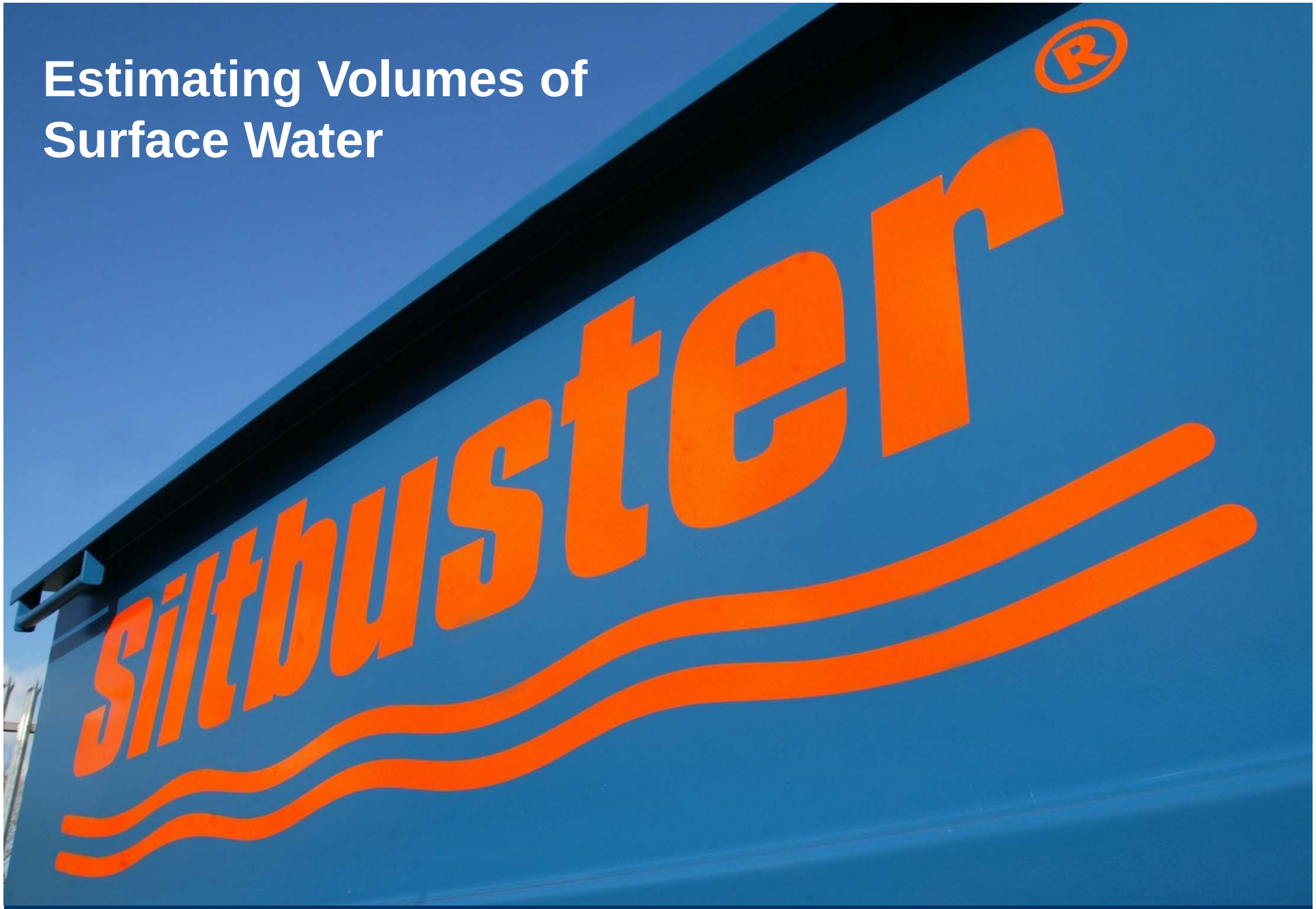
Estimating Volumes of Surface Water



Estimating Volumes of Surface Water

Introduction

– In this module we will review methods of estimating surface runoff from catchments.

– In particular we will:

- Establish why flood estimation is important
- Look at the underlying hydrological principles
- Consider the implication of project life on the rainfall return period selected
- Establish what data is required to make a runoff assessment
- Look at methods of estimating the runoff
- Consider the implication of storage on treatment capacity

– Demonstrate the application of these techniques using a worked example

Why is Flood Estimation Important ?

- Most Discharge and Trade Effluent Consents stipulate
  - A maximum flow rate
  - A maximum suspended solids concentration
  - Limit the concentration of other contaminants (e.g pH, oil, metals, ammonia, etc.)
- Hence to cope with any rain storm event we need to know
  - How much runoff is likely to occur
  - What size treatment plant is required to cope with the peak flow
  - How much storage will be required to attenuate the peak flow

(Remember the runoff catchment may well extend beyond the construction site boundaries)

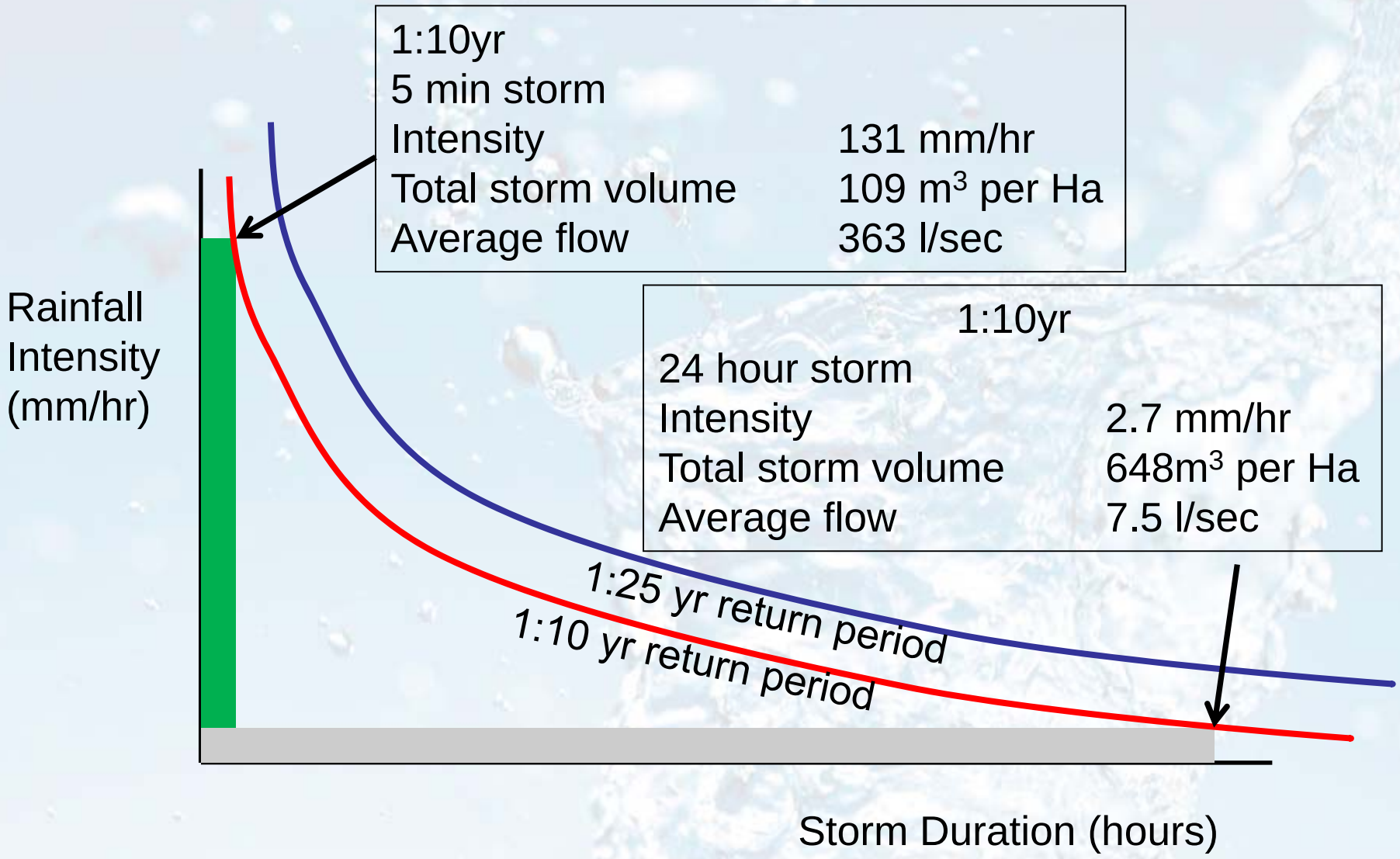
Factors Affecting Volume of Water to be Treated

