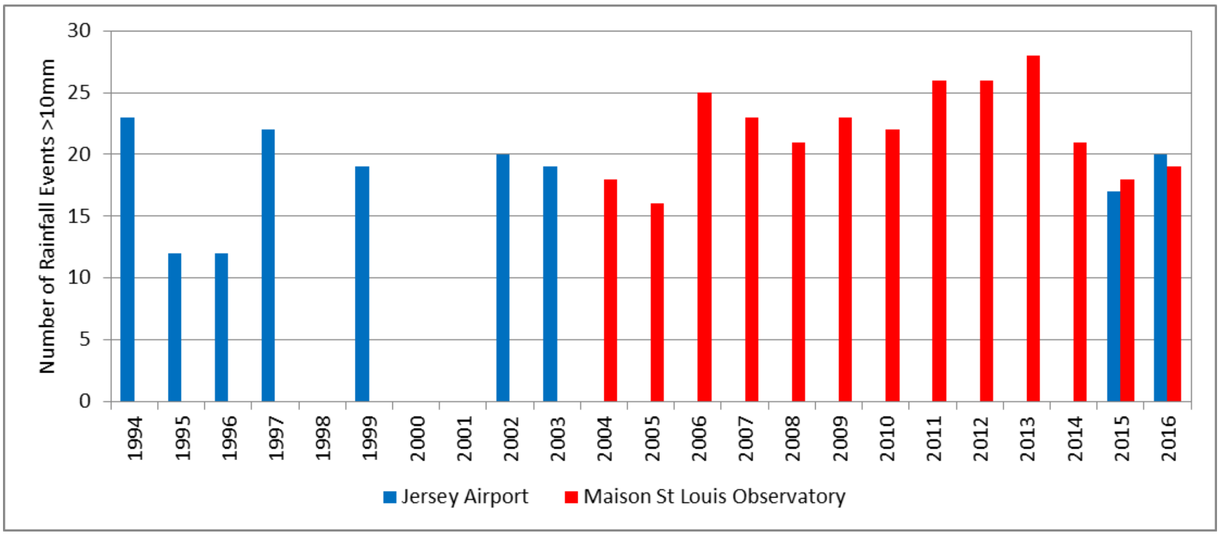

Figure J-14: Number of Rainfall Events ≥10mm Total Rainfall Depth at Jersey Airport and Maison St Louis Observatory (1994-2016)

J.4.1.1 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 on Jersey. The results are shown in Table J-6.

Table J-6: Variation in Rainfall Event Duration for Events >10mm

	Jersey Airport	Maison St Louis Observatory
Number	331	309
Maximum Duration (hrs)	27	30
Minimum Duration (hrs)	1	1
Mean Duration (hrs)	9.6	8.6
Median Duration (hrs)	9	8
25th Percentile Duration (hrs)	6	5
75th percentile Duration (hrs)	12	11
90th percentile Duration (hrs)	16	14
10th percentile Duration (hrs)	4	4

In view of the results in Table J-6 and the limited information from the flood history (Table J-1), the rainfall durations chosen for the modelled hyetographs for Jersey are 2, 6 and 12 hours. The 6 and 12 hour durations correspond to the 25th and 75th percentile duration values at Jersey Airport and are close to the 25th and 75th percentile duration values 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 J-1), ensuring that the intense events which caused pluvial flooding in the past are also considered in this study.

J.4.2 AMAX Analysis

J.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 hour. The results are presented in Table J-7 below.

Table J-7: Rainfall Depths in the Modelled 1 in 5 year Return Period Events

Duration (hours)	2	6	12
Rainfall Depth (mm)	24	33	42

J.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 J-15 to Figure J-17: 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 plot runs anticlockwise such that summer events plot on the left hand side of the graph and winter events plot on the right. 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.

Some caution is needed in interpreting this result as the short record means that there are few large rainfall events to analyse. However, for the shorter duration events (2 hours and 6 hours), the larger storms do occur more often in summer. Large events are more evenly distributed across the year for events with a duration of 12 hours. 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.

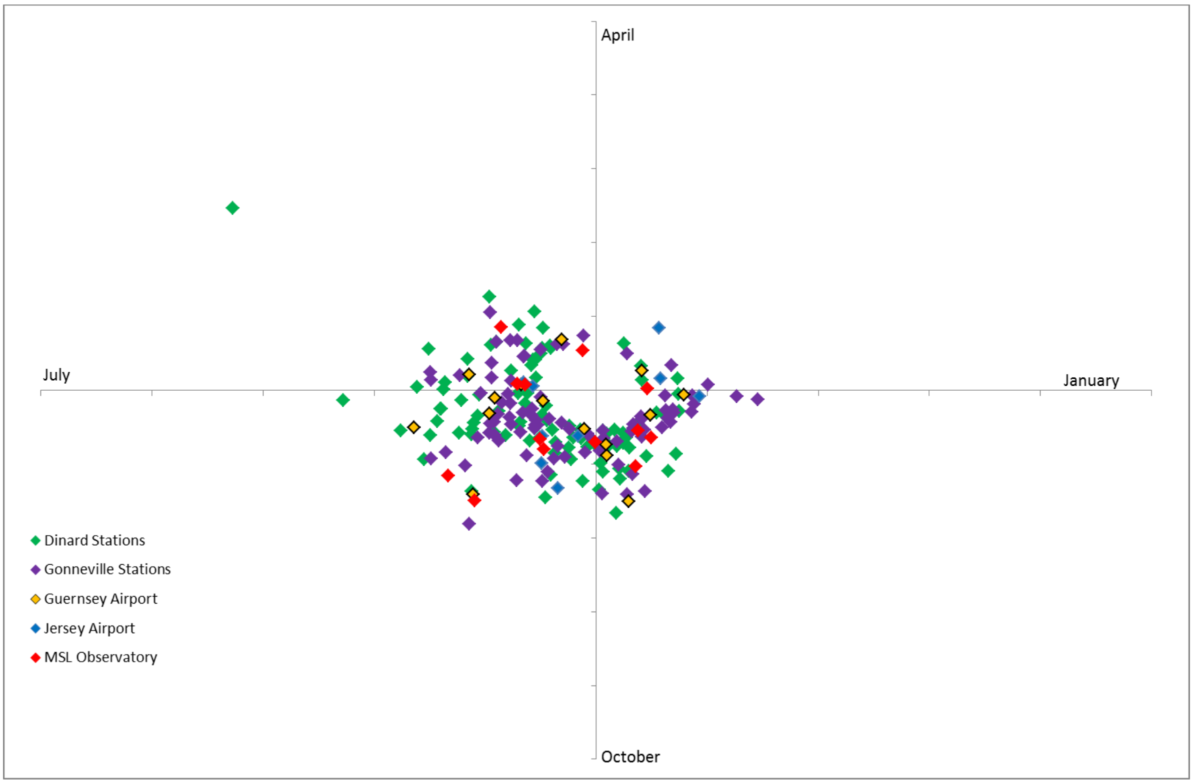

Figure J-15: Seasonal Plot for 2 hour duration AMAX series (all gauges)

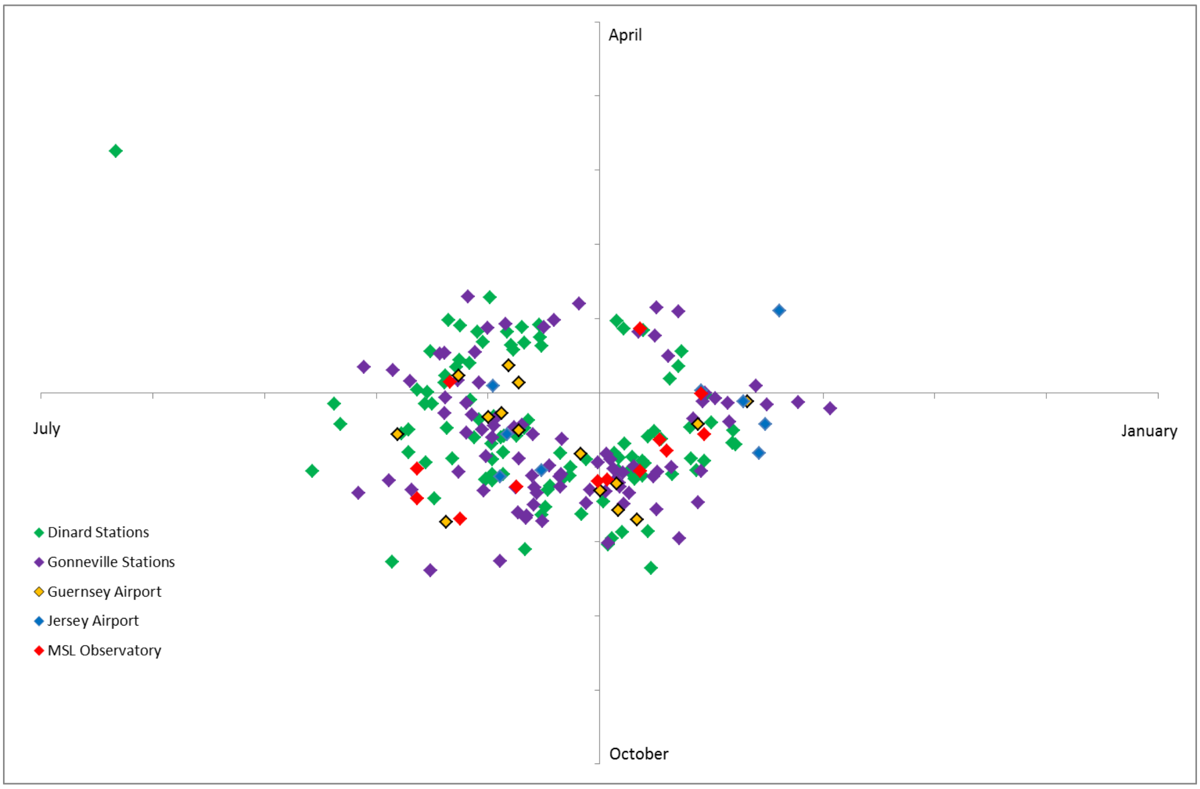

Figure J-16: Seasonal Plot for 6 hour duration AMAX series (all gauges)

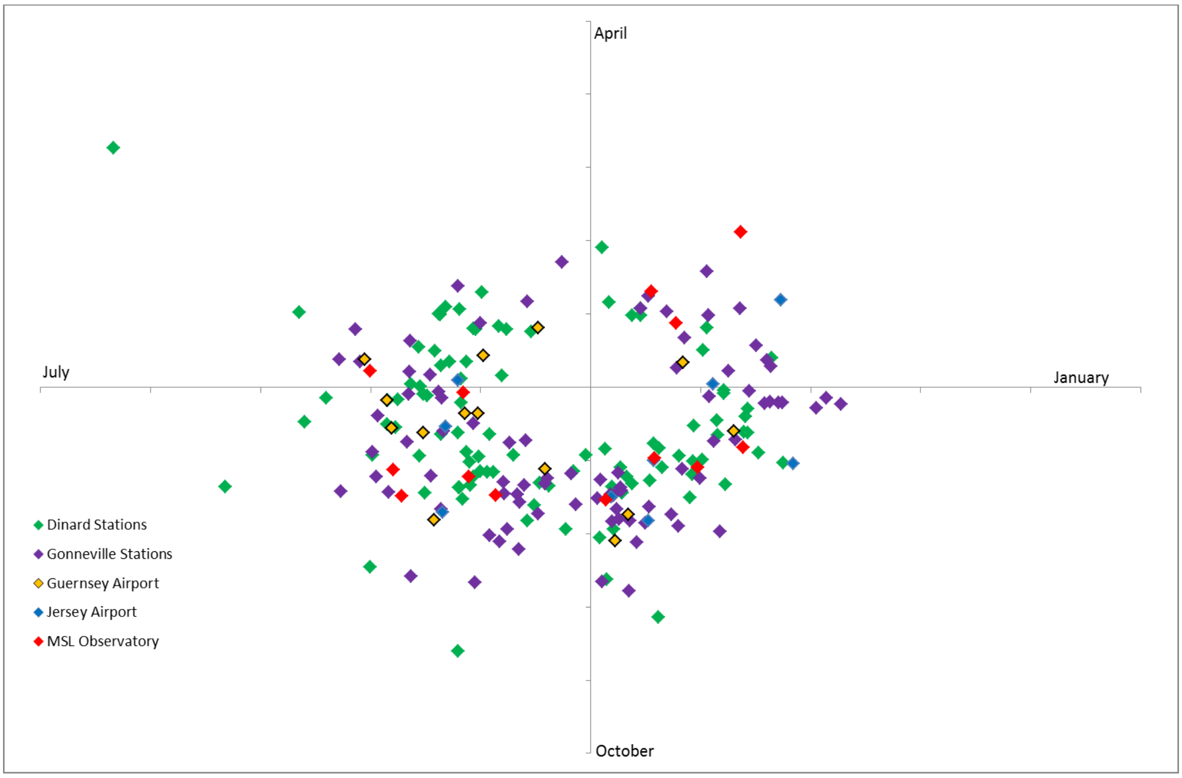

Figure J-17: Seasonal Plot for 12 hour duration AMAX series (all gauges)

J.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 Figure J-18 to Figure J-20. 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 record length at the various stations.

