Appendix E

Design of Stormwater Storage

E1. DESIGN OF STORMWATER STORAGE

This appendix contains an illustration of the drainage requirements, particularly storage, for a theoretical site in the Dublin region. It also provides a brief over-view statement as to why storage is needed.

This method provides quick and easy approximations of storage needs for a site to be evaluated. It is anticipated that most sites of any significant size would carry out detailed modelling of the proposed drainage systems to demonstrate the effectiveness of the drainage proposals and refine the results.

E1.1 Storage Requirements Over-View

Rainfall runoff from greenfield areas (whether agricultural land or virgin land) has very different characteristics to development runoff. These differences can be summarised under three main categories:

- Volume of runoff
  - No runoff for small events
  - Less runoff for large events

- Rate of runoff
  - Slower, later runoff for all events

- Quality of runoff
  - Cleaner runoff (BOD, sediment, pathogens, metals, hydrocarbons)

The objectives of the storage criteria are to address these three aspects and to design the urban runoff to mimic, as much as possible, the original greenfield behaviour. To do this, storage volumes should be specifically and separately calculated to address each of these criteria, and the means by which this may be achieved is briefly explained below.

E1.1.1 Volume of Stormwater Runoff – Small Rainfall Events

The volume of rainfall runoff is important at each end of the rainfall spectrum. Around 30 to 40 percent of rainfall events (probably in excess of 50 events a year in most areas) are sufficiently small that there is no measurable runoff taking place from greenfield areas into receiving waters. By contrast, runoff from developments takes place for virtually every rainfall event. The difference between the two states means that streams become more "flashy" and groundwater recharge is often lower, thus reducing base flows in the streams between events. (The related issues of water quality are addressed under quality of runoff). Where it is possible to provide replication of this behaviour (described as Interception) by preventing runoff from rainfall events of around 5mm, (by infiltration or other means), this should be provided. Certain SuDS features such as Swales and Pervious Pavements do provide runoff characteristics that reflect this behaviour to some degree.

E1.1.2 Volume of Stormwater Runoff – Large Rainfall Events

The total volume of runoff from extreme rainfall events (depths of around 40mm or more when river flooding might occur) from a developed site is typically between 1 and 10 times the runoff volume from the same site in a greenfield state. It is important to control this additional volume from the developed site as floodplains have finite storage volumes, and even if the runoff is attenuated over the period that greenfield runoff occurs, by definition there must be greater depths of flooding if more water is discharged (see Figure E1).

The criterion for Long Term Storage is a pragmatic approach to calculating an appropriate volume which should be retained and either discharged at sufficiently low flow rates (<2l/s/ha) to the receiving water, such that there is limited impact on exacerbating flooding downstream, or disposed of by infiltration. Theoretically, this form of storage needs only be mobilised at times of extreme rainfall. However in practice it is difficult to mobilise this storage only during extreme events. Figure E2 illustrates the effect of Long Term storage and demonstrates the reduced volume of runoff contributing to a river at times of flooding that this can achieve. The basis of calculating the Long Term Storage volume is to use a 6-hour 100-year event and the soil type of the site. Discussion on these criteria is given in Chapter 6.

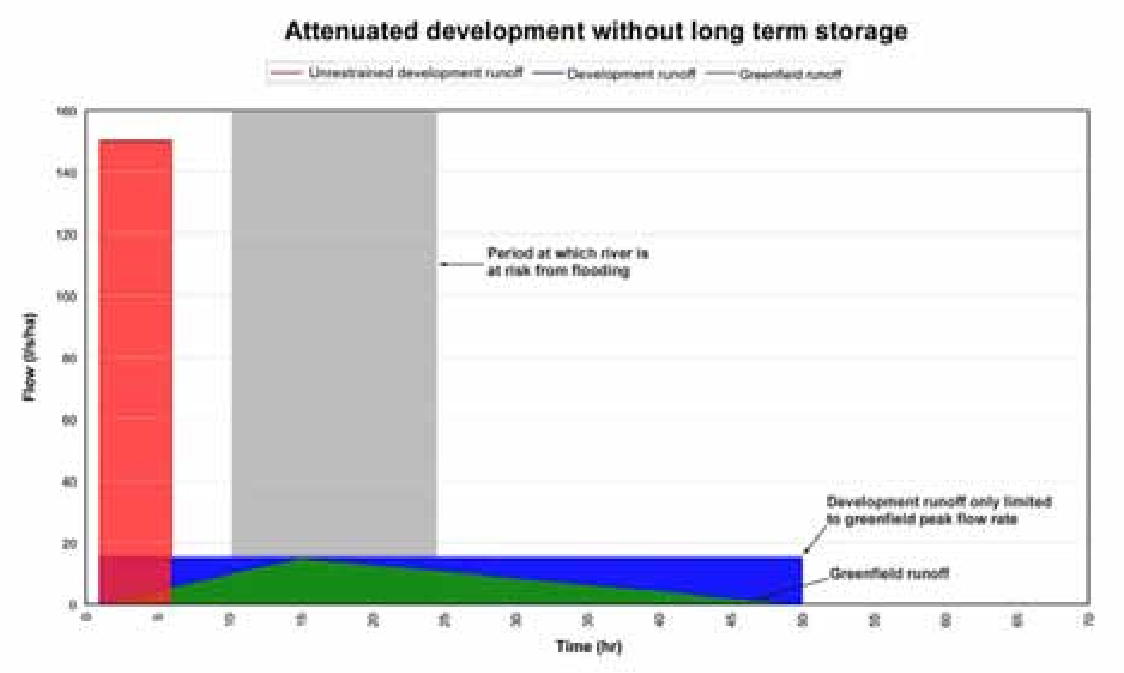


Figure E1 ***Schematic Illustrating River Flooding Protection using Greenfield Runoff Rate Criterion Only***

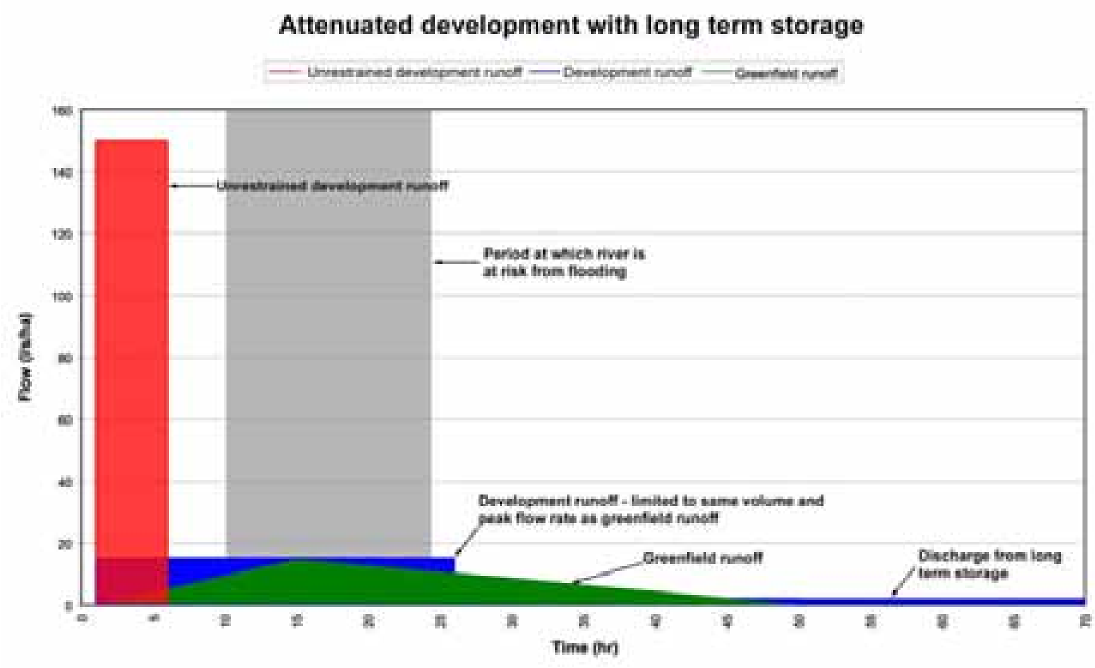


Figure E2 Schematic Illustrating River Flooding Protection using Long Term Storage

E1.1.3 Rate of Stormwater Runoff

Whatever the event, development runoff through traditional pipe networks, if allowed unchecked, will discharge into receiving waters at orders of magnitude greater than the undeveloped site. This causes flashy flow in the river that is likely to cause scour and erosion that may seriously affect the morphology and ecology of the stream.

