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Montserrat Airport Development Study

Phase II Design study

DESIGN FLOOD ESTIMATION FOR THE FARM RIVER

Report to Sir Alexander Gibb & Partners

April 1992

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EXECUTIVE SUMMARY

1. All proposed runway alignments for the extension of Blackburne Airport on the island of Montserrat crossed the Farm River, the main river on the eastern side of the island (SAG&P, 1988). Two solutions were proposed. First, a culvert beneath the runway on the line of the existing river and second, diversion of the river to follow a new alignment passing north of the airport.

2. The Institute of Hydrology was contracted to derive design flood hydrographs of return periods 5 to 100 years for the Farm River at the diversion dam/culvert inlet site.

3. The unit hydrograph and losses model was used to generate design flood hydrographs since the entire hydrograph was required and rainfall data were obtained as input to the model. No flow data were available, thus precluding calibration of a statistical flow model.

4. The unit hydrograph time to peak, T_p, was calculated to be about 2 hours as an average from a number of empirical formulae. Percentage runoff ranged between 78% for the 5 year flood and 84% for the 100 year flood based on recommendations in the UK *Flood Studies Report* and the US Soil Conservation Service methods.

5. Insufficient short duration rainfall data were available for Montserrat. In lieu of this, rainfall statistics were for Guadeloupe, an island some 100 km to the south east of Montserrat. As there was no information to suggest otherwise, a given return period rainfall was assumed to generate the same return period flood peak.

6. The resulting flood peaks ranged from 66.4 m^3s^{-1} for the 5 year flood and 117.6 m^3s^{-1} for 100 year flood. These estimates seemed to be intuitively reasonable, but could be considered as upper best estimates since the values of PR and rainfall depth used were generous.

1. BACKGROUND

A pre-feasibility study to extend the Blackburne Airport on the island of Montserrat was undertaken by Sir Alexander Gibb & Partners (SAG&P, 1988) for the Government of Montserrat funded by UK Overseas Development Administration. All proposed runway alignments crossed the Farm River, the main river on the eastern side of the island. Two solutions were proposed. First, a culvert beneath the runway on the line of the existing river and second, diversion of the river to follow a new alignment passing north of the runway and discharging into the sea at a new outlet.

As part of Phase II (Design study) Wallingford Water was contracted by Sir Alexander Gibb & Partners; the Institute of Hydrology to derive design flood hydrographs of return periods 5 to 100 years for the Farm River at the diversion dam/culvert inlet site and Hydraulics Research to provide geomorphological advice on the design of the diversion channel.

2. INTRODUCTION

2.1 General

Montserrat is a 102 km^2 island in the Leeward Islands of the Caribbean. The climate is tropical maritime with a mean of 26°C and little seasonal variation. Average annual rainfall varies between 1070 mm at sea level and 2050 mm at 365 m. Rainfall is variable but July to January is usually the wettest time of year. However, there is a risk of short term drought at any time. Montserrat is in the cyclone belt; the last to hit was cyclone Hugo in 1989. Severe flooding from the Farm River was reported to have occurred in 1955 and 1981.

2.2 Geology, soils and vegetation.

Montserrat is volcanic in origin and made up primarily of ashes and lavas ranging in age from 4.3 million to 400 years old. The Soufrieres volcano is dormant but not extinct. Consequently, the soils are almost entirely volcanic in origin. Clays are most common in the north and sandy loams in the south. Details given in Lang (1967) indicate that the soils in the Farm River catchment are predominantly clay loams. The natural vegetation is tropical forest but much has been cleared to grassland.