The extreme event at Dinard is a clear outlier on all plots and the return period for this event may in fact be longer than the current record implies. This will need to be considered when selecting the final growth curve.

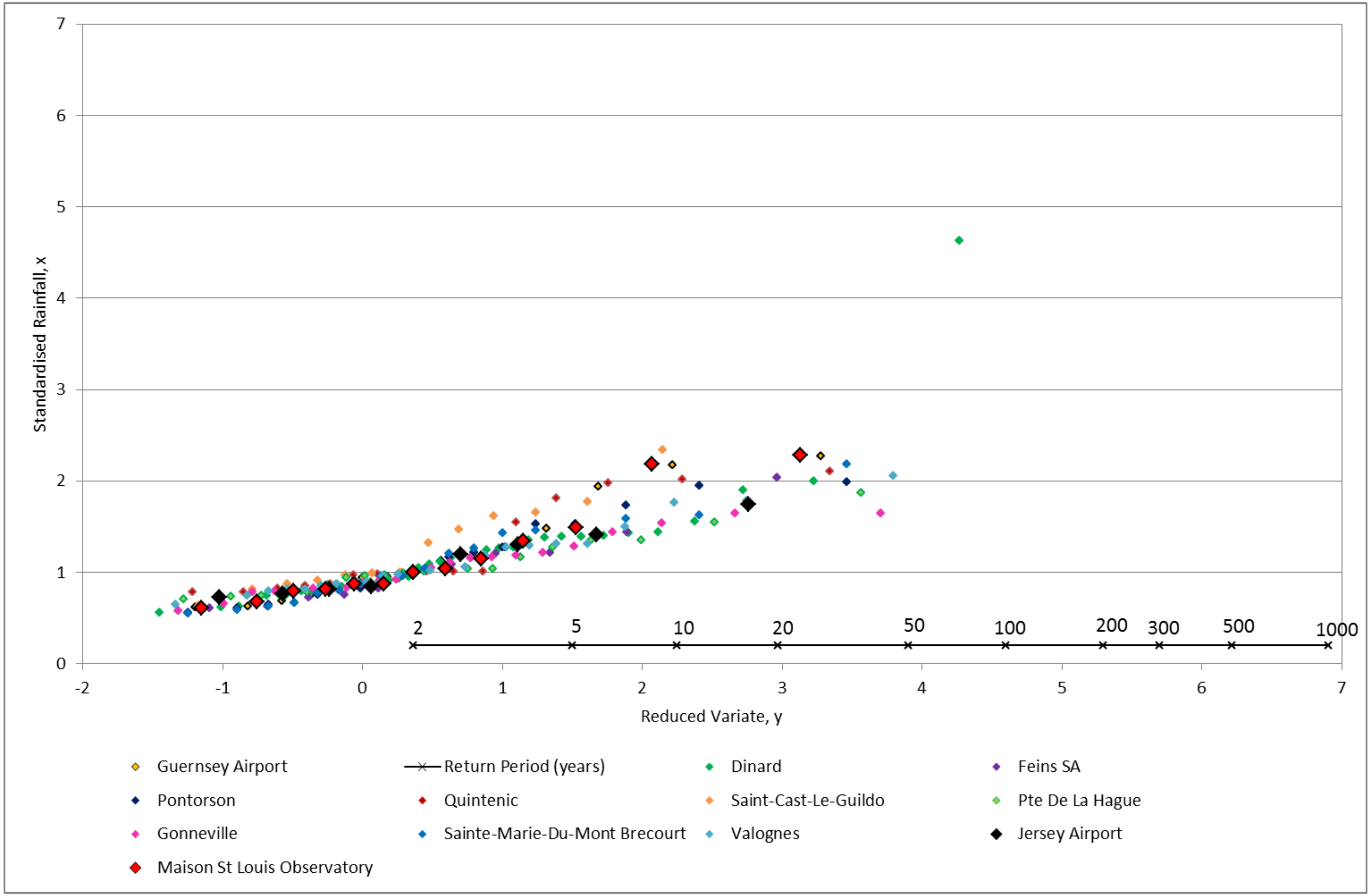

Figure J-18: Reduced Variate Plot for 2 hour AMAX Series (data from Jersey, Guernsey and France)

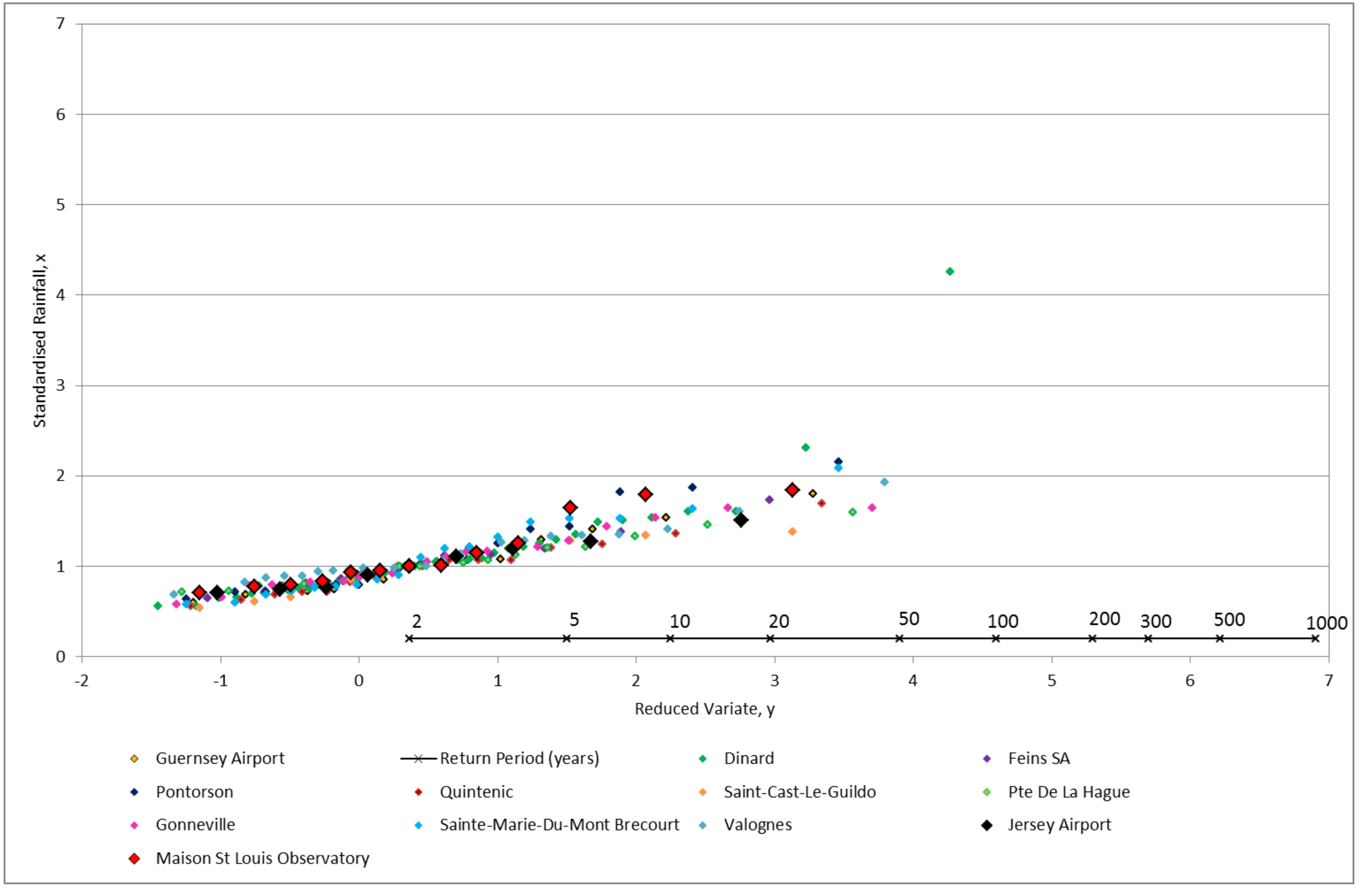

Figure J-19: Reduced Variate Plot for 6 hour AMAX Series (data from Jersey, Guernsey and France)

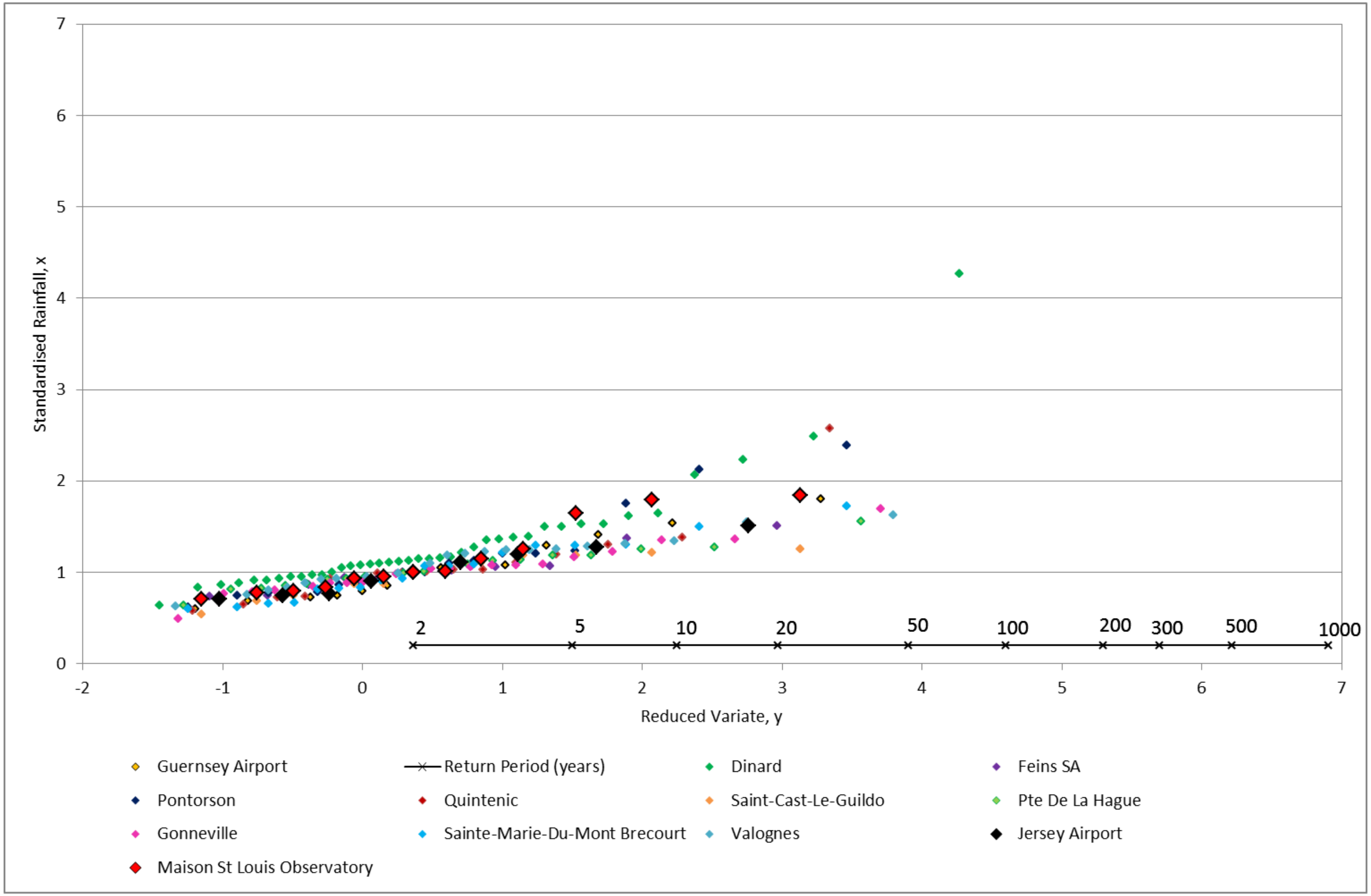

Figure J-20: Reduced Variate Plot for 12 hour AMAX Series (data from Jersey, Guernsey and France)

J.4.2.4 AMAX L-Moments Analysis

Based on the methodology outlined in the FEH, the L-moments (skew and kurtosis) have been calculated for the AMAX series. The datasets were analysed using Jersey data only (i.e. Jersey Airport and Maison St Louis Observatory), for the complete dataset including Guernsey and France, and lastly for the complete dataset but excluding the Dinard data. This last analysis was conducted because the longer record at Dinard has a significantly different distribution compared to the short records from other stations, which results in a plotting position which lies well above the probability distribution curves included in the FEH (Figure J-21). This is not a reason to exclude the Dinard dataset from the analysis as the long record at Dinard is important, but it does demonstrate the importance of having a complete dataset at Jersey because it is not currently possible, on the basis of the existing data, to determine whether rainfall conditions at Dinard (and north western France generally) is genuinely different from that of Jersey or if this is simply a result of the inability of short rainfall records to truly represent longer term trends.

