Wheal Jane Ltd

Clemows Valley Tailings Dam

Flood Study

March 2013

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Contents

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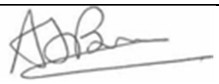
Signature:			
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1 Introduction

Clemows Valley Tailings Dam (CVTD) is not officially classified as a large raised reservoir but the Health and Safety Executive requires such tailings dams to meet the same flood safety standards as are applied to large raised reservoirs, as set out in "Floods and Reservoir Safety (3rd. edition) and associated DEFRA guidance. The current analysis brings the flood assessment in line with current standards (March 2013), taking account of the recommendations in the Flood Estimation Handbook.

2 Available Data

The following data and information was made available to Stillwater Associates during the preparation of this report:

- Survey drawings of the site (file "Topographical Survey of Wheal Jane Overall Site Dwgs 11-3138-022_026.DXF").
- Spillway length and level (communications from Cantab Consulting (CC) specify 2m wide broad crested weir set at 67.7mOD).
- Current water area and water area available for flood storage (communications from CC specify: combined area of all paddocks 86,409m^2; central reservoir and approach paddock area 46,802m^2; only the central 46,802m^2 is available for flood routing).
- Details of required flood standards (communications from CC specify: no outflow permitted in 1000 year event; spillway to accommodate PMF; diversion channel to accommodate PMF).

3 Probable Maximum Flood Assessment

The construction of the CVTD required the diversion of the Clemows stream round the western boundary of the dam site such that the direct catchment of the dam is reduced to the impounded area and an area of hillside to the north. The diversion channel is reported to have been designed to carry the Probable Maximum Flood (PMF) from its own catchment and the dam must accommodate the PMF from its direct catchment.

3.1 Diversion channel catchment

The diversion channel catchment increases along its length and is influenced by the CVTD which impounds part of the area which would have drained naturally to the channel. The areas have been assessed from Ordnance Survey contours and the detailed survey of the site as shown in Figure 1. The points for which the assessment has been made are the start of the diversion (A), the channel drop structure at the position shown (B) and a point just downstream from the works (C).

The catchment to the diversion point is the natural catchment to that location.

As noted, the catchment is reduced by the presence of the CVTD. The routes by which extreme flood flows from the incremental catchment between points A and B would enter the diversion channel will be heavily influenced by the detailed landform to the north west of the CVTD and it is considered that it would be prudent to use the flow assessed at the drop structure, point B, to design the channel between points A and B.

The further incremental catchment to the downstream limit of the analysis is largely the natural catchment to the west of the channel plus part of the downstream slope of the dam. It would be appropriate to design the channel between the points B and C to carry the flow assessed at the downstream limit, point C.