Farm River catchment/

proposed diversion dam/culvert inlet site/

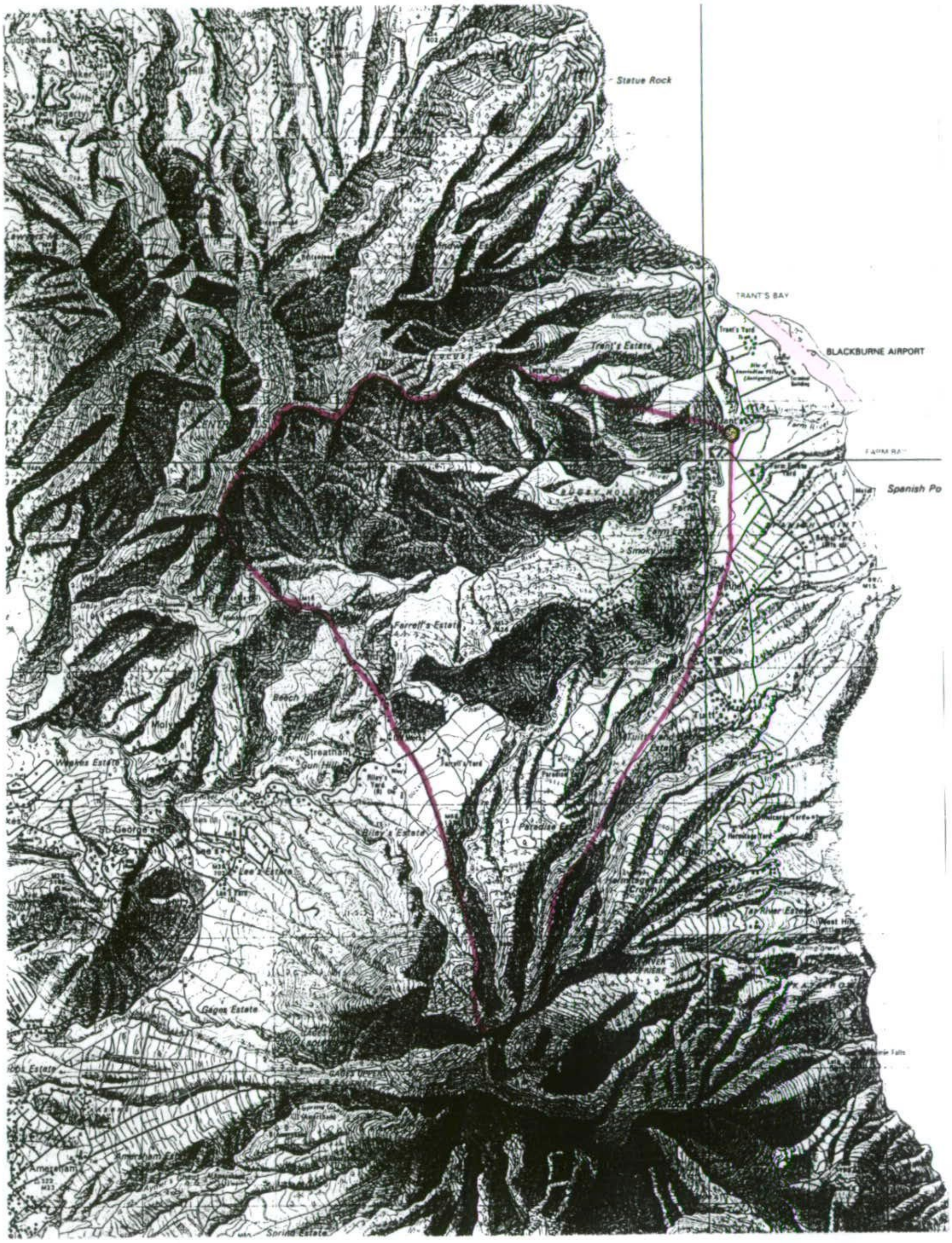

Figure 2.3.1 Location of the Farm River catchment, Blackburn Airport and proposed diversion dam/culvert inlet site.

2.3 Morphology

The relief of the island is rugged and slopes are locally very steep. The Farm River drains the south-eastern flanks of the Centre Hills and part of the northern slopes of the Soufriere Hills. The morphometric characteristics of the catchment at the proposed diversion dam/culvert inlet site are given in Table 2.3.1 as measured from the 1:25,000 series map published in 1983 (Figure 2.3.1).

Table 2.3.1 Morphometric characteristics

Drainage area	10.4	km^2
Main stream length	5.63	km
Main stream slope (10% - 85%)	0.0895	$m\ m^{-1}$

2.4 Rainfall

The average annual rainfall is given as 1490 mm by the Ministry of Natural resources from the Republic of Venezuela (MNRRV 1978) for a part of the Farm River catchment whose drainage area is 9.73 km^2, but the isohyetal map shown in Corker (1986) suggests a figure closer to 1650 mm for the catchment at the proposed diversion dam/culvert inlet site.

2.5 Runoff

MNRRV concluded that the catchment was impermeable since the soils have a low rate of infiltration. The catchment has a mix of grassland and timber vegetation. Monthly average runoff calculated by MNRRV, derived from rainfall 1935-1964 and a modified US Soil Conservation Service rainfall-runoff model, ranged from 64600 m^3 (an average flow of 0.03 m^3s^{-1}) for February to 586800 m^3 (0.22 m^3s^{-1}) in October.

3. DATA AVAILABILITY

3.1 Flow data

There were no continuous flow measurement stations on the island, all available estimates of flow had been made using rainfall data and rainfall-runoff models.

3.2 Rainfall data

Good records of monthly rainfall depths and their statistics were available for Montserrat, but these could not be used directly for design flood estimation. The only rainfall depths of shorter duration available were maximum 24 hour rainfalls for January 1982-August 1984. In lieu of data from Montserrat itself, rainfall statistics for durations 24 hours and shorter were obtained for Raizet Airport on the island of Guadeloupe from its Meteorological Office. Guadeloupe is some 100 km south east of Montserrat.

3.3 Runoff processes

Since there were no flow data available, there were also no measurements of runoff rates. Process rates were thus estimated indirectly from information on morphology and soil types using empirical equations.

4. PREVIOUS STUDIES

4.1 Small dams for irrigation study

A number of studies had considered water resources available from rivers but only one had considered flood flows. This was a feasibility study of small dams for irrigation purposes undertaken by the Ministry of Natural Resources from the Republic of Venezuela (MNRRV, 1978). The account of the work is very short and lacks details, however it indicates that empirical methods were used to derive flood estimates including the rational formula and US Soil Conservation tables. Results for the Farm River Basin are given in Table 4.1.1. The exact location on the river for which the estimates are applicable is not specified but the report refers to the catchment area of the Farm River as 9.73 km^2

The return period of the discharge estimate was not specified. SAG&P (1988) concluded that the return period was, most likely, 10000 years or a 'probable maximum flood'. Using this value SAF&P derived the provisional flood peak estimates given in Table 4.1.2, though these were considered to be no more than informed guesses and could not be rigorously justified. These were assumed to applicable for the diversion dam/culvert inlet site.

Table 4.1.1 Flood estimates for Farm River (after MNRRV, 1978)

Method	Flood estimate (m^3s^{-1})
Meyer	329
Scimeni	306
Triangular hydrogram*	384
Adopted	340

* 150 mm rainfall CN=78

Table 4.1.2 Flood estimates for Farm River (after SAG&P, 1988)

Return period (years)	Flood estimate (m^3s^{-1})
10	125
100	200
1000	270
10000	340

* 150 mm rainfall CN=78

4.2 Resources assessment

Corker (1986) produced a resource assessment for Montserrat. The report assesses the physical resources as they affect agriculture and rural planning. Climate was assessed by analysis of monthly rainfall probabilities. The report does not refer directly to floods but some of the information such as land use, soils and a map of average annual rainfall, provides useful background.

4.3 Soil and land use survey

Lang (1967) provides details of the geology and soils types found on the island. He reports that the soils in the Farm River catchment are predominantly clay loams giving an indication of the likely flood runoff coefficient.

5. METHODOLOGY

Complete flow hydrographs were required for the design of both options (culverts and diversion channel). Basic statistical methods normally only yield estimates of peak flow and require flow records for calibration, which were not available. In contrast the unit hydrograph and losses method is able to produce full design hydrographs and makes use of rainfall data, which were obtained. In addition, a number of empirical formula relating rainfall-runoff model parameters to the physical characteristics of the catchment have been published which could be applied in Montserrat. Furthermore many engineers prefer this approach to a purely statistical analysis of runoff data since the parameters tend to have a direct physical meaning, including catchment response time and proportion of rainfall which produces flood runoff. Application of the unit hydrograph and losses method is undertaken in two parts. First, a model to transform rainfall to runoff is constructed and second a design rainfall input is specified.

