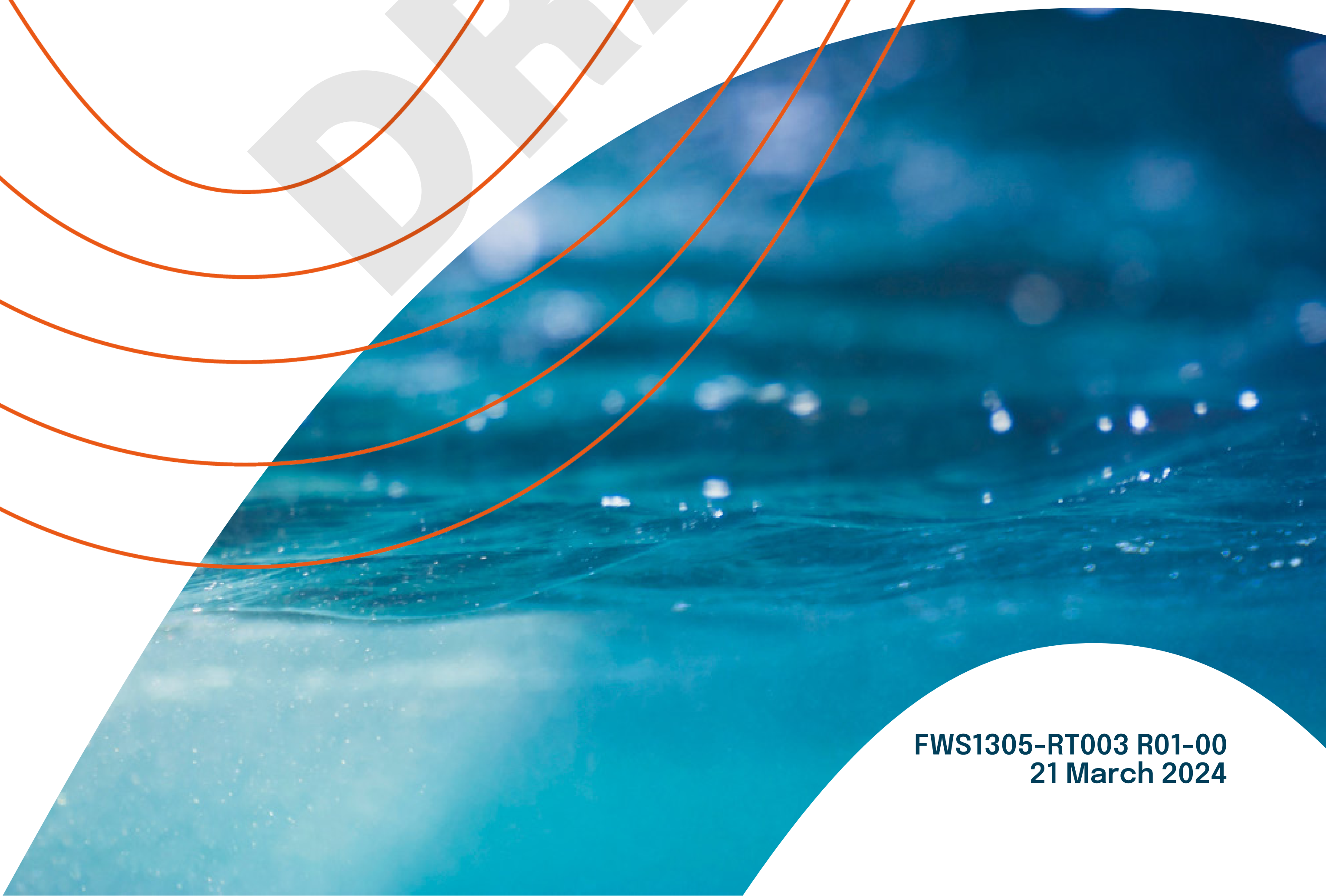
Stop UP

hr wallingford

Stop Urban Pollution (StopUP)

SuDS Tool Technical Guidance



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Prepared	Approved	Authorised
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1 Introduction

1.1 What is the reason for developing the StopUP SuDS tool?

SuDS drainage methods (particularly surface based vegetated SuDS) are widely acknowledged to be the best approach to managing surface water runoff from urban areas. This is because they can reduce runoff volumes and peak flows, provide partial capture and treatment of urban pollutants as well as providing a host of other additional benefits such as biodiversity, amenity and climate resilience.

A key issue for drainage designers is the lack of skills, information and tools to enable "good" SuDS design. This tool aims to address this deficiency by providing a simple facility (along with the necessary supporting information such as continuous rainfall data) to enable a proposed SuDS drainage system to be evaluated for their effectiveness.

1.2 What is the StopUP SuDS tool?

The StopUP SuDS tool has been built by HR Wallingford as part of the EC StopUP project (https://stopup.eu/).

The tool is a simplified web-based tool designed for non-technical drainage experts (e.g. planners, developers and their consultants) to assist in the design of SuDS, specifically encouraging reduction of surface water runoff (both volume and rate of flow), resource conservation and pollutant treatment on development sites.

The tool enables the representation of a SuDS drainage system and calculates and reports on its hydraulic and water treatment performance. An additional 'evaluation' functionality will soon be added to enable the modelled drainage system to be assessed against standards and best practice criteria (from the UK or elsewhere in the world).

The tool consists of a hydrological rainfall runoff model, a build-up and wash-off pollution model and hydraulic models of each type of SuDS. A drainage network of multiple SuDS can be modelled and analysed. The tool can run both design storms and time series rainfall. Reporting provides a summary of the system and its performance.

1.3 What are the StopUP SuDS tool capabilities?

The StopUP SuDS tool can model various hydrological, hydraulic and pollutant processes, which include:

- Design storms (to assess the drainage system against extreme events).
- Time series rainfall (to assess the drainage system for ordinary rainfall events).
- Filling of depression storage with initial rainfall on various surface types.
- Evaporation of surface water from depression storage.
- Evapotranspiration from the SuDS units, with variable rates depending on the site location and vegetation types.
- Fixed runoff from impervious surfaces.
- Variable runoff from pervious surfaces (not currently implemented).
- Non-linear reservoir routing of rainfall runoff.
- Storage of volumes in the SuDS unit including the sub-surface soil and drainage layers.
- Infiltration from SuDS into the ground.
- Pass-forward flows and flood flows from each SuDS unit.
- Rainwater harvesting and non-potable water demand.

- Pollutants build-up and wash-off from surfaces and removal of pollutants by SuDS.

The tool models each SuDS unit as an individual 'node' with contributing areas contributing flows and pollutants.

The tool is simplified in some key respects. The primary features are:

- It analyses each SuDS unit independently and there is no hydraulic influence considered from downstream SuDS units.
- The connecting pipework is not modelled for routing the water, but is only used to assess its capacity for limiting discharge out from the SuDS unit.
- There is no time delay or attenuation for flows passing out of a SuDS component into a downstream SuDS component.
- The SuDS units are modelled as simple reservoirs which store water. There is no routing of flows through them.

1.4 What can the StopUP SuDS tool be used for?

The objective of the StopUP SuDS tool is to evaluate the performance of the design of a SuDS system. The tool can be used to assess to the following:

- Assessment of the volume of surface water runoff from the site and how many rainfall events result in zero runoff from the site to assess the effectiveness of the reduction of runoff volume and compliance to Interception criteria used by regulators in the UK and also typical criteria used in other countries in the world.
- Assessment of resource conservation effectiveness by modelling rainwater harvesting and non-potable water demand (taking into account the variability of dwelling occupancy).
- Assessment of the network performance for extreme events in terms of peak flow rates leaving the site and total volume of flooding from the drainage system.
- Assessment of the treatment effectiveness of the SuDS system based on modelling a range of pollutants.

1.5 How do you get started with the StopUP SuDS tool?

A simple User Guide document complements this more in depth technical guidance document by demonstrating the principal steps to use the tool.

1.6 Do you want to provide any feedback?

The StopUP SuDS Tool is undergoing further development between March 2024 and the end of the StopUP project in September 2025. If you have any feedback or undertake any testing of the Tool against other drainage models or observed data we would be grateful if you can share those with us at email address support.stopup@hrwallingford.com.