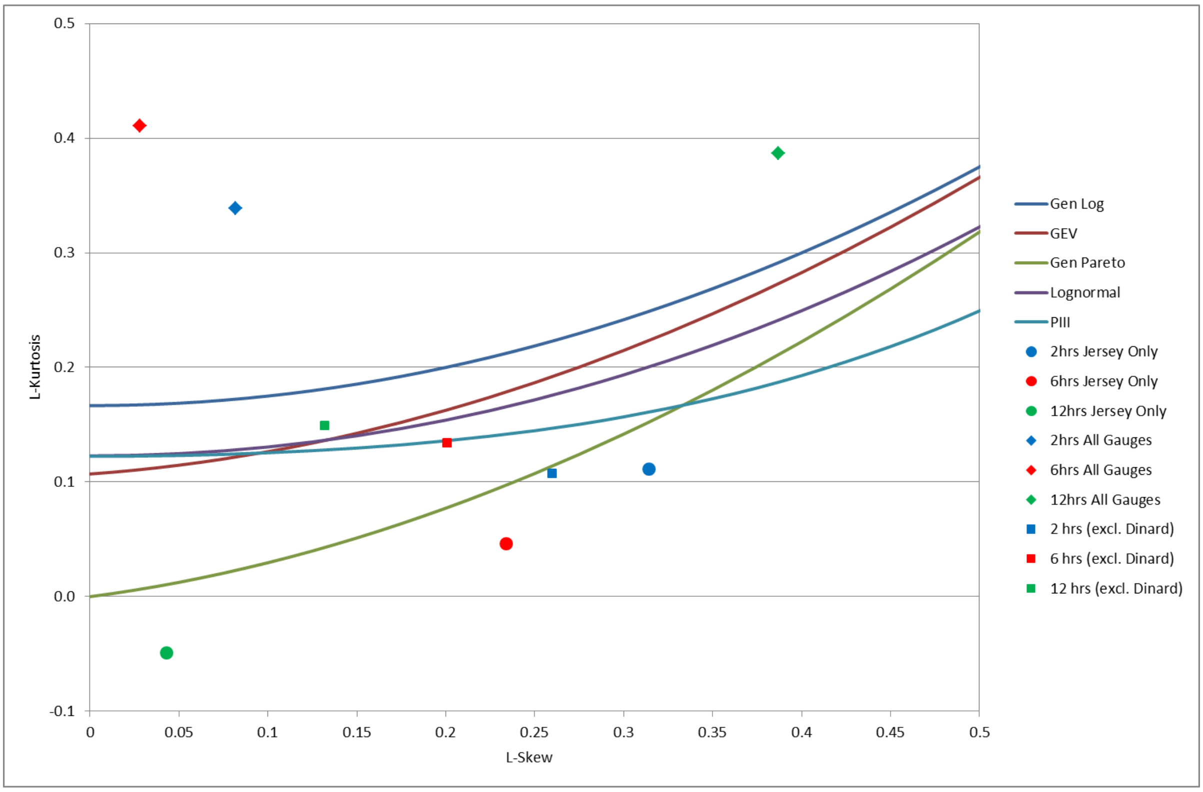

Figure J-21: Existing Data Distribution L-moments Plotting Position

Table J-8 gives distribution for the growth curve suggested by the L-moments plotting position in Figure J-21. There is considerable variation in the skewness and kurtosis of the existing dataset and this results in very different suggested probability distributions for the different events.

Table J-8: Growth Curve Probability Distribution Suggested by L-moments of Existing Datasets

Suggested Probability Distribution	Event duration		
	2 hours	6 hours	12 hours
Jersey Data Only	Generalised Pareto	Generalised Paaeto	Generalised Pareto
All Data	Generalised Logistic	Generalised Logistic	Generalised Logistic
All data (exc. Dinard)	Generalised Pareto	Pearson Type III	Generalised Extreme Value or Log Normal

According to Table J-8, the GP curve would be favoured for four out of nine of the datasets tested. However, the GP curve is not generally used in France, where the GEV is preferred, or the UK, where the GL is preferred. The GEV has been used to derive the growth curves for the Météo-France dataset and is considered appropriate for extreme event modelling as it is bounded above. For consistency, and in view of the variation in growth curves suggested by the datasets, the GEV and GP have both been used to create growth curves for the AMAX series for comparison with the FSR growth curves (see below).

J.4.3 Rainfall frequency curve estimation

J.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 relevant growth curve factors for 2, 6 and 12 hour storm duration are shown in Table J-9.

Table J-9: Rainfall Depth Growth Curve Factors for Modelled Return Period Events

Storm Return Period Event	Growth Curve Factor		
	2 hr event	6 hr event	12 hr event
2	0.728	0.756	0.774
5	1.10	1.09	1.08
10	1.37	1.34	1.31
20	1.58	1.54	1.50
30	1.72	1.68	1.63
50	1.90	1.85	1.78
75	2.01	1.95	1.87
100	2.07	2.00	1.92
500	2.65	2.53	2.39
1000	3.38	3.20	2.99

The final modelled rainfall depths (before adjustment for ARF) are shown in Table J-10.

Table J-10: Modelled Rainfall Depths (FSR Method)

Storm Return Period Event	Modelled Rainfall Depth (mm)		
	2 hr event	6 hr event	12 hr event
2	18	25	33
5	26	36	45
10	33	44	55
20	38	51	63
30	41	55	69
50	46	62	75
75	48	64	79
100	50	66	81
500	64	84	100
1000	81	106	126

The growth curves are shown on the Gumbel Reduced Variate plots in Figure J-23 to Figure J-25 for comparison with – existing AMAX data and with the GEV and GP growth curves.

J.4.3.2 Statistical analysis of local dataset

Statistical analysis software "Easyfit[4]" has been used to fit GP and GEV 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). The results are shown in Table J-11 and Table J-12 and the growth curves are shown in the graphs in Figure J-22 to Figure J-24 for comparison with existing AMAX data and the FSR curves.

Table J-11: Modelled Rainfall Depths (GEV Distribution)

Return Period Event	Modelled Rainfall Depth (mm)		
	2 hr event	6 hr event	12 hr event
2	17	25	31
5	24	33	40
10	29	39	47
20	34	46	53
30	38	49	57
50	42	54	62
75	46	59	67
100	49	62	70
500	67	81	89
1000	79	91	97

Table J-12: Modelled Rainfall Depths (GP Distribution)

Storm Return Period Event	Modelled Rainfall Depth (mm)		
	2 hr event	6 hr event	12 hr event
2	17	25	31
5	25	35	42
10	30	41	48
20	35	46	54
30	38	49	56
50	41	52	60
75	43	54	62
100	45	56	63
500	53	63	69
1000	55	65	71

J.4.4 Growth Curve Selection

Figure J-22 to Figure J-24 show the FSR, GP and GEV growth curves together with the complete AMAX dataset, while Figure J-25 to Figure J-27 show the growth curves with only the Jersey AMAX datasets. The curves show fairly close agreement for all higher frequency return period events (up to the 1 in 20 year event), both with each other and with the AMAX data. For the 2 hour duration, the FSR and GEV curves show good agreement for both smaller and more extreme events, although the FSR curve predicts higher rainfall totals for events with a return period of between 20 and 75 years. The GP curve for the 2 hour event agrees closely with the GEV curve for up to the 1 in 50 year event but produces much lower predicted rainfall events than either the FSR or GEV curves for all larger rainfall events.

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

In contrast, predicted rainfall depths for the FSR method are always above the GEV and GP predicted rainfall totals in the 6 hour event. The GEV and GP curves agree in up to the 1 in 30 year event but diverge for larger return periods with the GEV predicting significantly higher totals. Similarly, for the 12 hour event the FSR predicts the highest rainfall totals for all events, although there is closer agreement between the curves than for the 6 hour event. The GP and GEV curves agree in up to the 1 in 20 year event, after which the GEV again predicts significantly higher totals.

From the data available, it is not obvious which growth curve should be preferred. All curves fit similarly well to the available data. In Figure J-28 to Figure J-30 the three growth curves are compared with each other and with the Météo-France growth curves for Gonneville and Dinard. The modelled rainfall depths for Gonneville are considerably below those of Dinard. The FSR and GEV Jersey growth curves are both consistent with the Dinard data, while the GP curve is a better fit to the Gonneville data, suggesting that the analysis has produced a realistic model of regional rainfall conditions. However, the three curves do produce different results with closer agreement between the GEV and FSR curves.

In addition, a feature of the GEV and GP distributions is that they are bounded above. In this case, the upper bounding is apparent before the 1 in 1000 year event, so that the GEV and GP curves both predict lower rainfall totals than the FSR for the extreme event (Figure J-31). Although the agreement between the GEV and FSR is fairly close for all modelled return period events for the two hour storm duration, there is less agreement for the longer duration events and the GP curve is significantly flatter than either the GEV or FSR. The predicted maximum rainfall for both the GEV and GP curves is lower than the rainfall depth which has already been observed in the 2000 AMAX event at Dinard, considerably so in the case of the GP curve. It is unlikely that a theoretical maximum rainfall depth event has already been observed at Dinard in a record which comprises only 40 years of data. Due to the short-record length of the Jersey data and the lack of confidence we have in accurately assigning a specific return period to the extreme event at Dinard, there is less confidence that the GEV or GP growth curves are correct. Since the FSR growth curves are not bounded and continue to show significant increases in extreme rainfall with event duration, the FSR growth curve is preferred for the modelling of extreme rainfall on Jersey.

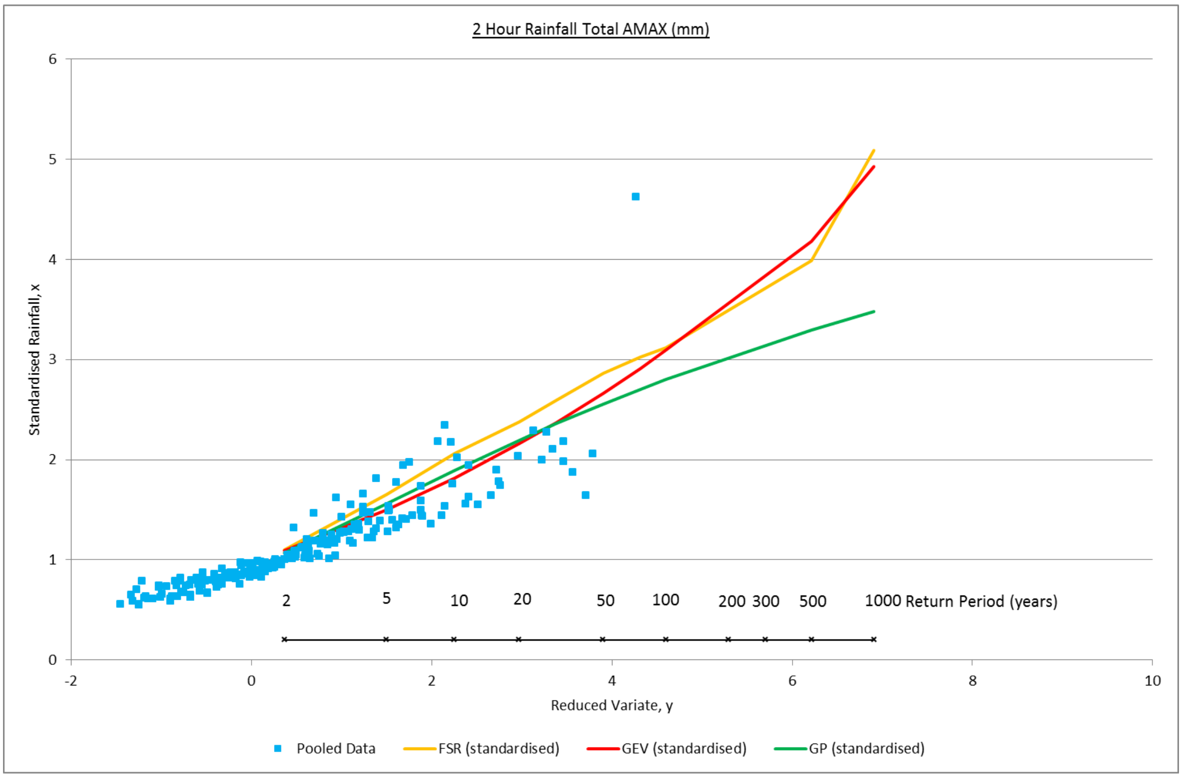

Figure J-22: Growth Curves with AMAX data (Jersey, Guernsey and France): Gumbel Reduced Variable Plot: 2 hour event