6. RAINFALL-RUNOFF MODEL SPECIFICATION

6.1 Choice of model

As the name implies, the unit-hydrograph and losses model consist of two components each having a primary parameter.

(1) The losses model separates total storm rainfall into effective rainfall which produces flood runoff and rainfall losses which are either evaporated or percolate to groundwater or deep soil storage. The main parameter is PR, the percentage of rainfall which generates storm runoff.

(2) The unit hydrograph transforms the effective rainfall profile into a runoff hydrograph. The primary parameter is Tp, the time-to-peak of the unit hydrograph. Details of model options are given in standard hydrology text books such as Shaw (1983).

6.2 Unit hydrograph derivation

Various equations were used to estimate the unit hydrograph time-to-peak, Tp, from the physical characteristics of the catchment. The *Flood Studies Report* of the British Isles (NERC, 1975) provides a formula based on stream length and slope:

$$\begin{aligned} Tp &= 2.8\,(L/\sqrt{S})^{0.47} \\ &= 2.19 \text{ hr} \end{aligned} \qquad (6.2.1)$$

where the slope, S, is in m km^{-1}.

The Soil Conservation Service (SCS) method, developed in the USA (McCuen, 1982) has several steps:

$$\text{lag} = L^{0.8}\,(SMR + 1)^{0.7} / 1900\,S^{0.5} \quad (6.2.2)$$
$$= 1.095 \text{ hr}$$

where SMR is the soil moisture retention potential and L is in feet, followed by

$$tc = 1.667 \text{ lag} \quad (6.2.3)$$
$$= 1.82 \text{ hr}$$

and

$$Tp = (tc + d)/1.7 \quad (6.2.4)$$
$$= 4.6 \text{ hr}$$

for d (storm duration) of 6 hours. Other formulae include that proposed by Kirpish (1940):

$$Tp = 0.0195\,L^{0.77}\,S^{-0.385} \quad (6.2.5)$$
$$= 0.64 \text{ hr}$$

and Synder (1938):

$$Tp = 2.0(L\,L_c)^{0.3} \quad (6.2.6)$$
$$= 3.38 \text{ hr}$$

where L_c is the length of the main stream to the catchment centroid in miles. Om Kar (Bell & Om Kar, 1969) derived several equations for estimating hydrograph rise times: (a) T = time from start of rise to peak flow; and (b) T' = time from 5% of total rise to peak flow :

(a) $$\log T = 0.06 + 0.47 \log L_c \quad (6.2.7)$$
$$= 1.44 \text{ hr}$$

and

(b) $$\log T' = -0.08 + 0.51 \log L_c \quad (6.2.8)$$
$$= 1.07 \text{ hr}$$

A summary of the results is given in Table 6.2.1 and indicates that a time-to-peak of around 2 hours seems to be a reasonable average estimate and is consistent with experience.

The use of empirical formulae derived from elsewhere in the world may be questionable. However, these formulae generally use channel length and slope to determine the typical catchment response time and these are physical characteristics of the catchment not unique to any climatic zone or region, although the exponents and multiples in the formulae may reflect local conditions. Nevertheless, if results from a range of formulae fall within a narrow range, there is no reason why an average value should not be applicable outside of the regions from where they were derived.

Table 6.2.1 Estimate of unit hydrograph Tp by various methods

Method	Flood estimate (m^3s^{-1})
Flood Studies Report	2.19
US SCS	4.60
Kirpish	0.64
Synder	3.38
Om Kar (a)	1.44
(b)	1.07
Chosen value	2.00

Research for the *Flood Studies Report* (NERC, 1975) revealed a consistent relationship between Tp and the 10 mm unit hydrograph peak flow, Q_p:

$$Q_p T_p = 220 \qquad (6.2.9)$$

where Q_p is in m^3s^{-1} $100km^{-2}$.

Using Equation (6.2.9) for the Farm River, Tp of 2 hours gives

$$Q_p = 11.4 \ m^3s^{-1}.$$

In the SCS method Q_p is given by

$$Q_p = 484 \ AQ/T_p \qquad (6.2.10)$$

where A is the catchment area (miles^2) and Q is the volume (inches). In this case the volume is 10 mm (0.39"), thus $Q_p = 17.4 \ m^3s^{-1}$. The SCS report suggests that for mountain areas the constant 484 could be increased to 600 producing an estimate of 21.6 m^3s^{-1}. This discharge was felt to be too high and equation (6.2.9) was adopted.

6.3 Percentage runoff specification

In the application of the US SCS method, derivation of percentage runoff requires selection of the appropriate curve number, CN, which relate runoff volume to rainfall volume assuming an initial loss followed by a decreasing loss rate. In its analysis of flood frequency, MNRRV (1978) employed CN = 78. This value is consistent with their description of catchment having mixed grassland and forest vegetation. However, for the steep slopes and impermeable soils a CN as high as 88 might be appropriate. Given the magnitude of the design rainfall storms to be used (Table 8.3.1) this is equivalent to approximately 80% runoff. This could be regarded as an upper limit.

To allow percentage runoff, PR, to vary with storm magnitude, the methodology adopted for the losses model in the *Flood Studies Report* (NERC, 1975) was used.

PR is made up of two components, a dynamic component (DPR) term and a standard, fixed, component (SPR). The form of the model used was as follows

$$PR = SPR + DPR_{rain} \qquad (6.3.1)$$

where

$$DPR_{rain} = 0.45\ (P - 40)^{0.7} \quad \text{where } P > 40 \text{ mm} \qquad (6.3.2)$$

$$= 0.0 \quad \text{where } P \leq 40 \text{ mm}$$

where P is the total rainfall depth.

Using an SPR value of 70%, this gave PR equal to 78-84% for the 5 - 100 year return period rainfall events. This is broadly similar to that which would be produced by application of the SCS method.

