Sizing of surface water management systems at landfill sites

LANDFILL GUIDANCE GROUP
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Prepared by the Engineering Subgroup of the Landfill Regulation Group. ICoPs are approved by the Landfill Guidance Group – an industry group of landfill professionals – with advice and input from regulatory bodies.

email *LandfillGuidance@esa.org*

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1 BACKGROUND AND INTRODUCTION

1.1 Background

1.1.1 This technical guidance document has been drafted to assist with the technical aspects of the design of surface water management schemes at both existing and at new landfill sites. The design of such schemes will usually be completed at the planning stage, although it is sometimes necessary to develop or revise designs on existing sites particularly where historical planning permissions may not have considered surface water management or flooding issues in detail.

1.1.2 This guidance is not intended to replace or conflict with planning requirements for the site. It is intended to provide technical guidance on the techniques available for the sizing of surface water management systems and considerations necessary in their design and is not intended to set out a specific set of requirements for all sites.

1.1.3 The need to design surface water management systems quantitatively is driven by the responsibility of a developer or landowner to mitigate potential risks from flooding at and around the site as a result of unmanaged surface water flow. The Non-statutory technical standards for sustainable drainage systems document, DEFRA 2015 (Reference 1) makes a distinction between new undeveloped sites in which landfilling and infrastructure construction is yet to receive permissions and permits, and existing site which have been developed and already have planning permissions and permits in place. For new landfill sites it may be necessary to demonstrate that a proposed development will not pose a significant additional risk of flooding of land in the vicinity of and downstream from a site for the purpose of satisfying the planning policies presented in the National Planning Policy Framework (Reference 2) formerly PPS25 (Reference 3), the Planning Practice Guidance to the National Planning Policy Framework (Reference 4) and the DEFRA 2015 document (Reference 1). As identified in the DEFRA 2015 document (Reference 1), for existing landfill sites it may not be practical to apply these policies and standards retrospectively due to existing site constraints such as the availability of land and site topography. For all sites a site specific assessment should be undertaken when designing surface water management systems. For existing landfill sites the site specific assessment should take into account the existing site constraints and permissions so that the amount of runoff generated at a site is minimised insofar as is practical with the site remaining compliant with current site permissions.

1.2 Introduction

1.2.1 Landfills are often constructed in former quarries which may act as collection areas for surface water runoff. As landfills are designed on the principle of containment, with low hydraulic conductivity barriers and caps and reduced infiltration, they have a significant effect on the way in which water drains from an area compared with the pre-development situation at the site. This effect needs to be quantified to prevent additional uncontrolled runoff which could lead to flooding in areas which were not affected by flooding prior to the development of the landfill or increased rates of discharge which increase flows and water levels in receiving watercourses and water bodies.

1.2.2 Surface water management systems should be considered for the periods both during and after the construction and operation of the landfill. It may also be necessary to consider the changes in landform over the extended life of the site resulting from settlement which could affect the integrity of drainage systems, gradients, runoff rates and the routes that runoff drains from the site.

1.2.3 The volume of surface water runoff and the runoff rate are calculated using several parameters and for each parameter a range of values may be appropriate. It is important to consider the range of possible values a parameter may have. A surface water management system should be designed to capture a reasonable range of uncertainty within the values for the parameters used in the design of the system. Parameters which may have a range of possible values with respect to the design of a surface water management system include rainfall intensity and duration, catchment size, slope gradient, vegetation cover and climate change factors.

1.2.4 The techniques discussed in the appendices to this document for estimating flows and volumes in relation to surface water management systems can be implemented using manual calculations, spreadsheets or bespoke surface water management design software. This document presents a summary of the techniques rather than the tools used to undertake the sizing of surface water management systems. The techniques presented in the appendices are relevant to existing and to new landfill sites.