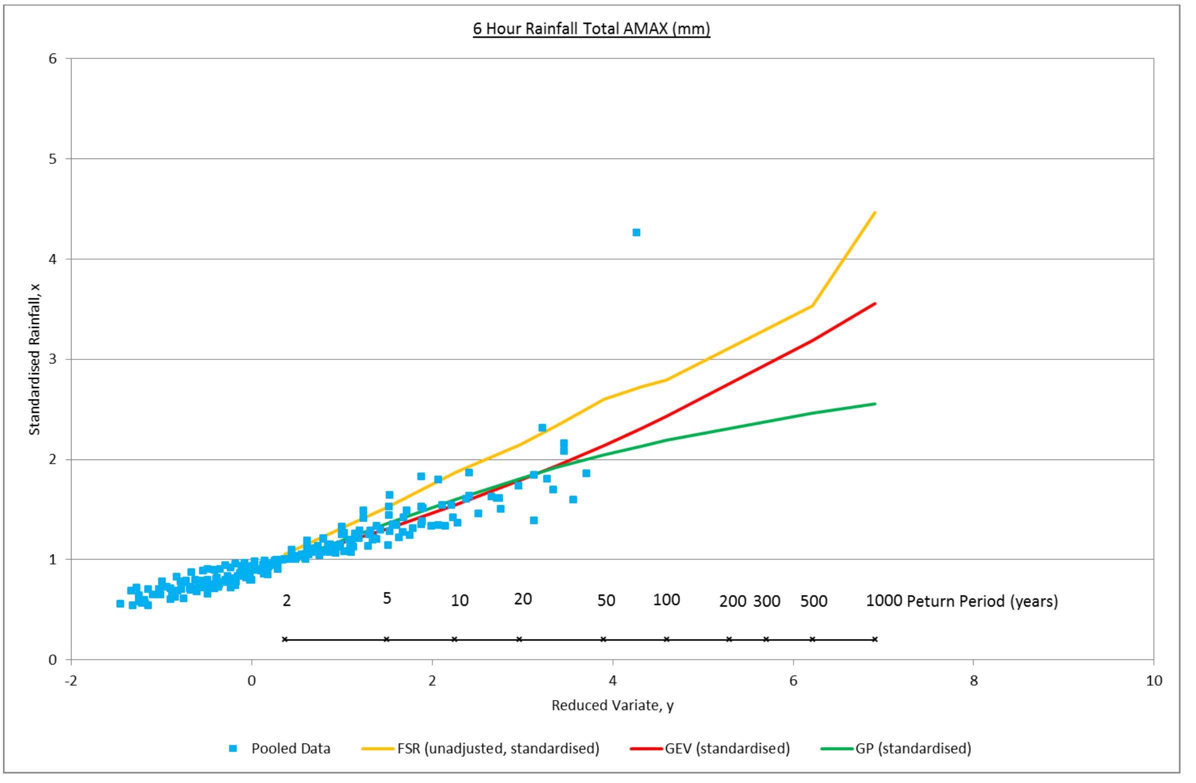

Figure J-23: Growth Curves with AMAX data (Jersey, Guernsey and France): Gumbel Reduced Variable Plot: 6 hour event

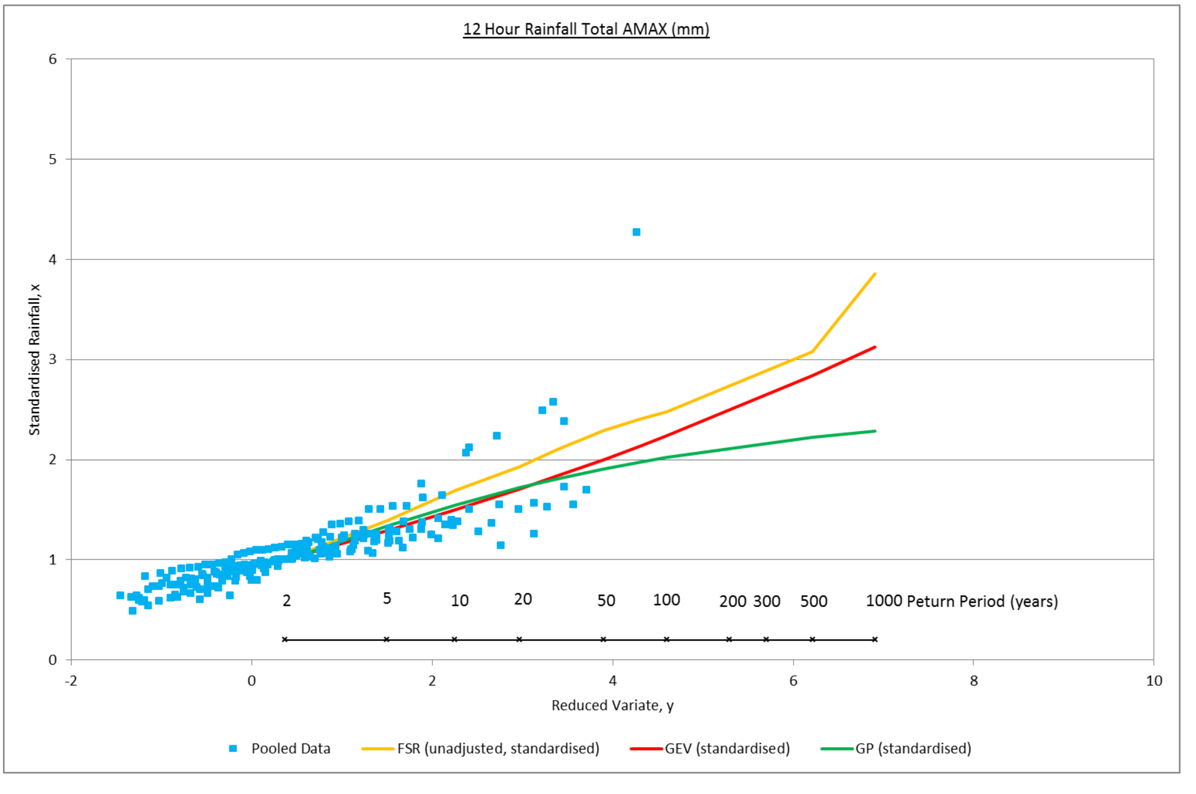

Figure J-24: Growth Curves with AMAX data (Jersey, Guernsey and France): Gumbel Reduced Variable Plot: 12 hour event

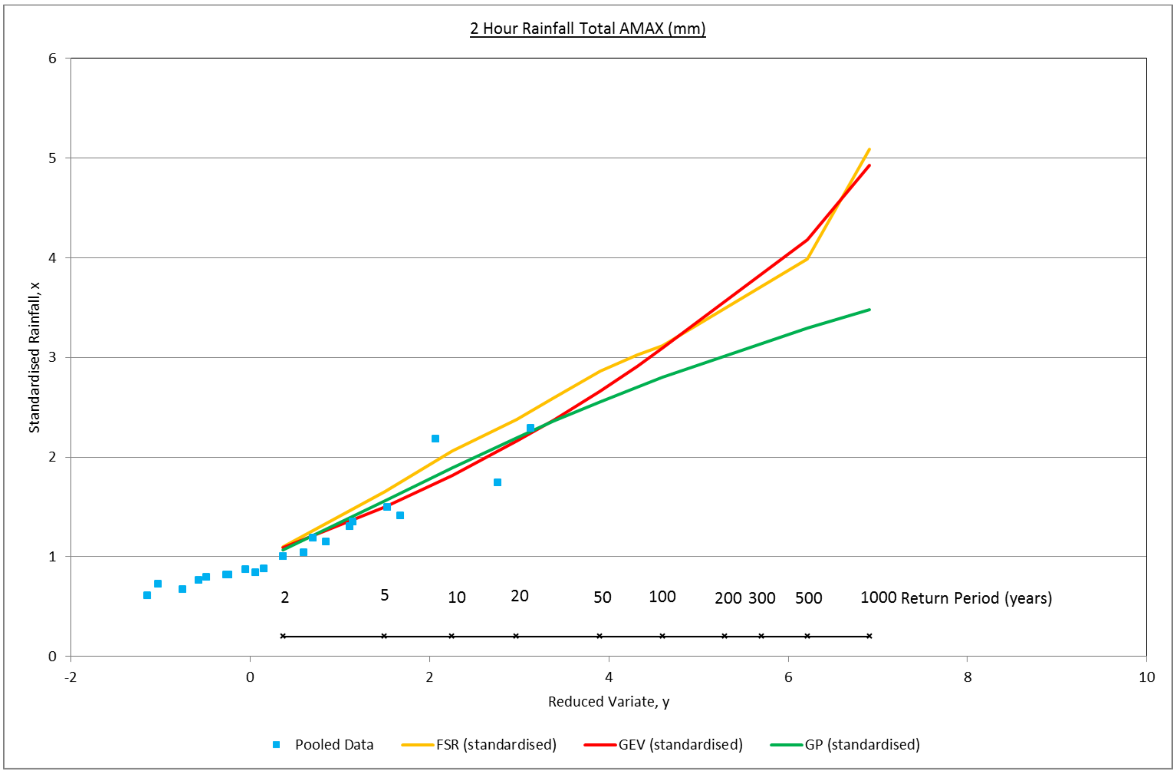

Figure J-25: Growth Curves and Jersey AMAX data (Gumbel Reduced Variate Plot): 2 hour event

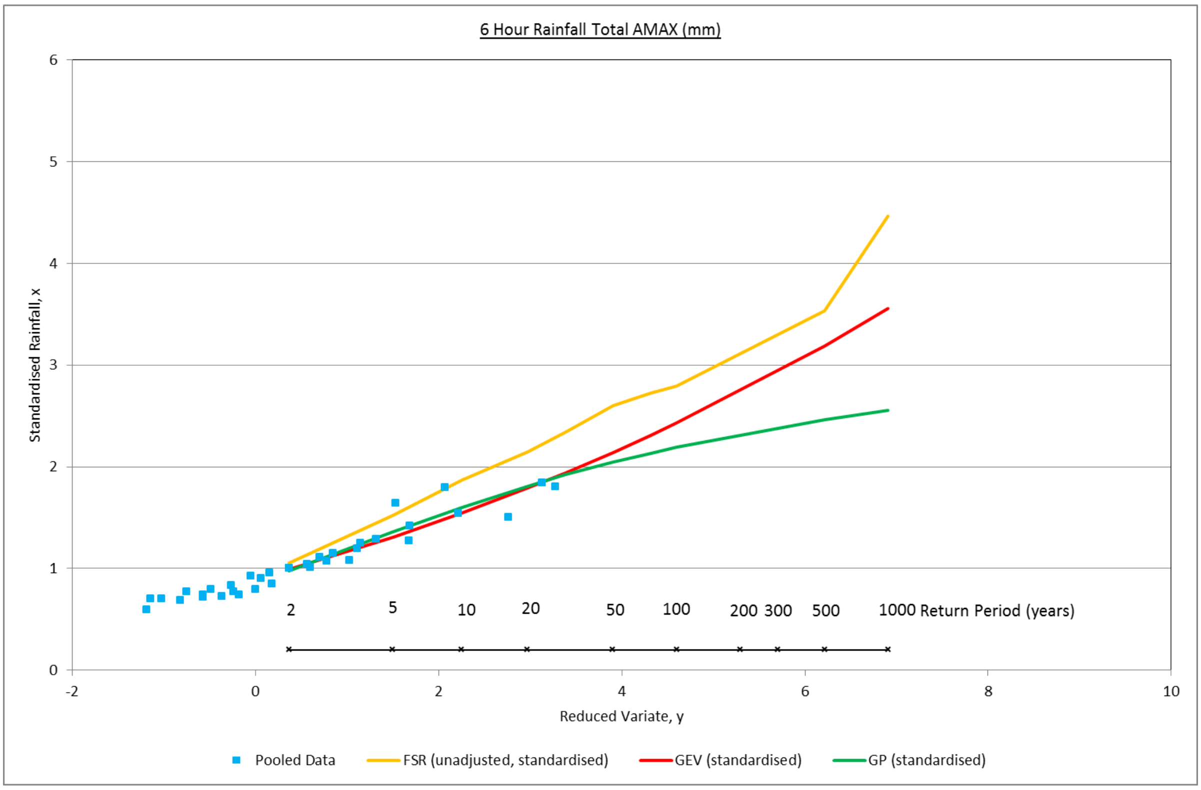

Figure J-26: Growth Curves and Jersey AMAX data (Gumbel Reduced Variate Plot): 6 hour event

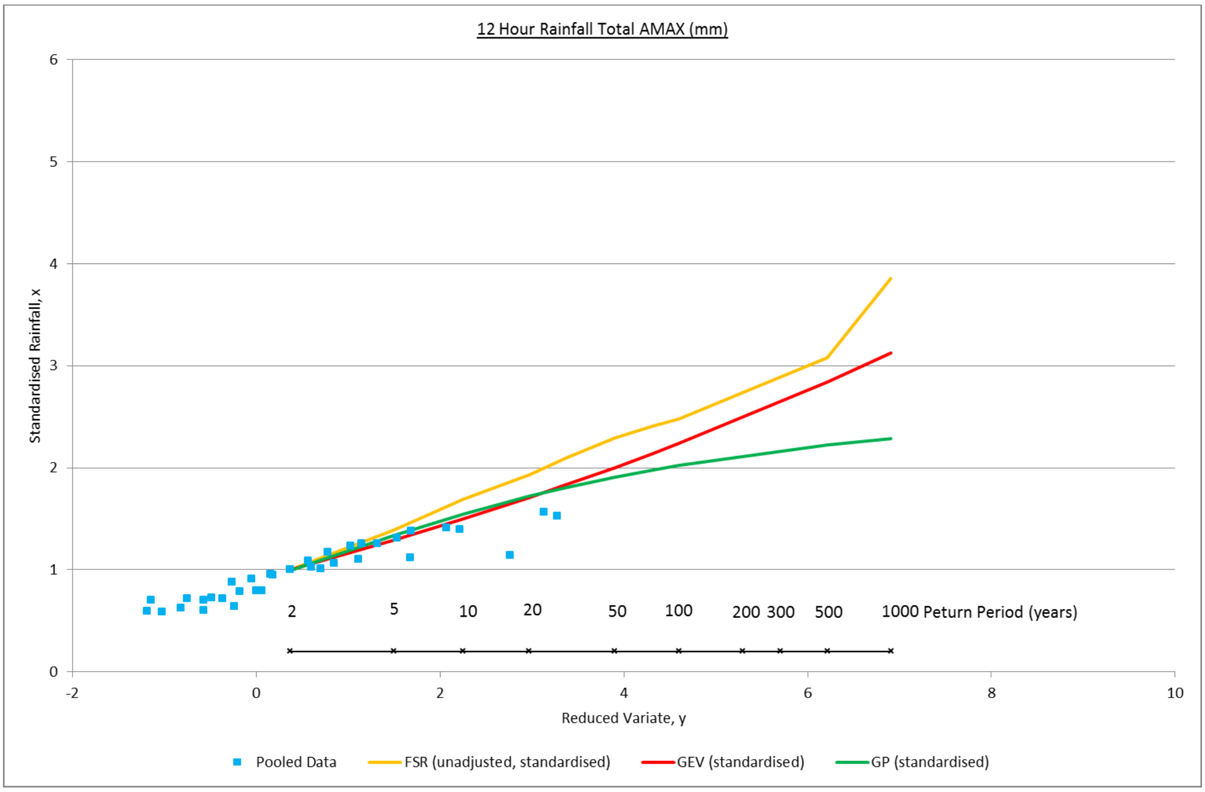

Figure J-27: Growth Curves and Jersey AMAX data (Gumbel Reduced Variate Plot): 12 hour event