7. DESIGN RAINFALL ESTIMATES

7.1 Rainfall data

The majority of rainfall data available for Montserrat were monthly totals. No short duration (less than 24 hours) data were available, but annual maximum 24 hour rainfalls for Blackburne Airport were provided by the Meteorological Service as given in Table 7.1.1.

Table 7.1.1 Annual maximum 24 hour rainfalls for Blackburne Airport

Year	Annual maximum inches	24 hour rainfall mm
1982	1.44	36.6
1983	2.20	55.9
1984 (Jan - Aug)	1.12	28.4

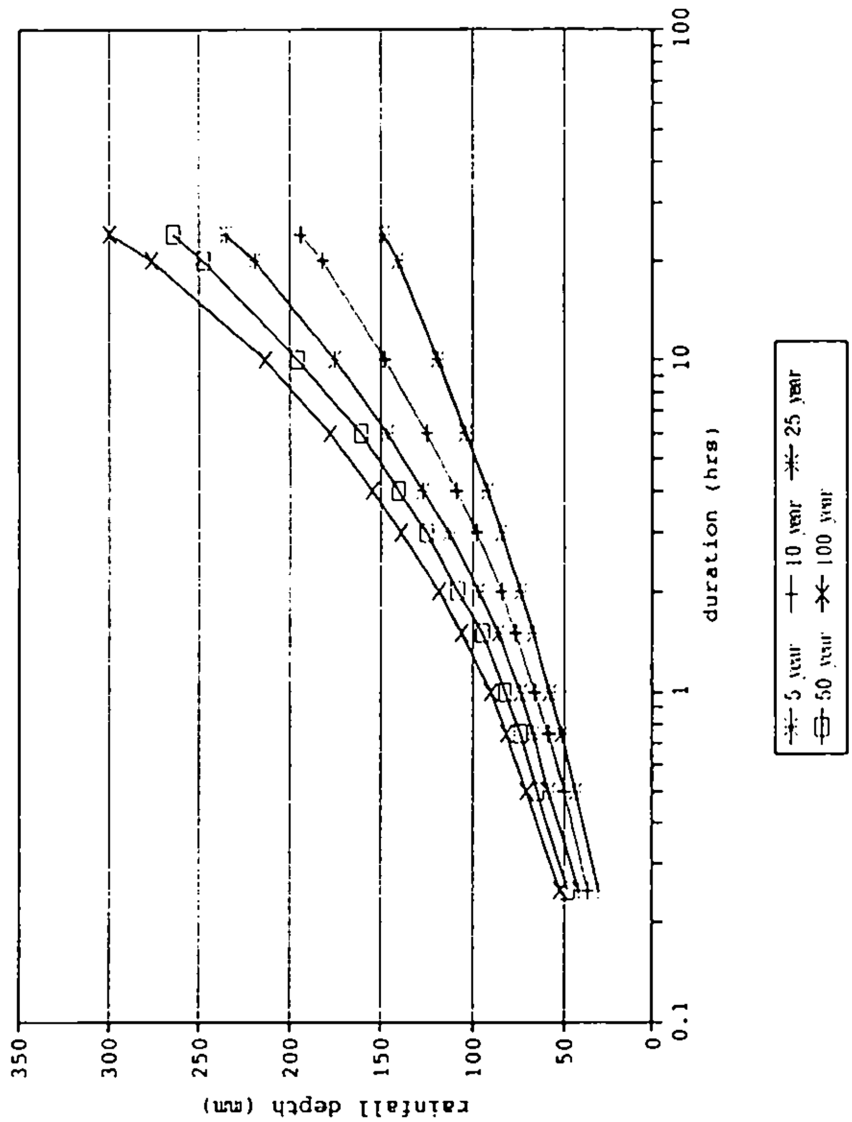

Figure 7.2.1 Depth duration frequency relationships for rainfall data from Raizet Airport, Guadeloupe

7.2 Depth-duration-frequency relationships

Due to the lack of sufficient data from Montserrat, short duration rainfall statistics were obtained for Raizet Airport on the nearby island of Guadeloupe from its Meteorological Office. Guadeloupe is only about 100 km south east of Montserrat and thus it was felt that the rainfall regime would be broadly similar. Annual maximum 24 hour rainfall data were also available for the island of St. Lucia, which lies some 400 km SSE of Monserrat. These data were very similar to those for Guadeloupe suggesting that the Guadeloupe statistics might be typical of the eastern Caribbean and hence appropriate for use on Montserrat.

These are given in Table 7.2.1 and are shown graphically in Figure 7.2.1. They are based on data for the period 1961-1990. The lowest 24 hour annual maximum for that period is about 55 mm (measured from a graph provided by the Guadeloupe Met Office). The year in which this was recorded is not known, but it is greater than the annual maxima for Montserrat given in Table 7.1.1, hence 24 hour rainfall depths appeared to be slightly greater on Guadeloupe. Nevertheless both airports are located virtually at sea level and it was assumed that rainfall intensities would be greater in the upper reaches of the Farm River than at its mouth (perhaps more similar to those experienced on Guadeloupe). Unfortunately, neither this rainfall gradient nor the relative wetness of the Montserrat and Guadeloupe airports could be readily quantified. Consequently the it was assumed that the rainfall statistics given in Table 7.2.1 were appropriate as an average for the Farm catchment, although they may be considered as 'upper best estimates'.

Table 7.2.1 Extreme rainfall statistics (mm) for Guadeloupe

Return period (years)	Duration		
	30 minutes	2 hours	24 hours
5	44	73	159
10	50	84	194
25	58	97	235
50	64	108	265
100	70	118	300

7.3 Areal reduction factor

Clearly areal rainfalls of specified return are less that point depths. However, the Farm catchment is only 10.4 km^2, thus an areal reduction factor would only be close to 100%. Thus, given that no data on the actual areal extent of storms was available and that the appropriateness of the rainfall statistics adopted was rather uncertain, no reduction for a catchment average rainfall was made.