Attenuation storage is provided to limit the runoff from the site to minimise these effects. The design principle is to limit the runoff for events of equivalent frequency of occurrence to the same peak rate of runoff as that which would take place from greenfield sites. However to achieve an exact equivalence of individual events would require a very complex approach to design and analysis. This is not justified based on water quality and hydraulic grounds, and also due to the limited accuracy of predicting the actual runoff from greenfield sites. To illustrate this, it is quite likely that a 50 year 15 minute event will not fill a storage unit designed to cater for the 1-year critical duration event, which might be a 12-hour event. Thus outflow from the site will be constrained to less than the 1-year flow rate. In terms of the greenfield runoff from the site, it is uncertain what the actual flow rate would be. Thus the 1-year storage provision actually controls an envelope of events that are equal to or larger than 1 year where the event durations are different to the 1-year critical duration.

In practice the actual rate of runoff is immaterial as long as it is appropriately low for the majority of events (river morphology), and not excessive for large events using the predicted greenfield runoff rates as a guide. Therefore the 1 and 100 year greenfield runoff rates are used for this purpose, with the 100-year event being used to define the maximum runoff rate from the site. The use of 30 years is really only a level of service criterion to ensure water levels are appropriately considered in the design process, but it can be used to provide an intermediate flow rate. Purists would like to see that the runoff rate for the critical duration event for any return period is equal to the runoff from the greenfield site calculated for the same return period, but the example above illustrates that this is an unreasonable requirement.

E1.1.4 Quality of Stormwater Runoff

The quality of stormwater runoff is an issue for frequent small events. This is due to the flush of debris and sediment from the catchment surface in the first part of the event together with any sediment deposits in the pipe network. This is compounded by the fact that this highly concentrated initial flow may enter the receiving water that is still flowing at base flow conditions, thus providing a minimum level of dilution. For large events, or during periods of high river flow, this water quality impact is much reduced, so the key period of concern is the summer months of low river flows and the small events that take place on a regular basis.

The concept of Treatment Storage is to provide a body of water in which dilution and partial treatment (by physical, chemical and biological means) of this runoff can take place. This is effectively the volume of water that remains in ponds during the dry weather periods between rainfall events. The amount of storage normally provided is often defined in terms of the equivalent volume of runoff from a rainfall depth, usually 10mm or 15mm, or a function of Vt (see section E2.1.2).

This storage should not be confused with the concept of Interception referred to earlier in this section in the discussion on the volume of runoff. Clearly if no runoff takes place for small events, maximum water quality protection is being achieved.

It should be stressed that drainage of a site should be designed using the treatment train concept using appropriate drainage mechanisms. Reliance on only a single pond prior to the outfall is not regarded as best practice in providing the best water quality protection for the receiving water. In some cases a wet pond (providing treatment storage) may not be the most appropriate solution. In this situation, treatment of surface water runoff would be achieved using other SuDS techniques.

E1.1.5 Drainage Design Process Flow Chart

Figure E3 summarises the main drainage design stages as a graphical flow chart. Figures E4 to E8 illustrate in more detail the analytical process that needs to be carried out to implement the design criteria in Table 6.3 in Chapter 6 of the document. Each figure details each of the sub-criteria in each of the 4 main criteria, which are:

- River water quality protection
  - Interception
  - Treatment volume
- River regime protection
  - Limit of discharge to receiving water, at 2 discharge rates
- Level of service
  - Flooding on the site
    - Internal protection against flooding of property
    - Temporary flooding from rare events, short intense storms
    - Long duration storms
- River flood protection
  - Long-term flood storage

Runoff models that are suggested for analysis of these various criteria are:

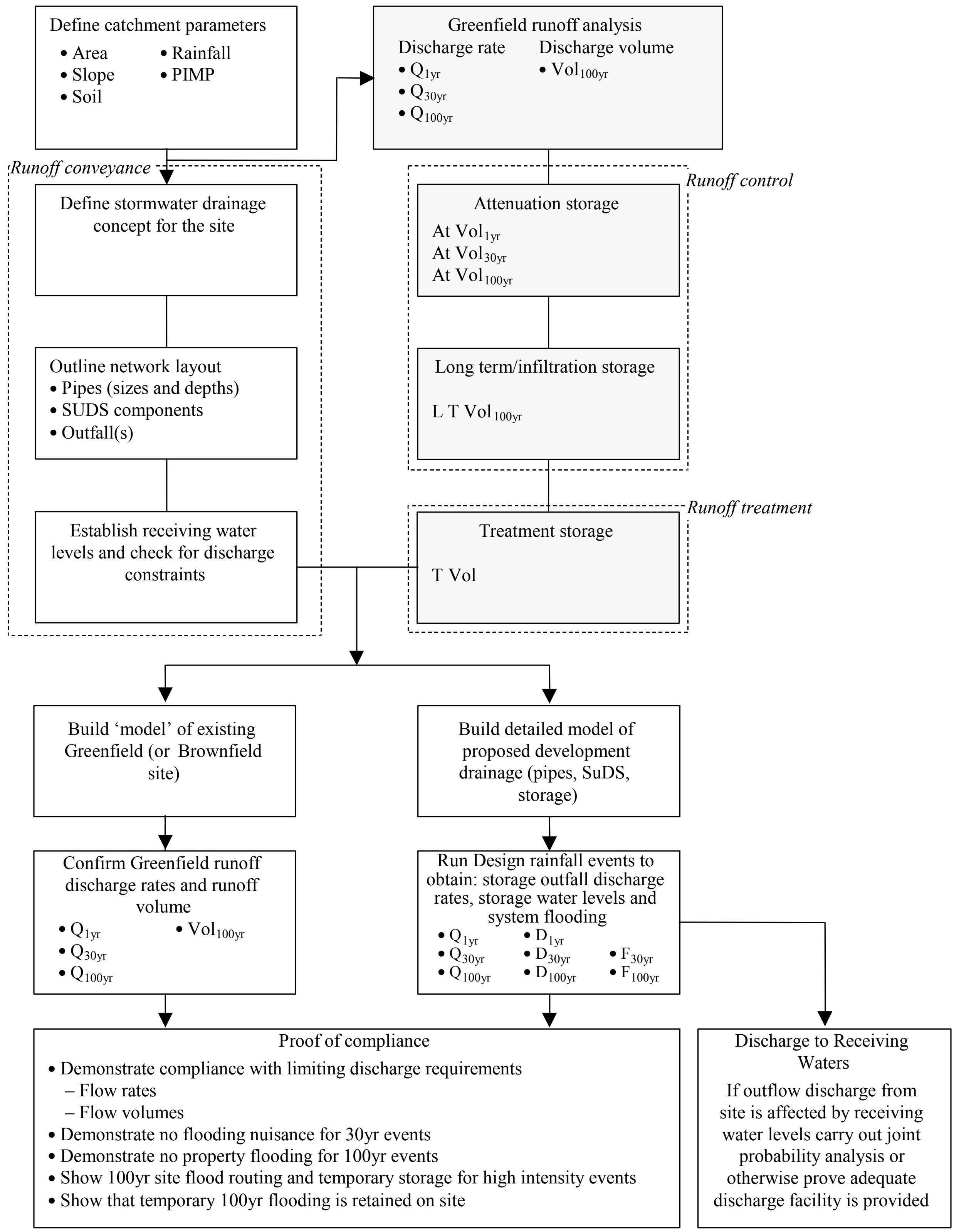
"Small" events

Criteria	Storage Type Assessment	Runoff Model (percentage rainfall-runoff)	Type of Event
River water quality	Interception & Treatment	80% paved, 0% permeable	Small events
River regime	Attenuation	100% paved, 0% permeable or New UK PR equation	Big events
Level of service	Temporary flooding and routing	New UK PR equation (detailed network model)	High intensity and Big events
River flood protection	Long term	80% paved & Soil SPR% for surfaces connected direct to drainage system	Big event

It should be noted that:

- these volumes are not cumulative.
- the provision of Interception storage also constitutes provision of Long-term storage by the amount provided.
- both long term storage and Interception storage reduce the Attenuation volumes by approximately the same amount, unless the model analysis explicitly excludes areas that are expected to contribute to these volumes separately.
- Treatment storage is not storage for attenuation of rainfall runoff. It is the permanent wet pond volume.
- Treatment storage can be reduced proportionately by any Interception storage volume provided. If Long-term storage is provided by infiltration (effective for all events) and not flooding from the attenuation pond, then treatment storage can be further reduced.
- Detailed simulation of the network and storage system is advised at detailed design to check all elements perform as expected.