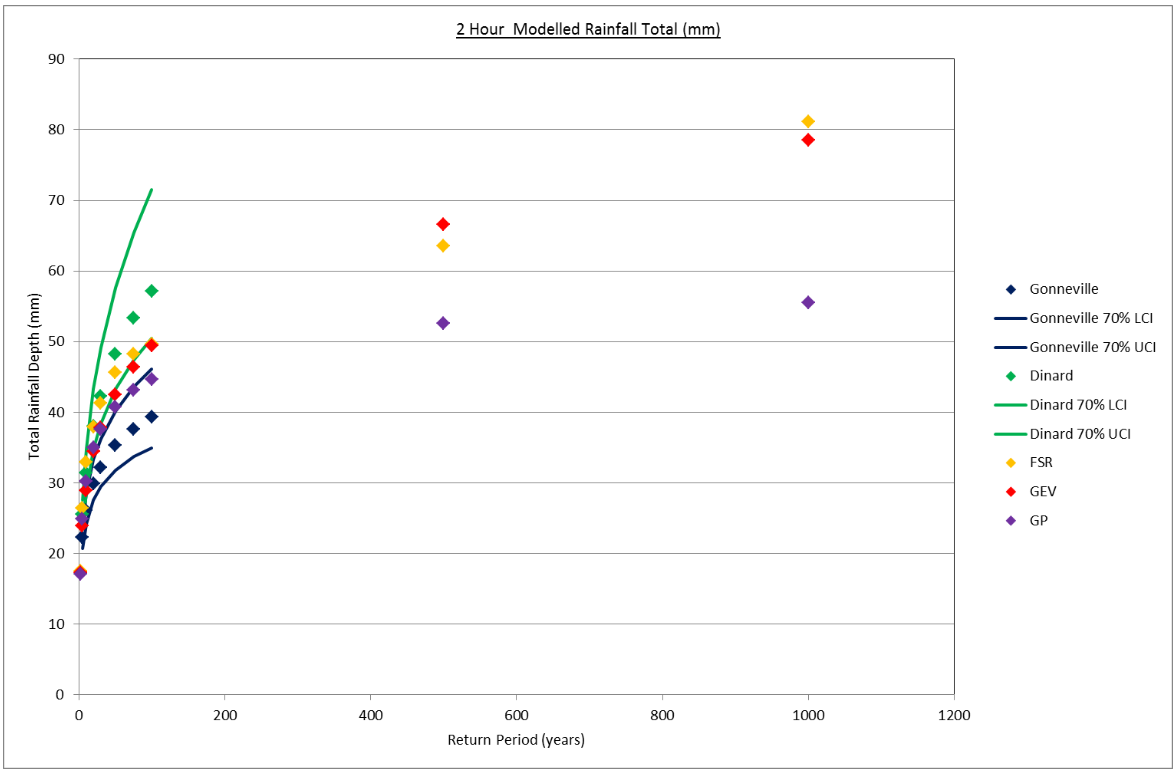

Figure J-28: Comparison of FSR, FEH and Météo-France Growth Curves (2 hour event)

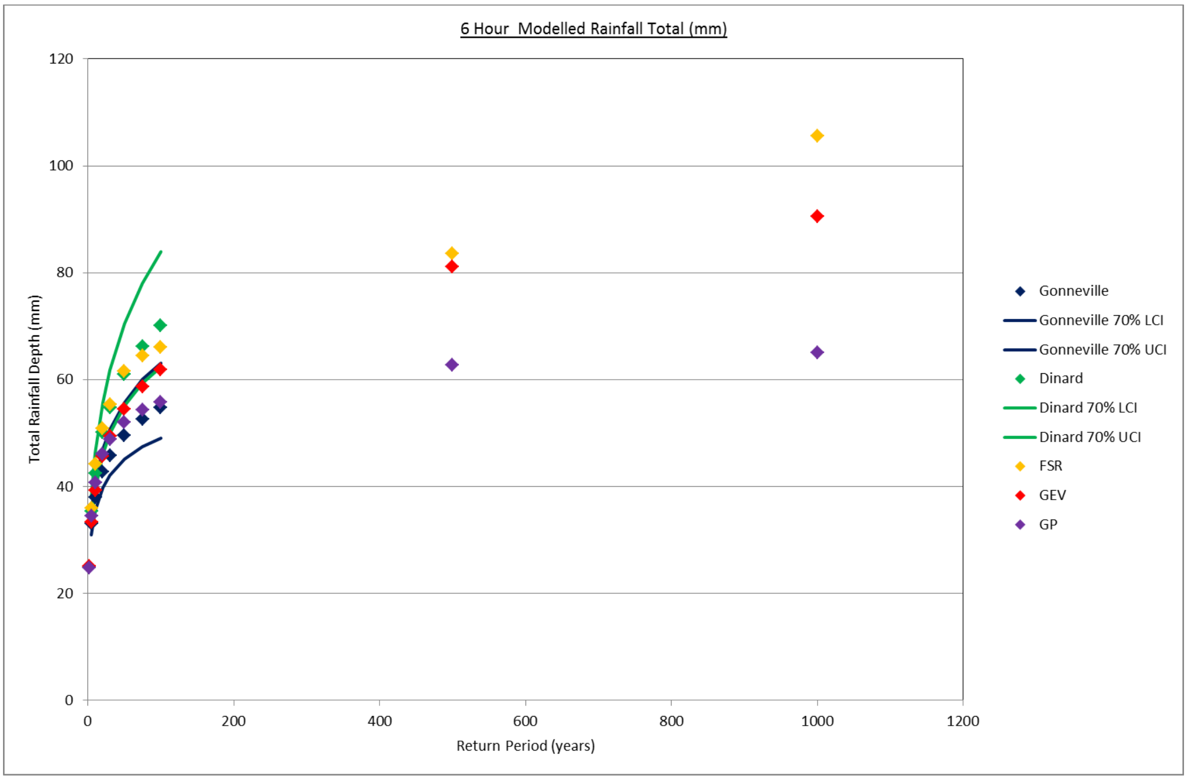

Figure J-29: Comparison of FSR, FEH and Météo-France Growth Curves (6 hour event)

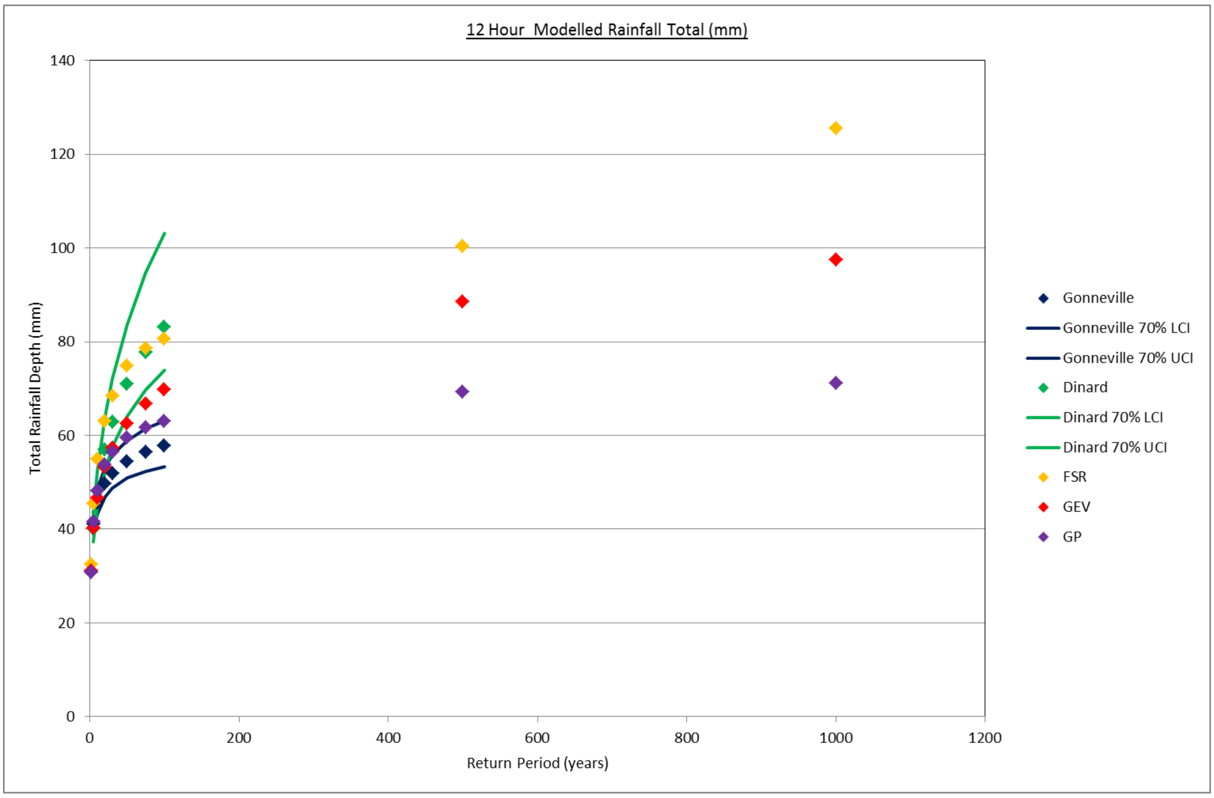

Figure J-30: Comparison of FSR, FEH and Météo-France Growth Curves (12 hour event)

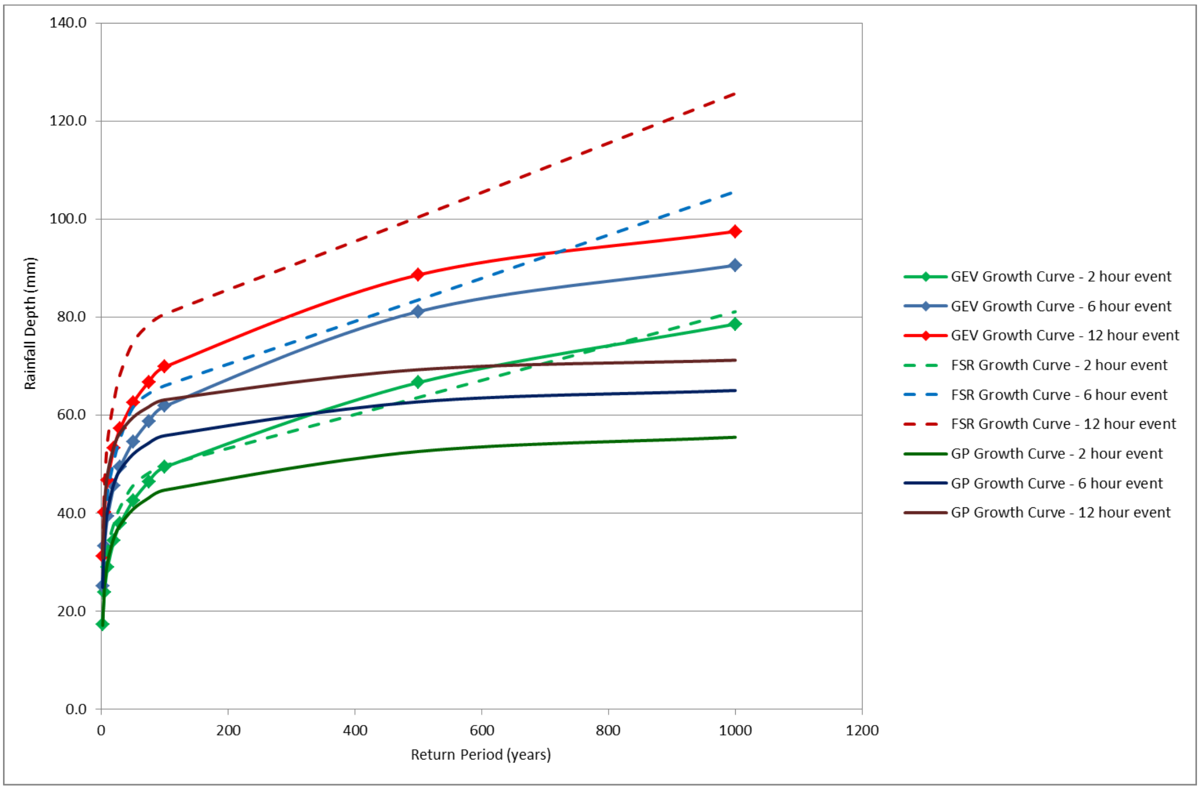

Figure J-31: Comparison of FSR, GEV and GP Growth Curves

J.5 Results and Conclusions

J.5.1 Hyetograph Calculations

An areal reduction factor (as outlined in Section 3.4) has been applied to the rainfall totals derived from the FSR 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 FSR hyetographs for Jersey have been reduced in line with this and are shown in Figure J-32 to Figure J-34. Each hyetograph has been distributed over 12 timesteps of 10, 30 or 60 minutes.