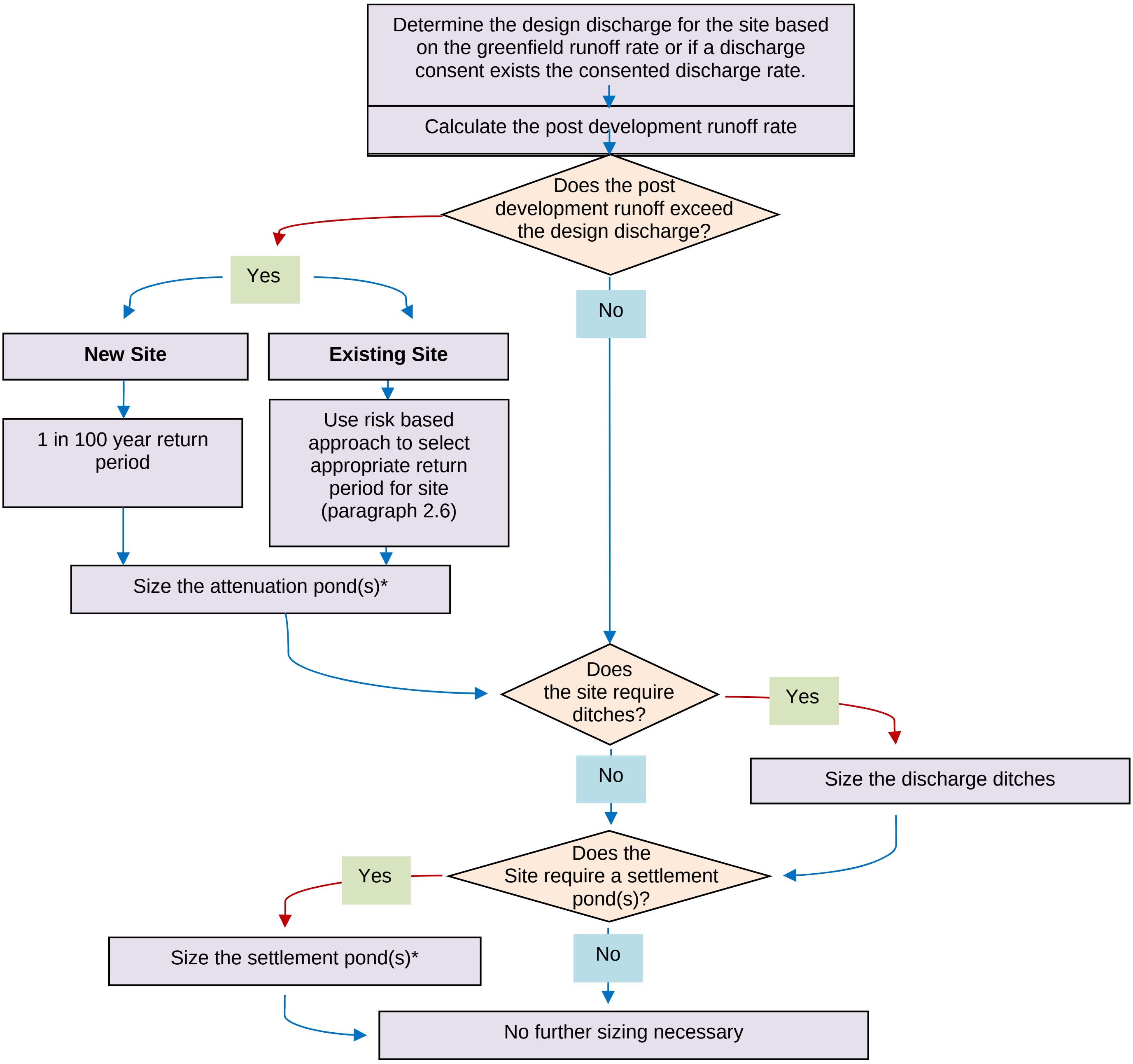
1.2.5 This document does not discuss the construction and design of surface water management systems beyond the sizing of the structures. No reference is made to the materials from which they could be constructed, the design of side slope gradients or the durability and maintenance of the structures. Clearly these issues will need to be considered and addressed as part of the detailed design of surface water management systems.

2 DESIGNING SURFACE WATER MANAGEMENT SYSTEMS

2.1 In this section an overview is presented of the issues which may need to be considered as part of the design process for a surface water management system:

- Conceptual site hydrological model
- Existing surface water infrastructure
- Existing discharge consents
- Existing landform
- Proposed development and pre settlement landform
- Proposed post settlement landform
- Impact on stability and hydrogeological risk assessments
- Receiving water bodies
- Off-site receptors
- Permitted discharge requirements.

2.2 The general methodology and design considerations are summarised in the following flow diagram:



* The design of the settlement pond(s) is dependent on the design discharge from the site. Consequently where the design discharge is high and space for the settlement pond(s) is limited it may be necessary to reduce the design discharge to allow a reduced settlement pond(s) size. This however will result in the need for larger attenuation storage.