7.4 Design rainfall profiles

Symmetrical profiles for the design rainfalls were constructed by nesting rainfall depths of various durations using a data interval of one quarter of an hour. The central quarter hour rainfall ordinate was set to be equal to the 15 minute rainfall of specified return period interpolated from Figure 7.2.1. In turn the total rainfall depth in the central three quarters of an hour of the design storm was set equal to the 45 minute rainfall as interpolated from Figure 7.2.1. Thus the ordinates on either side of the central ordinate have rainfall depths equal to half the difference between the 15 and 45 minute rainfalls. This process was continued until a design storm of required duration (which will have an odd number of data intervals) was derived. The resulting rainfall profiles for 5, 25, 50 and 100 years are given in Table 7.4.1.

Table 7.4.1 Design rainfalls storms for the Farm catchment. Depths in mm, each of 0.25 hr duration.

5	1.0	1.5	2.0	2.0	2.0	2.0	3.0	3.0
	4.0	5.5	10.0	31.0	10.0	5.5	4.0	3.0
	3.0	2.0	2.0	2.0	2.0	1.5	1.0	1.0
25	2.0	2.5	3.0	3.0	3.5	4.0	4.0	4.5
	6.0	7.0	12.0	42.0	12.0	7.0	6.0	4.5
	4.0	4.0	3.5	3.0	3.0	2.5	2.0	2.0
50	2.5	2.5	3.0	3.5	3.4	4.0	4.0	5.5
	7.0	7.5	13.5	46.0	13.5	7.5	7.0	5.5
	4.0	4.0	3.5	3.5	3.0	2.5	2.5	2.0
100	2.5	3.0	3.0	3.5	4.0	4.5	5.5	6.0
	7.0	8.5	14.5	52.0	14.5	8.5	7.0	6.0
	5.5	4.5	4.0	3.5	3.0	3.0	2.5	2.5

7.5 Design rainfall duration

When the design rainfall intensity is constant, as in the rational formula, design storm duration is critical. However, where a uni-modal storm profile is adopted a balance is achieved between increasing duration and decreasing average intensity. The peakedness of the design profiles shown in Table 7.4.1 suggests that storm duration would not be of great important.

To investigate the effects of design rainfall duration on the resulting peak flow a series of model runs was undertaken, once the rainfall-runoff model had been specified. For each run the same unit hydrograph time-to-peak of just over two hours was used.

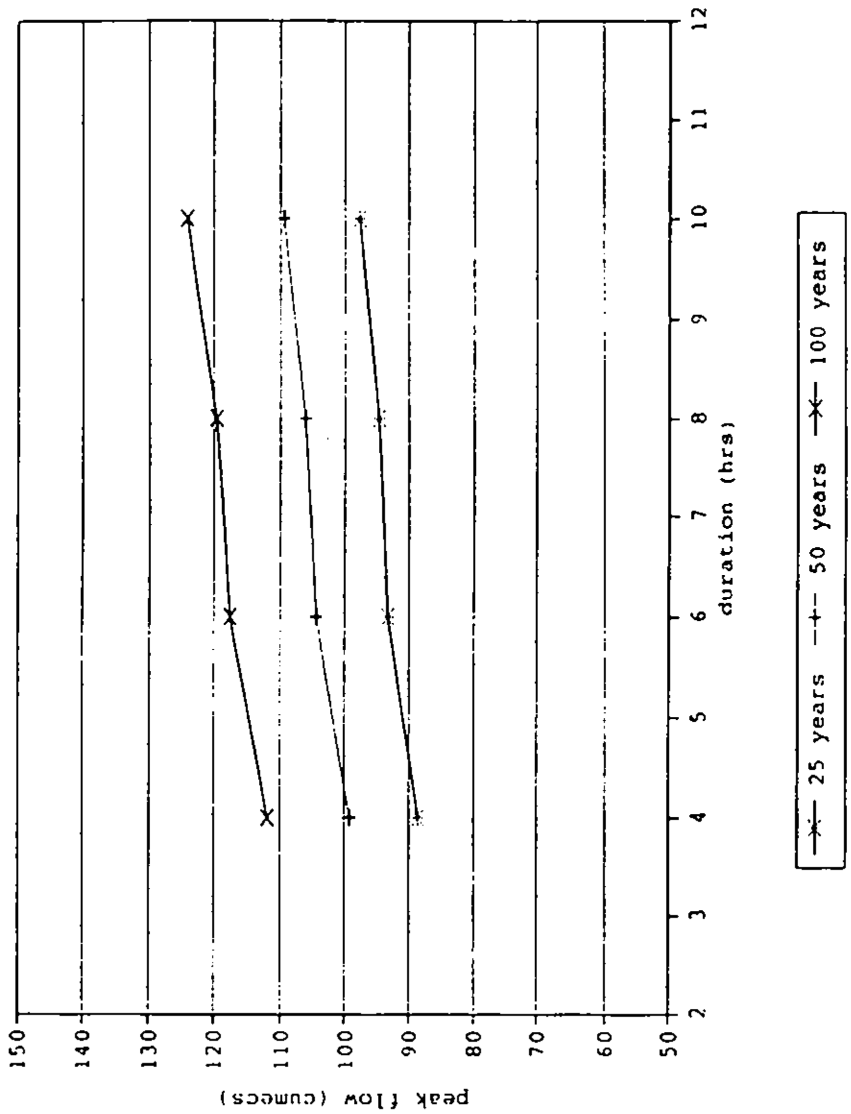

Figure 7.5.1 Peak flow rates from design rainfall storms of 4, 6, 8 and 10 hours duration for return periods 25, 50 and 100 years

Figure 7.5.1 shows the peak flow rates from design rainfall storms of 4, 6, 8 and 10 hours duration for return periods 25, 50 and 100 years. It can be seen that the 6 hour duration storm yields a peak flow significantly above the 4 hour storm, but that the increase from 6 to 8 hours is less pronounced. Consequently a design storm duration of 6 hours was chosen.