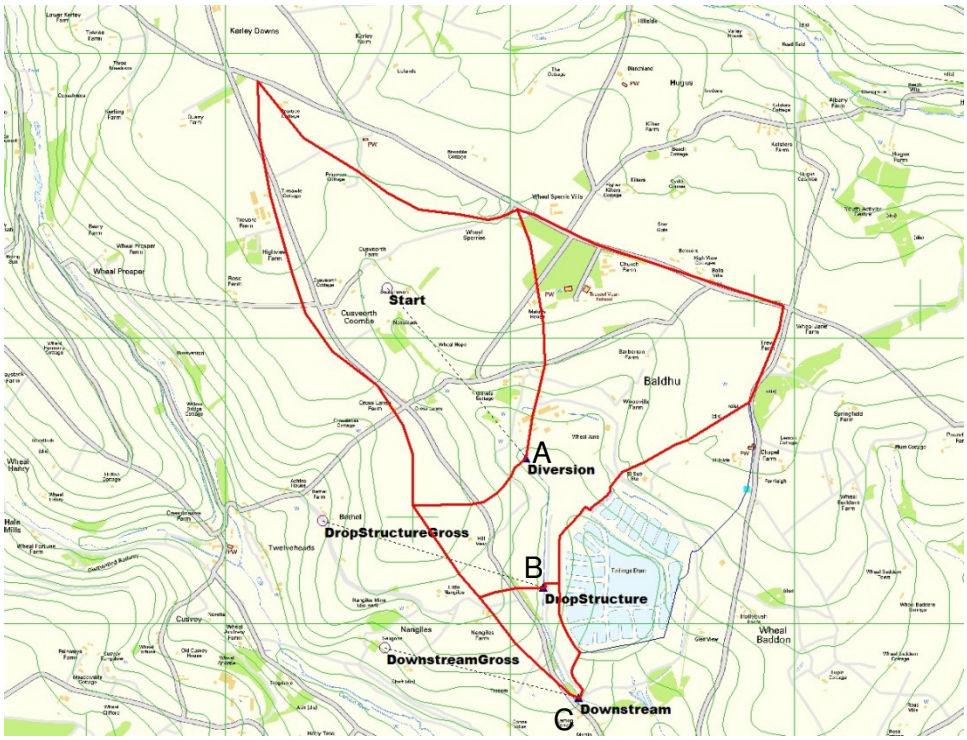

Figure 1 : Diversion Channel Catchments

3.2 Diversion channel PMF calculations

The catchment areas cannot be identified precisely in the FEH-CDROM software as the presence of the dam is not taken fully into account in the ground model used in that program. The best analysis point available is apparently within the CVTD water area, as shown in Figure 2. It is considered that the analysis should be based on the catchment parameters to this point, modified by substituting the catchment areas estimated from the OS contours and site survey for each of the points of interest, as described above.

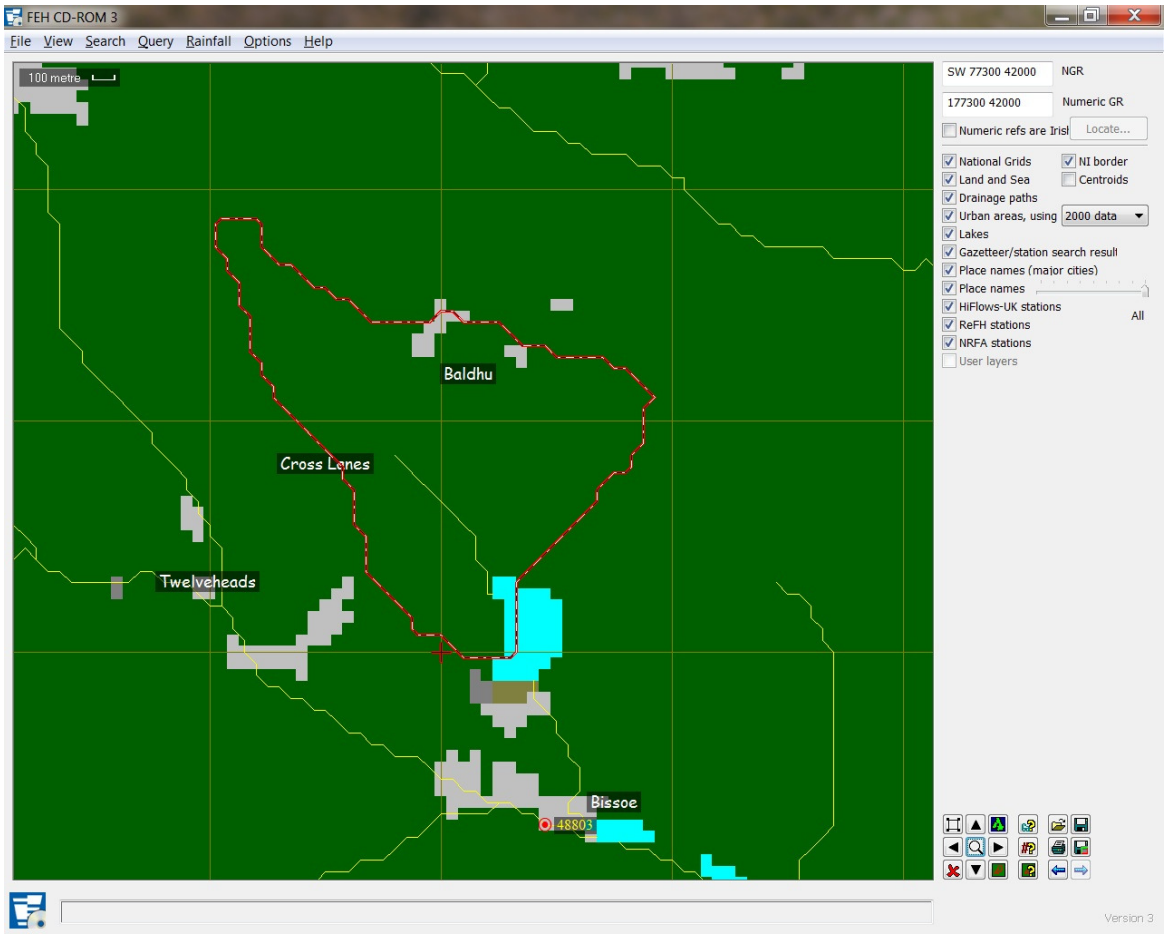

Figure 2: FEH-CDROM Catchment Area

The peak PMF flood flow calculations have been carried out using InfoWorksRS v12.5 for summer and winter PMF and the summary results are included in Appendix A.

The catchment areas assessed and the calculated peak flows are summarised below in Figure 3. The Summer PMF hydrograph for point C is shown in Figure 4.