- Rainfall duration and Intensity
  - Typically the longer the duration
    - the smaller the intensity
    - but the greater the total volume of water to be dealt with
- Catchment characteristics
  - Shape
  - Slope
  - Soil type, impermeable areas, etc. (run off coefficient)
- Storm Return Period
  - Return Period is the severity of the storm, eg:
    - a 1:10 is 1 in 10 year storm
  - The greater the return period the larger the volume to be treated

Rainfall intensity (mm/hr)- Duration Data from the Bilham Formula

Duration	1:2yr	1:5yr	1:10yr	1:20yr
5min	71.9	102.0	130.7	165.4
10min	47.0	65.3	82.7	103.8
15min	36.4	50.1	63.1	78.8
30min	23.2	31.5	39.4	49.0
1h	14.6	19.7	24.5	30.3
2h	9.2	12.3	15.2	18.7
4h	5.7	7.0	9.4	11.5
6h	4.3	5.7	7.0	8.6
12h	2.7	3.5	4.3	5.3
18h	2.0	2.6	3.3	4.0
24h	1.6	2.2	2.7	3.2
30h	1.4	1.8	2.3	2.8
36h	1.2	1.6	2.0	2.4
42h	1.1	1.5	1.8	2.2
48h	1.0	1.3	1.6	2.0

Rainfall Intensity and Storm Duration (The Bilham Formula)



Effect of Storm Duration on Storm Volume and Average Flow rate

Duration	Rainfall intensity (1 in 10 yrs)	Storm volume (m^3)	Average flow rate
5min	130.7mm/h	109m^3/ha	363l/s/ha
1hr	24.5mm/hr	245m^3/ha	68l/s/ha
12hr	4.3mm/hr	516m^3/ha	12l/s/ha
24hr	2.7mm/hr	648m^3/ha	7.5l/s/ha
48hr	1.6mm/hr	768m^3/ha	4.4l/s/ha

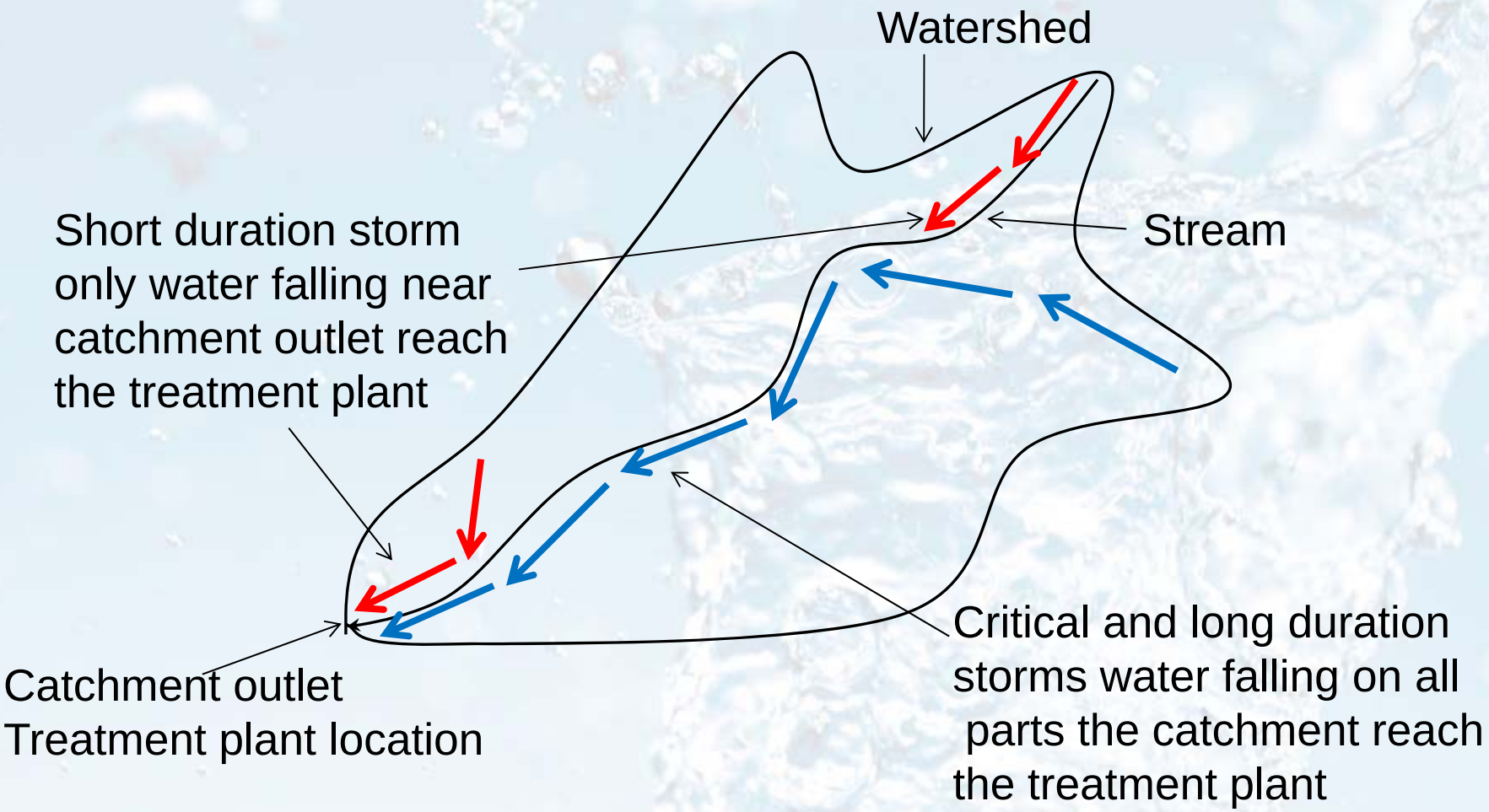
Conclusion:

Shorter the duration – higher the average flow rate.