8. RESULTING FLOOD ESTIMATES

8.1 Choice of rainfall return period

In some design methods, such as for rural catchments the *Flood Studies Report* (NERC, 1975), the return periods of the rainfall input to the unit hydrograph/losses model and the resulting flood peak are not equal. For example, a 140 year rainfall is used to derive a 100 year flood event. However, that return period relationship was defined by simulation experiments and only holds if other parameters, such as a catchment wetness index, have the specified design values. It was not aimed at recording a fundamental truth. Due to there being no information to suggest otherwise, a given return period rainfall was assumed to generate the same return period flood peak.

8.2 Running the model

The model was run using rainfall return periods of 5, 25, 50 and 100 years of six hours duration. PR was calculated using Equation (6.3.1) with SPR equal to 70%. This was applied to each rainfall ordinate. For the unit hydrograph, Tp was taken as 2 hours and the peak flow was 11.4 m^3s^{-1} (109.45 m^3s^{-1} km^{-2}).

8.3 Results

The estimates of flood peaks of return periods 5, 25, 50 and 100 years using the unit hydrograph and losses model are given in Table 8.3.1. The resulting flood frequency curve is shown graphically in Figure 8.3.1. These can be considered as upper best estimates since liberal values of PR and rainfall were incorporated. Full hydrographs are shown graphically in Figure 8.3.2 and their ordinates are given in Appendix I.

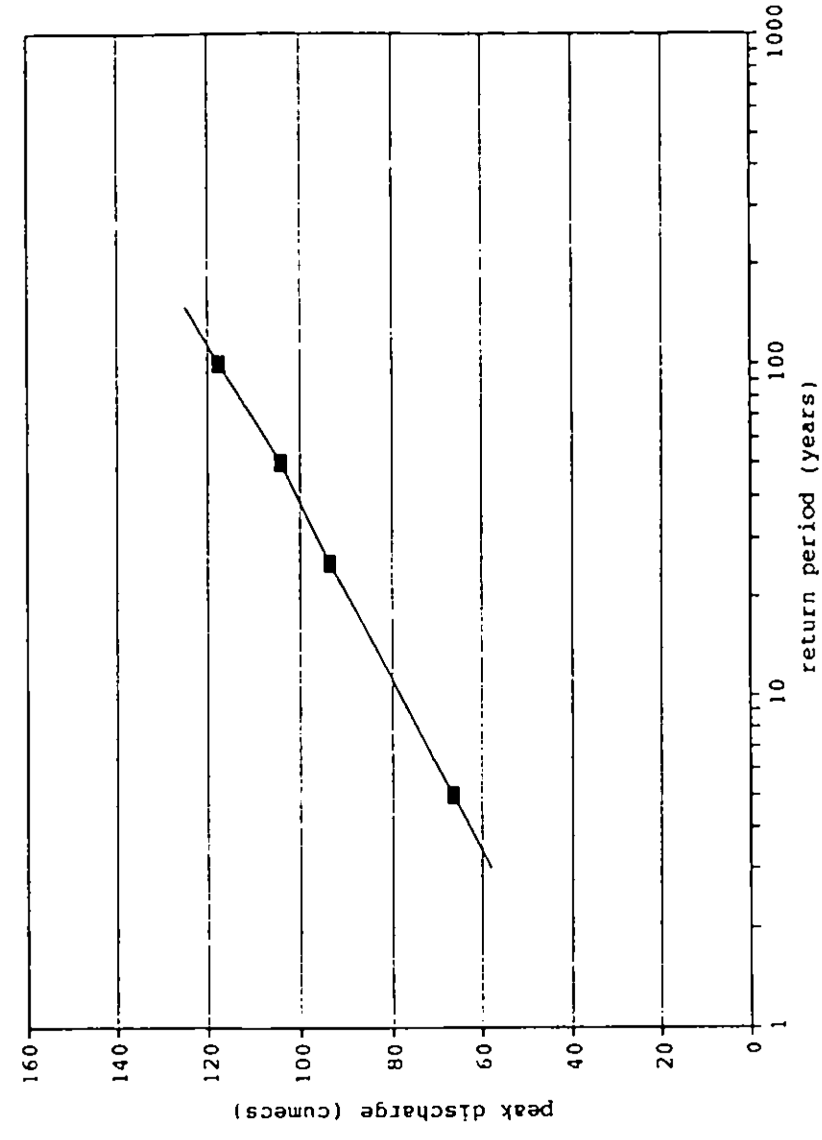

Figure 8.3.1 Flood frequency curve for the Farm River, Montserrat at the proposed diversion dam/culvert inlet site