2 Hydrological model

2.1 Rainfall

2.1.1 Time series rainfall

The tool allows time series rainfall (TSR) to be imported. This could be present day time series or adjusted to account for climate change and the tool has fields for the user to record what type of rainfall timeseries they have used. The tool does not contain any functionality to modify provided present day timeseries for climate change as this would need to be done outside of the tool if necessary. Imported rainfall time series should have a single header line and one column for the date time and another for rainfall intensity (mm per hour). Additional columns will be ignored.

The minimum duration of a TSR is one year however a warning message will occur if the TSR is less than three years. The maximum duration is ten years.

Alternatively, there are preloaded present day rainfall time series for ten locations across England. Summary statistics are available to help the user pick a rainfall series by hydrological characteristics rather than necessarily the closest in proximity.

2.1.2 Design storms

The tool allows the user to manually specify the rainfall depths for a matrix of design storm return periods and durations. Alternatively, the user can import a FEH22 rainfall file. The tool converts the rainfall depths to a profile using the summer profile derived from the ReFH2.3 software.

A climate change uplift factor can be applied to design storms using either of these methods. This is treated as a global multiplier for total storm rainfall depth.

2.2 Surface runoff

The conceptual model of surface runoff consists of three components:

- A depression storage depth;
- A net runoff assessment of the rainfall falling on each surface type;
- Routing of the runoff from the catchment surfaces contributing to the SuDS component.

A depression storage depth fills with rainfall at the start of an event and empties via evaporation (see Section 2.3). Only when the depression storage is exceeded does runoff occur. This depth of storage is small, but it is important as many rainfall events are also very small.

Four surface types produce rainfall runoff that enter the SuDS units. These are paved surfaces, roofs, pervious areas and the above ground SuDS components themselves. The parameters used for each surface are shown in Table 2.1. A fixed percentage runoff model is used for the catchment impervious surfaces (roads and roofs) and is usually set at 100%, i.e. 100% of the rainfall is converted to runoff. A fixed pervious runoff factor is selected by the user based on the soil characteristics of the site.

A variable percentage runoff model is proposed for development, but is not available for the current version of the tool. The proposed approach is however described in Appendix D.

A routing model is applied to the catchment surface runoff to represent the attenuation process of rainfall runoff routing to the drainage network. The Double Linear Reservoir (Wallingford) Model has been implemented. The speed routing depends on the slope of the catchment, therefore the tool allows for the user to specify whether the site catchment areas have 'shallow' slopes (1 in 125, 0.008 m/m), 'normal' slopes (1 in 50, 0.02m/m), or 'steep' slopes (1 in 12, 0.083 m/m). The default is 'normal'.

Rainfall that lands directly on the above ground SuDS components have no depression storage, no volume loss or routing of the runoff applied.

Table 2.1: Surface runoff parameters

Surface	Depression storage	Volume of runoff	Routing of runoff
Catchment - roof	Default = 0.2 mm (allowable range 0.2 to 1 mm)	Fixed percentage runoff model Default = 100% (not editable)	Double Linear Reservoir (Wallingford) Model

Surface	Depression storage	Volume of runoff	Routing of runoff
Catchment - paved	Default = 1 mm (allowable range 1 to 2 mm)	Fixed percentage runoff model Default = 100% (allowable range 85-100%)	Double Linear Reservoir (Wallingford) Model
Catchment - pervious	Default = 5 mm (allowable range 2 to 10 mm)	Fixed percentage runoff model. Default = 40% (allowable range 0-50%) [A variable percentage runoff model is proposed, but this is not yet implemented]	Double Linear Reservoir (Wallingford) Model
Above ground SuDS	0mm (not editable)	Fixed percentage runoff model Default = 100% (not editable)	None

2.3 Evaporation and evapotranspiration

Two mechanisms of evaporation are represented by the tool:

- Evaporation from the depression storage of the upstream catchment areas draining to the SuDS (see Section 2.2); and
- Evapotranspiration from the soil layer of the SuDS units (see Section 3.1).

Both of these use the same underlying equations.

Note that, as the evaporation method is based on monthly temperatures, it is only applied for time series rainfall and no evaporation or evapotranspiration is applied for design storms.

Reference evapotranspiration, ET_o

A reference evapotranspiration is calculated using the 1985 Hargreaves (Allen, et al., 1998) reference evapotranspiration equation:

$$ET_o = 0.0023(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5} R_a$$

Where:

- ET_o (mm/day) is the reference evapotranspiration. The reference surface is a hypothetical grass reference crop. The only factors affecting ET_o are climatic parameters;
- T_{mean} (˚C) is the daily mean air temperature $\frac{T_{max}+T_{min}}{2}$;
- T_{max} (˚C) is the daily maximum air temperature;
- T_{min} (˚C) is the daily minimum air temperature;
- R_a (mm/day) is the extraterrestrial radiation, which is a function of the latitude.

$$R_a = \frac{24 \times 60}{\pi} G_{SC} d_r [\omega_s \, sin(\varphi) \, sin(\delta) + \cos(\varphi) \, cos(\delta) \, sin(\omega_s)]$$

Where:

- R_a (MJ m^{-2} day^{-1}) is the extraterrestrial radiation (mm/day = 0.408 x MJ m^{-2} day^{-1});
- G_{SC} is the solar constant, 0.0820 MJ m^{-2} day^{-1};
- d_r is the inverse relative distance between Earth – Sun; $d_r = 1 + 0.033 cos\left(\frac{2\pi}{365} J\right)$;
- ω_s is the sunset hour angle; $\omega_s = arccos[-tan(\varphi) \tan(\delta)]$;
- φ is the latitude (rad); (radians = $\frac{\pi}{2}$ x decimal degrees);
- δ is the solar declination (rad); $\delta = 0.409 \, sin\left(\frac{2\pi}{365} J - 1.39\right)$;

- J is the number of the day in the year between 1 (1 January) and 365 or 366 (31 December).

The parameters required from the user are the latitude and the daily minimum and maximum air temperatures for each month. The default parameters provided in the tool are for London obtained from https://weatherspark.com/countries/GB/ENG.

From this a reference evapotranspiration ET_o curve variable throughout the year can be developed for the site. This value is calculated for each day (and does not take temperature fluctuations through the day into consideration as this information is not required by the tool).

The reference evapotranspiration ET_o can be converted into specific surface or vegetation evapotranspiration values, ET_c, using different coefficient, K_c, values, where $K_c = \frac{ET_c}{ET_o}$.

Surface evaporation, ET_c

Evaporation from the depression storage of the upstream catchment areas draining to the SuDS uses the following fixed values for each surface:

- Paved, K_c = 1;
- Roof, K_c = 1;
- Pervious, K_c = 0.95.

If it is raining, then no evaporation from depression storage occurs.

No evaporation is applied to the rainfall landing directly onto the above ground SuDS as this is accounted for via the evapotranspiration from the soil store.

SuDS vegetative evapotranspiration, ET_c

For evapotranspiration from the soil store of the SuDS units, the vegetation type (and thus K_c) is fixed for all of the SuDS units, except for the bioretention unit where the user can define which vegetation from a drop down list (see Table 2.2).

The rate of evapotranspiration from the soil store of the SuDS units depends on how full the soil store layer is. If the soil store layer is 100% full, the evapotranspiration rate is 100% of the ET_c rate. The evapotranspiration rate reduces linearly to 0% of the ET_c rate when the soil layer is 10% or less full.

If it is raining, then evapotranspiration from the soil store of SuDS continues.

Table 2.2: SuDS vegetation evapotranspiration parameters

SuDS unit	Vegetation	K_c
Bioretention	User editable to: Trees Grass Herbaceous plants Shrubs	User editable to: 1.0 0.95 0.8 0.6
Tree pit	Fixed - Trees	1.0
Green roof	Fixed - Grass	0.95
Pervious pavement	N/A	N/A
Swale (standard)	Fixed - Grass	0.95
Swale (under-drained)	Fixed - Grass	0.95
Basin	Fixed – Grass	0.95
Pond	Fixed – Open water	1.05
Rainwater harvesting	N/A	N/A
Soakaway/infiltration trench	N/A	N/A
Attenuation tank	N/A	N/A

3 SuDS hydraulic model

Sustainable Drainage Systems (SuDS) are a collection of drainage components designed to manage rainfall close to where it falls, to mimic natural drainage and encourage stormwater infiltration, evapotranspiration, reuse, storage, control and passive treatment.

The StopUP SuDS tool can model the SuDS components listed in Table 3.1.