Calculation point	Incremental catchment area	Gross catchment area	Winter PMF peak flow	Summer PMF peak flow
	km^2	km^2	m^3/s	m^3/s
Diversion point (A)	-	0.760	7.284	8.661
Drop structure (B)	0.714	1.474	14.010	16.652
Downstream limit (C)	0.067	1.541	14.638	17.397

Figure 3: Diversion channel PMF flows

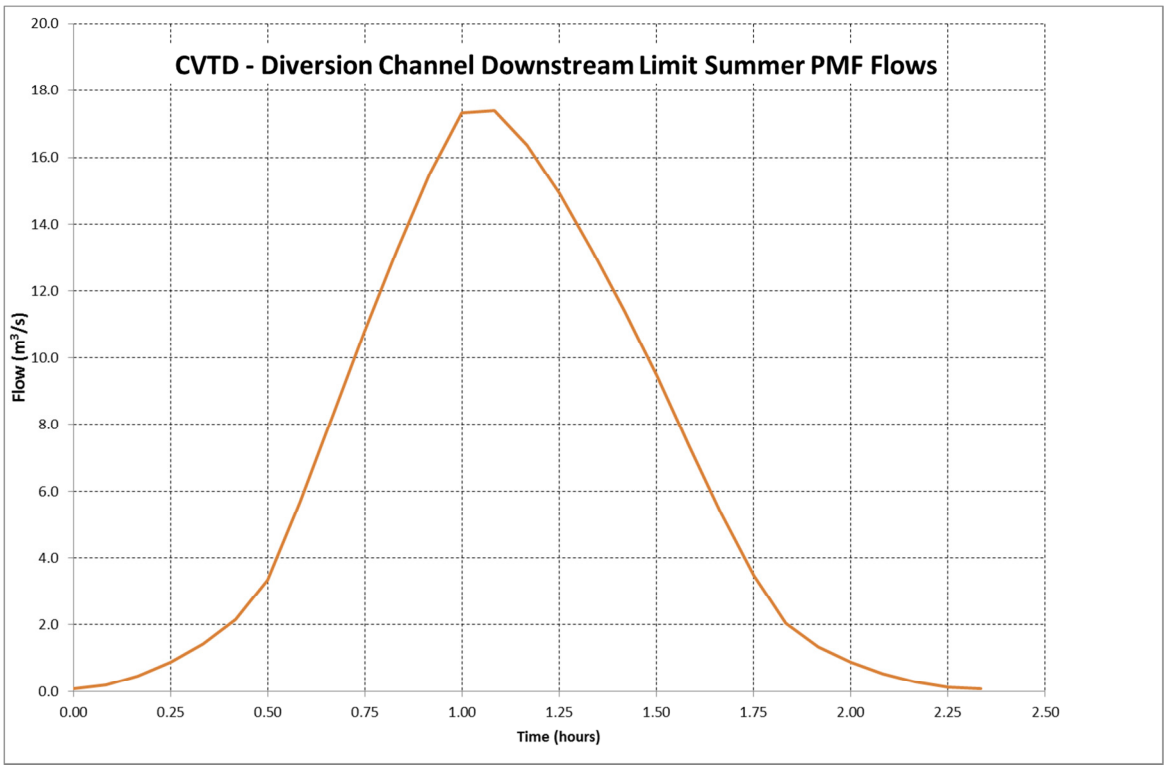

Figure 4: Point C PMF Hydrograph

3.3 Dam catchment and reservoir configuration

The gross catchment of the dam as assessed from the contours is shown in Figure 5. The total water surface area is stated to be 86,409m^2 and the total catchment area is measured as 329,032m^2. Given the particular circumstances, it is considered appropriate to assess the inflow from direct rainfall on the water surface separately from the runoff from the rest of the catchment.

The overflow weir is said to be a 2m wide broad crested structure at a level of 67.70mOD. Only the 46,802m^2 central reservoir and approach paddock are assumed to be available for flood storage. This central reservoir and approach paddock area is referred to as “paddock” in the flood calculations.

Figure 5: Dam Direct Catchment

3.4 Dam PMF inflow and routing calculation

The dam catchment is too small to assess its unit hydrograph time to peak fully from the FEH catchment characteristics. The length of the longest drainage path to the drop structure is about 2180m. The distance from the furthest point of the catchment to the centre of the reservoir is 700m and the ratio of these lengths is 0.32. Taking the catchment characteristics to the drop structure, inserting the non-water catchment area and adding a time-to-peak scaling factor of 0.32, gives a time to peak of 0.5hours which is considered to be suitably conservative.