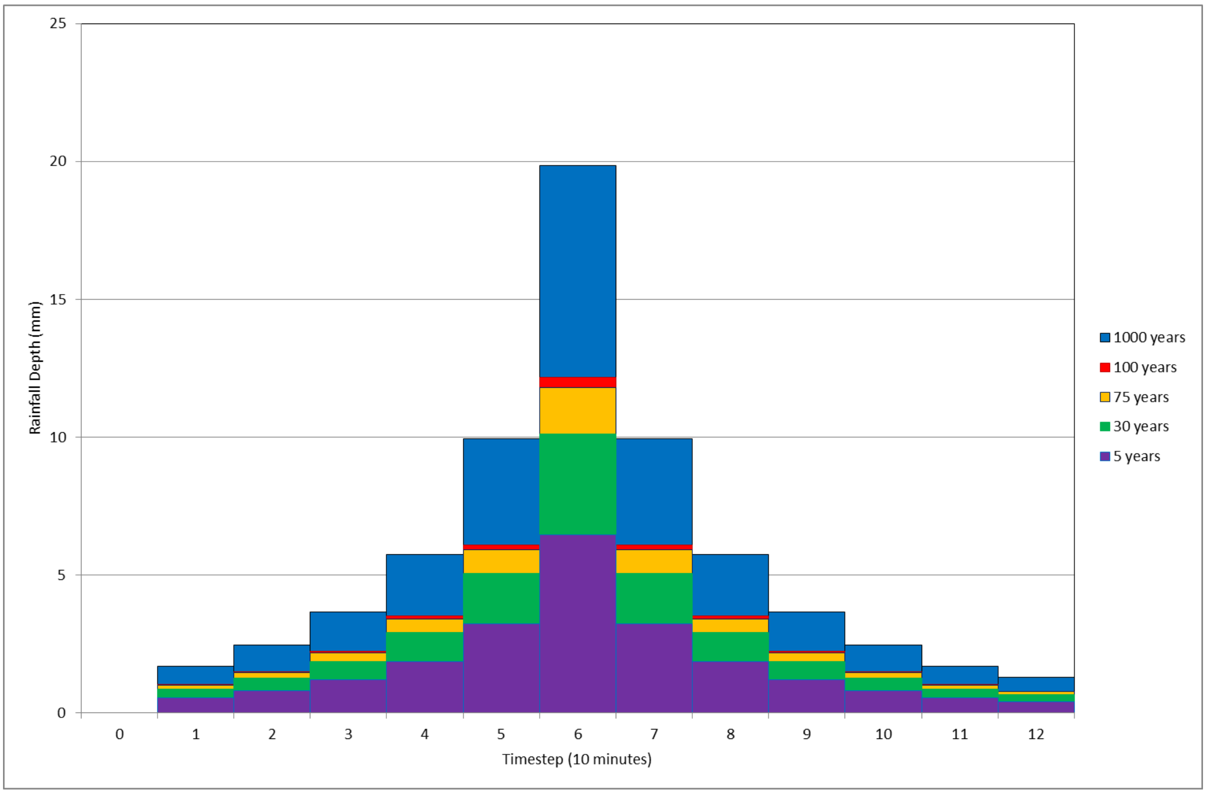

Figure J-32: Final Modelled Hyetograph for Summer - 2 Hour Event

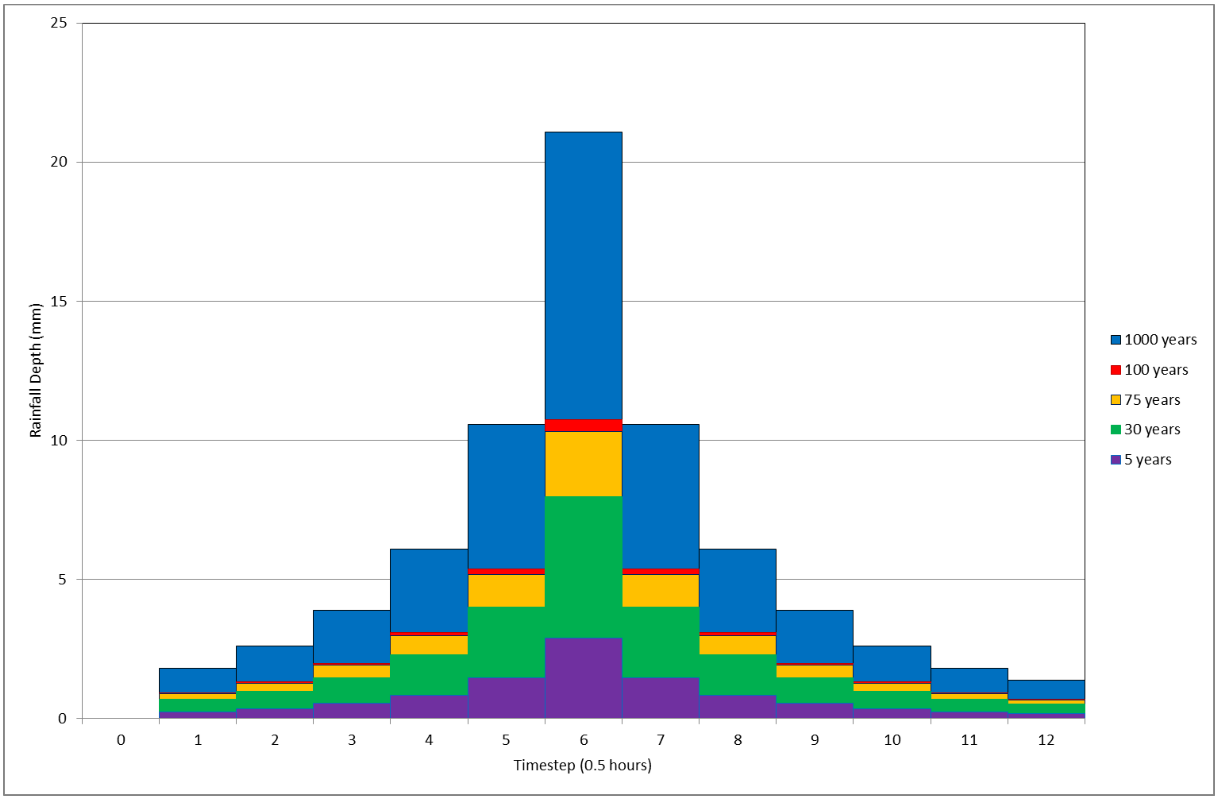

Figure J-33: Final Modelled Hyetograph for Summer - 6 Hour Event

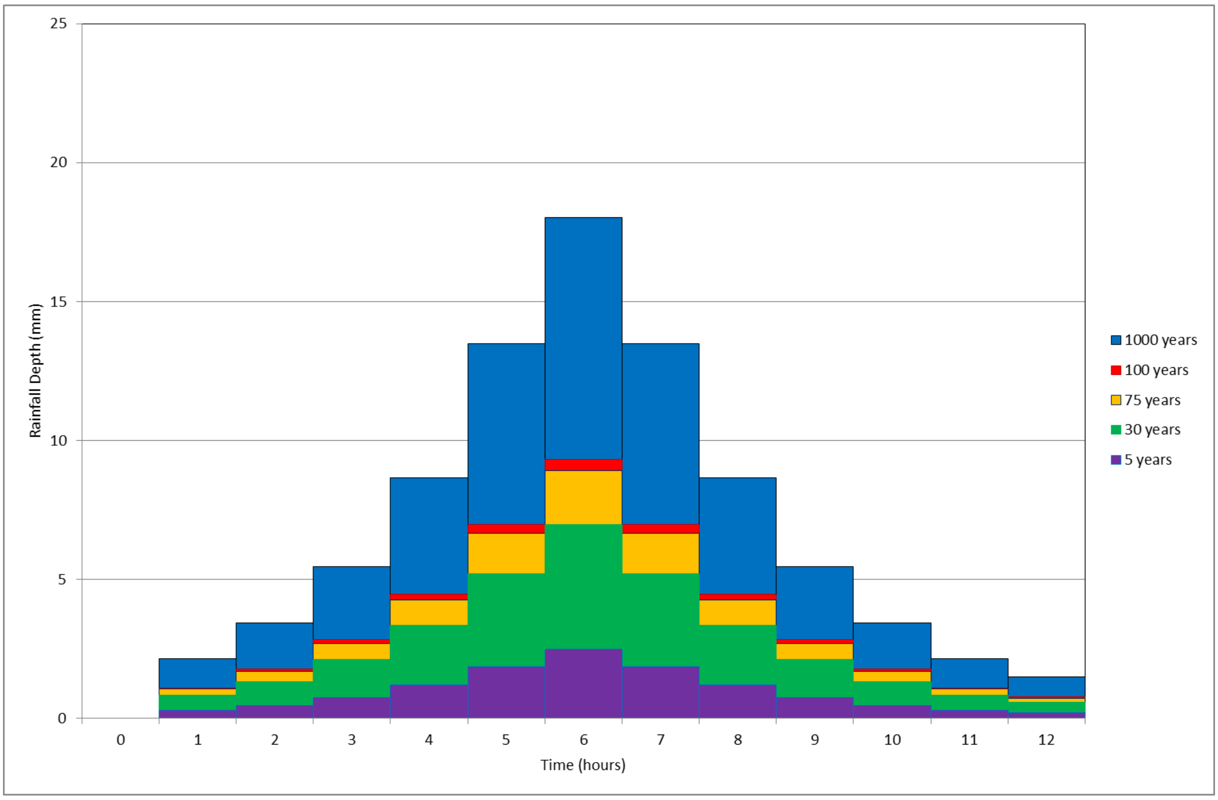

Figure J-34: Final Modelled Hyetograph for Winter - 12 Hour Event

J.5.2 Conclusions

Extreme rainfall depths have been estimated for Jersey based on FSR regional growth curves and on statistical analysis of existing rainfall data.

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 found to be sufficiently similar to that of Jersey to allow for a pooled AMAX analysis to extend the rainfall record for Jersey. AMAX analysis for the relevant durations suggests a seasonal difference in storm duration, with more high intensity, low duration events seen in the spring and summer. The AMAX data were also analysed to determine the M5 rainfall depth for each duration which was combined with the modelled duration to produce FSR growth curves. The AMAX dataset was then further analysed using a number of standard probability distributions. In view of considerable disagreement in the dataset concerning which frequency distribution was most appropriate, and in order to be consistent with methods followed in France, the GEV and GP distributions were selected and used to generate statistical growth curves.

The two approaches show good agreement for short return period events, with the growth curves agreeing with each other and with the AMAX data. The curves are also similar to the Météo-France growth curve for Dinard and Gonneville, suggesting that the analysis successfully reproduces regional rainfall patterns. There is, however, significant disagreement between the curves for larger return period storms with the GP curve predicting significantly lower extreme rainfall depths compared with the FSR and GEV for all duration events. In addition, the FSR predicts higher rainfall totals for larger events for both the 6 and 12 hour modelled duration. The short record length at the rainfall gauges makes it difficult to confidently select the most appropriate growth curve and to assign a reliable return period to extreme events in the existing dataset.

Overall, the FSR growth curve is preferred over the GEV and GP growth curves. This is because the FSR curve is not influenced by extreme events within the dataset and because the GEV and GP curves show significant upper bounding which results in a theoretical maximum rainfall below what has already been observed. Given the short duration of the rainfall record this is not realistic.

The FSR growth curves have therefore been used to derive modelled rainfall depths have been corrected for areal losses using the ARF and distributed according to the relevant seasonal hyetograph profile. Based on the results of the seasonality analysis, the summer profile has been chosen for the 2 hour and 6 hour event and the winter profile has been chosen for 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 is in order to represent 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.

There remains considerable uncertainty concerning the rainfall analysis carried out. Further work to reduce the uncertainty is recommended below.

J.5.3 Recommendations for Further Analysis

The analysis set out above is based on datasets of very limited duration. This makes it difficult to put historic events into context or derive an accurate return period. This may introduce a bias in the results and make the results overly sensitive to variations between individual gauges.

One way to reduce this source of error would be to digitise the complete hourly rainfall record at Jersey Airport and Maison St Louis Observatory. This would provide significant additional information which may make it unnecessary to rely on rainfall data from elsewhere. The analysis would then focus on Jersey only and it would be possible to select an appropriate frequency distribution for the growth curve with more certainty.

A single rainfall hyetograph has been derived for the whole Island. This approach may need to change if there is significant variation in extreme rainfall across the island. Analysis of the existing data suggests that this is not the case but the record is so short that it is not possible to confirm this for certain. A review of daily records from gauges across the island would demonstrate whether this assumption is correct.