Longer the duration- greater the volume to be treated

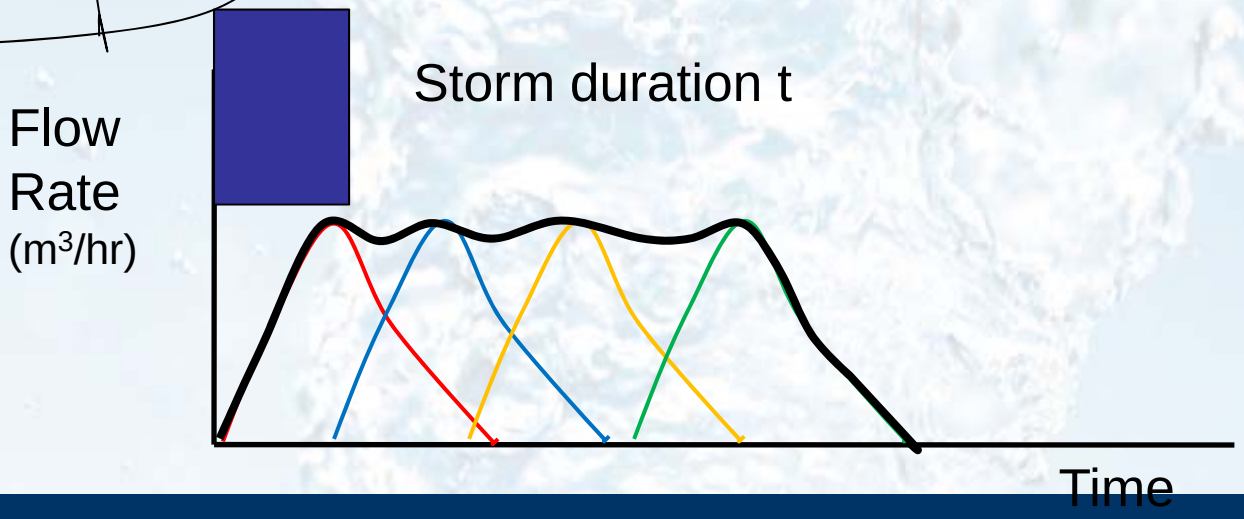
However need to take into account catchment characteristics as shown on the next slides