Figure E5 below provides the alternative of using either 15mm or Vt to calculate the Treatment storage volume. It is recommended that 15mm is used for the Dublin region.



Notes:

Q_{1yr}	Peak discharge rate for 1 year return period
D_{1yr}	Depth of water for 1 year return period
F_{30yr}	Flooding volume (and location) for 30 year return period
Vol_{1yr}	The volume of storage for 1 year return period
Vol_{100yr}	The volume of storage for 100 year return period
PIMP	Percentage of the catchment which is impervious (roofs and roads)
(shaded box)	Storage related analysis

Figure E3 Initial and Detailed Design of Stormwater Drainage for New Developments

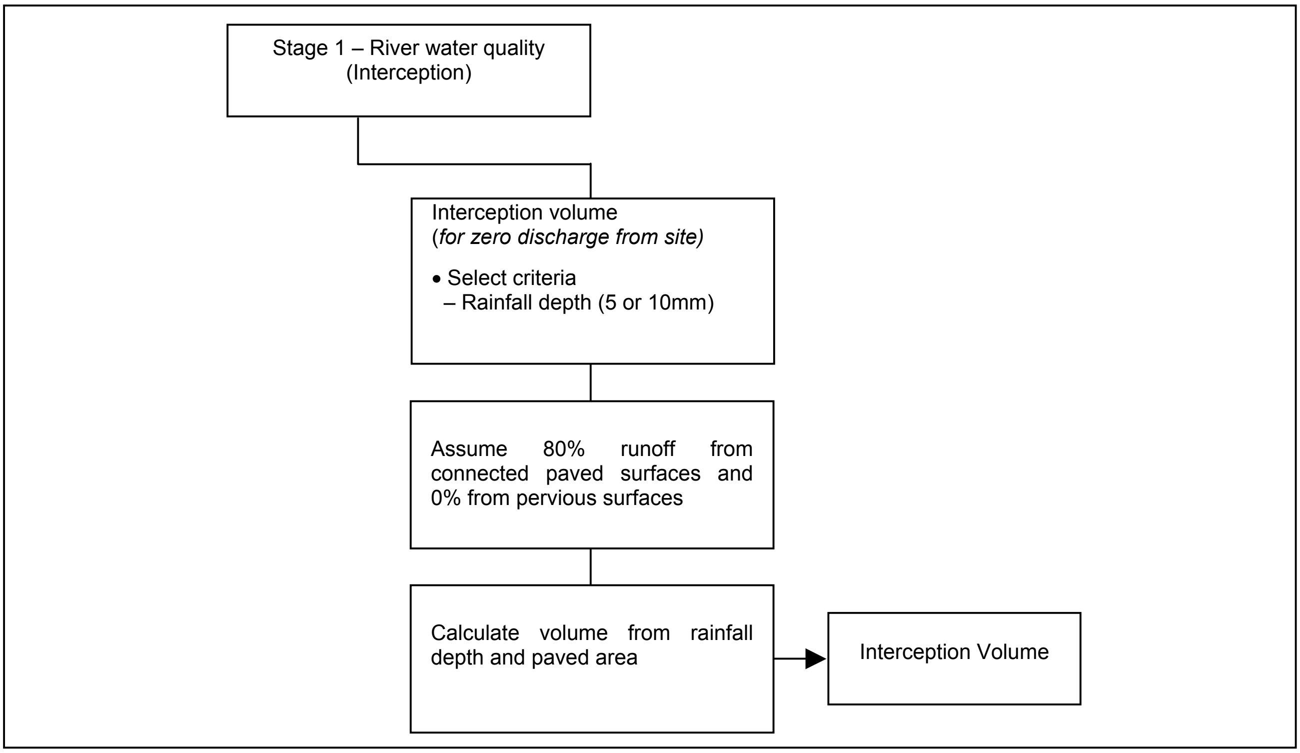


Figure E4 River Water Quality – Criterion 1.1; Interception Storage

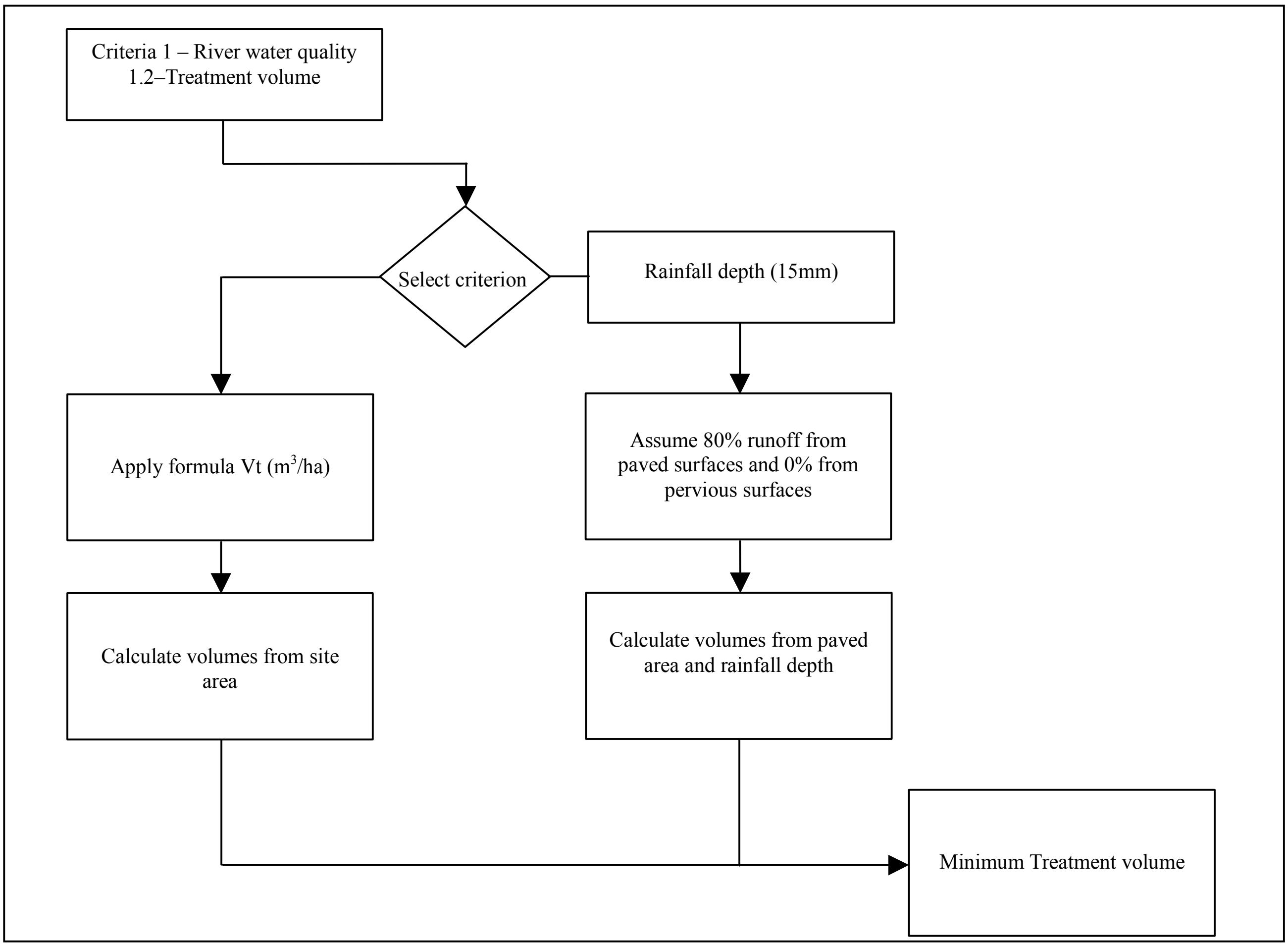


Figure E5 River Water Quality – Criterion 1.2; Treatment (wet pond) Volume

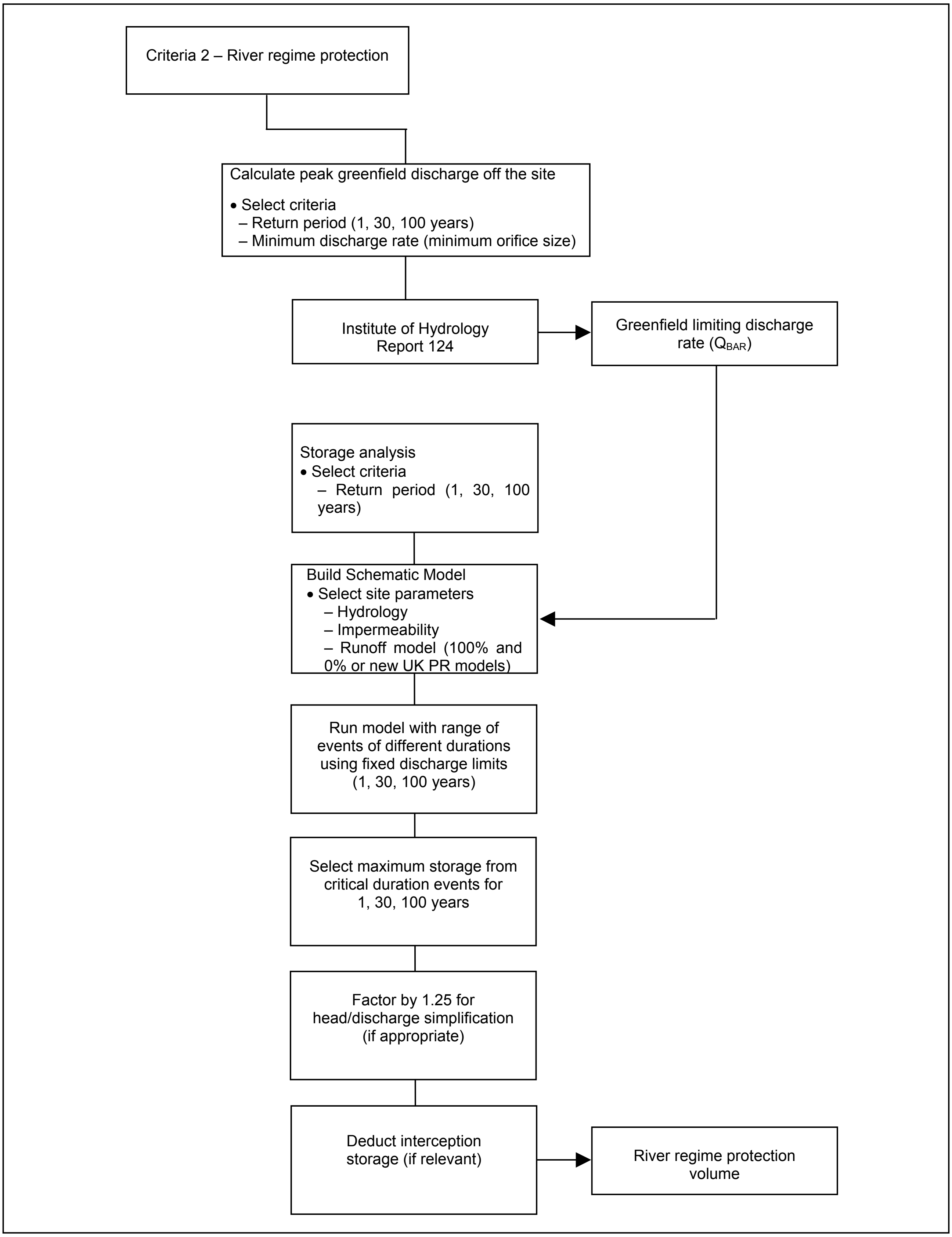
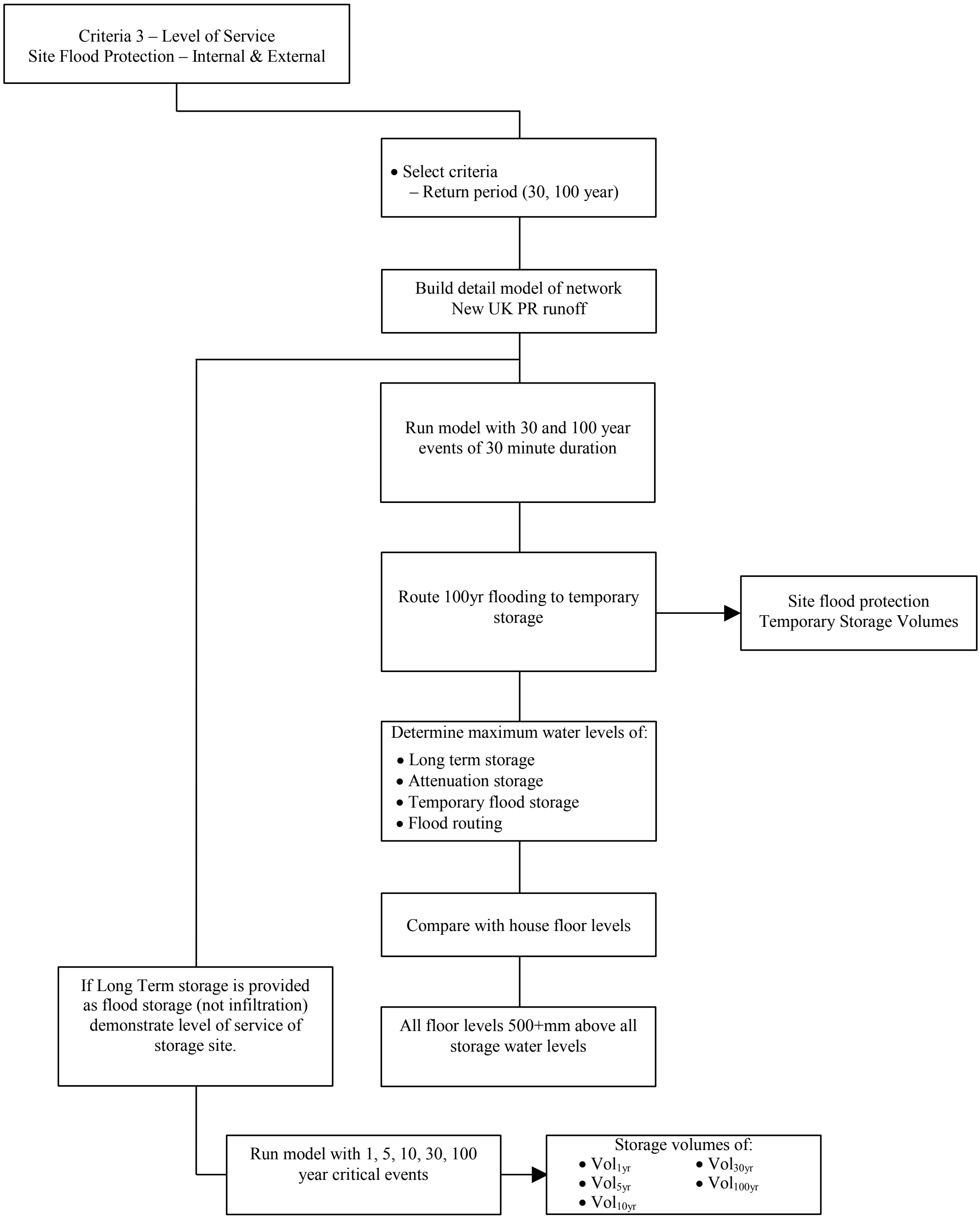