As there are many similarities between all SuDS components, a conceptual SuDS unit (Section 3.1) is used as a reference against which only the differences are described for the other types of SuDS (Sections 3.2 to 3.11).

Section 3.12 details the additional elements which can be added to the network (the contributing areas and outfalls). Section 3.13 summarises the storage layers and the volume transfer within a SuDS component for each SuDS type.

Table 3.1: SuDS types

Bioretention	Bioretention systems (including rain gardens) are shallow landscaped depressions that can reduce runoff rates and volumes, and treat pollution through the use of engineered soils and vegetation
Tree pit	Tree pits are similar to bioretention systems in structure, with the addition of a tree. They can collect and attenuate runoff, and the tree enhances the evapotranspiration
Green roof	Green roofs are roofs with a vegetated surface that provide a degree of retention, attenuation and treatment and promote evapotranspiration
Pervious pavement	Pervious pavements provide a impervious surface for pedestrian or vehicular use, while allowing rainwater to infiltrate through the surface to be temporarily stored, infiltrated into the ground or realised at a controlled rate
Swale (standard and under drained)	Swales are shallow, flat bottomed, vegetated open channels designed to convey, treat and often attenuate surface water runoff. Swales may be under drained with a drainage layer or not
Basin	Basins are landscaped vegetated depressions that are normally dry except during and immediately following storm events. They are designed to attenuate and provide treatment and may also infiltrate some of the water
Pond	Ponds are features with a permanent pool of water but can also temporarily store surface water. They provide attenuation
Rainwater harvesting	Rainwater harvesting is the collection and storage of rainwater for use. This does not include water butts as it must include regular daily demand for non-potable water
Soakaway/ infiltration trench	Soakaways are excavations that are filled with a void-forming material that allows the temporary storage of water before it soaks into the ground. Infiltration trenches are linear soakaways
Attenuation tank	Attenuation storage tanks are used to create a below ground void space for the temporary storage of surface water with a controlled release rate

3.1 Conceptual model

A typical bioretention cell is used as a generic SuDS model which is then customised for all other SuDS types. This section outlines the conceptual unit in detail and the following sections on each of the other SuDS types only detail the differences from this.

3.1.1 Storage layers

Figure 3.1 shows a schematic which describes the basis of the model.

Conceptually, the SuDS unit can be represented by three horizontal storage layers:

1. The **Surface Layer** represents the ground surface and fills if there is excess volume within the soil layer. Volume leaves the surface layer and re-enters the soil layer if capacity comes available. Water can also leave the surface layer via an overflow structure, or via flooding if it overfills.
2. The **Soil Layer** is the engineered soil mixture used to support vegetative growth. It receives the rainfall that lands directly onto the SuDS and also any inflow from upstream catchment area or SuDS. Evapotranspiration removes volume from the soil layer. When the soil layer reaches 85% full water percolates into the drainage layer at 85 mm/hr. The choice of 85% represents the effective saturation of the soil when the soil media layer hydraulic conductivity rate (85 mm/hr, ~$2x10^{-5}$ m/s) starts (De-Ville et al, 2022 & Zhang, 2010).
3. The **Drainage Layer** is a layer of fill material that provides storage. Water enters the drainage layer via percolation from the soil layer, but no reverse flow is allowed. Water leaves the drainage layer via infiltration through the sides and base of the structure and via an outfall structure.

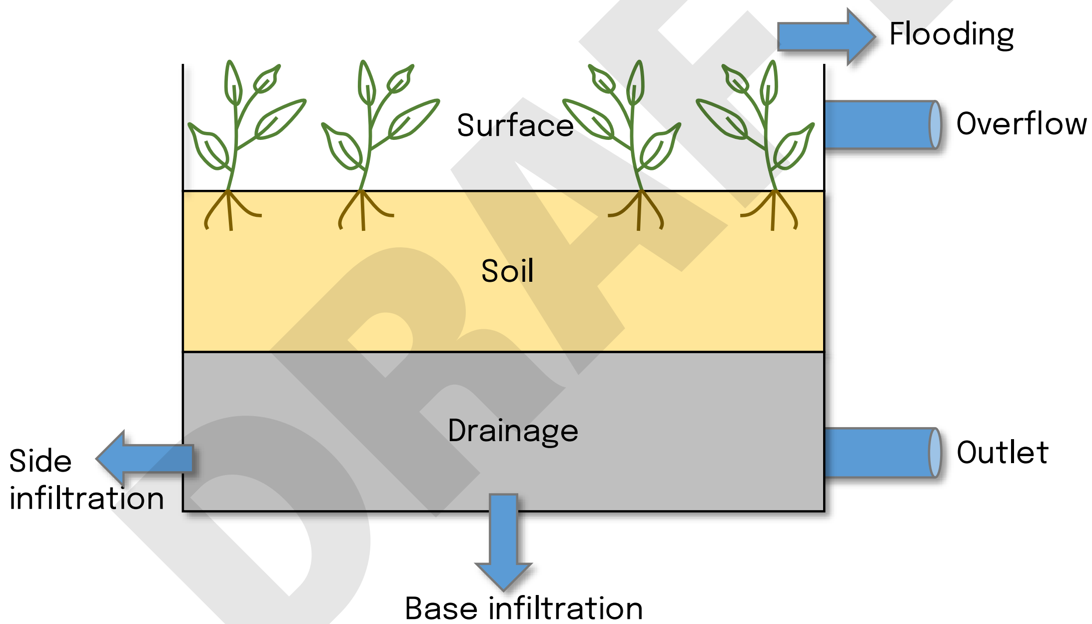

Figure 3.1: Conceptual SuDS (bioretention) units schematic

Source: HR Wallingford

3.1.2 Volume transfers

Transfers in and out of the three storage layers are further detailed as follows. This process is carried out for every timestep in the model:

1. The **rainfall falling onto the SuDS** reflects the rainfall that lands directly onto the SuDS plan area and can enter the SuDS storage volume. 100% rainfall runoff is assumed, and no depression storage is applied. The volume enters the soil layer (or preferentially the drainage then surface layer if the SuDS unit does not have a soil layer).
2. The **rainfall runoff from the SuDS catchment area** reflects the rainfall-runoff from the catchment which drains to the SuDS unit. The upstream catchment can be a mixture of roads,

paved or pervious surfaces each with their own runoff percentages and depression storage depths. Evaporation reduces the volume stored in the depression storage. See Section 2 for more detail. The volume enters the soil layer (or preferentially the drainage then surface layer if the SuDS unit does not have a soil layer).

3. The **inflow from upstream SuDS** is inflow from other SuDS units whose outfalls and overflows drain to the SuDS unit. Any flooding from a SuDS unit is assumed to also enter the next downstream SuDS unit. The volume enters the soil layer (or preferentially the drainage then surface layer if the SuDS unit does not have a soil layer).
4. **Evapotranspiration** reflects the movement of water from the soil layer into the atmosphere, via both evaporation (the movement of water to the air directly from the soil) and transpiration (the movement of water from the soil, through the roots, bodies of vegetation and leaves before exiting into the air). The evapotranspiration from the SuDS is modelled as one loss removing water from the soil layer (except for a pond where evaporation occurs from the surface layer).
5. **Transfer from the soil to the drainage layer** reflects the movement of water through the soil when the water content of the soil exceeds the field capacity. When the soil layer exceeds 85% full water percolates into the drainage layer at 85 mm/hr. The choice of 85% represents the effective saturation of the soil when the soil media layer hydraulic conductivity rate (85 mm/hr, ~$2x10^{-5}$ m/s) starts (De-Ville et al, 2022 & Zhang, 2010).
6. **Infiltration** is the process by which water from the drainage layer (or soil layer from SuDS without a drainage layer) enters the underlying (base) or surrounding (side) soils or bedrock. Side infiltration is calculated based on the depth of water in the SuDS, and base infiltration is a fixed rate.
7. **Transfer from the soil to the surface layer** happens when the total volume of water in the soil layer is greater than its capacity after all flows have been removed. Any volume above the soil layer's capacity is transferred to the surface layer with no limit on transfer rate. (The same process is true if there is no soil layer, for example the pervious pavement where transfer occurs from the drainage to the surface layer).
8. **Outfall** is the frequent and planned discharge point from the SuDS unit. It could be an orifice, weir or not exist (if it is an infiltration designed SuDS). The outfall could be positioned at the base or raised above the base of the layer.
9. **Overflow** is the infrequent discharge point from the SuDS unit that would be used in times of exceedance. It could be an orifice, weir or not exist. The overflow could be at ground level or raised above ground level.
10. **The downstream pipe** into which the SuDS outfalls and overflows connect into could cause a hydraulic limit on the flow leaving the SuDS units, therefore the model limits flow out of the outfall and overflow based on the connecting pipe-full capacity or a user defined peak flow rate limit.
11. **Flooding** is the unplanned excess of volume. If the water level in the surface layer exceed the surface layer depth (or in the case of the attenuation tank, soakaway or rainwater harvesting the water level in the drainage layer exceed the drainage layer depth), the excess volume is removed from the surface layer and applied to the next downstream SuDS unit with no limit on flow rate. The final SuDS unit is not allowed to flood, but instead stores the water above the SuDS unit.