Catchment Response

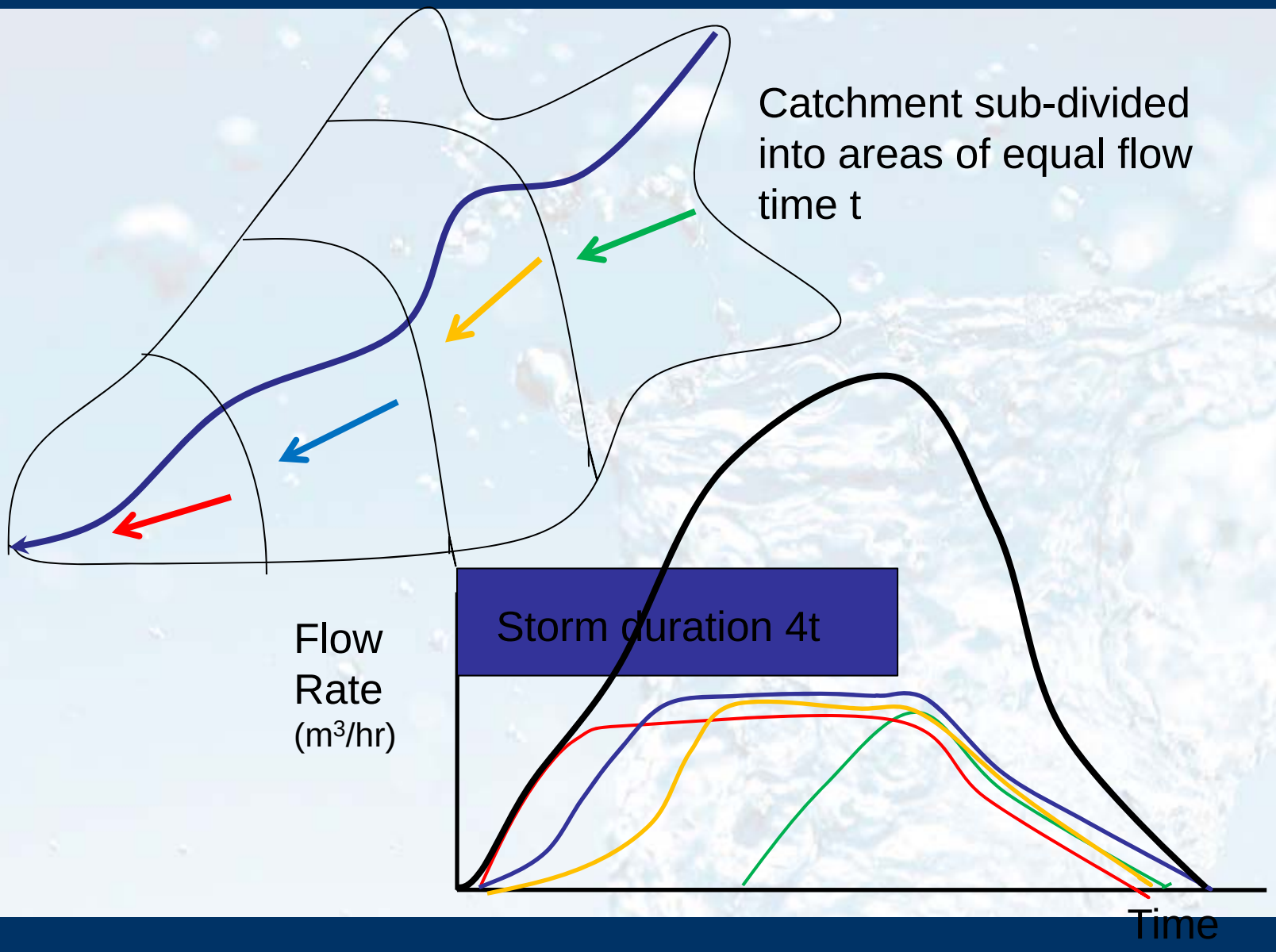


Catchment Response – short duration storm

Catchment sub-divided into areas of equal flow time t

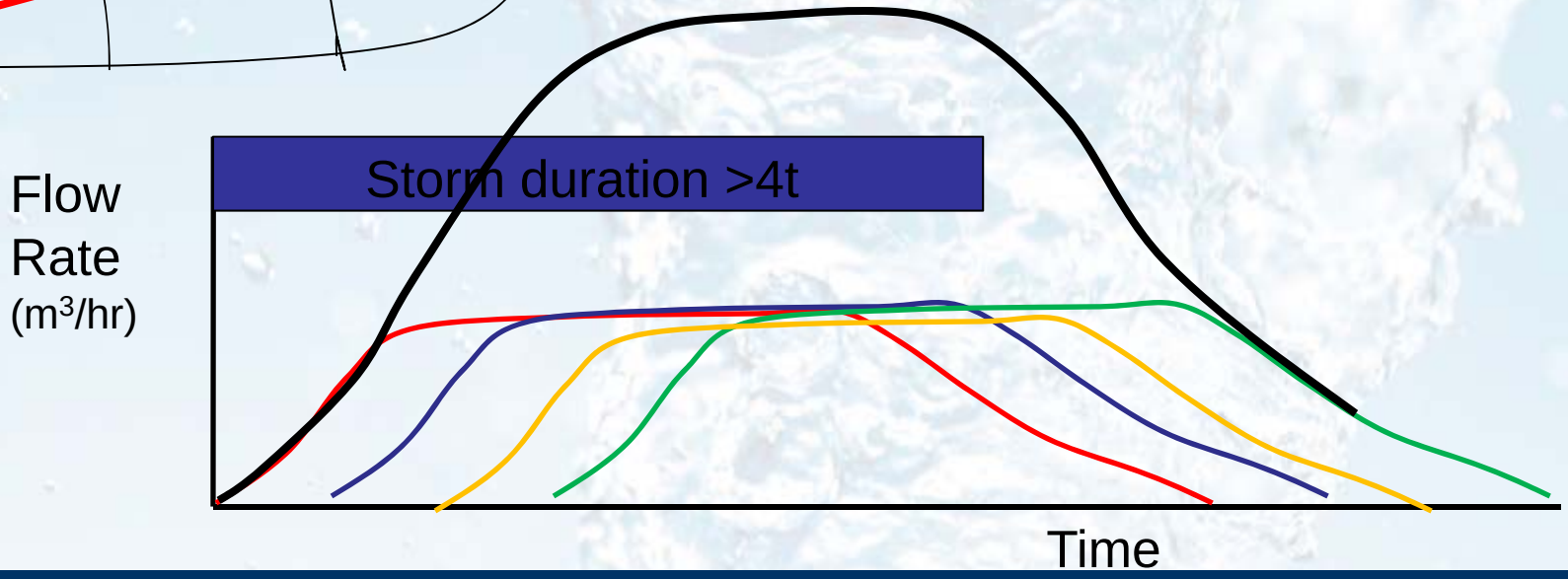


Catchment Response – Critical duration storm (4t)

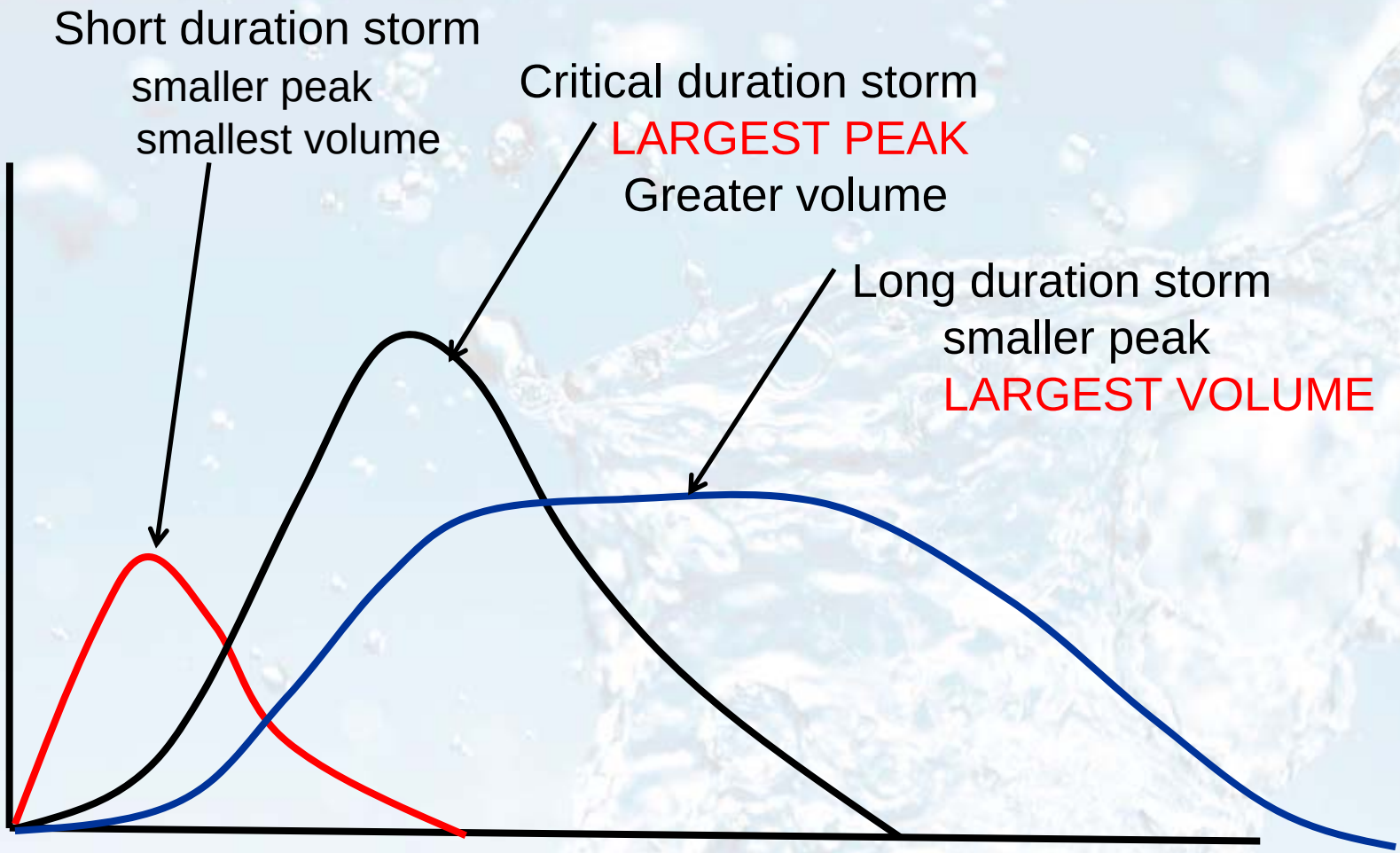


Catchment Response – Long duration storm (<4t)