2.3 References and techniques for calculating the required design parameters are presented in Appendices A to E.

Surface water runoff

2.4 Attenuation storage is likely to be required if a site development will increase surface water runoff. It is usual to begin by determining the existing surface water runoff which is permitted at the site. This can be specified in existing discharge consents or based on the current/pre-development greenfield runoff rate for the critical storm event for the site. The post-development critical storm runoff rate can then be calculated and if found to exceed the permitted flow in the discharge consent or the pre-development critical storm runoff rate for the site, it is likely to be necessary to provide on-site attenuation of surface water as part of the development. Typically most landfill developments are likely to increase runoff from a site and therefore an assessment of the increased runoff will be necessary together with consideration of surface water attenuation and management systems. Techniques for the calculation of runoff are discussed in Appendix A and references are provided in respect of documents where techniques for the calculation of runoff are presented.

Attenuation storage

2.5 For new sites the sizing of the attenuation requirements of the site is usually undertaken by considering the different intensities and durations of a 1 in 100 year storm event to determine the critical storm which would produce the maximum volume of storage required for the given permitted maximum discharge or pre-development runoff rate. The SuDS Manual (Reference 5) states that "*As peak runoff rates will usually require control up to the 1 in 100 year (see water quantity standard 2), components may be designed to manage events up to this size.*" Water quantity standard 2: Control of peak runoff rate in The SuDS Manual (Reference 5) states that drainage systems should be designed so that:

- Peak runoff rates from the site for events likely to be significant for the morphology, ecology or capacity of receiving surface waters or the capacity of receiving sewers (normally specified as approximately a 1 in 1 year event) are constrained to the greenfield runoff rates of runoff for the same return period and

- Peak runoff rates for extreme rainfall events (normally specified as a 1 in 100 year event) are constrained to the greenfield runoff rates of runoff for the same event.

2.6 For existing sites it may be more appropriate to use an alternative return period dependent on the sensitivity of the site and local receptors. For example a reduced return period such as a 1 in 10 year event may be a more appropriate for an existing site with limited additional space for the construction of ponds. If a reduced return period is to be used the residual impact of a 1 in 100 year event on site receptors should be assessed and appropriate precautions and contingencies considered. It will be necessary to discuss and agree with the appropriate regulatory bodies any reduction in the return period used in sizing the ponds for a site. Return periods are discussed in Appendix B and techniques for estimating attenuation storage are referenced and presented in Appendix C.

Ditches and settlement ponds

2.7 The sizing of the settlement ponds and ditches is undertaken to meet attenuation needs for the site during the design storm event based on the appropriate return period for the site, an allowance for climate change (see Appendix B), the discharge consent and the space available for infrastructure construction. Techniques for estimating ditch and settlement pond requirements for storage are presented in Appendices D and E respectively.

2.8 If a development will result in high levels of suspended solids within surface waters, such as within the operational life of the site where ground surfaces may be bare and un-vegetated, provision should be made for sufficient silt management capacity. Minimising the area of ground uncovered or the length of time it is left uncovered will reduce the level of storage required for dealing with suspended solids in surface water discharge. Possible approaches include rapid seeding or vegetation.

Location and relative elevations

2.9 Consideration should be given to the location and elevation of each element of the surface water management system infrastructure. Falls between the base of the attenuation pond(s) and the outfall need to be considered. The schematic diagram presented on Figure 1 shows the typical relative elevations of the different elements of the surface water management system. In practice these may vary to reflect existing site systems and topography. In some cases the settlement pond is incorporated as a forebay into a larger attenuation pond, however this may require more frequent maintenance and dredging to maintain the attenuation pond capacity. It is not recommended that the settlement and attenuation ponds are combined because the outfall for an attenuation lagoon is at the bottom of the pond which may allow the discharge of water with elevated levels of suspended solids. When designing the relative positions of each element of the surface water management system consideration should be given to existing landforms on site, the proposed development landform and the proposed restored landform. It may also be necessary to consider incorporating any pre-existing surface water management system into the new surface water management system.

Space limitations

2.10 Where limited space is available it may be necessary to calculate the maximum storm event which could be contained and dealt with on site and to put in place contingencies for larger storm events. Where it is proposed that temporary storage of flood event surface water is provided on capped areas of sites consideration should be given to the effect such as increased loading and seepage through the cap.

Hydrogeological and stability risk assessments

2.11 The design, sizing and location of the surface water management infrastructure should consider any stability or hydrogeological risk assessments undertaken for the site. For example consideration should be given to the placement of ponds and ditches in areas of capping and restoration which may be affected adversely by extra loading or seepage.