The calculations are set out in Appendix B and the corresponding hydrographs are plotted in Figure 6. The results may be summarised as:

Peak total inflow in PMF = 10.329 m^3/s

Peak outflow in PMF = 1.703 m^3/s

Maximum water level in Paddock in PMF = 68.330 mAOD

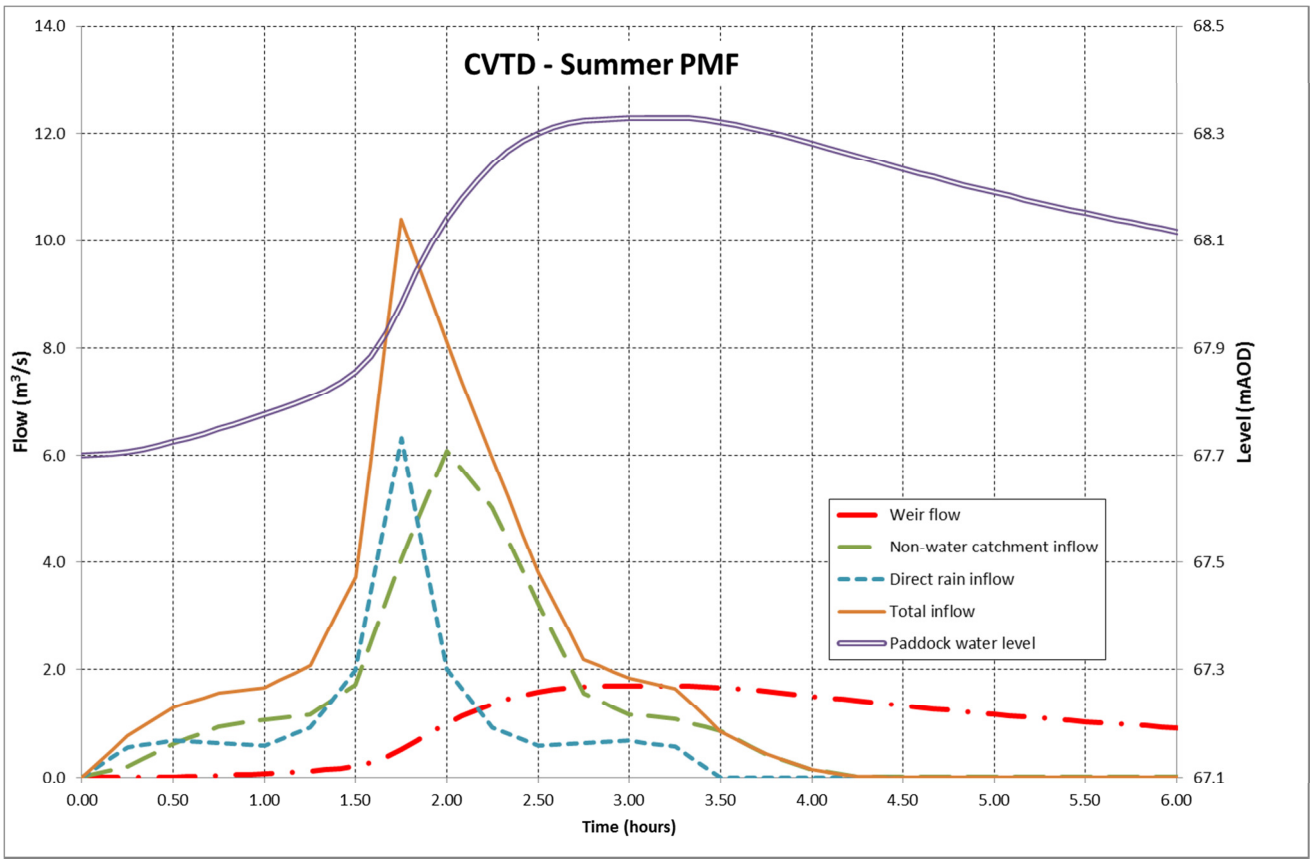

Figure 6 – PMF routing

3.5 1000 year flood events for CVTD dam

It is a requirement that no spill occurs from the dam in events of up to 1000 years return (0.1% annual probability). It is understood that the storage considered above for flood routing purposes is also the area available for storing lower events and that water can be abstracted to the adjacent treatment works to keep the water level low enough to provide the necessary storage.

For this assessment, it is reasonable to assume that all possible 1000 year rainfall depth and duration combinations will need to be accommodated. The FEH Depth-Duration-Frequency (DDF) model has been used to estimate rainfall depths with a 1000 year return period for the dam location for a range of durations, as tabulated in Figure 7.