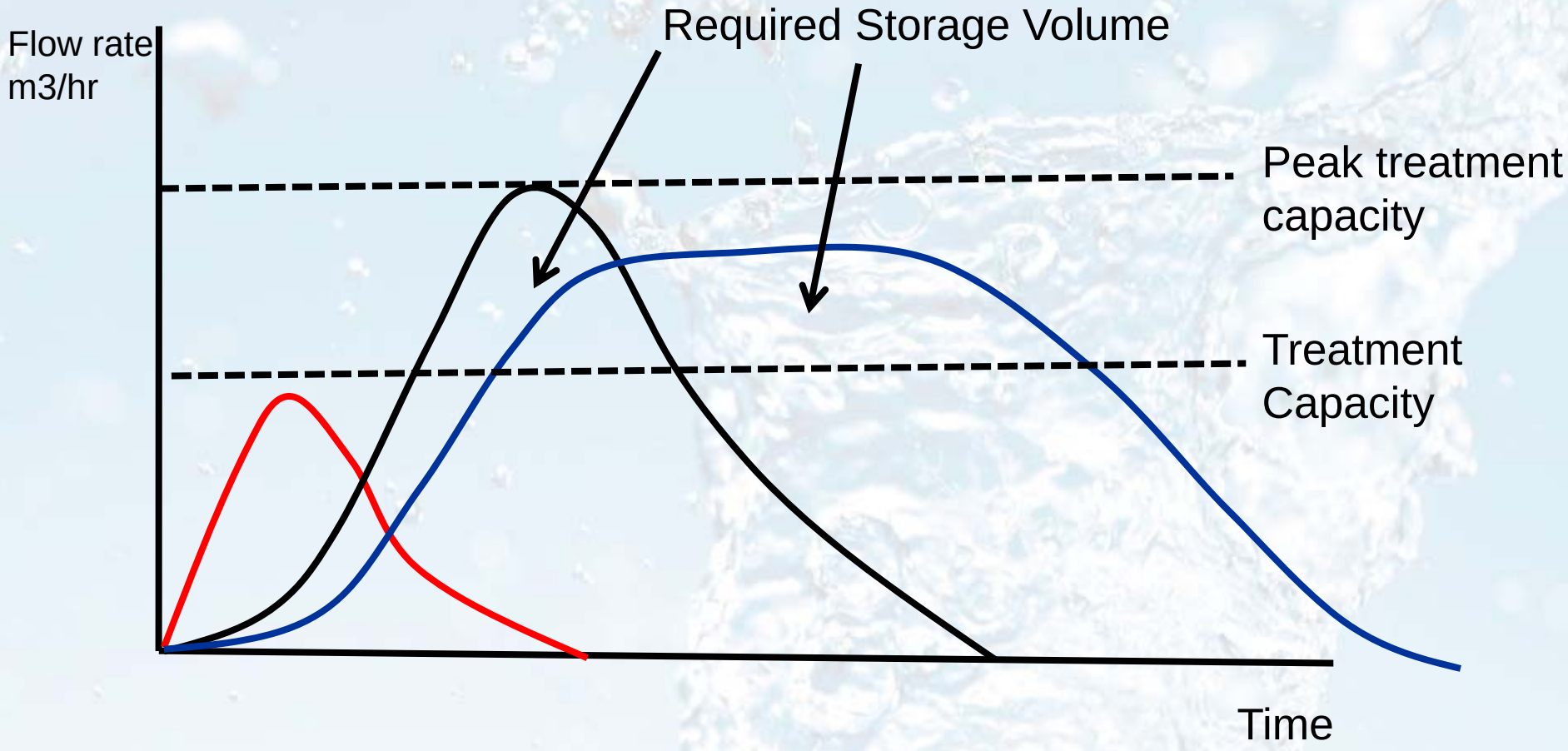
Catchment sub-divided into areas of equal flow time t



Effect of Storm Duration on Hydrographs



Effect of Storm Duration on Treatment Capacity



Project Return Periods

- It is not normally economically viable to install a treatment facility to cope with ALL potential STORM events.
- Treatment capacity can be reduced by storing runoff peaks (flood attenuation).
- Normal practice is to:
  - design the treatment facility for a particular return period, and;
  - accept that for more extreme events only partial treatment will be possible.
- i.e. a risk based approach with offsetting/balancing
  - The cost of treatment
  - Against the probability of a more extreme events occurring during the project.

Project Return Periods - Risk of Exceedence

Return periods on probability of exceedence

$P_e = 1- (1-1/\text{Return Period})^{\text{Duration}}$

$$P_e = 1 - \left(1 - \frac{1}{\text{Return Period}}\right)^{\text{Duration}}$$

- Where Return Period and Project Duration are in years

Theoretical Probability of Exceedence

Project Duration	Return Period (yrs)				
	2	5	10	25	50
6months	29%	11%	5%	2%	1%
1 year	50%	20%	10%	4%	2%
2 years	75%	36%	19%	8%	4%
5 years	97%	67%	21%	18%	10%

Project Return Periods

- Selected Return Period depends on
  - The nature of the project
  - The consequences of a more extreme event on
    - The Project
    - Downstream structures, etc.
    - The Environment

- For low risk projects a 10% to 20% probability of exceedence is commonly adopted. i.e.
  - Short duration projects (<6months) 1:2 years
  - Medium duration projects (<2years) 1:10 years
  - Long duration projects (>2 years) Risk based
  - Normally suggested minimum return period is 10 yrs

Runoff Estimation Methods

- Estimate peak runoff:
  - Small rural catchments (<50ha)
    - Circa Report (does not take into account slopes, etc.)
    - MAFF/Highway's Agency method
  - Large rural Catchments (>50ha but < 250ha)
    - CEH methodology
  - Very large catchments (>250ha)
    - Flood Estimation Handbook –seek specialist hydrological advice