Figure E6 River Regime Protection – Criterion 2; Attenuation Storage



Notes: The model is built with the storage volumes evaluated for Criteria 1 and 2
Temporary flood storage is unlikely to be built as a formal storage unit, but use car parks or areas of open space

Figure E7 Levels of Service – Criterion 3; Flood Routing and Temporary Storage Operation

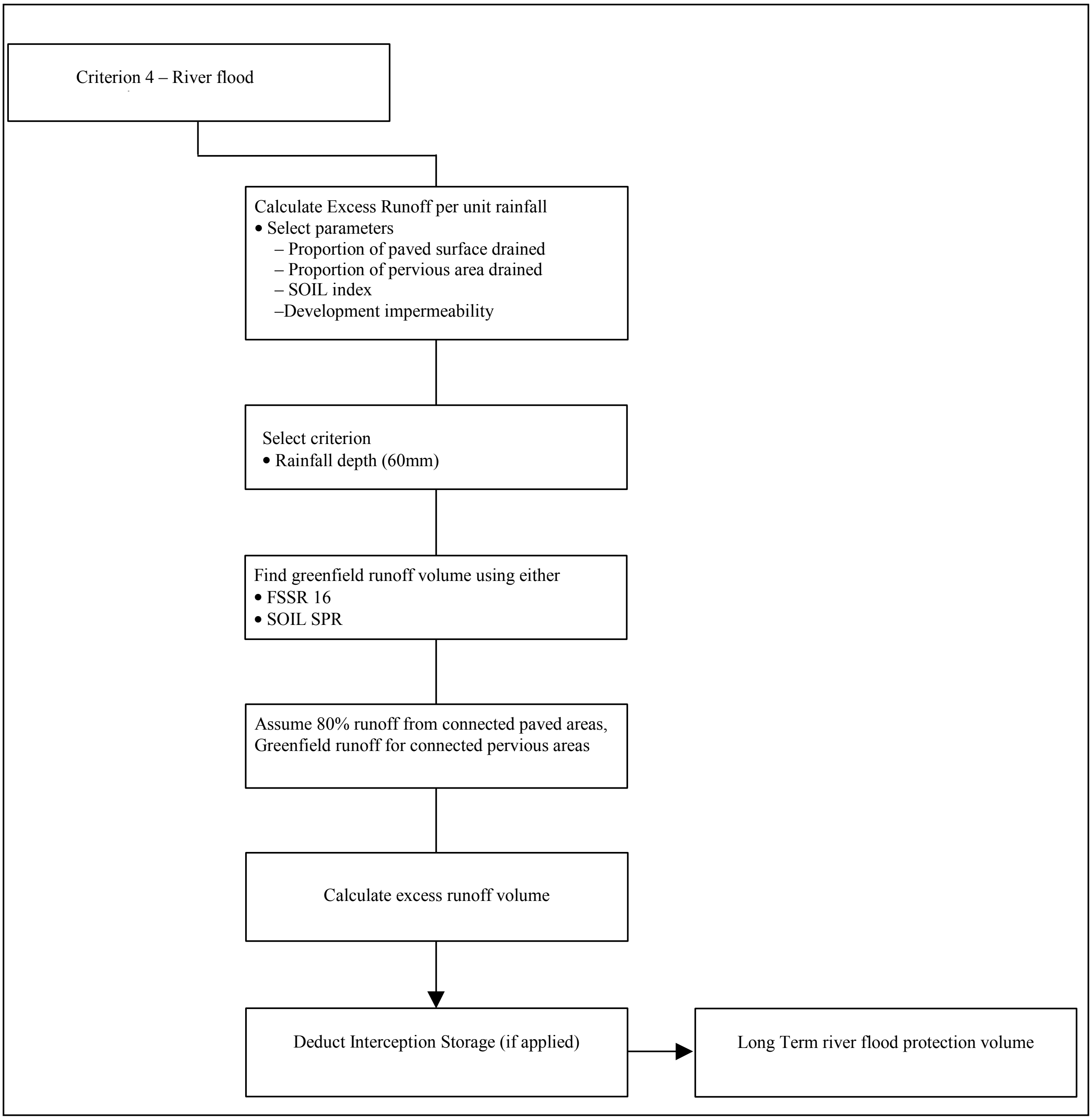


Figure E8 Storage Design – Criterion 4; River Flood Protection

E2. WORKED EXAMPLE

The following example is an illustration of the process of applying the design criteria for stormwater storage for discharge attenuation and volume reduction. The example does not illustrate design of pipe systems nor does it look into the treatment train process in terms of effectiveness of the SuDS system in protecting the environment from urban pollution washoff.

Catchment Characteristics

Site Area	= 70ha
SAAR	= 750mm
SOIL	= 3
M5-60	= 17mm
r	= 0.30
PIMP	= 65%

In addition it is assumed that:
- climate change factor for rainfall is 1.1 (10% increase)
- 25% of the paved surface drains to infiltration, and
- 60% of the pervious area is positively drained by the drainage system

The remaining 40% of the pervious area is assumed to infiltrate with surface flow paths preventing runoff from entering the drainage system.

E2.1 River Water Quality Protection – Criterion 1

Water quality protection (Figure E4) is provision of either interception and/or treatment volume. Both are calculated below.

E2.1.1 Interception – Criterion 1.1

Assume 80% runoff from paved surfaces and 0% from pervious surfaces for the first 5mm of rainfall. This is a conservative value for applying to small rainfall events. The paved runoff proportion is actually likely to be around 60% for most small events with the first 0.5mm of rainfall being lost in depression storage and evaporation before any runoff takes place. Interception volume is calculated in Table E1.

Table E1 Calculation of Interception Volume

Item	Measurement / calculation	Comment / clarification
Paved surfaces connected to the drainage system	0.75 x 0.65 x 700,000 = 341250 m^2	75% of the paved area 65% of the site is paved 70ha development in m^2
Volume of interception storage	341250 x 0.005 x 0.8 1365m^3	Paved area directly drained 5mm rainfall depth 80% paved runoff factor

Interception could be achieved by a number of means. These include infiltration and pumping to treatment.

Pumping to treatment is highly unlikely to be feasible as it is costly in terms of the infrastructure required, the running costs and, most importantly, very difficult to manage to ensure that only the first 5mm is catered for.

Infiltration using infiltration trenches for roof runoff and filter trenches for road runoff is probably the most effective way of meeting this criterion. Direct runoff into soakaways is generally not regarded as sustainable without a high level of maintenance provision. However soil type needs to be considered and in this example SOIL type 3 may be considered to be unsuitable for infiltration.

Pond top water level design may be a useful way of addressing part or all of this volume. The period when water quality is most an issue is in summer when dry periods between events are measured in days or even weeks and river levels are low. If a pond liner is finished 150mm below the outfall invert, the pond perimeter can be designed to maximise infiltration, it is likely that the top water level of the pond will be below the outlet level for many events, especially those in summer. It is quite possible that a retention pond serving 70ha might amount to around 10,000m^2. Assuming 7 days of dry weather with an evaporation rate of 3mm/day and an equivalent loss from infiltration of 5mm/day, this amounts to 560m^3 of storage. Although this is less than 1365m^3, it goes some way to providing much of the storage needed.

Different surface types have different pollution characteristics. Paved surfaces served by SuDS (such as swales and pervious pavements) may be considered to have relatively clean runoff compared to runoff from roads served by pipes. Interception volume should therefore be focused on serving these areas, which are more of a pollution problem.

E2.1.2 Treatment Volume – Criterion 1.2

For events larger than 5mm, and in situations where "Interception storage" cannot be provided, surface water runoff treatment is provided using a retention pond or wetland in accordance with the CIRIA design manual C521. This storage volume is the permanent wet pool of the retention pond.

The approach (Figure E5) proposed is to use a 15mm event, while the accepted formula for Vt in CIRIA 521 can also be used.

The treatment storage (wet pond volume) needed for 15mm is shown in Table E2.