A conventional rainfall-runoff assessment involves assumptions about “rapid runoff” and “losses” commonly based on a percentage of rainfall assessed from information on hydrological soil type. A runoff percentage of 47.0 is predicted for a 1000 year flood in the area of CVTD. “Losses” represent rainfall which does not contribute to rapid response flood flows but which may appear over a longer time scale as seepage through soil horizons or via deeper geological strata. Local flow records would normally be required for this effect to be quantified properly. In the absence of this information, there may be some risk involved in allowing only for rapid response flows whilst allowing for the total rainfall may be rather conservative. The table shows the depth required to store the runoff volume with and without losses for a range of event durations up to 7 days. In each case the assumed runoff volume loss is shown and quantified as an average flow rate over the event duration. Note that 100% runoff is assumed for the whole area of the paddocks.

For example, for a 7 day design duration, 1.62m of freeboard would be sufficient to contain the full rainfall volume on the catchment. Reducing the freeboard to 0.99m would

be sufficient to store the estimated rapid response flow which requires losses to occur at an average equivalent flow rate of 1.179m^3/s.

Duration days	1000 year rainfall depth (mm)	Total rainfall volume (m^3)	Corresponding depth in paddock (m)	Rapid response flow volume (m^3)	Corresponding depth in paddock (m)	Rainfall loss (m^3)	Rainfall loss as flow (m3/s)
0.25	126.38	41631	0.89	25358	0.54	16273	18.081
0.50	148.41	48888	1.04	29778	0.64	19110	10.617
0.75	158.6	52244	1.12	31822	0.68	20422	7.564
1.00	166.25	54764	1.17	33357	0.71	21407	5.946
1.25	172.44	56803	1.21	34599	0.74	22204	4.934
1.75	182.21	60022	1.28	36560	0.78	23462	3.724
2.00	186.24	61349	1.31	37368	0.80	23981	3.331
3.00	199.59	65747	1.40	40047	0.86	25700	2.380
4.00	209.64	69057	1.48	42063	0.90	26994	1.875
5.00	217.78	71739	1.53	43697	0.93	28042	1.558
6.00	224.67	74008	1.58	45079	0.96	28929	1.339
7.00	230.67	75985	1.62	46283	0.99	29702	1.179

Figure 7 – 1000 year rainfall volumes

The assessment as presented ends at seven days but a 1000 year rainfall event could be of any duration and the contributing rainfall could be distributed in any way through the event duration considered. However, the above assessment suggests that the difference between a 6 day and a 7 day event could be of the order of 2000m^3 over 24 hours or an average of 0.023m^3/s.

4 Conclusions

- The CVTD diversion channel is said to have been designed for a flow of 20m^3/s which is greater than the PMF flows assessed above. It is concluded that it should be able to carry the PMF without out-of-bank flows occurring.
- A PMF on the direct catchment of CVTD is estimated to give rise to a maximum wave-free water level 0.63m above the spillway level.
- A 1000 year flood event on the CVTD direct catchment of 24 hour duration is estimated to give rise to a gross rainfall volume of 54,764m^3. 33,357m^3 of this volume is expected to enter the reservoir as “rapid runoff”, after allowance for “losses”. 33357m^3 represents a depth of 0.71m over the area of the central reservoir and approach paddock.

Appendix A Diversion Channel PMF Calculations

IW RS Network, FILE=CHD.dat,   ISIS VER= 12.5.4.23211

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ISIS
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HYDROLOGICAL DATA

Catchment: Start
****
Catchment Characteristics
****
Easting	:	0	Northing	: 0
Area	:	0.760	km2	
DPLBAR	:	1.240	km	
DPSBAR	:	63.400	m/km	
PROPWET	:	0.420		
SAAR	:	1104.000	mm	
Urban Extent	:	0.008		
c	:	0.000		
d1	:	0.000		
d2	:	0.000		
d3	:	0.000		
e	:	0.000		
f	:	0.000		
SPR	:	34.060	%	

****
Summary of estimate using Flood Estimation Handbook rainfall-runoff method
****
Estimation of Probable Maximum flood
==========

Unit hydrograph time to peak	:	1.563	hours
Instantaneous UH time to peak	:	2.146	hours
Data interval	:	0.250	hours
Design storm duration	:	3.250	hours
Critical storm duration	:	3.288	hours
em-2h	:	146.000	
em-24h	:	320.000	
em-25d	:	500.000	
ARF	:	0.000	
Design storm depth	:	175.821	mm
CWI	:	176.489	
Standard Percentage Runoff	:	34.060	%
Percentage runoff	:	60.982	%
Snowmelt rate	:	0.000	mm/day
Unit hydrograph peak	:	140.787	(m3/s/cm/100km2)
Quick response hydrograph peak	:	8.622	m3/s
Baseflow	:	0.038	m3/s
Baseflow adjustment	:	0.000	m3/s
Hydrograph peak	:	8.661	m3/s
Hydrograph adjustment factor	:	1.000	