Figure 3.2 shows the conceptual model of how the three layers interact, and the inflows and outflows from each layer.

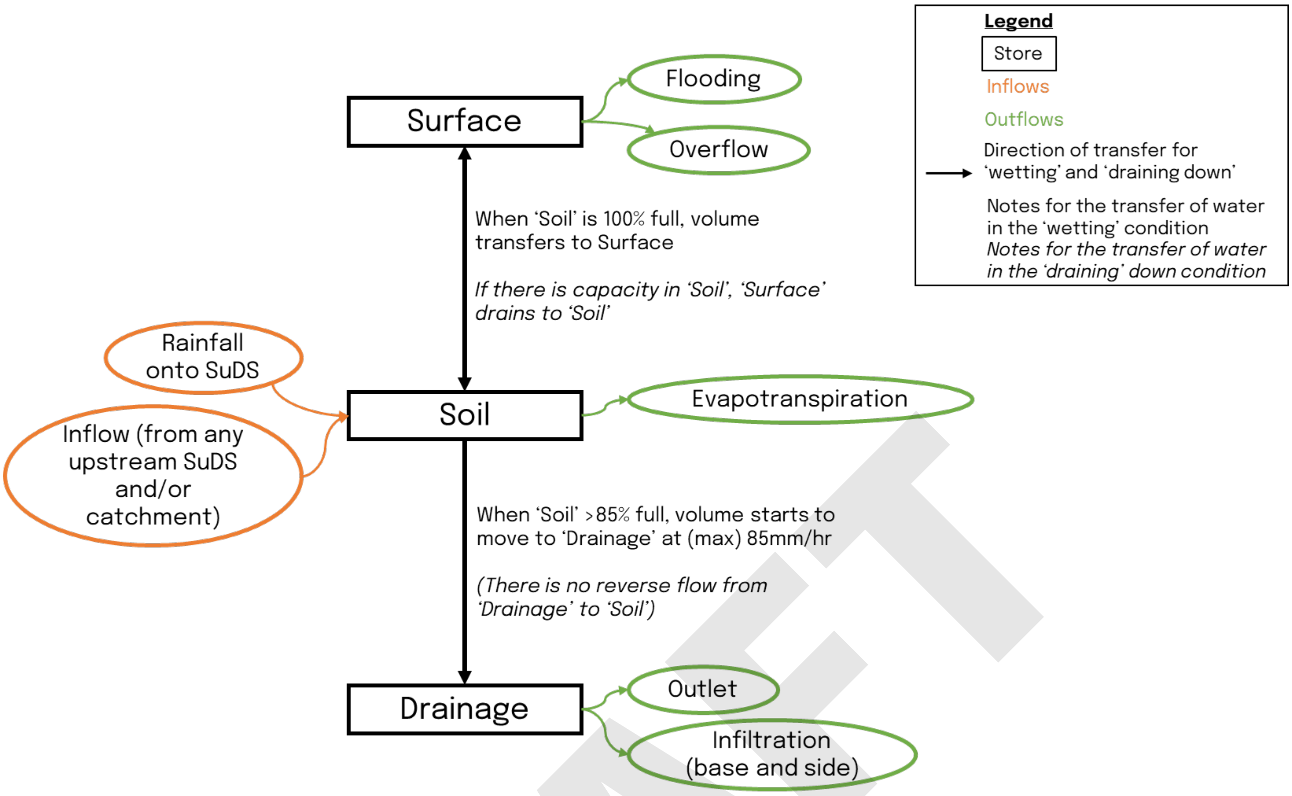

Figure 3.2: Interaction between the storage layers and inflows and outflows

Source: HR Wallingford

3.1.3 Model assumptions

To model the hydraulic performance of the conceptual SuDS unit the following simplifying assumptions are made:

1. The cross-sectional area of the unit remains constant throughout its depth except for:
    a. Ponds and basins, where the cross sectional area of the surface is assumed to increase linearly from the bottom to the top;
    b. Swale geometry is more complex and allows for a sloped base and sides.
2. Flow through the unit is one-dimensional in the vertical direction.
3. The layers act as simple reservoirs that store water from the bottom up.
4. Inflow to the unit is uniformly distributed into the soil layer (or drainage layer where there is no soil layer).
5. Flooding occur at the final SuDS unit stores the water above the SuDS unit with a continuation of the same plan area.

3.1.4 Timestep calculations

Timesteps are either the same as the input time series rainfall, or are set to 1/100 of the duration of the design storm.

The order of the calculations controlling the movement of volume within the model is as follows:

1. For nodes with a soil layer it is topped up with rainfall falling onto the SuDS and inflow from other SuDS and/or catchment. Some SuDS don't have a soil layer (e.g. pervious pavements) and therefore the rainfall and inflows are added to the drainage layer.

2. Reduce volume in soil layer by evapotranspiration. Evapotranspiration rate linearly varies with how full the soil layer is. When the soil layer is 100% full, 100% of the evapotranspiration rate is applied. The evapotranspiration rate reduces linearly with water depth such that 0% of the evapotranspiration rate is applied when the soil layer is 10% full. If the soil layer is less than 10% full, zero evapotranspiration is applied.
3. For nodes where infiltration occurs from the soil layer, volume is then removed (e.g. basins). Side infiltration is calculated first followed by base infiltration.
4. Calculate the transfer of volume between soil layer store and the drainage layer:
   a. If soil layer is <85% full, no flow occurs to the drainage layer;
   b. If soil layer is >=85% full, volume is transferred to the drainage layer at a rate of the hydraulic conductivity (85 mm/hr). The excess/remainder continues to fill the soil layer;
   c. (Upon "draining down"/"drying up" of the SuDS, no flow can occur from the drainage layer to the soil layer).
5. Reduce volume in drainage layer by infiltration (side infiltration followed by base infiltration).
6. If soil layer is full, transfer volume to surface layer (note drainage layer won't necessarily be full).
7. Reduce volume in surface layer through the overflow, up to the capacity of the continuation pipe.
8. If the volume in the surface layer still exceeds the storage capacity, any remainder is removed as flooding directly to the next node downstream (bypassing the continuation pipe). Except for the final SuDS unit in the network where additional volume continues to fill the surface layer as all flood volumes are assumed to remain on site and all flows off site are to go via the outfall.
9. Reduce volume in the drainage layer by flow through the outfall, up to the remaining flow rate capacity of the continuation pipe taking into account flows taking place through the overflow.
10. Upon "draining down"/"drying up" of the SuDS if the soil layer is not full and surface layer contains a volume, transfer volume from surface layer to soil layer.
11. Continue on to the next timestep until the entire inflow hydrograph (and for design storms the drain down) has been simulated.

3.1.5 Outfall and overflow equations

The conceptual SuDS unit allows for an outfall and an overflow to be modelled. Depending on the SuDS unit the user has choices or fixed options as to whether the structure is an orifice/pipe, a weir, or if it doesn't exist.

Orifice/pipe

The hydraulic equation used to calculate the flow through an orifice or pipe depends on the water level relative to the orifice/pipe soffit. If the water level is not above the orifice/pipe soffit a thin plate rectangular weir under free discharge equation is applied:

$$Q = C_d \sqrt{g} B D_u^{\frac{3}{2}}$$

Where:

- Q is flow (m³/s);
- C_d is the discharge coefficient where a value of 0.85 is applied (based on WAPUG user note 27 (Balmforth, 2009));
- g is the gravitational acceleration constant of 9.81 m/s²;
- B is the effective rectangular width (m). A value of $0.56D_o$ is used, where D_o is the orifice diameter (mm);

- D_u is the upstream depth with resect to the crest (m) (i.e. water level minus orifice invert level).