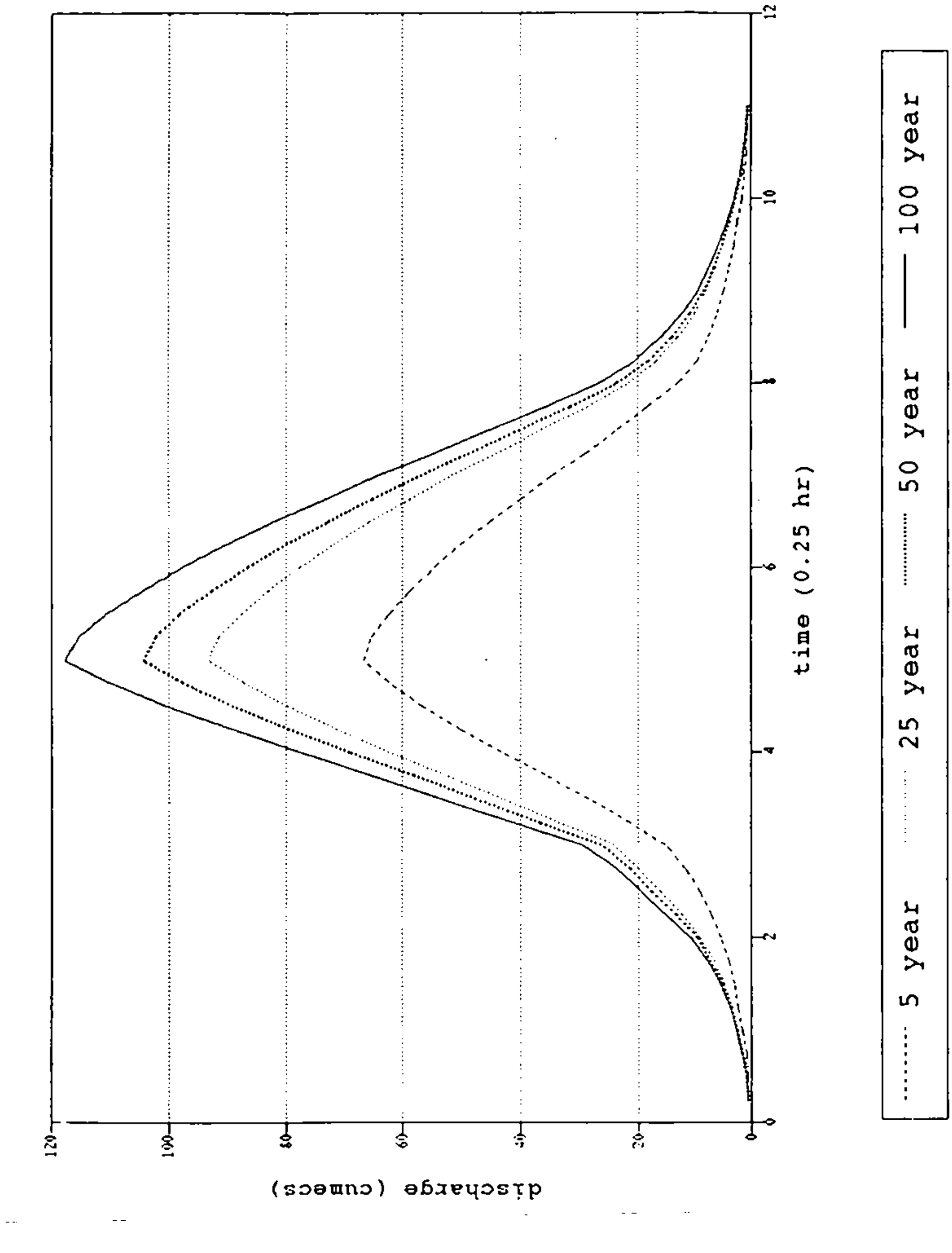

Figure 8.3.2 Flood hydrographs for the Farm River at the proposed diversion dam/culvert inlet site

Table 8.3.1 Design flood peak flow estimates

Return period (years)	Rainfall total (mm)	Percentage runoff (%)	Peak flow (m^3s^{-1})
5	104.0	78.3	66.4
25	147.0	81.9	93.4
50	161.0	83.0	104.3
100	178.5	84.2	117.6

9. SUMMARY

The unit hydrograph and losses model were used to generate design flood hydrographs on the Farm River at the diversion dam/culvert inlet site, of return periods 5 to 100 years. The unit hydrograph time to peak, T_p, was calculated to be about 2 hours and the percentage runoff ranged between 78% for the 5 year flood and 84% for the 100 year flood. Rainfall data from Guadeloupe were used as input to the model.

The resulting flood peaks ranged from 66.4 m^3s^{-1} for the 5 year flood and 117.6 m^3s^{-1} for 100 year flood. These estimates seemed to be intuitively reasonable, but could be considered as upper best estimates since the values of PR and rainfall depth used were generous.

10. REFERENCES

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APPENDIX I **Design flood hydrographs for the Farm River at the diversion dam/culvert inlet site, Blackburne Airport, Montserrat.**

5 year design rainfall storm

Area (sq.km)	10.40
Data interval (hr)	0.25
Design duration (hr)	6.00
Total rain (mm)	104.00
Percentage runoff	78.27
Baseflow	0.05

Traingular unit hydrograph computed from Tp= 2.01

Convolution of unit hydrograph and net rainfall profile

Time	Total Rain mm	Net Rain mm	Unit Hydrograph ordinate	Total Hydrograph cumecs	
0.00	1.00	0.78	0.00	0.47	
0.25	1.50	1.17	13.68	0.58	
0.50	2.00	1.57	27.36	0.86	
0.75	2.00	1.57	41.04	1.36	
1.00	2.00	1.57	54.73	2.08	
1.25	2.00	1.57	68.41	3.03	
1.50	3.00	2.35	82.09	4.20	
1.75	3.00	2.35	95.77	5.70	
2.00	4.00	3.13	109.45	7.54	
2.25	5.50	4.30	100.96	9.64	
2.50	10.00	7.83	92.02	12.08	
2.75	31.00	24.26	83.08	15.27	
3.00	10.00	7.83	74.14	21.54	
3.25	5.50	4.30	65.19	28.56	
3.50	4.00	3.13	56.25	35.82	
3.75	3.00	2.35	47.31	42.98	
4.00	3.00	2.35	38.37	49.92	
4.25	2.00	1.57	29.43	56.46	
4.50	2.00	1.57	20.48	62.22	
4.75	2.00	1.57	11.54	66.37	-Peak-
5.00	2.00	1.57	2.60	65.12	
5.25	1.50	1.17		62.22	
5.50	1.00	0.78		58.56	
5.75	1.00	0.78		54.40	
6.00				49.94	
6.25				45.07	
6.50				39.98	
6.75				34.72	
7.00				29.31	
7.25				23.80	
7.50				18.38	
7.75				13.40	
8.00				10.06	
8.25				7.88	
8.50				6.20	
8.75				4.84	
9.00				3.72	
9.25				2.82	
9.50				2.09	
9.75				1.50	
10.00				1.06	
10.25				0.76	
10.50				0.58	
10.75				0.49	

Total Flood Volume (cubic metres) 867255.508

25 year design rainfall storm

Area (sq.km)	10.40
Data interval (hr)	0.25
Design duration (hr)	16.00
Total rain (mm)	147.00
Percentage runoff	81.85
Baseflow	0.05