Flags
=====

Unit hydrograph flag	:	FSRUH
Tp flag	:	FEHTP
Event rainfall flag	:	PMFER
Rainfall profile flag	:	SUMPMP
Percentage Runoff flag	:	FEHPR
Baseflow flag	:	F16BF
CWI flag	:	PMFCW

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IW RS Network, FILE=CHD.dat,   ISIS VER= 12.5.4.23211

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ISIS
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HYDROLOGICAL DATA

Catchment: Start
****
Catchment Characteristics
****
Easting	:	0	Northing	: 0
Area	:	0.760	km2	
DPLBAR	:	1.240	km	
DPSBAR	:	63.400	m/km	
PROPWET	:	0.420		
SAAR	:	1104.000	mm	
Urban Extent	:	0.008		
c	:	0.000		
d1	:	0.000		
d2	:	0.000		
d3	:	0.000		
e	:	0.000		
f	:	0.000		
SPR	:	53.000	%	

****
Summary of estimate using Flood Estimation Handbook rainfall-runoff method
****
Estimation of Probable Maximum flood
==========

Unit hydrograph time to peak	:	1.563	hours
Instantaneous UH time to peak	:	2.146	hours
Data interval	:	0.250	hours
Design storm duration	:	3.250	hours
Critical storm duration	:	3.288	hours
em-2h	:	146.000	
em-24h	:	320.000	
em-25d	:	500.000	
ARF	:	0.000	
Design storm depth	:	127.424	mm
CWI	:	169.870	
Standard Percentage Runoff	:	53.000	%
Percentage runoff	:	74.506	%
Snowmelt rate	:	0.000	mm/day
Unit hydrograph peak	:	140.787	(m3/s/cm/100km2)
Quick response hydrograph peak	:	7.248	m3/s
Baseflow	:	0.036	m3/s
Baseflow adjustment	:	0.000	m3/s
Hydrograph peak	:	7.284	m3/s
Hydrograph adjustment factor	:	1.000	

Flags
=====

Unit hydrograph flag	:	FSRUH
Tp flag	:	FEHTP
Event rainfall flag	:	PMFER
Rainfall profile flag	:	WINPMP
Percentage Runoff flag	:	FEHPR
Baseflow flag	:	F16BF
CWI flag	:	PMFCW

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IW RS Network, FILE=CHD.dat,   ISIS VER= 12.5.4.23211

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ISIS
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HYDROLOGICAL DATA

Catchment: DropStru_1
****
Catchment Characteristics
****
Easting	:	0	Northing	: 0
Area	:	1.474	km2	
DPLBAR	:	1.240	km	
DPSBAR	:	63.400	m/km	
PROPWET	:	0.420		
SAAR	:	1104.000	mm	
Urban Extent	:	0.008		
c	:	0.000		
d1	:	0.000		
d2	:	0.000		
d3	:	0.000		
e	:	0.000		
f	:	0.000		
SPR	:	34.060	%	

****
Summary of estimate using Flood Estimation Handbook rainfall-runoff method
****
Estimation of Probable Maximum flood
==========

Unit hydrograph time to peak	:	1.563	hours
Instantaneous UH time to peak	:	2.146	hours
Data interval	:	0.250	hours
Design storm duration	:	3.250	hours
Critical storm duration	:	3.288	hours
em-2h	:	146.000	
em-24h	:	320.000	
em-25d	:	500.000	
ARF	:	0.000	
Design storm depth	:	174.737	mm
CWI	:	176.548	
Standard Percentage Runoff	:	34.060	%
Percentage runoff	:	60.919	%
Snowmelt rate	:	0.000	mm/day
Unit hydrograph peak	:	140.787	(m3/s/cm/100km2)
Quick response hydrograph peak	:	16.578	m3/s
Baseflow	:	0.074	m3/s
Baseflow adjustment	:	0.000	m3/s
Hydrograph peak	:	16.652	m3/s
Hydrograph adjustment factor	:	1.000	

Flags
=====

Unit hydrograph flag	:	FSRUH
Tp flag	:	FEHTP
Event rainfall flag	:	PMFER
Rainfall profile flag	:	SUMPMP
Percentage Runoff flag	:	FEHPR
Baseflow flag	:	F16BF
CWI flag	:	PMFCW

****

IW RS Network, FILE=CHD.dat,   ISIS VER= 12.5.4.23211

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ISIS
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HYDROLOGICAL DATA

Catchment: DropStru_1
****
Catchment Characteristics
****
Easting	:	0	Northing	: 0
Area	:	1.474	km2	
DPLBAR	:	1.240	km	
DPSBAR	:	63.400	m/km	
PROPWET	:	0.420		
SAAR	:	1104.000	mm	
Urban Extent	:	0.008		
c	:	0.000		
d1	:	0.000		
d2	:	0.000		
d3	:	0.000		
e	:	0.000		
f	:	0.000		
SPR	:	53.000	%	