If the water level is above the orifice/pipe soffit an orifice under free discharge condition equation is applied:

$$Q = C_d A_o \sqrt{g} {D_{cl}}^{0.5}$$

Where:

- Q is flow (m³/s);
- C_d is the discharge coefficient where a value of 0.85 is applied (based on WAPUG user note 27 (Balmforth, 2009) and Butler & Davies (2010) 0.6*sqrt(2));
- A_o is the orifice/pipe cross sectional area (m²);
- g is the gravitational acceleration constant of 9.81 m/s²;
- D_{cl} is the height of water above the centroid of the orifice/pipe (m).

Weir

The hydraulic equation used to calculate the flow through a weir is the thin plate rectangular weir under free discharge equation:

$$Q = C_d \sqrt{g} B {D_u}^{\frac{3}{2}}$$

Where:

- Q is flow (m³/s);
- C_d is the discharge coefficient where a value of 0.6 is applied (based on WAPUG user note 27, sharp edged weir crest (Balmforth, 2009) and Butler & Davies (2010) 2/3*sqrt(2));
- g is the gravitational acceleration constant of 9.81 m/s²;
- B is the effective rectangular width (m) which is a user input. Note, to model a vertical pipe B should be set to a length equal to the circumference of the pipe;
- D_u is the upstream depth with resect to the crest (m).

Effect of downstream connecting pipe

Between SuDS units are connecting pipes which the SuDS outfalls and overflows connect into. These pipes could cause a hydraulic limit on the flow leaving the SuDS units as calculated from the orifice or weir outlets and therefore the model carries out a check of the flow out of the outfall and overflow based on the connecting pipe-full capacity or a user defined peak flow rate limit. If the flow calculated using the weir and/or orifice equations exceeds the connecting pipe-full capacity or a user defined peak flow rate limit, the flow out of the outfall and/or overflow will be limited to the connecting pipe-full capacity. Any flooding from the SuDS unit is not limited by the connecting pipe limit. See Figure 3.3.

The rules which dictate the flow out of the SuDS outlets are as follows:

- If flow through the outfall plus flow through the overflow (using weir and/or orifice equations) is less than or equal to the pipe-full flow rate of receiving pipe or user defined peak flow rate, then flow through outfall and overflow are equal to the weir and/or orifice equations.
- If flow through outfall plus flow through overflow (using weir and/or orifice equations) is greater than the pipe-full flow rate of receiving pipe or user defined peak flow rate, then flow through outfall and overflow based on the weir and/or orifice equations need to be limited:
  - Primarily limit/reduce flow through the outfall, and leave the flow through the overflow equal to the weir/orifice equations based on the assumption that the greater hydraulic head from the overflow will dominate the outflows.
  - If flow through the outfall is reduced to 0 and flow through overflow is still greater than flow through connecting pipe, then the flow through overflow is reduced accordingly.

Note, the drainage layer cannot be filled by reverse flow (by assuming the limiting pipe flow condition results in the surface storage emptying into the drainage layer).

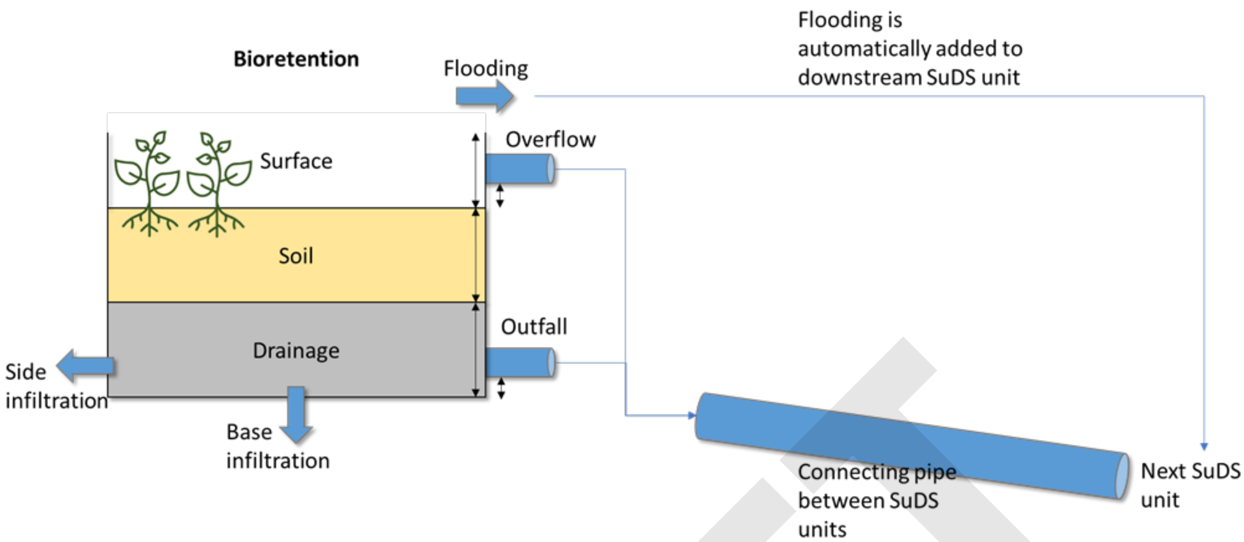

Figure 3.3: Downstream connecting pipe

Source: *HR Wallingford*

The Colebrook White equation for the receiving pipe pipe-full flow rate based on the pipe gradient and diameter is:

$$V = -2\sqrt{2gDS}log\left[\frac{k}{3.7D} + \frac{2.51v}{D\sqrt{2gDS}}\right]$$

Where:

- V is velocity (m/s);
- g is the gravitational acceleration constant of 9.81 m/s^2;
- D is the pipe internal diameter (m) defined by the user;
- S is the hydraulic gradient (m/m) defined by the user (allowable values within the tool are: $0 < S \leq 0.2$);
- k is the hydraulic roughness (m) where a value of 1.5 mm=0.0015 m is applied;
- v is the kinematic viscosity of water (m^2/s) where a value of 1.3 mm^2/s = 0.0000013 m^2/s for water at 10^{0}C is applied.

To convert from velocity (m/s) to flow (m^3/s), multiply the velocity V by area of receiving pipe (A), $Q = VA$.

3.2 Bioretention

The bioretention unit is modelled in the same way as the conceptual unit with the following differences:

- Unlike the other SUDS units, which fix the vegetation type, the user can define the bioretention unit vegetation type which affects the evapotranspiration rate (Section 2.3).
- The outfall structure from the drainage layer is fixed as an orifice.
- The overflow structure from the surface layer can be a weir or orifice, not none.

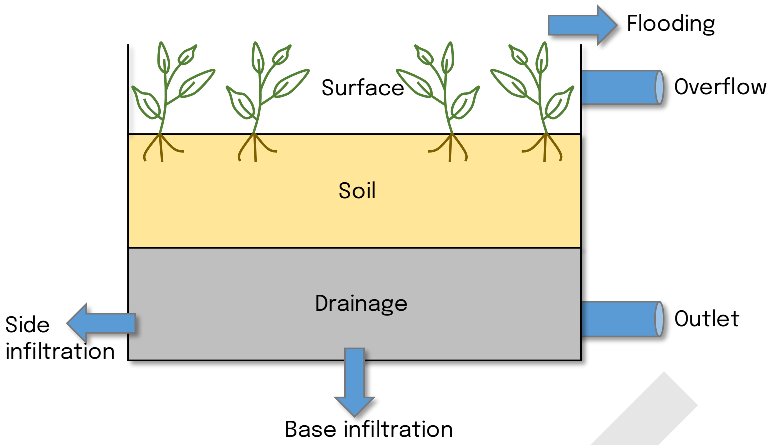

Figure 3.4: Bioretention

Source: HR Wallingford

3.3 Tree pit

A tree pit is modelled in the same way as the conceptual unit with the following differences:

- The surface layer can be a different plan area to the soil and drainage layers.
- No overflow structure from the surface layer is modelled.
- The outfall structure from the drainage layer is fixed as an orifice.