3 MANAGEMENT AND MAINTENANCE

3.1 Considerations for the maintenance and management of surface water systems at landfill sites include:

- Maintenance of ditches and ponds
- Management and control of vegetation
- Habitats and ecology
- Monitoring and permitted discharge requirements
- Control systems
- Storage on site for dust suppression and fire fighting

The following summaries of these considerations are not intended as an exhaustive checklist, but present a range of the possible post-construction issues which may need to be considered at the planning and design stage. A detailed study should be undertaken to identify the relevant post-construction issues which may need to be considered on a site specific basis. Guidance on the maintenance of surface water management systems is provided in the MIRO Handbook of Methods for Controlling Surface Water in and Around Aggregate Quarries, Reference 6.

Maintenance of ditches and ponds

3.2 Enabling easy maintenance for the lifetime of the surface water management system should be a key consideration. The surface water infrastructure should be designed for safe and easy access for maintenance and repair. Maintenance should include regular inspection of the integrity of all components of the surface water infrastructure and arrangements for periodic removal of silt from ponds, lagoons or other areas. All drains, culverts and ditches should be regularly inspected to verify their integrity and ensure that they are free from obstructions. The frequency of inspection will be dependent on the size of channels and infrastructure and the consequences of failure.

Management and control of vegetation

3.3 Regular management of vegetation growth in the surface water management system should be undertaken to maintain the designed efficiency and capacity. Vegetation in ponds should be controlled so that the function or capacity of the pond is not impaired having regard for ecological constraints. Vegetation in ditches may be required to provide attenuation, silt entrapment or barriers to access. In these cases the vegetation growth should be maintained such that the intended function is not compromised.

Habitats and ecology

3.4 The effect of the design and construction of the surface water management system on habitats and ecology within and outside the site boundaries should be considered. In some locations it may be required that ponds are provided for the creation of wildlife habitats. In these cases additional capacity may be required to maintain a specified water level.

Monitoring and permitted discharge requirements

3.5 The design of surface water management systems will need monitoring to verify that the quantity and quality of water being discharged from the site meets the permitted discharge requirements. This typically consists of regular sampling and testing of discharge waters sufficient to comply with the site permits and consents. At some sites it may be operationally beneficial to install water quality monitoring instrumentation. Water quality instrumentation may include turbidity meters for measuring the suspended solids content and conductivity meters for measuring salinity i.e. the concentration of dissolved salts or ion selective electrodes to measure concentrations of soluble ionic species such as chloride. Instrumentation such as flow meters can be used to measure the output of different components of the surface water management infrastructure.

Control systems

3.6 The need for control systems should be considered during the design process. These control systems should facilitate the movement of surface water between different components of the surface water infrastructure and enable rapid manual or automatic cut-off of discharge from the site should discharge consents or water quality limits be exceeded.

3.7 Control system components may include penstock and outlet valves which respond automatically if exceedances of pre-set levels for discharge water quality or volume are detected by the monitoring instrumentation. These systems may include the capacity to be controlled from a remote location.