Appendix A Jersey Flood History Report

Flooding Type	Date	Details	Source
Tidal	3rd January 2018	Storm Eleanor causes tidal flooding which closes roads and damages 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	27th November 2017	Torrential downpours cause flooding. Roads and properties flooded at Beaumont, several inches deep at the bottom of Beaumont Hill. Also flooding in St Peter, St Lawrence and Grands Vaux.	https://jerseyeveningpost.com/news/2017/11/27/jersey-hit-by-flooding/
Pluvial/Fluvial	16th September 2017	Flash flooding in Jersey. Roads left underwater after torrential rain. St Ouen and St Peter 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	8th February 2016	Storm Imogen floods roads including Victoria Avenue	https://www.bbc.co.uk/news/world-europe-jersey-35526934
Pluvial/Fluvial	12th June 2015	Roads flooding 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	3rd March 2014	High tide (12m) and heavy winds combine to cause flooding. Rue Verte at L'Etacq severely damaged by the high tides. Victoria Avenue closed.	https://www.bbc.co.uk/news/world-europe-jersey-26390204
Tidal	2nd 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	17th October 2012	High tides cause flooding to various areas, including Beaumont	https://www.youtube.com/watch?v=vPlYf8u5jMs
Tidal	8th March 2008	"Johanna" Storm causes 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. **Report suggests this event has a return period of around 1 in 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 additional landslips, although no property flooding noted. Surface water ponding northeast of Kemp Tower, near La 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.

Flooding Type	Date	Details	Source
Pluvial/Fluvial	8th to 9th 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 Mews and Goose Green Marsh. Also flooding at the Montrose Testate at Grand Vaux along the road at Vallee de Vaux. Additional landslips also occurred.	Jersiaise 2002, 28(2), 242-248)
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	31st 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 Merage, 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 Garden 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. Fire brigade 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	23rd 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	5th 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	31st March 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
Tidal	27th 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.	"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

Flooding Type	Date	Details	Source
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/Fluvial	28th 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	3rd to 4th 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.	

Flooding Type	Date	Details	Source
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 GOJ 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 Saviours 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 Garden.	Government 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

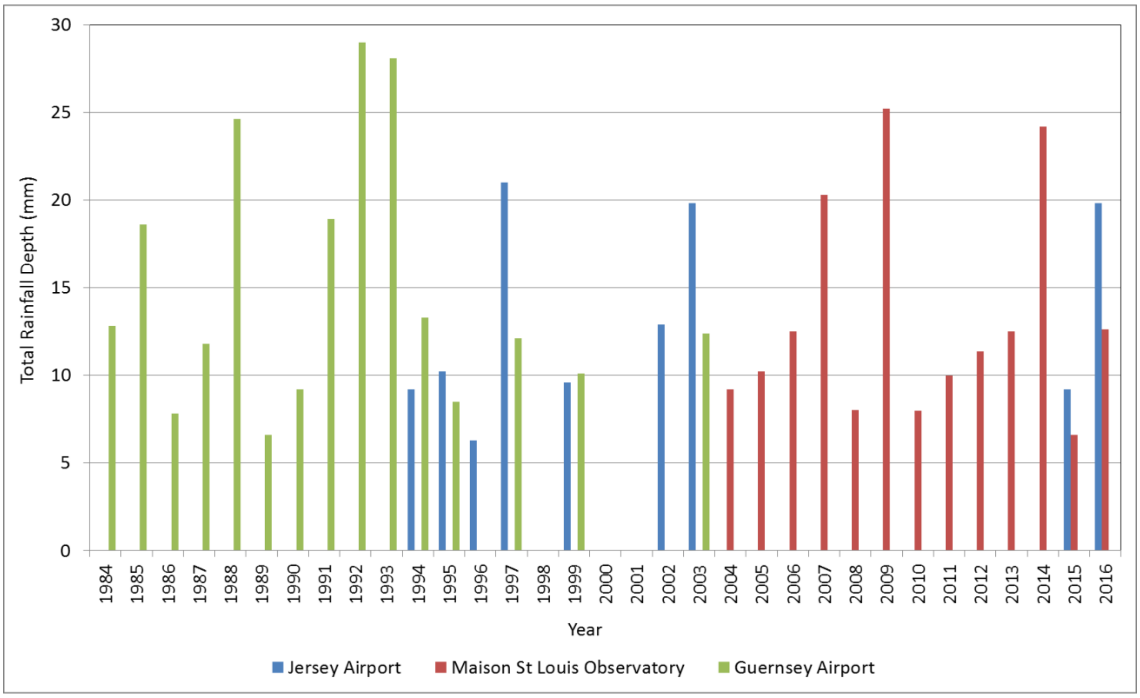

Figure C1: Hourly AMAX Series for sub-daily Rainfall Gauges on Jersey and Guernsey

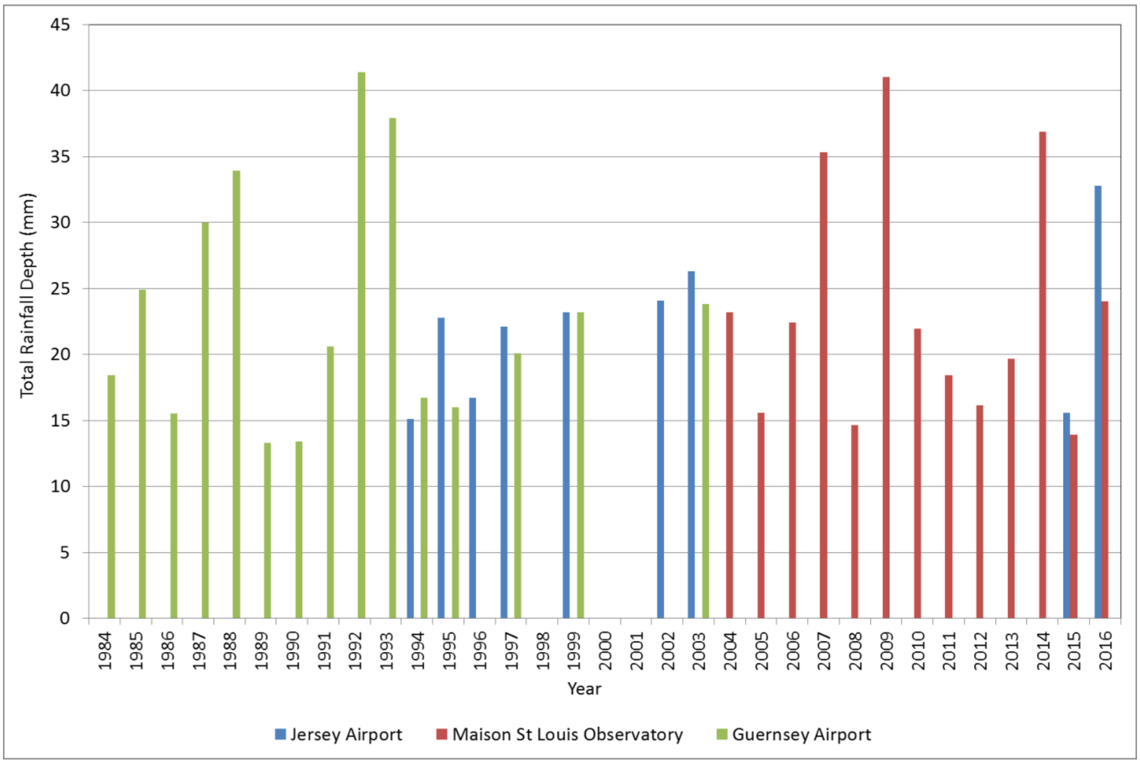

Figure C2: Four Hour Total AMAX Series for sub-daily Rainfall Gauges on Jersey and Guernsey

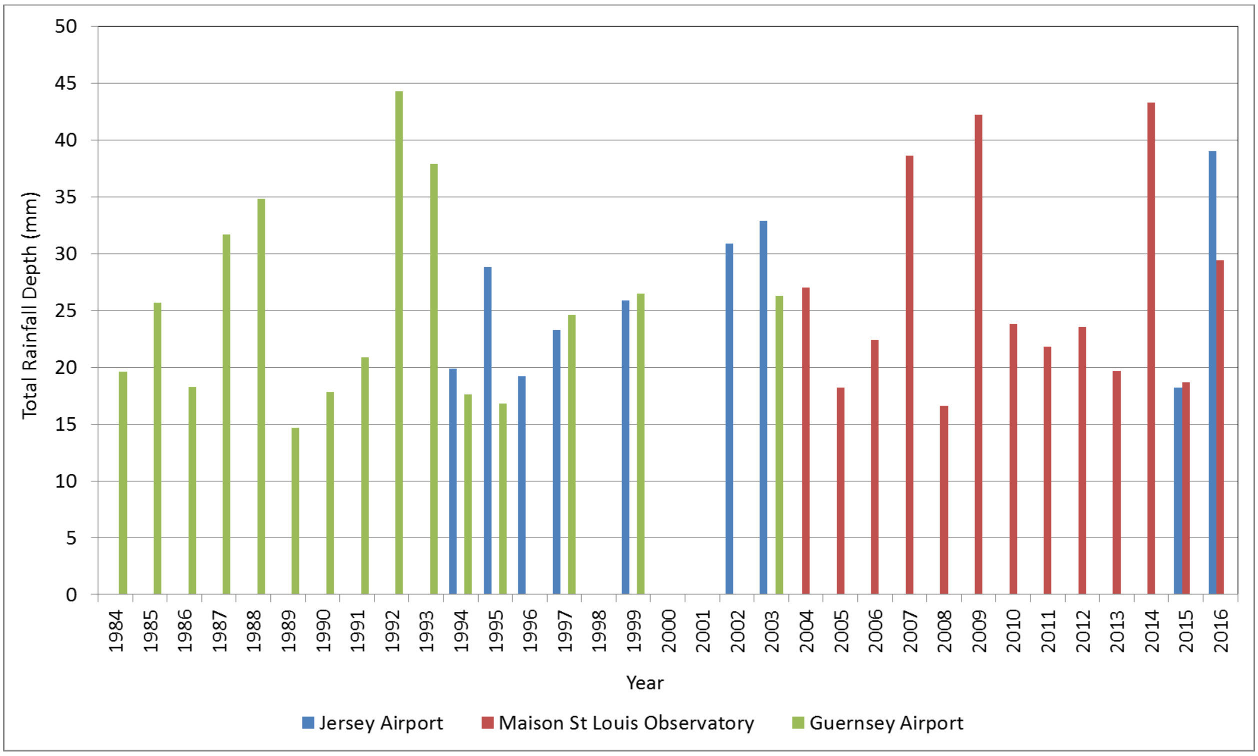

Figure C3: Six Hour Total AMAX Series for sub-daily Rainfall Gauges on Jersey and Guernsey

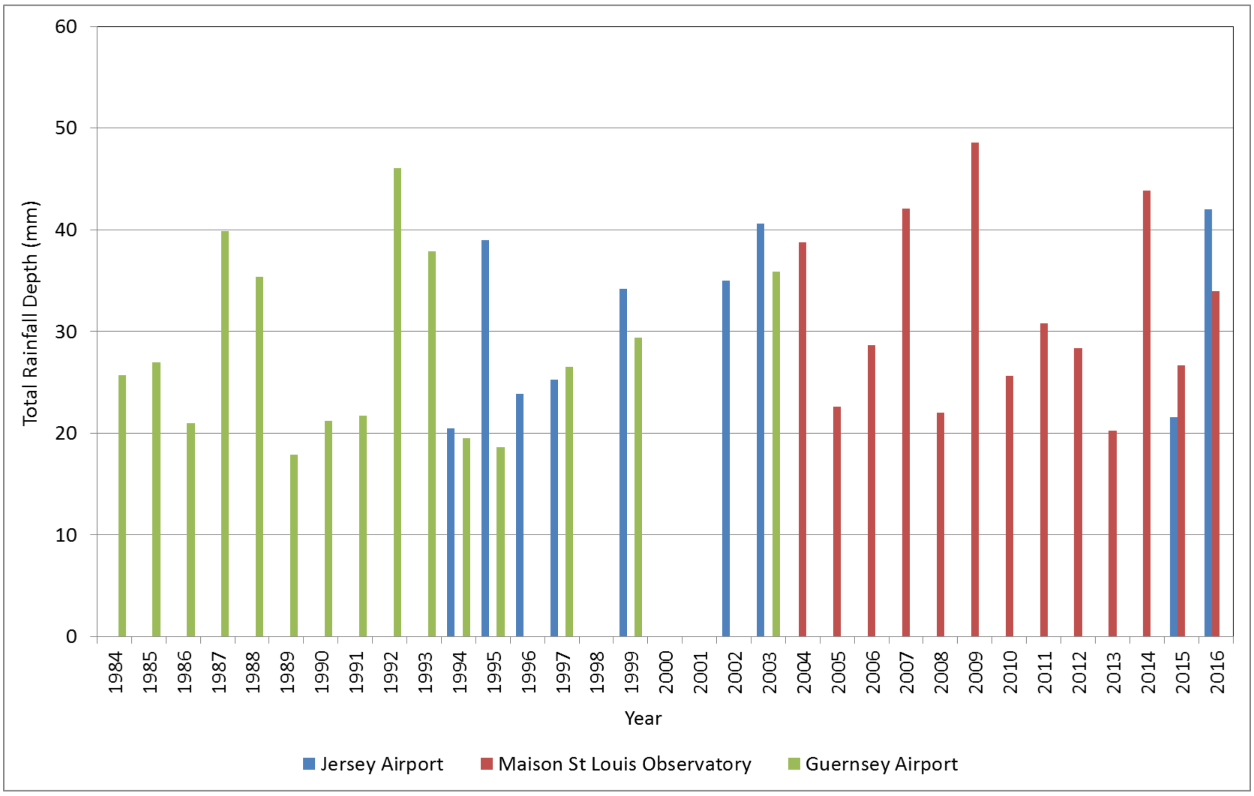

Figure C4: Ten Hour Total AMAX Series for sub-daily Rainfall Gauges on Jersey and Guernsey