Estimating Peak Flow – Data Required

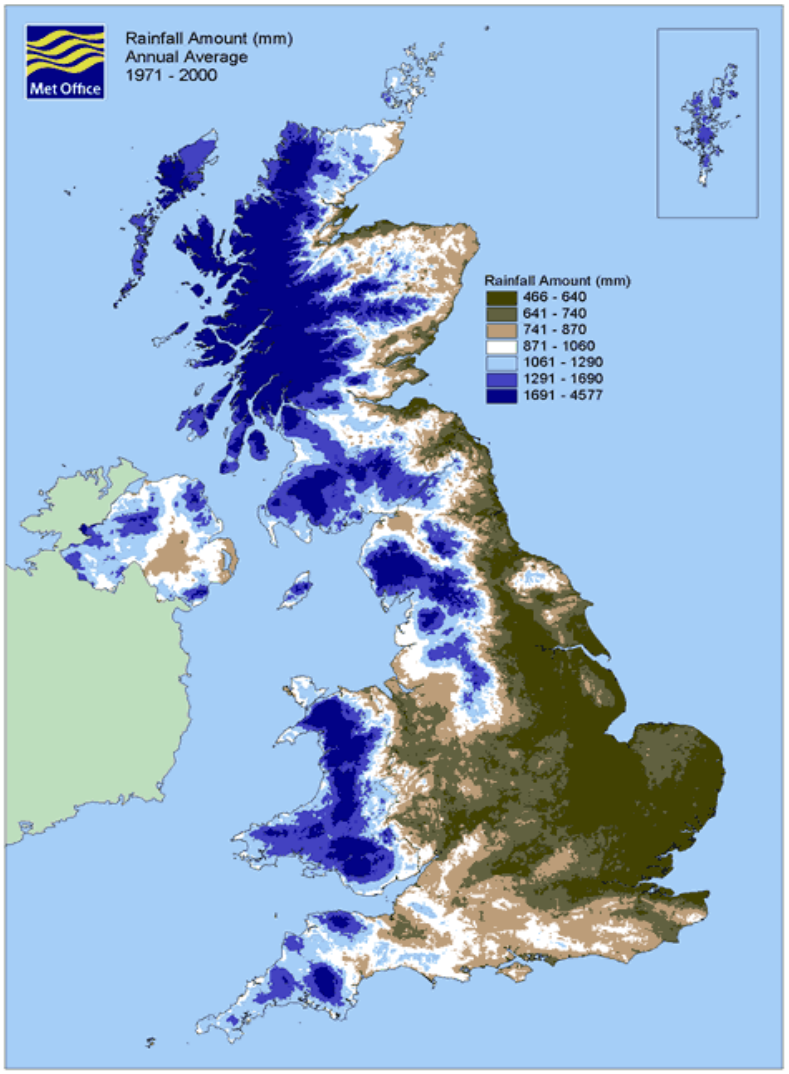
- Rainfall data:
  - Usually derived from national rainfall maps
  - Local rainfall records
  - Bilham Formula

- Catchment(s) characteristics:
  - Area
  - Soil type
  - Length of longest drainage path
  - Elevation difference

Runoff Estimation Small Catchment (<50ha) CIRIA Method

- Step 1 Establish site annual average rainfall.
- Step 2 Calculate catchment area (ha)
- Step 3 Determine soil type
- Step 4 Read unit runoff from table (litres per second per hectare)
- Step 5 Select Return Period
- Step 6 Peak flow (l/s) = Catchment area (ha) x Runoff Factor x Return Period Factor

Runoff Estimation Small Catchment - (<50ha) CIRIA



Step 1 - Determine the site Annual Average Rainfall

Step 2 - Determine the Catchment Area (may not be the same as the Site Area)

Runoff Estimation Small Catchment - (<50ha) CIRIA Method

Step 3 - Determine the Soil Class and hence the Site Runoff Potential

Soil Class	Runoff potential	Description
1	Very Low	Well drained, sandy, loamy or earthy peat soils
2	Low	Very permeable soils (e.g. gravels, sands with shallow groundwater or rock)
3	Moderate	Very fine sands, silts and clays. Permeable soils with shallow groundwater in low lying areas
4	High	Clayey or loamy soils
5	Very high	Wet uplands, shallow rocky soils on steep slopes, peat with impermeable layers at shallow depth

Runoff Estimation Small Catchment (<50ha) CIRIA Method

Step 4 - Determine the Mean Annual Peak Flood Flow (litres/sec/ha)

Soil type	Annual Rainfall (mm)					
	<600	600 - 800	800-1200	1200- 1600	1600 3200	>3200
1	0.3	0.4	0.6	0.9	1.7	2.4
2	1.4	1.8	2.8	4.1	7.7	10.8
3	2.6	3.4	5.2	7.7	14.4	20.1
4	3.3	4.4	6.7	9.9	18.6	26.0
5	4.2	5.5	8.4	12.4	23.3	32.7

Runoff Estimation Small Catchment - (<50ha) CIRIA Method

Step 5 - Calculate the Peak Flow (litres/sec)

Peak flow (l/s) = Catchment area (ha) x Runoff Factor x Return Period Factor

Return Period Factor:

Return period	2	5	10	25	50
Factor	1	1.22	1.48	1.88	2.22

Note:

This method does not take into account catchment slope (use MAFF method for better estimate)

The method tends to overestimates the peak flows

Worked example CIRIA Method (1 of 3)

Construction project in the S E England

Duration	2yrs
Catchment Area	5ha
Soil type	clayey
Project risk	Medium

Step 1 Annual rainfall (S E England):<600mm/yr

Step 2 Catchment Area 5Ha

Step 3 Soil class: Class 4 (clayey)

Worked example CIRIA Method (1 of 3)

Step 4 - Determine the Mean Annual Peak Flood Flow (litres/sec/ha)

Soil type	Annual Rainfall (mm)					
	<600	600 - 800	800-1200	1200- 1600	1600 3200	>3200
1	0.3	0.4	0.6	0.9	1.7	2.4
2	1.4	1.8	2.8	4.1	7.7	10.8
3	2.6	3.4	5.2	7.7	14.4	20.1
4	3.3	4.4	6.7	9.9	18.6	26.0
5	4.2	5.5	8.4	12.4	23.3	32.7

Worked example CIRIA Method (2 of 2)

Step 5 Select Return period

2 year duration

Medium Risk

Selected return period: 1:10 yrs

(giving a 19% probability of exceedence)

Return period multiplication factor 1.48

Step 6 Calculate Peak flow:

Catchment Area x Average unit runoff x Return period factor

5 x 3.3 x 1.48 = 24.4l/s

= 88m^3/hr

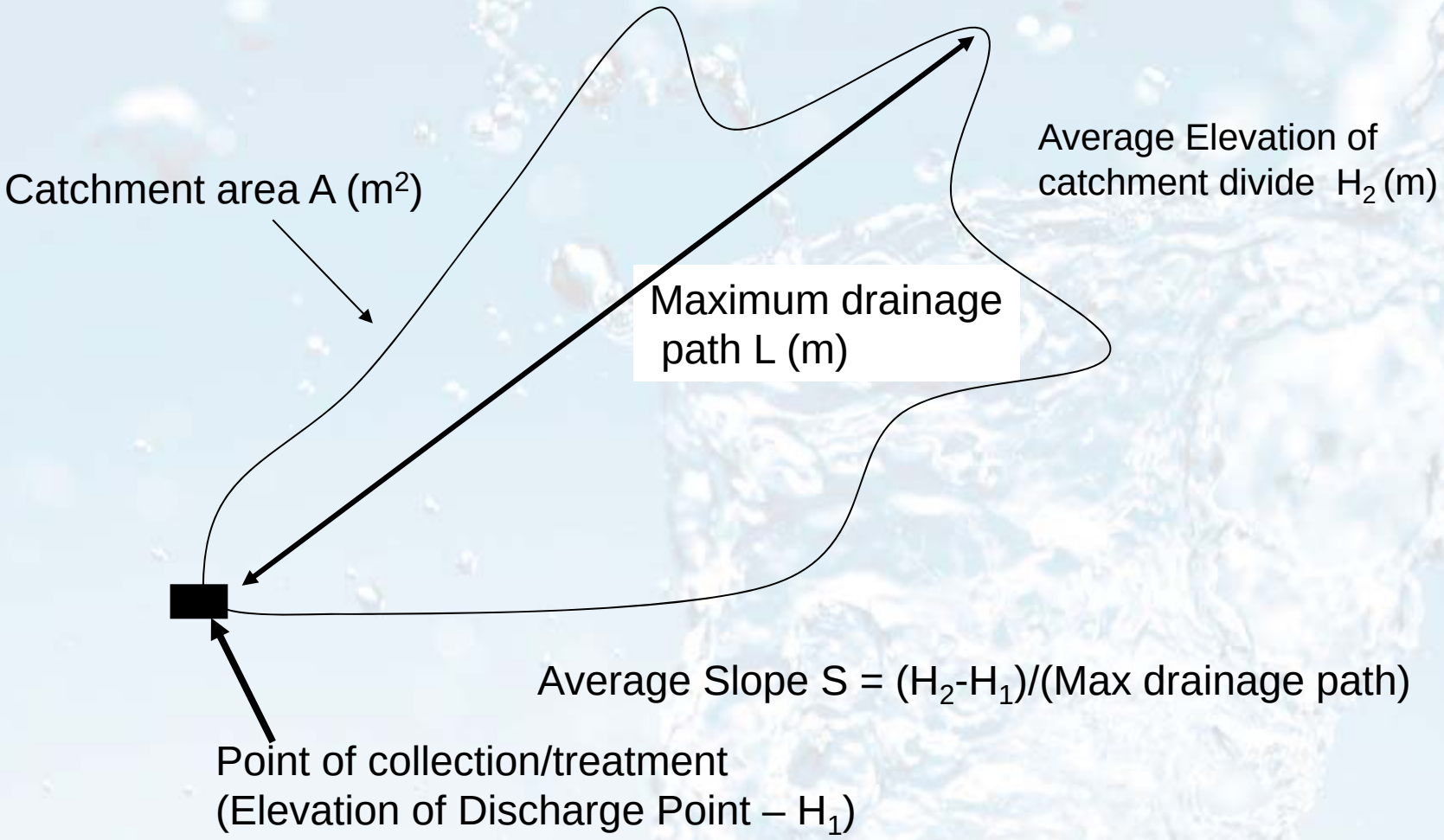
Runoff Estimation Small Catchment (<50ha)MAFF- HA106/04 Method

Calculation requires 8 steps:

1. Determine catchment characteristics:
2. Determine soil type
3. Estimate annual average rainfall (from rainfall map)
4. Calculate the time of concentration
5. Select an appropriate return period
6. Determine rainfall intensity
7. Calculate Runoff
8. Determine total flood volume

Runoff Estimation Small Catchment (<50ha) MAFF- HA106/04 Method

Step 1 - Determine Catchment Characteristics



Runoff Estimation Small Catchment <50ha) MAFF- HA106/04 Method

Step 2 – Determine Area weighted SOIL Class

Soil Class	Runoff potential	Description
1	Very Low	Well drained, sandy, loamy or earthy peat soils
2	Low	Very permeable soils (e.g. gravels, sands with shallow groundwater or rock)
3	Moderate	Very fine sands, silts and clays. Permeable soils with shallow groundwater in low lying areas
4	High	Clayey or loamy soils
5	Very high	Wet uplands, shallow rocky soils on steep slopes, peat with impermeable layers at shallow depth

Area weighted average soil class (SOIL)

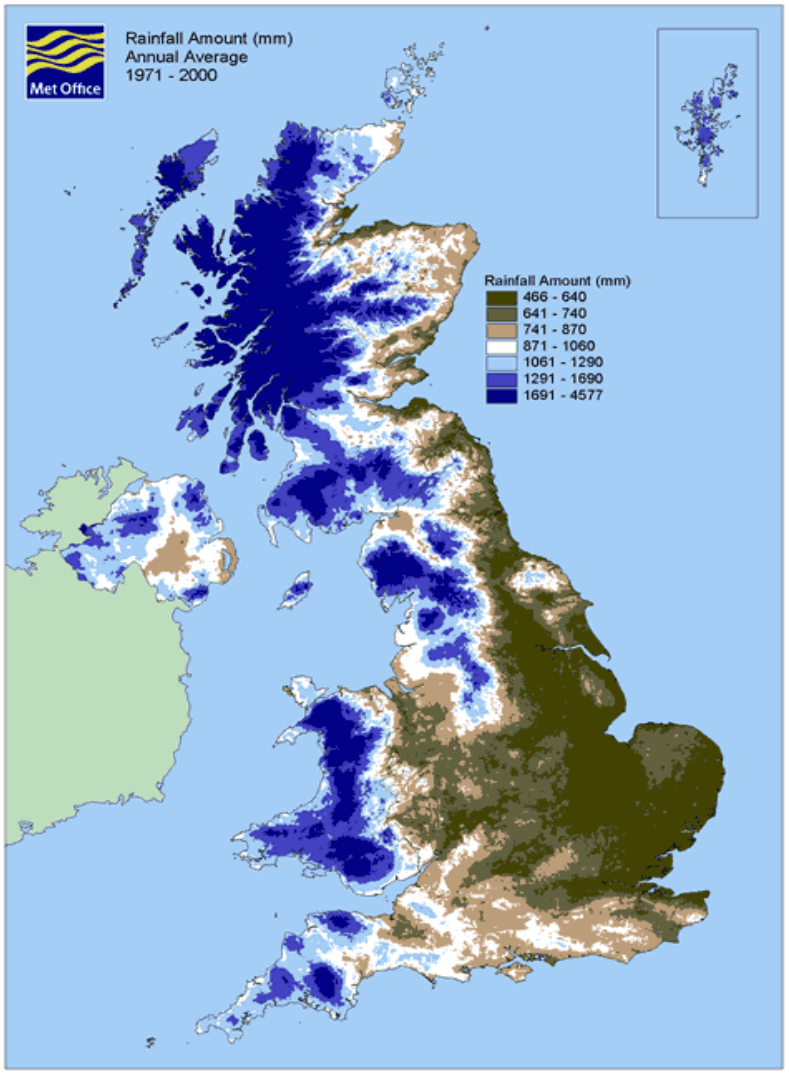
$$SOIL = (0.15S_1 + 0.30S_2 + 0.40S_3 + 0.45S_4 + 0.5S_5)/ (1-S_u)$$

Where:

S_1, S_2, S_3, S_4, S_5 proportion of catchment covered by soil classes 1 to 5

S_u proportion of catchment unclassified (covered by water or pavement, etc)

Runoff Estimation Small Catchment <50ha) MAFF- HA106/04 Method



Step 3 – Determine Average Annual Rainfall

Runoff Estimation Small Catchment (<50ha) MAFF- HA106/04 Method

Step 4 – Calculate Time of Concentration

- Time of Concentration in hours (Tc)
  - $T_C = 0.1677\ L^{0.78}/Z^{0.38}$
  - Where
  - L = Max drainage path length from Step 1 (m)
  - Z = Average height of the catchment divide in metres above discharge point ($H_2 – H_1$ from Step 1)