****
Summary of estimate using Flood Estimation Handbook rainfall-runoff method
****
Estimation of Probable Maximum flood
==========

Unit hydrograph time to peak	:	1.563	hours
Instantaneous UH time to peak	:	2.146	hours
Data interval	:	0.250	hours
Design storm duration	:	3.250	hours
Critical storm duration	:	3.288	hours
em-2h	:	146.000	
em-24h	:	320.000	
em-25d	:	500.000	
ARF	:	0.000	
Design storm depth	:	126.638	mm
CWI	:	169.888	
Standard Percentage Runoff	:	53.000	%
Percentage runoff	:	74.446	%
Snowmelt rate	:	0.000	mm/day
Unit hydrograph peak	:	140.787	(m3/s/cm/100km2)
Quick response hydrograph peak	:	13.940	m3/s
Baseflow	:	0.071	m3/s
Baseflow adjustment	:	0.000	m3/s
Hydrograph peak	:	14.010	m3/s
Hydrograph adjustment factor	:	1.000	

Flags
=====

Unit hydrograph flag	:	FSRUH
Tp flag	:	FEHTP
Event rainfall flag	:	PMFER
Rainfall profile flag	:	WINPMP
Percentage Runoff flag	:	FEHPR
Baseflow flag	:	F16BF
CWI flag	:	PMFCW

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HYDROLOGICAL DATA

Catchment: Downstre_1
****
Catchment Characteristics
****
Easting	:	0	Northing	: 0
Area	:	1.541	km2	
DPLBAR	:	1.240	km	
DPSBAR	:	63.400	m/km	
PROPWET	:	0.420		
SAAR	:	1104.000	mm	
Urban Extent	:	0.008		
c	:	0.000		
d1	:	0.000		
d2	:	0.000		
d3	:	0.000		
e	:	0.000		
f	:	0.000		
SPR	:	34.060	%	

****
Summary of estimate using Flood Estimation Handbook rainfall-runoff method
****
Estimation of Probable Maximum flood
==========

Unit hydrograph time to peak	:	1.563	hours
Instantaneous UH time to peak	:	2.146	hours
Data interval	:	0.250	hours
Design storm duration	:	3.250	hours
Critical storm duration	:	3.288	hours
em-2h	:	146.000	
em-24h	:	320.000	
em-25d	:	500.000	
ARF	:	0.000	
Design storm depth	:	174.655	mm
CWI	:	176.553	
Standard Percentage Runoff	:	34.060	%
Percentage runoff	:	60.914	%
Snowmelt rate	:	0.000	mm/day
Unit hydrograph peak	:	140.787	(m3/s/cm/100km2)
Quick response hydrograph peak	:	17.320	m3/s
Baseflow	:	0.077	m3/s
Baseflow adjustment	:	0.000	m3/s
Hydrograph peak	:	17.397	m3/s
Hydrograph adjustment factor	:	1.000	

Flags
=====

Unit hydrograph flag	: FSRUH
Tp flag	: FEHTP
Event rainfall flag	: PMFER
Rainfall profile flag	: SUMPMP
Percentage Runoff flag	: FEHPR
Baseflow flag	: F16BF
CWI flag	: PMFCW

****

IW RS Network, FILE=CHD.dat,   ISIS VER= 12.5.4.23211

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ISIS
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HYDROLOGICAL DATA

Catchment: Downstre_1
****
Catchment Characteristics
****
Easting   :   0 Northing   :   0
Area   :   1.541 km2
DPLBAR   :   1.240 km
DPSBAR   :   63.400 m/km
PROPWET   :   0.420
SAAR   : 1104.000 mm
Urban Extent   :   0.008
c   :   0.000
d1   :   0.000
d2   :   0.000
d3   :   0.000
e   :   0.000
f   :   0.000
SPR   :   53.000 %
****
Summary of estimate using Flood Estimation Handbook rainfall-runoff method
****
Estimation of Probable Maximum flood
==========
Unit hydrograph time to peak   :   1.563 hours
Instantaneous UH time to peak :   2.146 hours
Data interval   :   0.250 hours
Design storm duration   :   3.250 hours
Critical storm duration   :   3.288 hours
em-2h   :   146.000
em-24h   :   320.000
em-25d   :   500.000
ARF   :   0.000
Design storm depth   :   126.579 mm
CWI   :   169.890
Standard Percentage Runoff   :   53.000 %
Percentage runoff   :   74.441 %
Snowmelt rate   :   0.000 mm/day
Unit hydrograph peak   :   140.787 (m3/s/cm/100km2)
Quick response hydrograph peak :   14.564 m3/s
Baseflow   :   0.074 m3/s
Baseflow adjustment   :   0.000 m3/s
Hydrograph peak   :   14.638 m3/s
Hydrograph adjustment factor   :   1.000