Table E2 Calculation of Treatment Volume

Item	Measurement / calculation	Comment / clarification
Paved surfaces draining to river	0.75 x 0.65 x 700,000 = 341250 m^2	75% of the paved area 65% of the site is paved 70ha development in m^2
Volume of treatment storage	341250 x 0.015 x 0.8 4095m^3	Paved area directly drained 15mm rainfall depth 80% runoff from paved surfaces

If the use of Vt is preferred:

Vt (m^3/ha) = 9 x D(SOIL/2 + (1 - SOIL/2) x I)

Vt = 9 x 17 (0.4 /2 + (1 – 0.4 /2) x 0.65 x0.75)

Vt = 90m^3/ha

Therefore Vt for a 70ha site is 6300 m^3

This is effectively asking for around 20mm of rainfall as the treatment volume. The CIRIA document suggests 4Vt for extended retention ponds to ensure a good level of treatment is achieved. This would amount to over 25,000m^3 being required for this 70ha site. Until it is demonstrated that 4 times Vt is much more effective in treating surface water runoff, it is recommended that the normal requirement should be 15mm.

E2.2 River Regime Protection – Criterion 2

River regime protection is achieved by limiting the discharge to greenfield runoff rates for return periods of 1, 30 and 100 years which therefore requires attenuation storage to enable stormwater discharges to meet this criterion. This is best evaluated using a simulation model to calculate this volume by using the estimated greenfield runoff rates as fixed throttle rates for these three return periods.

Before carrying out the calculations, a few notes on using simulation models are given.

E2.2.1 General Comments on the Use of Models

The New PR Equation
As detailed in Appendix D, it is normal to use the New UK PR equation when doing detailed modelling. However much of this analysis is more easily carried out using fixed percentage runoff assumptions as defined earlier and detailed modelling is only normally applied for the Level of Service stage where the actual performance of the system needs to be established in detail. The New UK PR model allows for some contribution from pervious areas, which increases with event size. As storms become larger, this is a reasonable premise to make. This pervious term is controlled by the parameter NAPI (Net Antecedent Precipitation Index).

NAPI increases with rainfall depth during the event and therefore PR also increases. Design values for NAPI are a function of SOIL type and selected (usually) on the basis of the mean winter value from analysis of a rainfall time series for attenuation storage analysis. Values for Dublin are assumed to be:

SOIL type 1	1mm
SOIL type 2	5mm
SOIL type 3	10mm
SOIL type 4	25mm
SOIL type 5	40mm

The moisture depth parameter (PF) is a standard default value of 200mm.

Use of Hydrodynamic Models
When modelling to determine the approximate storage required, the pipe system is often modelled with a limit of discharge throttle and an overflow, and using either a fixed percentage runoff model or the New UK PR model. The volume passing over the overflow is the storage needed. A range of different storm durations is used to determine the maximum volume. This is done three times, each time the storage for the lower return period is included as storage in the node from which the overflow takes place.

This method under-predicts the volume of storage needed, as the head-discharge relationship of the hydraulic control(s) is not being represented. An additional allowance of 25% should therefore be applied to this first estimate of storage to allow for this approximation. This will be partially offset by the use of the conservative results found if the fixed percentage runoff model (paved 100%, permeable 0%) is applied. Detailed design, using the actual head-discharge relationship, will be needed to check whether the storage provision has been estimated correctly.

E2.2.2 Greenfield Runoff Rate Analysis

The formula from report IoH 124 is:

$$QBAR_{rural} = 0.00108AREA^{0.89}SAAR^{1.17}SOIL^{2.17}$$

The site is greater than 50ha; therefore apply the formula for the actual site area.

$$QBAR_{rural} = 0.00108 \times 0.7^{0.89} \times 750^{1.17} \times 0.37^{2.17}$$

$$QBAR_{rural} = 0.00108 \times 0.728 \times 2311 \times 0.116$$

$$QBAR_{rural} = 211 l/s$$

Therefore $QBAR_{rural}$ / ha is 3.0l/s/ha

Note that the FSR SPR value for SOIL type 3 is 0.37.

To get the 1, 30 and 100 year throttle rates the growth curve advised for use for developments, which is shown in appendix C is needed. Proposed values for Dublin are:

1 year factor	0.85
30 year factor	2.10
100 year factor	2.60

Therefore greenfield limiting discharge rates are:

1 year throttle	2.55 l/s/ha (178l/s)
30 year throttle	6.30 l/s/ha (441l/s)
100 year throttle	7.80 l/s/ha (546l/s)

E2.2.3 Attenuation Storage Analysis Using a Computer Model

Assuming that 25% of the paved surface does not contribute direct runoff even in the 100-year event, build a simple model of 70ha with an impervious connected area of 48.8% (0.65 x 0.75).

Figure E9 illustrates the modelling process.

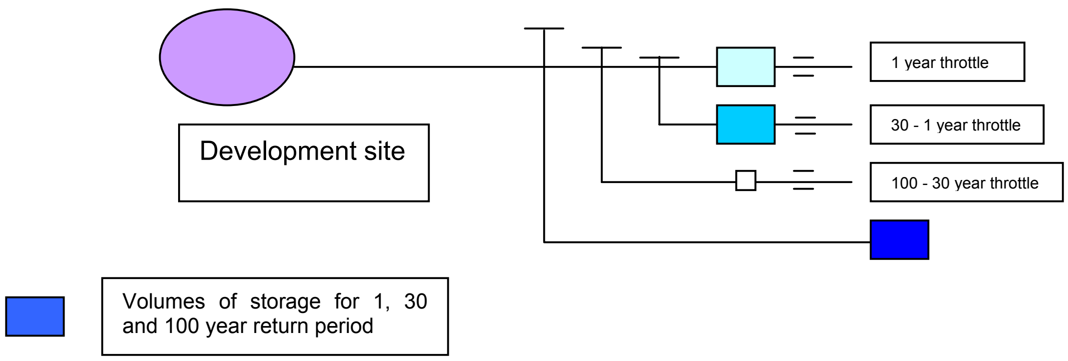


Figure E9 Modelling for River Regime Protection

Figure E9 illustrates the nodes, links, throttles and overflow structures that are represented in the model. The process of the model construction and analysis is discussed below.

Create rainfall files for range of durations (6, 12, 18, 24, 36 hours) for 1, 30, and 100-year events.

Factor all hyetograph (rainfall intensity) values by 1.1 to allow for climate change.

Use fixed discharge rates as calculated for greenfield runoff rates for 1, 30 and 100-year events.

Run 1
Run model for 1-year event with storage node set with a nominal volume (1m^3) with 1-year throttle of 178l/s.

Spill volume = 5250m^3

Run 2
Alter 1st storage node in model to provide 5250m^3 before spill occurs from overflow. Run model for 30-year event with 2nd storage node set at nominal volume (1m^3) with outflow rate equal to 263l/s (441 – 178). This is the 30-year throttle minus the 1-year throttle rate.

Spill volume = 5820m^3 from second overflow

Run 3
Alter 2nd storage node in model to provide 5820m^3 before spill occurs from overflow. Run model for 100-year event with 3rd storage node volume of 1m^3 with outflow rate equal to 283l/s (546 - 441). This is the 100-year throttle minus the 30-year throttle rate.

Spill volume = 2990m^3

Therefore total storage volume is approximately equal to:

1-year	5250m^3
30-year	5820m^3
100-year	2990m^3
Total	14060m^3

An allowance to account for the simplifying assumption of head – discharge relationship of 1.25 may then be needed depending on the design of the storage structure. This is because the model assumes the maximum flow rate can be mobilised immediately for each design return period.

Therefore an estimate of the attenuation storage of (14060 x 1.25) = 17575m^3 is required. This figure would be refined at the stage of detailed design.

Analysis then needs to be undertaken to evaluate the impact of high river levels on the discharge arrangements for the attenuation storage. This is described in the main document in chapter 6 and is not illustrated here. This needs to be carried out at detailed design, but some analysis at initial design is appropriate if it is clearly evident that river water levels will influence discharges from the site.