Dust suppression

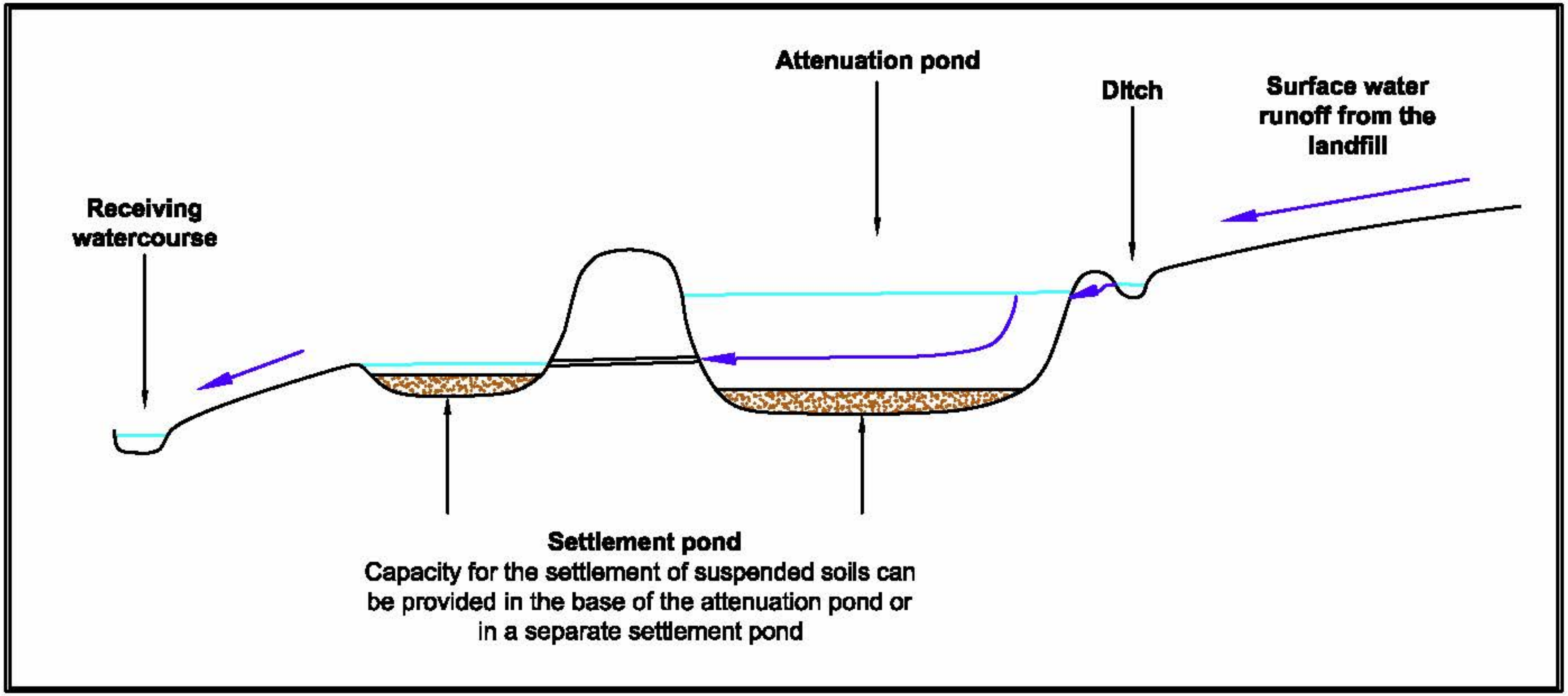
3.8 Surface water storage may provide useful storage capacity for use in dust suppression particularly in relatively dry areas of the United Kingdom such as the south east. If this is the case, provision should be made in the design of the surface water storage ponds for periodic tractor-bowser access to the pond.

Fire fighting

3.9 Surface water storage may provide a useful reservoir in the event that water is needed for fire-fighting on site. However if site specific requirements necessitate a permanent reservoir of water specifically for fire-fighting this will need to be designed in addition to the required storage for storm events.

FIGURES

Figure 1
Typical relative elevation and arrangement of surface water management infrastructure components.



APPENDICES

APPENDIX A

RUNOFF

A RUNOFF

A.1 For the purpose of determining the impact of the site on the runoff and discharge rate from the site it is necessary to determine the runoff prior to the proposed development. Irrespective of whether the site is already developed, this is termed the greenfield runoff rate (Reference 5). The pre-development greenfield runoff rate can be compared with the post-development runoff rate to determine the magnitude of the impact of the proposed development.

A.2 There are a large number of methods for estimating runoff for urban and rural settings. Appropriate methods for estimating greenfield runoff and post-development runoff for landfill sites which have been used widely historically comprise the Institute of Hydrology 124 method (IoH124) (Reference 7), the Agricultural Development and Advisory Service reference book 345 (ADAS 345) (Reference 8and Reference 9) and the Rational Method as presented in the National Coal Board – Mining Department handbook on managing water (Reference 10). These three methods have different limitations which preclude their use from certain situations. Interim guidelines presented in the Environment Agency scoping study on Estimating flood peaks and hydrographs for small catchments: Phase 1 (Reference 11) state that the Flood Estimation Handbook (FEH) methods including the statistical method (Reference 12) and the Revitalised Flood Hydrograph (ReFH) method (Reference 13 and Reference 14) are the preferred methods across the catchments with areas up to 25km^2. This preference is confirmed in The SuDS Manual (Reference 5). It is stated in the The SuDS Manual (Reference 5) that where FEH tools are not available and with the agreement of the approving body the IoH 124 method can be used for developing runoff estimates in surface water management design. It is anticipated that from 2017 new recommendations for estimating greenfield runoff rates and volumes will be published (Reference 5). These recommendations will be based on the results of Phase 2 of the Environment Agency project on estimating flood peaks and hydrographs for small catchments:

A.3 It is recommended that the The SuDS Manual (Reference 5) is used for guidance to determine the pre-development greenfield runoff rate compared with the post-development runoff rate at a site using the methods mentioned above and set out or referenced in the SuDS Manual.