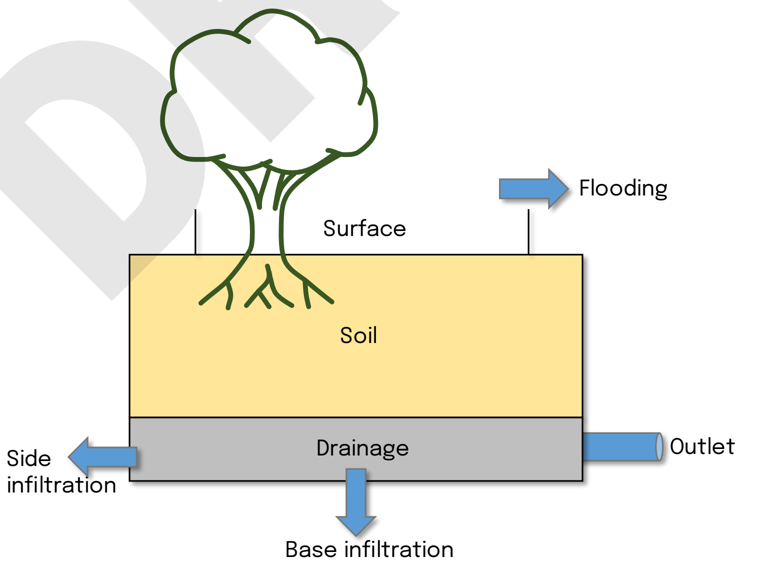

Figure 3.5: Tree pit

Source: HR Wallingford

3.4 Green roof

The green roof is modelled in the same way as the conceptual unit with the following differences:

- No base or side infiltration can occur from the drainage layer.
- The height of the outfall from the drainage layer is not variable and sits at the base of the drainage layer.
- There is no rainfall runoff from any upstream catchments area entering the green roof.
- Other SuDS units cannot be connected upstream of a green roof.
- The outfall structure from the drainage layer can be a weir or orifice, not none.

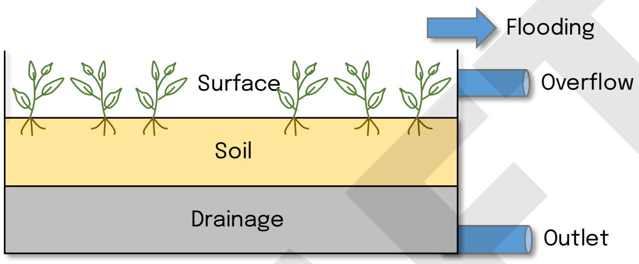

Figure 3.6: Green roof

Source: HR Wallingford

3.5 Pervious pavement

The pervious pavement is modelled in the same way as the conceptual unit with the following differences:

- No soil layer exists and consequently no evapotranspiration from the SuDS unit occurs.
- A depression storage is applied to the pervious pavement to represent the wetting of the surface. The depression storage depth is a user editable parameter (with a default of 4 mm) and is emptied via evaporation using a coefficient value, K_c of 1 (see Section 2.3).
- The outfall structure from the drainage layer is fixed as an orifice.

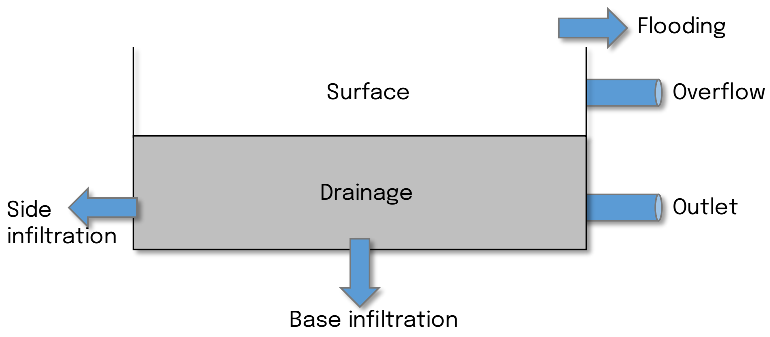

Figure 3.7: Pervious pavement

Source: HR Wallingford

3.6 Swale

The swale (both under-drained and standard types) are modelled in the same way as the conceptual unit with the following differences:

- The surface layer is represented with side slopes, a longitudinal slope and a longitudinal length. The longitudinal gradient and length effects the storage capacity and the depth at the overflow structure. Note, no travel time or velocities are calculated; the surface layer continues to act as a simple reservoir that stores water from the bottom up.
- The plan area of the soil and drainage layers are calculated from the length of the swale and setting the base width of the swale equal to the width of the surface layer at 100 mm water depth[1]. 100 mm is used in order to represent how the soils extend beyond the base width of a swale and partly up the sides. The soil and drainage layers continue to be represented as vertical sided, flat bottomed reservoirs.

In addition the under-drained swale also has the following difference:

- No overflow outlet from the surface layer is modelled.
- The outfall structure from the drainage layer is fixed as an orifice.

In addition the standard swale also has the following difference:

- No drainage layer exists and consequently no outlet from the drainage layer is modelled.

The geometry equations for the relationship between water depth and storage volume is provided in Appendix A.

[1] Plan area = Length * (Width + ((2 * 100 mm)/side slope))

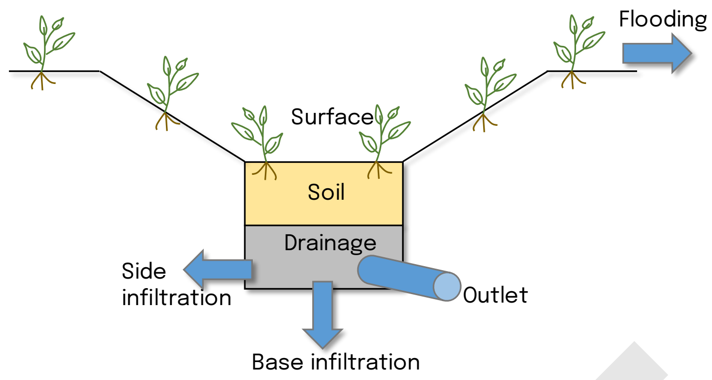

Figure 3.8: Swale (under-drained)

Source: HR Wallingford

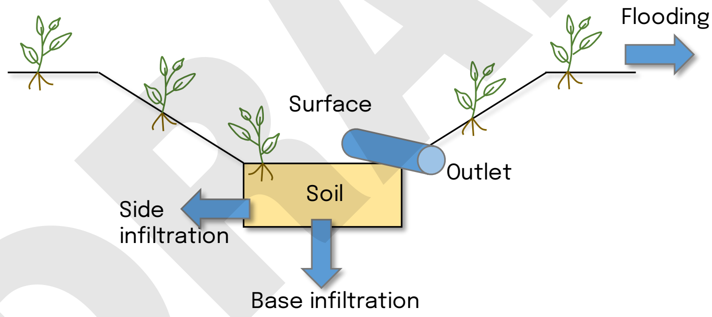

Figure 3.9: Swale (standard)

Source: HR Wallingford

3.7 Basin

The detention basin is modelled in the same way as the conceptual unit with the following differences:

- The surface layer is represented with variable plan area. A base (soil layer) and top surface layer are set by the user and it is assumed that the change in plan area with height is linear.
- No drainage layer exists and consequently no outlet from the drainage layer is modelled.
- Two 'outfall' structures can represent flow from the surface layer. An outfall (orifice or none) which represents the main and normal discharge outfall, and an overflow (weir or orifice) which comes into effect less frequently. Flooding, should the overflow also be exceeded, continues to be represented.

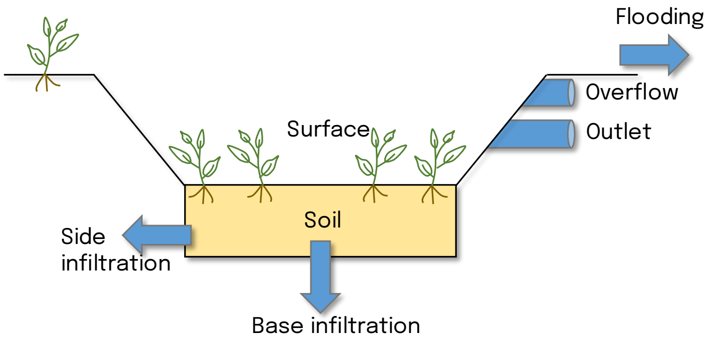

Figure 3.10: Basin

Source: HR Wallingford

3.8 Pond

The pond is modelled in the same way as the conceptual unit with the following differences:

- The surface layer is represented with variable plan area. A base and top surface layer are set by the user and it is assumed that the change in plan area with height is linear.
- No drainage layer exists and consequently no outfall structure from the drainage layer is modelled and no infiltration is modelled.
- No soil layer exists.
- Evapotranspiration removes volume from the surface layer (as opposed to the soil layer) using a coefficient value, K_c of 1.05 (see Section 2.3).
- Two 'outfall' structures can represent flow from the surface layer. An outfall which represents the main and normal discharge outfall (orifice or weir), and an overflow (orifice or weir) which comes into effect less frequently. Flooding, should the overflow also be exceeded, continues to be represented.
- The pond starts with a normal water level equal to the invert level of the outfall height.