E2.3 Levels of Service – Criterion 3

There are four criteria for levels of service. These are:

Criterion 3.1 - No external flooding except where specifically planned. (30-year high intensity rainfall event).
Criterion 3.2 - No internal flooding. (100-year high intensity rainfall event).
Criterion 3.3 - No internal flooding. (100-year river event and critical duration for site storage)
Criterion 3.4 - No flood routing off site except where specifically planned. (100-year high intensity rainfall event)

Criteria 3.1 and 3.2 can only be analysed using a detailed drainage model of the proposed system. (Current models are still not sufficiently developed to do this as accurately as is really needed, but these will be developed in due course).

Criterion 3.3. Assessment of river levels requires either good knowledge of local flood levels or the use of a suitable hydrodynamic river model to predict them. On site retention storage levels can only be defined at detailed design stage when ground levels and storage unit arrangements have been defined in detail.

Criterion 3.4. Similarly detailed topographical information is needed to evaluate runoff routing. Detailed modelling work from criteria 3.1 and 3.2 will provide information on the relevant flood volumes.

Where Long term flood storage is to be provided by diverting flows from the Attenuation storage system, this needs to be checked by running the proposed storage system arrangement with a range of events to check how frequently and to what extent the Long term storage comes into effect.

E2.4 River Flood Protection – Criterion 4

The volumetric analysis for “River Flow Protection” is purely a comparison of pre- and post-development runoff volumes and can be described as “Long term” storage volume. The objective is to limit the runoff discharged to the river after development to the same as that which occurred prior to development.

There are three ways of ensuring that this volume is prevented from passing to the river. These are criteria 4.1, 4.2 and 4.3 respectively.

The first assumes that this volume can be designed to come into effect during extreme events only. This requires very careful modelling and analysis. Although design storm events can be used to evaluate the design proposals to check that long term storage is mobilised effectively and does not come into operation too frequently, it should be recognised that real rainfall is only being approximated by these profiles. Theoretically a check should be carried out using time series rainfall that is sufficiently long that suitable extreme events are represented. However as high resolution recorded data does not extend for more than a few decades, even if there are suitable gauges locally, there are unlikely to be sufficient extreme events to carry out a comprehensive check. New stochastic rainfall tools are being developed which will enable this type of testing of proposed solutions to be carried out more easily.

The second approach assumes that the Long Term storage volume is provided in the form of infiltration volume that provides sufficient storage at the time of an extreme event occurring. In the case of this example of a site with SOIL type 3, it is probable that much of the infiltration volume provided might only have a small proportion of the volume available if such an event took place in a wet period. Although both approaches have difficulties to overcome, it does not alter the need to try and address the requirement to provide long-term storage.

However if it is considered that either solution approach is not possible, a third approach allows for long term storage to be ignored, but that all runoff should be limited to QBAR (approximately 2 year return period), or 2 l/s/ha which ever is the greater. This should ensure sufficient stormwater runoff retention is achieved to protect the river during extreme events. In this case QBAR is 211l/s and would be used rather than 2l/s/ha (140l/s).

The formula for long-term storage is:

$$\mathrm{Vol}_{xs} = \mathrm{RD.A.10}\left[\frac{\mathrm{PIMP}}{100}(\alpha 0.8) + \left(1 - \frac{\mathrm{PIMP}}{100}\right)(\beta.\mathrm{SOIL}) - \mathrm{SOIL}\right]$$

where:

Vol_{XS} is the extra runoff volume (m^3) of development runoff over Greenfield runoff
RD is the rainfall depth for the 100 year, 6-hour event (mm)
PIMP is the impermeable area as a percentage of the total area (values from 0 to100)
A is the area of the site (ha)
SOIL is the “SPR” index from FSR
$\alpha 0.8$ is the proportion of paved area draining to the network or directly to the river (values from 0 to1) with 80 percent runoff
β is the proportion of pervious area draining to the network or directly to the river (values from 0 to1)

If it is assumed that 60% of the pervious area can be positively drained:

Vol_{xs} = 60 x 70 x 10 [(0.65 x 0.75 x 0.8) + (1 – 0.65) x 0.6 x 0.37 – 0.37]

Vol_{xs} = 42000 [0.39 + 0.078 - 0.37]

$Vol_{xs} = 4116m^3$

This volume is not additional to the attenuation storage volume, but it is effectively an element of it. This point is discussed further below.

It should be noted that this calculation assumes that the 25% of paved area is drained by infiltration and is not contributing any direct runoff. It can be seen by inspection that SOIL type 2 (with an SPR value of 0.3 rather than 0.37) would have significantly more volume to be stored while SOIL type 4 (SPR of 0.47) would need none.

If this Long term storage is not provided then the attenuation volume increases from 14060m^3 to 20450m^3 (calculated using the 1 year and QBAR throttle rates for the 100 year event in accordance with criterion 4.3 described above. The storage volumes are respectively 5250m^3 and15200m^3). This is assessed using the same approach described in E2.2.3. As before, this volume may need to be increased by 25% to take account of the head-discharge curve affects. This therefore could increase the total attenuation storage volume up to 25562 m^3 (20450 x 1.25).

E2.5 Storage Solutions for the Site

Having calculated all the elements of storage needed to comply with the various stormwater control criteria, the actual drainage solution needs to be developed. From the points made earlier as to difficulties that can exist in providing various forms of storage, 2 options are described below which illustrate two sets of drainage solutions for this example situation.

E.2.5.1 Option 1

Assume that Interception storage (criterion 1.1) and long term storage (criterion 4.1) can be provided and that the long term storage is in the form of flooding from the attenuation pond during extreme events.

Criterion 1 – River water quality protection
1. Interception storage = 1365 m^3 from Table E1

2. Treatment volume = 4095 –1365 = 2730 m^3 from Table E2

Treatment storage is reduced by 1365 m^3 as Interception storage has been provided.

Criterion 2 – River regime protection
3. Attenuation storage (5250 x 1.25) + 5820 + 2990 – 4116 = 11256m^3 from Section E2.2.3. The following explains the volumes calculated above.

It has been assumed that the additional provision of 25% due to head-discharge assumptions in the model is only needed for the 1 year event and that the design of the pond inlet structure mobilises the 30 year discharge rate immediately once the 1 year storage volume has been exceeded. Similarly the same assumption is made when the water level in the pond rises above the 30-year level. Figure E10 illustrates this assumption.

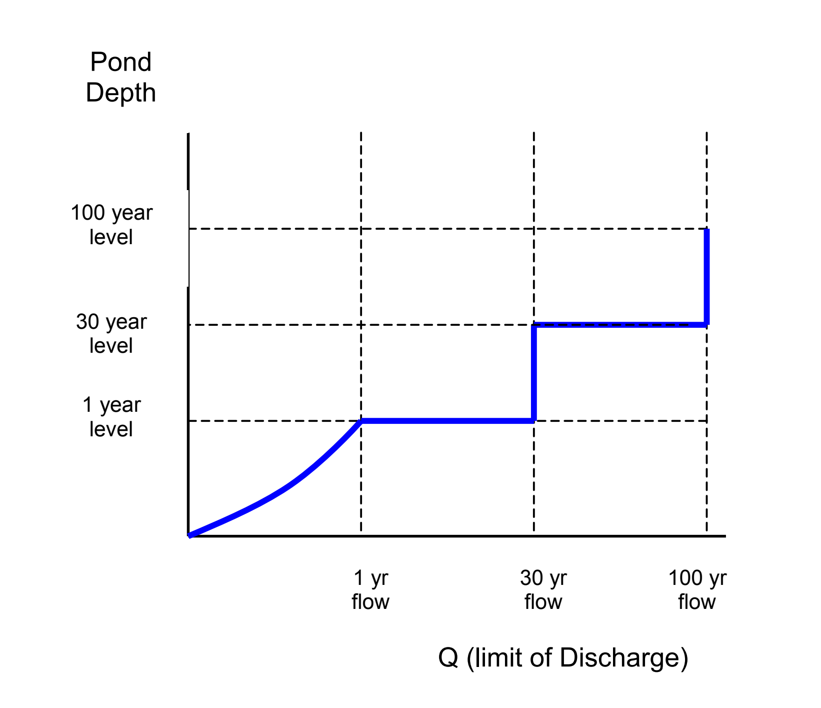


Figure E10 Flow Rate Increase to 30-year Limit of Discharge for Events Longer than 1-year Return Period

In addition, a reduction in the attenuation storage volume can be made equal to the Long Term storage volume of 4116 m^3 (criterion 4.1) as this volume of water is being stored elsewhere. At the detailed design stage these estimates would be checked in more detail using the actual head-discharge and depth-storage relationships.