Flags
=====
Unit hydrograph flag   : FSRUH
Tp flag   : FEHTP
Event rainfall flag   : PMFER
Rainfall profile flag   : WINPMP
Percentage Runoff flag   : FEHPR
Baseflow flag   : F16BF
CWI flag   : PMFCW
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Appendix B Paddock PMF Calculations

IW RS Network, FILE=CHD.dat,   ISIS VER= 12.5.4.23211

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ISIS
****

HYDROLOGICAL DATA

Catchment: Non-Water
****
Catchment Characteristics
****
Easting	:	0	Northing	: 0
Area	:	0.243	km2	
DPLBAR	:	1.240	km	
DPSBAR	:	63.400	m/km	
PROPWET	:	0.420		
SAAR	:	1104.000	mm	
Urban Extent	:	0.008		
c	:	0.000		
d1	:	0.000		
d2	:	0.000		
d3	:	0.000		
e	:	0.000		
f	:	0.000		
SPR	:	34.060	%	

****
Summary of estimate using Flood Estimation Handbook rainfall-runoff method
****
Estimation of Probable Maximum flood
==========

Unit hydrograph time to peak	:	0.500	hours
Instantaneous UH time to peak	:	2.146	hours
Time to peak coefficent	:	0.320	
Data interval	:	0.250	hours
Design storm duration	:	3.250	hours
Critical storm duration	:	1.052	hours
em-2h	:	146.000	
em-24h	:	320.000	
em-25d	:	500.000	
ARF	:	0.000	
Design storm depth	:	176.880	mm
CWI	:	176.434	
Standard Percentage Runoff	:	34.060	%
Percentage runoff	:	61.044	%
Snowmelt rate	:	0.000	mm/day
Unit hydrograph peak	:	439.958	(m3/s/cm/100km2)
Quick response hydrograph peak	:	6.081	m3/s
Baseflow	:	0.012	m3/s
Baseflow adjustment	:	0.000	m3/s
Hydrograph peak	:	6.093	m3/s
Hydrograph adjustment factor	:	1.000	

Flags
=====

Unit hydrograph flag	:	FSRUH
Tp flag	:	FEHTP
Event rainfall flag	:	PMFER
Rainfall profile flag	:	SUMPMP
Percentage Runoff flag	:	FEHPR
Baseflow flag	:	F16BF
CWI flag	:	PMFCW

****

IW RS Network, FILE=CHD.dat,   ISIS VER= 12.5.4.23211

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Catchment: Non-Water

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Rainfall Profile - Unit and Flow Hydrograph Using
FEH rainfall-runoff method
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Hydrograph adjustment factor =   1.000
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TABULAR RESULTS

time (hours)	areal rainfall (mm)	net rainfall (mm)	unit hydrograph (m3/s/cm/100km2)	flow hydrograph (m3/s)
0.000	5.839	3.564	0.000	0.012
0.250	7.004	4.276	219.958	0.203
0.500	6.519	3.980	439.917	0.622
0.750	6.076	3.709	295.276	0.938
1.000	9.493	5.795	150.567	1.073
1.250	20.707	12.641	5.857	1.165
1.500	65.603	40.047	0.000	1.725
1.750	20.707	12.641		4.061
2.000	9.493	5.795		6.093
2.250	6.076	3.709		5.017
2.500	6.519	3.980		3.220
2.750	7.004	4.276		1.557
3.000	5.839	3.564		1.162
3.250				1.089
3.500				0.851
3.750				0.430
4.000				0.149
4.250				0.017
4.500				0.012

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Volumetric analysis of results
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Total volume of rainfall   :   42981.9 m3
Total volume of net rainfall   :   26238.0 m3
Total volume of rain loss   :   16743.9 m3
Total volume of baseflow   :   208.4 m3
Total volume of quick runoff   :   26249.0 m3
Total volume of runoff   :   26457.4 m3

PMF inflow from water area:

Time (hours)	Areal rainfall (mm)	Inflow in m^3/s from Water area = 86,904.00 m^2
0.00	5.839	0.000
0.25	7.004	0.564
0.50	6.519	0.676
0.75	6.076	0.629
1.00	9.493	0.587
1.25	20.707	0.917
1.50	65.603	1.999
1.75	20.707	6.335
2.00	9.493	1.999
2.25	6.076	0.917
2.50	6.519	0.587
2.75	7.004	0.629
3.00	5.839	0.676
3.25		0.564
3.50		0.000
3.75		0.000
4.00		0.000
4.25		0.000
4.50		0.000