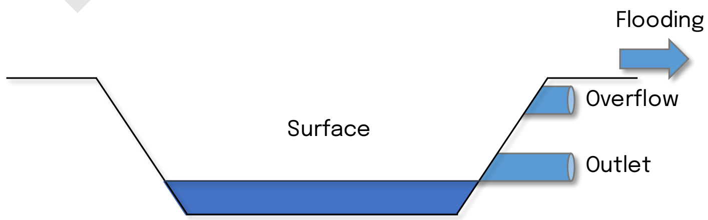

Figure 3.11: Pond

Source: HR Wallingford

3.9 Rainwater harvesting

The rainwater harvesting system is modelled in the same way as the conceptual unit with the following differences:

- No surface or soil layers exist.
- No infiltration or evapotranspiration is modelled.
- One or two 'outfall' structures can represent flow from the drainage layer. There will always be a higher level 'overflow' (orifice) which comes into effect when the rainwater harvesting system is almost full.
- Depending on the design of the system, there may also be a second lower 'outfall' (orifice) where a tank is designed to act as an attenuation structure as well as storage for non-potable supply.
- Flooding occurs if the tank fills completely.
- No rainfall failing directly onto the plan area of the attenuation tank is represented as an inflow volume.
- The model allows for multiple independent tanks in a single node.
- The demand from water reuse is modelled as being associated with residential or commercial properties, as described below.

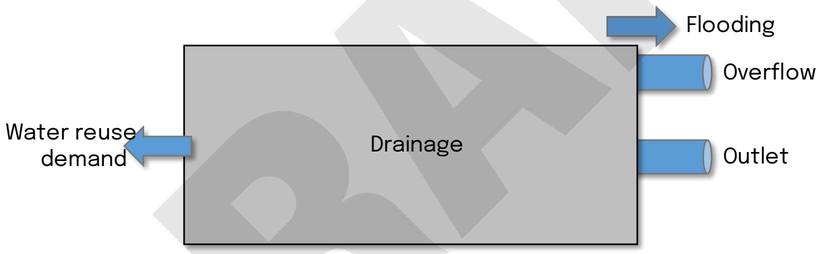

Figure 3.12: Rainwater harvesting system

Source: HR Wallingford

3.9.1 Rainwater harvesting demand – residential

The input data for rainwater harvesting (RWH) serving residential properties are:

- Number of properties;
- Number of bedrooms per property[2];
- Consumption rate per person per day;
- Roof area[3] per property;
- Tank dimensions per property.

The number of occupants in a residential property is related to the number of bedrooms, and is a probability distribution based on UK census data. For example, a 1 bedroom property is most likely

[2] Note that if there are properties with different numbers of bedrooms a separate rainwater harvesting node will need to be used for each separate number of bedrooms (e.g. 1 bed properties is a separate node to 2 bed properties)
[3] The roof area refers to the part of the roof which drains to the RWH unit. If some of the roof does not drain to the RWH system, this remaining area would normally be explicitly addressed using other drainage units

to have an occupancy of 1 person, but a small proportion of properties will have 2 people, and very few would have 3 people (see Table 3.2).

It is possible to analyse a number of houses (of the same design) as a single RWH unit and the tool will apply a distribution of occupancy based on a binomial distribution using recorded UK statistics. If the user models each property separately, the occupancy will be the mode (most likely) occupancy. Therefore modelling 10 properties as one node or 10 nodes will result in different hydraulic results. It is advised that to use the distribution of occupancy data within the tool and use a single node for houses of the same arrangement which will result in a more accurate assessment of the performance of the RWH units.

The probabilistic approach to occupancy levels is based on Kellagher (2012) which uses a binomial distribution backed by statistics from 772 properties in the Cherwell District of Oxfordshire, UK and other similar data. The distribution of occupancy level per number of bedrooms is shown in Table 3.2.

Table 3.2: Distribution/proportion of occupancy for residential properties based on number of bedrooms

Occupancy	1 bedroom	2 bedrooms	3 bedrooms	4+ bedrooms
1	0.7000	0.4390	0.1841	0.0817
2	0.2500	0.4159	0.3877	0.2657
3	0.0500	0.1313	0.3064	0.3455
4	0	0.0138	0.1076	0.2246
5	0	0	0.0142	0.0730
6	0	0	0	0.0095

The model takes into account the distribution of occupancy levels to calculate the number of properties with each occupancy level. Table 3.3 shows an example of how the numbers of properties are calculated using the probabilistic approach, but then rounding to integer number of houses. If rounding changes the property count then a property is added/removed to preserve the distribution of the number of properties while keeping occupancy levels as close to the probabilistic distribution as possible. Note that the rounding means that splitting a group of properties into multiple nodes is likely to result in a slightly different total number of occupants. The tool assumes that there are only integer numbers of houses and people.

The model applies the consumption rate as a constant rate at each timestep (i.e. an average consumption over 24 hours). No diurnal variation is applied.

Table 3.3: Example of determining number of properties per occupancy level for 20no. 4+ bedroom properties

Occupancy level	Proportion of properties	Number of properties (fraction)	Number of properties (integer)	Number of properties (integer adjusted)
1	0.0817	1.634	2	2
2	0.2657	5.314	5	5
3	0.3455	6.910	7	8
4	0.2246	4.492	4	4
5	0.0730	1.460	1	1
6	0.0095	0.190	0	0
Total	**1.0**	**20 properties 59.4 occupants**	**19 properties 54 occupants**	**20 properties 57 occupants**

3.9.2 Rainwater harvesting demand – commercial/industrial

The input data for rainwater harvesting serving generic commercial/industrial land use and flats are:

- Average daily consumption rate;
- Whether the building is in use over 12 hours (7am-7pm) or 24 hours;
- Whether the building is in use 7 days a week or only 5 days a week (Monday-Friday);
- Roof area;
- Tank dimensions.

Unlike the residential land use where a whole development of properties of the same type can be modelled with a single SuDS unit, the commercial/industrial properties use a separate RWH unit (or more than one if appropriate) for each building.

A water demand profile will be built up from four defined periods: Weekdays 7am-7pm; weekdays 7pm-7am; weekends 7am-7pm; and weekends 7pm-7am.

3.10 Soakaway/infiltration trench

The soakaway/infiltration trench are modelled in the same way as the conceptual unit with the following differences:

- No surface or soil layers exist.
- No evapotranspiration is modelled.
- One 'overflow' (orifice) structure can represents flow from the drainage layer or it can be excluded if the system drains via infiltration only. There is no outfall structure as the main and normal discharge is via infiltration. The overflow comes into effect when the soakaway/infiltration trench is almost full. Flooding, should the overflow also be exceeded, continues to be represented.
- For a soakaway without an overflow, the "To ground" outfall type should be used as these SuDS units do not connect to the network which is served by the outfall to the sewer or river (see Section 3.12). For reporting purposes, any volumes going to a "To ground" outfall are counted as infiltrated volumes, but "To ground" nodes do not count towards water quality outputs.
- No rainfall failing directly onto the plan area of the soakaway/infiltration trench is represented as an inflow volume.