The assumption that the attenuation storage above the 1-year event can avoid the variable head-discharge due to storage depth presumes that:

1. The authority allows discharge to increase to the 30 year rate immediately after the 1 year storage volume has been mobilised
2. The water levels in the pond and receiving water allow for a hydraulic design that enables this to be achieved.

In the case of the first assumption, it seems reasonable to discharge the 30-year flow rate once the storage has filled above the 1-year storage volume. The river flows are likely to be fairly high by this stage and the important morphological protection would have been provided for the vast majority of events. Many events of greater magnitude than the 1-year event will also be controlled to the 1-year criteria where the duration of the event is significantly different to the critical duration used for determining the 1-year storage. Thus a significant step in runoff (around 2.5 times) does not contravene the concept of protecting the river.

The second assumption is needed because the design approach to achieve this step change in discharge could require a flow control arrangement that involves headloss to mobilise the additional flow effectively.

Criterion 4 – River flood protection

4. Long Term storage 4116 – 1365 = 2751 m^3 from Section E2.4

Long-term storage is reduced by 1365 m^3 as Interception storage has been provided.

It can be seen by inspection from the figures for River Regime Protection, that to mobilise 2751 m^3 for Long term storage, the flooding will have to start coming into effect at about the 30 year return period. This is because the volume needed for attenuation storage between the 30 and 100-year events is only slightly larger at 2990 m^3. If interception storage is not provided and all the long-term storage (of 4116 m^3) is to be mobilised from flooding from the attenuation storage structure, it will start coming into effect for events that are significantly less than a 30-year return period.

E2.5.2 Option 2

The drainage assumptions (interception and Long term flood storage) made in the first option may not be possible. This second option looks at providing a drainage solution that does not utilise interception storage and that long-term storage cannot be provided as either infiltration or extreme event flood storage.

Volumes to be provided would then be:

Criterion 1 – River water quality protection
1. Treatment storage = 4095m^3 from Table E2

Criterion 2 and 4 – River regime and flood protection
2. Attenuation storage (5250 x 1.25) + 15200 = 20,662m^3 from Section E2.4

Attenuation storage is based on criterion 4.3 of using Qbar for the throttle rate for events greater than 1 year. This is used as long-term storage is not being provided.

This example and the 2 solution options demonstrate the importance of using the greenfield runoff rates of 30 and 100 years to minimise storage volumes.

E2.5.3 Options 1 and 2 Storage Summary

To assist in illustrating the differences between the two drainage solution options, table E3 has been produced which provides the information more succinctly.

Table E3 Storage Requirements Summary for Options 1 and 2

Criterion	Storage for Option 1	Storage for Option 2	Calculated storage for each criterion
1. River Water Quality Protection			
Criterion 1.1 "Interception storage"	1365 m^3	-	5mm – 1365 m^3
Criterion 1.2 "Treatment" Storage	4095 – 1365 = 2730 m^3	4095m^3	15mm – 4095m^3 (Vt – 6300 m^3)
2. River Regime Protection			
Criteria 2.1 & 2.2 "Attenuation" Storage	5250x1.25 + 5820 + 2990 – 4116 = 11256 m^3	See River Flood protection	1year – 5250 m^3 30year – 5820 m^3 100year – 2990m^3
3. Level of Service for the Site *			
Criteria 3.1 to 3.4	defined at detailed design	defined at detailed design	-
4. River Flood Protection			
Criterion 4.1 "Long term" Storage	4116 - 1365 m^3 = 2751 m^3	-	100yr, 6hr = 4116 m^3
Criterion 4.3 "Attenuation & Long term" Storage	-	5250x1.25 + 15200 = 20,662 m^3	1year – 5250 m^3 Qbar – 15200m^3

** Level of Service requires detailed modelling to determine network performance, flood routing, temporary storage volumes and locations and operational characteristics of long-term flood storage*

E2.6 Time Series Rainfall (TSR) Analysis for Long Term Storage Performance Evaluation

To test the operation of the long-term storage volume that was designed to come into effect during extreme events, a time series rainfall analysis was run. A schematic model of the proposed storage system (not the illustration above) was built with the intention of the long-term flood storage coming into operation for events greater than a 5-year return period. It was designed to provide the full amount of long-term storage for the 100-year event. The reason for the Long term storage to start coming into effect at the relatively low frequency of 5 years is that the site comprised type 2 SOIL and therefore the volume of storage was quite large. The model was run with 21 years of recorded time series rainfall.

The result was that the long-term storage was mobilised 15 times in the 21 years. This is more frequent than expected, slightly less often than once a year. 11 of the 15 events, in which the long-term storage area was mobilised, were events where flooding occurred in the river (flows were above the Q_{10} flow rate). One event fully mobilised the long-term storage volume requirement for a 100-year event (1540m^3).

This example illustrates the need for careful design of the long-term storage provision, but effectively illustrates the application of the principle. Figure E11 below shows the long-term storage volumes that were mobilised for each of these events. It also demonstrates that time series rainfall can produce different results to design rainfall events. It also draws attention to the problems of not having a sufficient duration of data to test for extreme events. This is one of the reasons why stochastic series rainfall (generated by software) is important in being able to evaluate certain aspects of drainage system performance.

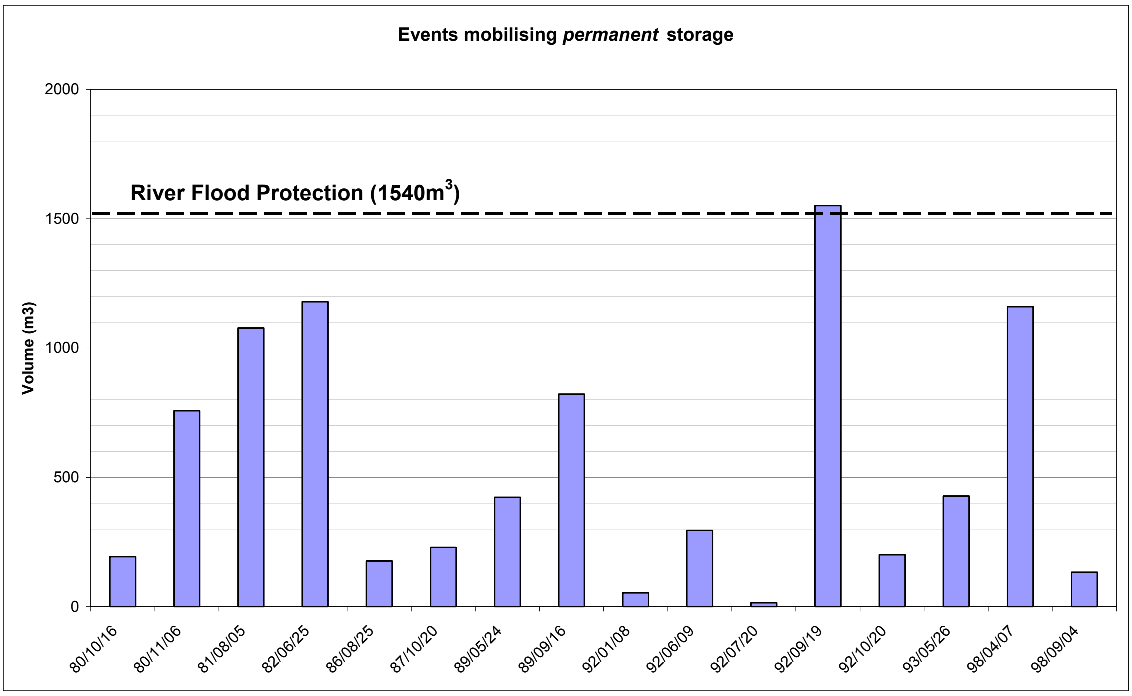


Figure E11 Time Series Rainfall Check for Events Mobilising Long-term Storage