A.4 The catchment of the surface water management system should be considered carefully as natural watersheds are not defined by site boundaries hence a catchment for a surface water management system could extend well beyond a site. Designers must consider if a surface water management system can be sized adequately to cope with water from off-site or whether runoff from off-site should be prevented from entering the on-site surface water management system. Natural processes such as siltation and the growth of vegetation in ponds and ditches can have a significant effect on the ability of the designed features to function in accordance with the design and should be taken into account in the design.

APPENDIX B

RETURN PERIODS AND CLIMATE CHANGE

B RETURN PERIODS AND CLIMATE CHANGE

B.1 Runoff rates calculated using the FEH methods including the statistical method (Reference 12) and the ReFH (Reference 13 and Reference 14) can include runoff rates for different return periods. Where the runoff rates calculated relate to discrete return periods it may be necessary to determine a runoff rate for an event with a different return period. A conversion between return periods can be made using growth curves for different regions of the United Kingdom presented in the FSSR report 14 (Reference 15).

B.2 The growth curves convert a runoff rate for an event with a return period of between 1 in 2 years and 1 in 1000 years to that for another event with a return period within the same range. There are also conversion factors for events with a return period of less than 1 in 2 years and these are presented in FSSR 2 (Reference 16).

B.3 Under the previous planning policy statements (PPS25 Reference 3) and current planning policy statements (NPPF Reference 1) and Planning Practice Guidance (Reference 4) it is necessary to consider climate change in the design of a proposed surface water management system. Table 2 in the internet based guidance “Flood risk assessments: climate change allowances” (Reference 17) presents the recommended precautionary increase in peak rainfall intensity to accommodate climate change.

B.4 Table 2 in the internet based guidance “Flood risk assessments: climate change allowances” (Reference 17) is split into three broad time periods for which there is a corresponding recommended percentage increase in respect of the central and upper end allowances. To incorporate a suitable factor of safety into the design of a surface water management system which takes into account the potential effects of climate change the rainfall intensity is multiplied by the peak rainfall intensity correction factor for both the central and upper end allowances.

B.5 The effects of climate change should be taken into account for the periods both during and following the site development.

APPENDIX C

ATTENUATION STORAGE

C ATTENUATION STORAGE

C.1 Once it has been established that the post-development runoff exceeds the designed discharge rate which could comprise either the pre-development runoff rate, the consented discharge rate or another rate as agreed with the relevant authority, it is necessary to determine the runoff volume to be attenuated. Guidance on calculating the attenuation storage needed is presented in the Environment Agency document entitled "Rainfall runoff management for developments" (Reference 18).

C.2 Once the post-development peak runoff rate has been calculated the method presented below can be used to estimate the necessary attenuation storage. The method is based on a methodology described in the National Coal Board Method (Reference 10) and has been amended to calculate the volume of water from a storm event rather than the flow rate and to incorporate a climate change factor. The volume of water which will be attenuated for a specified storm period and return period is:

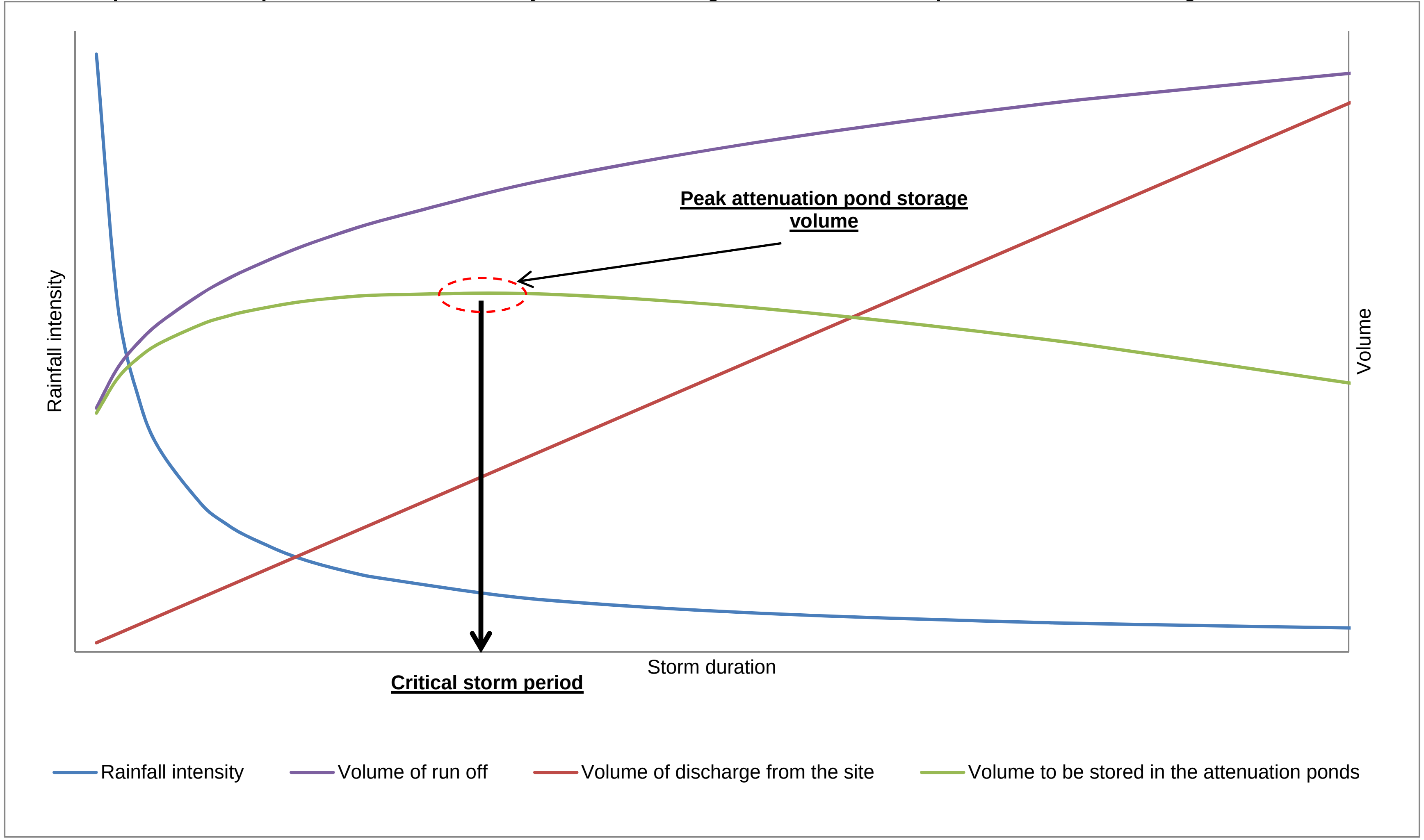
(1) $$V = (QtW) - (Q_x t)$$

Where:

- V is the calculated volume of water retained as a consequence of throttling the post-development discharge to the design discharge rate (l).
- Q Is the peak runoff rate calculated using the appropriate method for the specified return period and rainfall intensity (l/s).
- t is the length of time of the specified storm with intensity (s).
- W is the climate change factor (unitless).
- Q_x is the designed discharge rate which could comprise either the pre-development runoff rate, the consented discharge rate or another rate as agreed with the relevant authority (l/s).

C.3 The volume calculation is repeated for increasing storm durations until the volume to be attenuated reaches a maximum as shown on Figure C which presents an example of the relationship between rainfall intensity, runoff, discharge, and attenuation requirements for increasing storm durations. Rainfall intensities for different storm durations for different parts of the country and for different return periods can be obtained from the Flood Estimation Handbook Web Service (Reference 19). Based on this calculation the maximum volume of water retained is the minimum design volume for which attenuation is necessary. The storm duration which produces the maximum amount of storage is known as the critical storm duration. The critical storm duration is different for each catchment and discharge and should be determined on a site by site basis. For certain sites the critical storm duration may be very long. It should be noted that the very long storm periods obtained from the Flood Estimation Handbook Web Service (Reference 19) represent the combined effect of more than one rainfall event over a long time period.

Figure C
Example relationship between rainfall intensity, runoff, discharge and attenuation requirements for increasing storm durations



APPENDIX D

DITCHES

D DITCHES

D.1 The method of sizing an open channel is obtained from the Handbook of Methods for Controlling Surface Water in and Around Aggregate Quarries, MIRO, (Reference 6).

D.2 The equation used to calculate the flow rate in an open channel is the Chezy-Manning formula (Reference 6). From this equation it is possible to calculate appropriate widths and depths of the ditches to permit the necessary flow to pass along the ditch.

(2) $$Q = \frac{A_c R^{0.667} S^{0.5}}{n}$$

Where:

Q	is the flow rate (m^3/s)
A_c	is the cross sectional area of the drainage ditch (m^2)
R	is the hydraulic radius (cross sectional area divided by the wetted perimeter[1])
S	is the drainage ditch bed gradient (change in elevation divided by length)
n	is the Manning's roughness coefficient

D.3 Using the runoff rate in this equation will yield the ditch size required for the total runoff rate. A smaller ditch may be appropriate for the upper reaches of the drainage system where flows will be lower. Adjustments in ditch depth may affect the fall of the ditch along its length which should be accommodated in the calculations. Flow along the ditch will be affected by the ratio of depth to width. Flow in open rectangular drainage ditches is more efficient when the width of the base is approximately twice the depth (Reference 20).