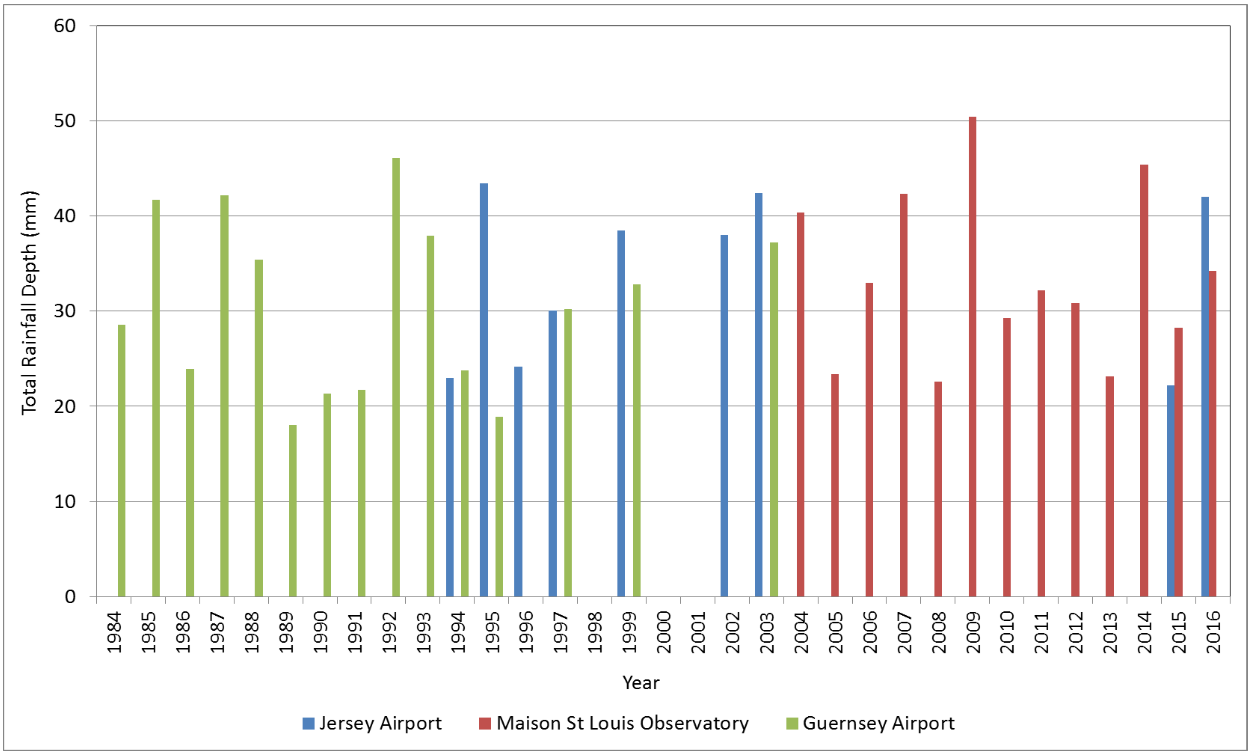

Figure C5: Twelve Hour Total AMAX Series for sub-daily Rainfall Gauges on Jersey and Guernsey

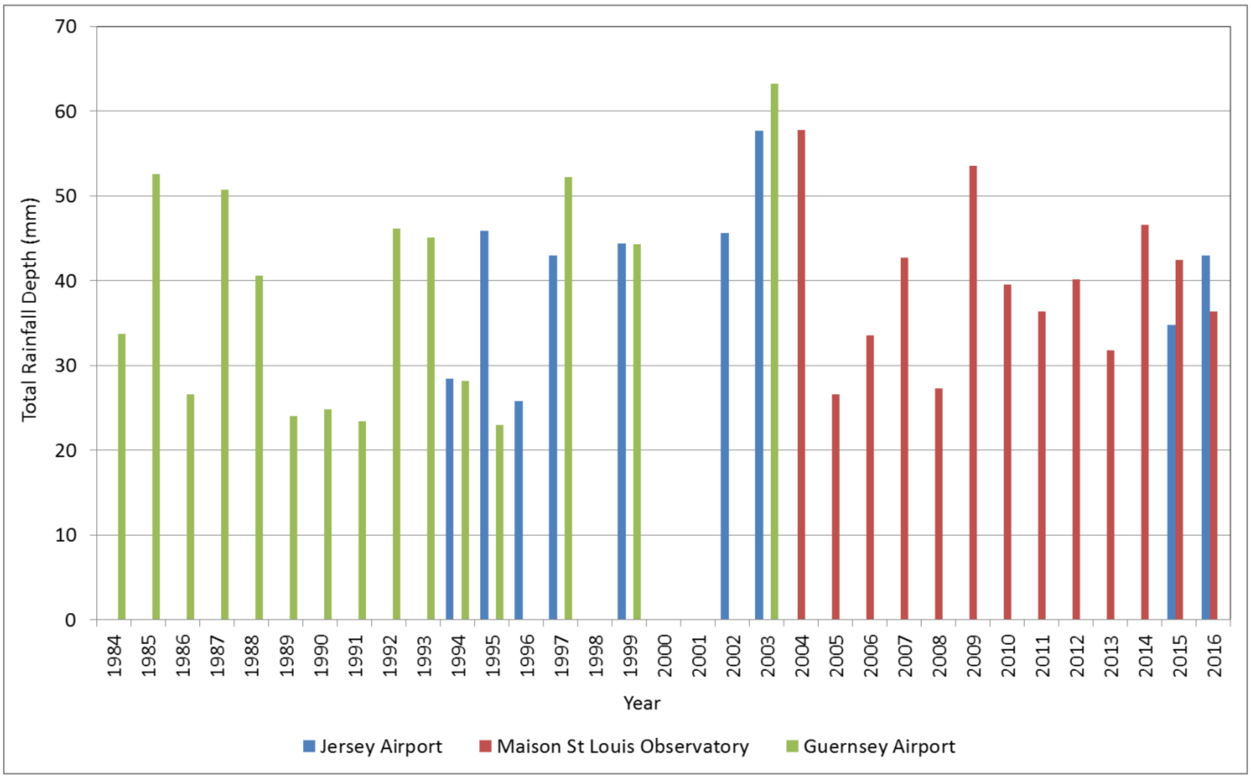

Figure C6: Twenty Four Hour Total AMAX Series for sub-daily Rainfall Gauges on Jersey and Guernsey

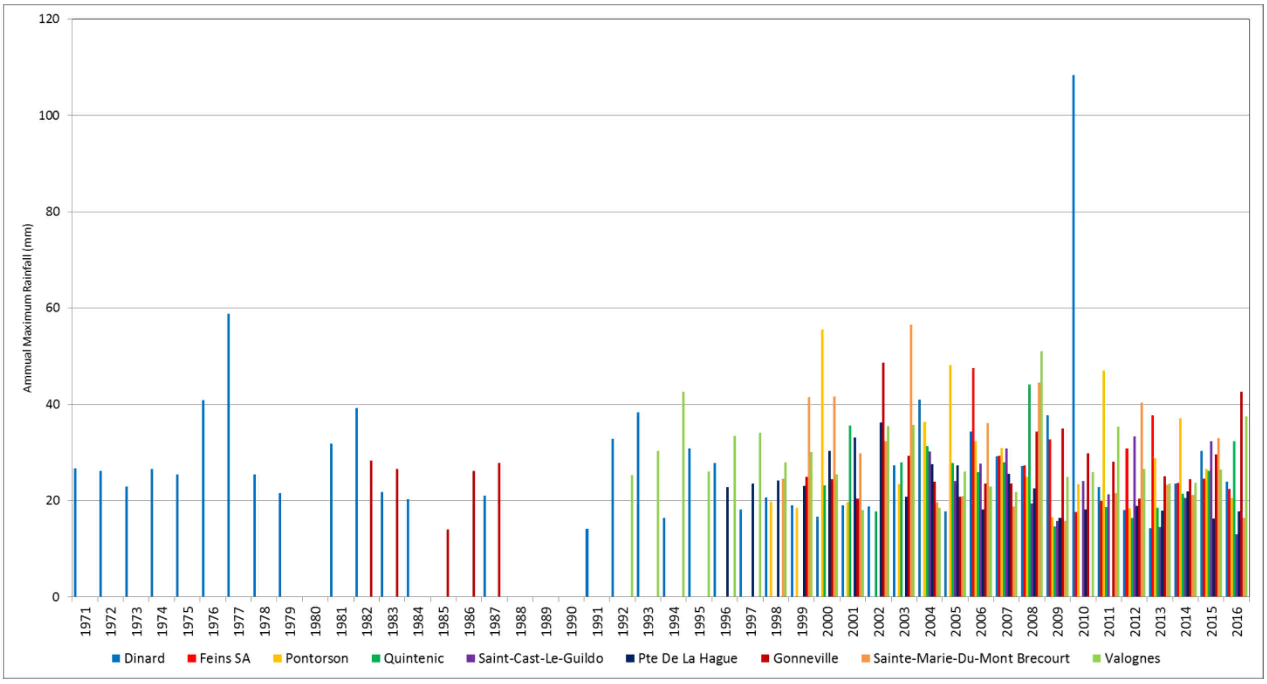

Figure C7: Six Hour Total AMAX Series for Météo-France Rainfall Gauges

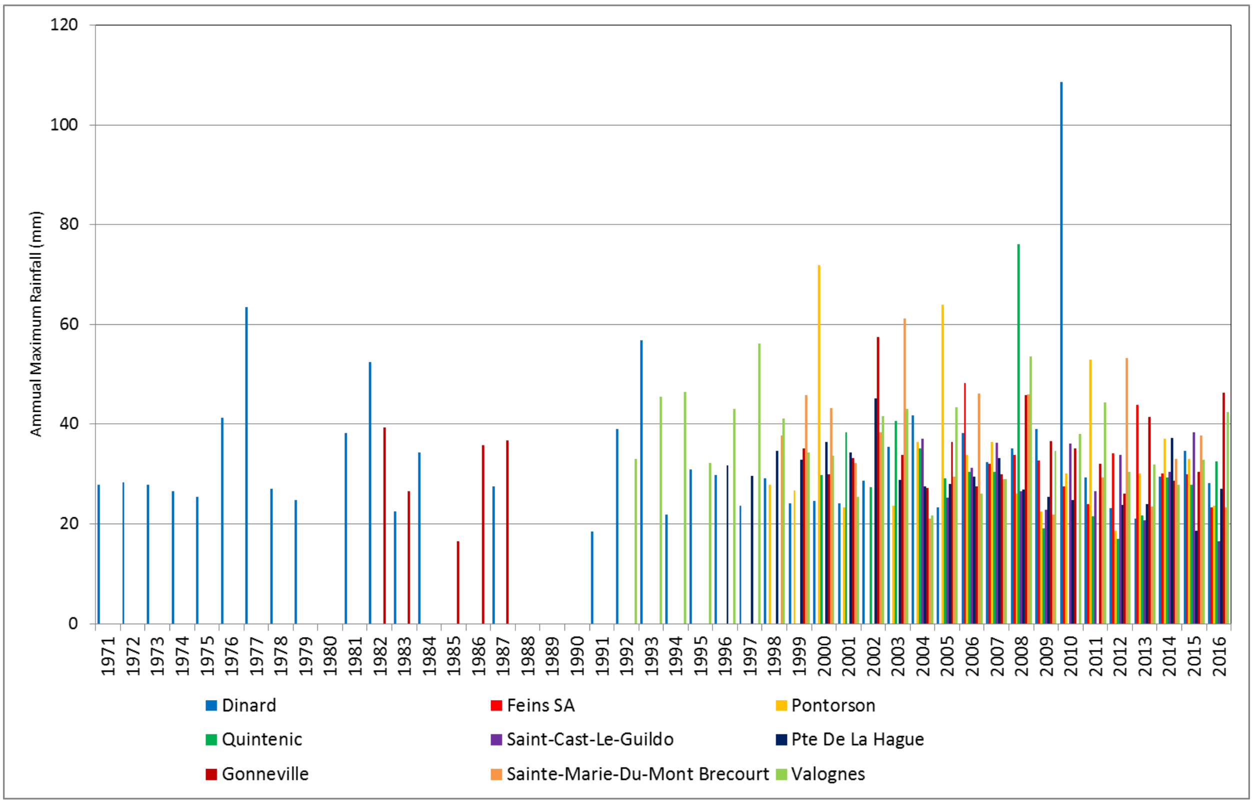

Figure C8: Twelve Hour Total AMAX Series for Météo-France Rainfall Gauges

Appendix C Notes on Quality and Availability of Jersey Rainfall Data