Traingular unit hydrograph computed from Tp= 2.01

Convolution of unit hydrograph and net rainfall profile

Time	Total Rain mm	Net Rain mm	Unit Hydrograph ordinate	Total Hydrograph cumecs	
0.00	2.00	1.64	0.00	0.47	
0.25	2.50	2.05	13.68	0.70	
0.50	3.00	2.46	27.36	1.23	
0.75	3.00	2.46	41.04	2.10	
1.00	3.50	2.86	54.73	3.32	
1.25	4.00	3.27	68.41	4.95	
1.50	4.00	3.27	82.09	7.05	
1.75	4.50	3.68	95.77	9.61	
2.00	6.00	4.91	109.45	12.70	
2.25	7.00	5.73	100.96	16.11	
2.50	12.00	9.82	92.02	19.85	
2.75	42.00	34.38	83.08	24.41	
3.00	12.00	9.82	74.14	33.29	
3.25	7.00	5.73	65.19	42.90	
3.50	6.00	4.91	56.25	52.55	
3.75	4.50	3.68	47.31	62.13	
4.00	4.00	3.27	38.37	71.37	
4.25	4.00	3.27	29.43	79.92	
4.50	3.50	2.86	20.48	87.60	
4.75	3.00	2.46	11.54	93.39	-Peak-
5.00	3.00	2.46	2.60	91.56	
5.25	2.50	2.05		87.76	
5.50	2.00	1.64		83.06	
5.75	2.00	1.64		77.66	
6.00				71.84	
6.25				65.50	
6.50				58.69	
6.75				51.51	
7.00				44.08	
7.25				36.49	
7.50				28.94	
7.75				21.79	
8.00				16.80	
8.25				13.38	
8.50				10.59	
8.75				8.29	
9.00				6.37	
9.25				4.76	
9.50				3.45	
9.75				2.42	
10.00				1.63	
10.25				1.07	
10.50				0.71	
10.75				0.51	

Total Flood Volume (cubic metres) 1273045.680

50 year design rainfall storm

Area (sq.km)	10.40
Data interval (hr)	0.25
Design duration (hr)	16.00
Total rain (mm)	161.00
Percentage runoff	82.92
Baseflow	0.05

Unit hydrograph used from previous case (see above)

Convolution of unit hydrograph and net rainfall profile

Time	Total Rain mm	Net Rain mm	Unit Hydrograph ordinate	Total Hydrograph cumecs	
0.00	2.50	2.07	0.00	0.47	
0.25	2.50	2.07	13.68	0.76	
0.50	3.00	2.49	27.36	1.35	
0.75	3.50	2.90	41.04	2.30	
1.00	3.50	2.90	54.73	3.65	
1.25	4.00	3.32	68.41	5.42	
1.50	4.00	3.32	82.09	7.67	
1.75	5.50	4.56	95.77	10.38	
2.00	7.00	5.80	109.45	13.74	
2.25	7.50	6.22	100.96	17.45	
2.50	13.50	11.19	92.02	21.56	
2.75	46.00	38.14	83.08	26.68	
3.00	13.50	11.19	74.14	36.54	
3.25	7.50	6.22	65.19	47.31	
3.50	7.00	5.80	56.25	58.19	
3.75	5.50	4.56	47.31	69.12	
4.00	4.00	3.32	38.37	79.62	
4.25	4.00	3.32	29.43	89.24	
4.50	3.50	2.90	20.48	97.87	
4.75	3.50	2.90	11.54	104.30	-Peak-
5.00	3.00	2.49	2.60	102.30	
5.25	2.50	2.07		98.03	
5.50	2.50	2.07		92.76	
5.75	2.00	1.66		86.63	
6.00				79.93	
6.25				72.70	
6.50				65.00	
6.75				56.91	
7.00				48.54	
7.25				40.08	
7.50				31.70	
7.75				23.74	
8.00				18.20	
8.25				14.43	
8.50				11.37	
8.75				8.86	
9.00				6.81	
9.25				5.10	
9.50				3.70	
9.75				2.58	
10.00				1.73	
10.25				1.13	
10.50				0.72	
10.75				0.51	

Total Flood Volume (cubic metres) 1410402.800

100 year design rainfall storm

Area (sq.km)	10.40
Data interval (hr)	0.25
Design duration (hr)	16.00
Total rain (mm)	178.50
Percentage runoff	84.20
Baseflow	0.05

Unit hydrograph used from previous case (see above)

Convolution of unit hydrograph and net rainfall profile

Time	Total Rain mm	Net Rain mm	Unit Hydrograph ordinate	Total Hydrograph cumecs	
0.00	2.50	2.10	0.00	0.47	
0.25	3.00	2.53	13.68	0.77	
0.50	3.00	2.53	27.36	1.43	
0.75	3.50	2.95	41.04	2.45	
1.00	4.00	3.37	54.73	3.88	
1.25	4.50	3.79	68.41	5.80	
1.50	5.50	4.63	82.09	8.26	
1.75	6.00	5.05	95.77	11.37	
2.00	7.00	5.89	109.45	15.20	
2.25	8.50	7.16	100.96	19.39	
2.50	14.50	12.21	92.02	24.00	
2.75	52.00	43.78	83.08	29.76	
3.00	14.50	12.21	74.14	41.05	
3.25	8.50	7.16	65.19	53.30	
3.50	7.00	5.89	56.25	65.66	
3.75	6.00	5.05	47.31	77.79	
4.00	5.50	4.63	38.37	89.44	
4.25	4.50	3.79	29.43	100.37	
4.50	4.00	3.37	20.48	110.17	
4.75	3.50	2.95	11.54	117.59	-Peak-
5.00	3.00	2.53	2.60	115.28	
5.25	3.00	2.53		110.44	
5.50	2.50	2.10		104.48	
5.75	2.50	2.10		97.67	
6.00				90.22	
6.25				81.98	
6.50				73.19	
6.75				64.01	
7.00				54.60	
7.25				45.11	
7.50				35.66	
7.75				26.72	
8.00				20.49	
8.25				16.25	
8.50				12.81	
8.75				9.95	
9.00				7.58	
9.25				5.65	
9.50				4.10	
9.75				2.87	
10.00				1.93	
10.25				1.24	
10.50				0.78	
10.75				0.53	

Total Flood Volume (cubic metres) 1585530.190