Runoff Estimation Small Catchment (<50ha) MAFF- HA106/04 Method

Step 5 – Select Return Period

- Return period depends on;
  - Duration of project
  - Consequence of flooding, etc

- Suggested values
  - Short duration projects (<6month) 2yr
  - Medium duration projects (<2 yrs) 10yr
  - Long duration projects based on risk assessment

Runoff Estimation Small Catchment (<50ha) HA106/04 Method

Step 6 – Determine rainfall intensity

Duration	1:2yr	1:5yr	1:10yr	1:20yr
5min	71.9	102.0	130.7	165.4
10min	47.0	65.3	82.7	103.8
15min	36.4	50.1	63.1	78.8
30min	23.2	31.5	39.4	49.0
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2h	9.2	12.3	15.2	18.7
4h	5.7	7.0	9.4	11.5
6h	4.3	5.7	7.0	8.6
12h	2.7	3.5	4.3	5.3
18h	2.0	2.6	3.3	4.0
24h	1.6	2.2	2.7	3.2
30h	1.4	1.8	2.3	2.8
36h	1.2	1.6	2.0	2.4
42h	1.1	1.5	1.8	2.2
48h	1.0	1.3	1.6	2.0

Runoff Estimation Small Catchment (<50ha) MAFF - HA106/04 Method

Step 7 – Calculate Peak flow

- Peak flow Q (m^3/hr)

- $Q = AREA(0.0443*SAAR - 11.19)*SOIL^2*(R/T)$

- Where:
  - AREA = catchment Area (ha) — From site plan
  - SAAR = average annual rainfall (mm) — From rainfall map
  - SOIL = average catchment soil classification — From calculation
  - R/T = Rainfall intensity — From Bilham formula

Worked example MAFF Method

Construction project in the S E England

Duration	2yrs
Site area	5ha
Soil type	clayey

Medium risk project

Catchment characteristics:

Maximum drainage path length	500m
Average perimeter height	1.5m

Worked example MAFF Method

Step 1 Catchment Characteristics

Drainage path length	500m
Average watershed height	2m

Step 2 Soil parameter

Clayey soil – type S4	0.45

Step 3 Annual average rainfall

S E England	600mm/yr

Step 4 Time of concentration

$T_C = 0.1677 \times 500^{0.78}/2^{0.38}$

$T_C = 18$ hrs

Step 5 Return period

Medium risk project	1:10 yrs

Step 6 Rainfall Intensity

1:10yr 18 hour event	3.3mm/hr

Step 7 Calculated Flow

$Q = 5*(0.0443*600 - 11.19)*0.45^2*3.3$

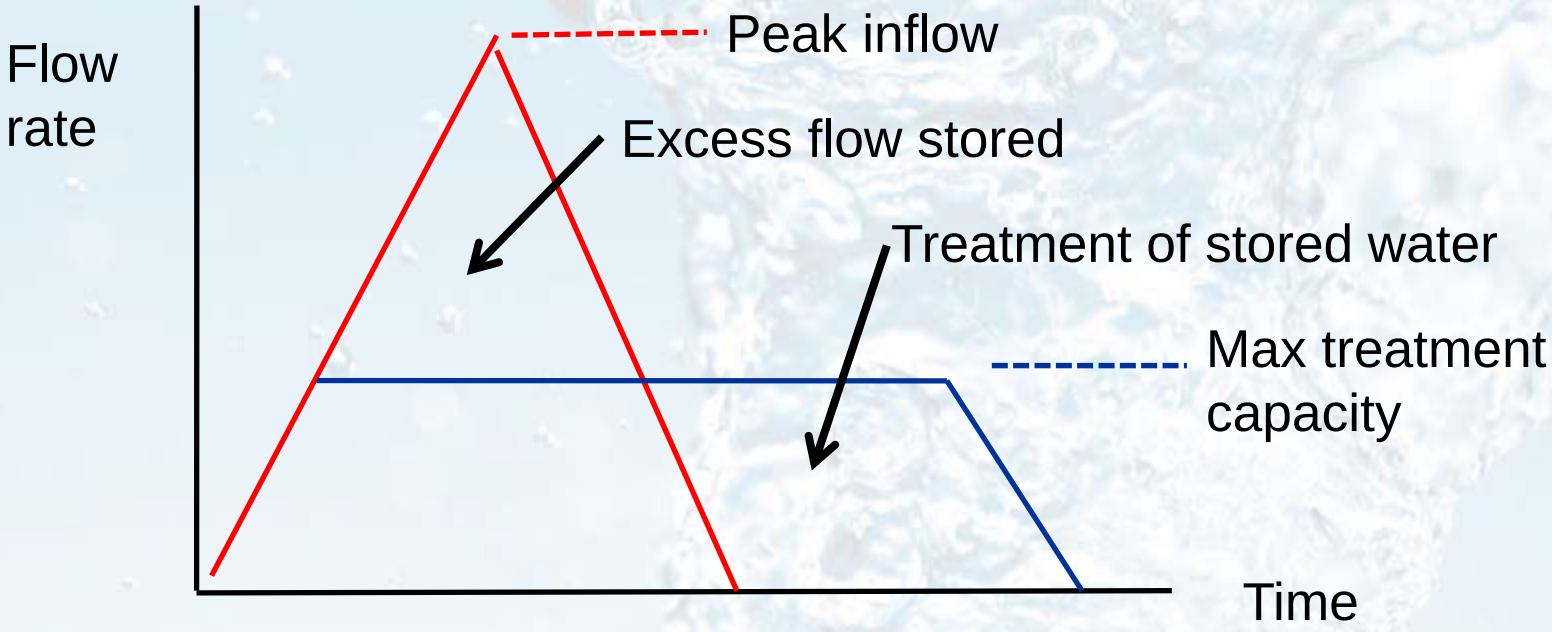
$Q = 14$l/s

$Q = 51 m^3/hr$

Simplified Storage Assessment

Where temporary storage can be provided:

- The peak flow can be attenuated
- Volume treated over a longer period



Indicative storage assessment

Step 1 Determine site characteristics:

Area

Runoff coefficient

Step 2 Select return period

Step 3 Read off the rainfall intensity for various storm durations

Step 4 Tabulate volumes and flows :

4a) Total runoff = 10 x intensity (mm/h) x duration(hr) * area (Ha) * Runoff Coefficient

4b) Average inflow rate = (total runoff)/Duration

4c) Volume treated = Treatment rate * Duration

4d) Storage required = Inflow – treated volume

Indicative storage assessment

Storm Duration	Rainfall Intensity (mm/hr)	Runoff Volume (m^3)	Ave inflow Rate (m3/hr)	Ave treat rate (m3/hr)	Min Storage Requried (m3)
1hr	24.5	612	612	70	542
6hr	7.0	1056	176	70	636
12hr	4.3	1298	108	70	456
18hr	3.3	1462	81	70	198
24hr	2.6	1591	67	67	0
36hr	2.0	1792	50	50	0

(eg 10 x 7 x 6 x 5 x 0.5 = 1056)

Assumptions

5ha site

50% runoff

Catchment characteristics ignored

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