D.4 The calculated flow rate is sensitive to the Manning's roughness coefficient which in turn is affected by the amount of vegetation in a ditch. Ditch vegetation changes from season to season and without regular maintenance may increase over time. Consequently a representative roughness coefficient incorporating a suitable factor of safety should be used and it may be prudent to undertake a sensitivity analysis. Values for Manning's n can be obtained from various sources including Reference 6. Manning's n can also be calculated for a range of ditch shape and vegetation situations based on the methods and guidance presented in the United States Geological Survey Water Supply Paper 2329 (Reference 21).

[1] The wetted perimeter is the cross sectional length of the drainage ditch channel in direct contact with the water in the ditch (m).

APPENDIX E

SETTLEMENT PONDS

E SETTLEMENT PONDS

E.1 The method of sizing settlement ponds is obtained from the Handbook of Methods for Controlling Surface Water in and Around Aggregate Quarries, MIRO, (Reference 6).

E.2 Settlement ponds are used to reduce the sediment load of the water discharged from a site and thus reduce the risk of potential pollution of the receiving water by suspended solids in the discharge water. Settlement ponds usually are required only when there is an increased likelihood that the runoff will contain a higher sediment load than would have been present in the pre-development runoff. Vegetation limits the erosion of soil hence mobilisation of suspended solids and consequently settlement ponds are more relevant to sites where vegetation is not established such as operating sites or sites which are being restored. Once sites are restored and vegetation is established it is not usually necessary to include a settlement pond in the surface water management system.

E.3 The size of a settlement pond can be estimated using Stokes' Law for settling (Reference 6). Stokes' Law for settling estimates the surface area needed to reduce the velocity of the water to a rate where a particle with a specific settling velocity will settle out of suspension. The equation assumes all particles are the same size.

(3) $$A = Q / u_s$$

Where:
- A is the calculated area of the settlement pond (m^2)
- Q is the flow rate though the settlement pond (m^3/s)
- u_s is the settlement velocity of a particle (m/s)

E.4 As the only dimensional values used in the Stokes' equation are the flow rate and velocity of the particle, a value for pond depth is not necessary in the equation. Consequently the settling calculation is not sensitive to the depth of the pond. However it is recommended in Reference 6 that settlement ponds are maintained at approximately 1m depth so that the settlement ponds have a sufficient depth to minimise erosion of the base of the pond and re-suspension of settled sediment. In addition it is recommended in Reference 6 that designers should attempt to avoid long, thin settlement ponds to prevent scouring and to dissipate the energy in the inflowing waters thus widening the area where settlement occurs. It is recommended that the outlet should be located as far as possible from the inlet. Sharp corners and dead end sections in ponds do not play an active part in transmitting flow across the pond hence are not included in the surface area over which flow is occurring. Consequently it is recommended in Reference 6 that ponds are designed as oval shapes which are longer in the direction of flow.

E.5 A maximum settlement velocity of 10^{-5} m/s is used in Equation 3 as it has been shown to achieve a settlement removal efficiency of 95% (Reference 6). This is equivalent to a particle with a diameter of 5×10^{-6}m (0.005mm) which is a fine silt particle as classified in BS5930:2015 (Reference 22). The fine silt particle size represents the point where particles become so small that the attraction of water molecules to the electrostatic charges on the particles begins to affect their ability to settle under gravity. Should it be anticipated that many of the particles will have a diameter less than fine silt, flocculant can be added to the settlement pond to assist in settlement. To assist in the settlement of suspended solids and improve the appearance of the settlement pond, based on the guidance in Reference 6 it is recommended that the growth of reeds and other plants is encouraged in the settlement pond provided that they do not prevent the effective periodical removal of sediment from the pond. Further advice concerning the design and management of settlement ponds is presented in Section 5.3.3 of Reference 6.

E.6 As the flow rate through the settlement pond affects the surface area and at certain sites space for a large settlement pond may not be available it may be necessary to reduce the discharge rate to allow a settlement pond with a small surface area to be considered. This would increase the storage requirement of the attenuation lagoon. Consequently in situations where space for a large settlement pond may not be available it may be necessary to size the settlement pond first followed by the attenuation lagoon. It is not recommended that the settlement and attenuation ponds are combined because the outfall for an attenuation lagoon is at the bottom of the pond which may allow the discharge of water with elevated levels of suspended solids.

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