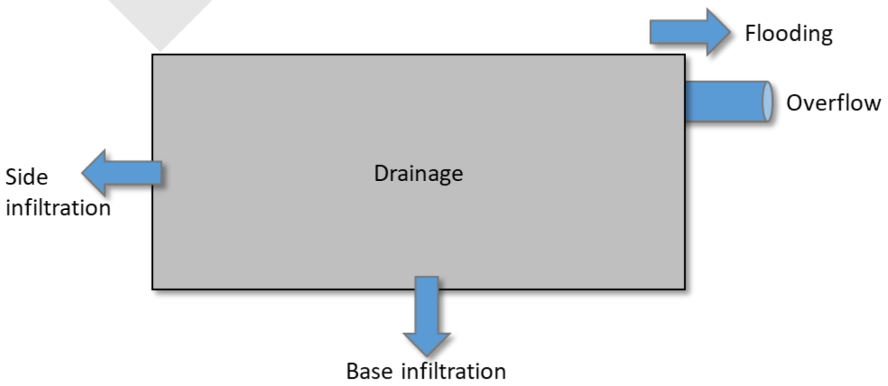

Figure 3.13: Soakaway/infiltration trench

Source: HR Wallingford

3.11 Attenuation storage tank

The attenuation storage tank is modelled in the same way as the conceptual unit with the following differences:

- No surface or soil layers exist.
- Two 'outfall' structures can represent flow from the drainage layer. An outfall (orifice) which represents the main and normal discharge outfall, and an overflow (orifice or weir) which comes into effect when the attenuation tank is almost full. Flooding, should the overflow also be exceeded, continues to be represented. The outfall is always at the base of the layer.
- No infiltration or evapotranspiration is modelled.
- No rainfall failing directly onto the plan area of the attenuation tank is represented as an inflow volume.

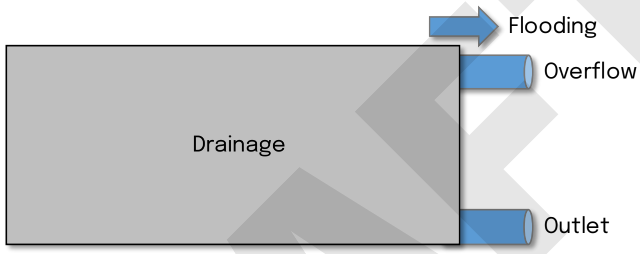

Figure 3.14: Attenuation storage tank

Source: HR Wallingford

3.12 Non-SuDS nodes

The model also allows for several elements to be added to the network that do not represent SuDS:

- Contributing areas represent the areas and land use types that drain to the network. The land use and area define the surface water runoff volume (see Section 2.2) and the pollutant concentration build-up and wash-off (see Section 4).
- One sewer or river outfall can be represented per network. The outfall represents whether the site drains to either a receiving sewer network or a river.
- "To ground" outfalls can be used to represent where SuDS units do not connect to the sewer or river outfall. Whilst one river or sewer outfall can be included per network, any number of "To ground" outfalls can be used in conjunction with the river or sewer outfall. They should be used where all contributing areas/SuDS drain via infiltration to the ground (or where information does not exist and it can be assumed that all runoff is infiltrated). For reporting purposes, any volumes going to a "To ground" outfall are counted as infiltrated volumes and therefore users can report on areas of the site which do not drain off site.

3.13 Summary

Table 3.4 summarises the layers which are used within each of the SuDS types.

Table 3.5 summarises the volume transfers which are used for each of the SuDS types.

Table 3.4: Layers within each SuDS types

	Soil Layer	Drainage Layer	Surface Layer
Bioretention	✓	✓	✓
Tree pit	✓	✓	✓
Green roof	✓	✓	✓
Pervious pavement		✓	✓
Swale (standard)	✓		✓
Swale (under drained)	✓	✓	✓
Basin	✓		✓
Pond			✓
Rainwater harvesting		✓	
Soakaway/infiltration trench		✓	
Attenuation tank		✓	

Table 3.5: Volume transfers within each SuDS types

	Rainfall falling onto SuDS	Rainfall runoff from the SuDS upstream catchment area	Inflow from upstream SuDS	Evapotranspiration	Transfer from the soil to the drainage layer	Infiltration	Outlet (from drainage layer)	Overflow (from surface layer)	Flooding	Rainwater harvesting daily property demand
Bioretention	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Tree pit	✓	✓	✓	✓	✓	✓	✓		✓	
Green roof	✓			✓	✓		✓	✓	✓	
Pervious pavement	✓	✓	✓			✓	✓	✓	✓	
Swale (standard)	✓	✓	✓	✓		✓		✓	✓	
Swale (under drained)	✓	✓	✓	✓	✓	✓	✓		✓	
Basin	✓	✓	✓	✓		✓	✓[4]	✓	✓	
Pond	✓	✓	✓	✓			✓[4]	✓	✓	
Rainwater harvesting		✓					✓	✓[5]	✓	✓
Soakaway/ infiltration trench		✓	✓			✓		✓[5]	✓	
Attenuation storage tank		✓	✓				✓	✓[5]	✓	

[4] Outlet from surface layer
[5] Overflow from drainage layer

4 Water quality

A water quality model has been implemented in the tool in order to assess the performance of the SuDS components in reducing contaminants from surface water wash-off due to rainfall.

4.1 Urban pollutants represented in this model

The following urban pollutants have been included as default within the model:

- Sediments, TSS;
- Chromium, Cr;
- Copper, Cu;
- Nickel, Ni;
- Zinc, Zn.

All of the above pollutants are represented for their suspended (adsorbed onto sediments) and dissolved fractions, with the exception of sediments which are only represented as suspended (total suspended solids, TSS).

Advanced users can add their own pollutants if they wish by downloading the pollutant profile CSV file (see Appendix B) and completing the appropriate columns for the 3 blank “User Defined” profiles for paved and roof surfaces. The modified pollutant profile csv file then needs re-uploading.

4.2 Modelling approach

To reflect SuDS pollution reduction mechanisms the following three components need to be represented:

1. The contaminant concentrations (and thus loads) from a range of land use surface types;
2. The contaminant build-up and wash-off processes due to dry periods and rainfall respectively;
3. The SuDS component performance related to pollutant retention and/or treatment reduction which results in concentration and/or load reductions.

This tool does not look at the impact on the receiving systems, but just reports on the degree of reduction of pollutant load and concentrations of pollutant discharges from the site. This is based on running a continuous rainfall record of several years through the network. As the water quality model uses the hydraulic model to dictate the movement of pollutants the calculations are carried out on a mass rate (mg/s) and mass balance basis.

Water quality modelling is carried out only for a time series and not design storms.

The principal steps of the pollutant flow through each SuDS units are:

1. Input pollutants to the SuDS unit are combined from a) any contributing surfaces and b) the output pollutants from any upstream SuDS draining to this SuDS.
2. The pollutants are routed through the SuDS relative to the flow of water through the SuDS (e.g. infiltration vs outflow).
3. The pollutant concentration leaving the SuDS via outflows are reduced to reflect the (best estimate) SuDS pollutant removal efficiency.

4.3 Pollutant build-up model

A pollutant build-up model describes the rate of build-up of a pollutant building up on a land use during dry periods. The model allows for multiple different build-up methodologies and the most appropriate has been chosen as default for each pollutant type:

- No build-up – for modelling surfaces where a given pollutant isn't built up in measurable quantities. By default, this is mainly used for pervious surfaces.
- Infinite build-up – the model will always wash-off pollutants at the full Event Mean Concentration (EMC). By default, this is only used in specialised cases (e.g. zinc runoff from zinc roofs).
- Linear build-up – pollutants build-up at a constant rate (mg/ha/day) while no rainfall is taking place.
- Exponential build-up – pollutants initially build-up rapidly, with build-up rate decreasing as more pollutant load is on the surface.

The "Pollutant Profile" is the combination of build-up model, build-up parameters and wash-off rate and dissolved fraction for each pollutant-surface combination. There are default values for all surfaces and it does not need to be edited. However advanced modellers can define their own pollutant profile by downloading the pollutant profile CSV, modifying it and then re-uploading the modified file. The default pollutant profile is derived from available literature (Djukić et al., 2018) and is included in Appendix B.

Each pollutant builds up separately, with dissolved and suspended pollutants building up at a combined rate until they are split into two different phases at the time of wash-off (based on the default pollutant profile).

Pollutants build-up on impervious surfaces only (paved and roof), however no pollutant build-up is represented on pervious surfaces.

4.3.1 Linear build-up

When the linear build-up equation for pollutants is applied. The equation for build-up of pollutant is:

$$b = K_B t$$

Where:

- b is the build-up mass (kg/ha);
- K_B is the surface build-up rate (kg/ha/day);
- t is time (days).

The build-up is not capped at a maximum amount, but instead keeps building during dry periods, but pollutant build-up halts during the period when rain occurs. The amount of pollutant on the surface is continuously calculated with the build-up process adding mass and the wash-off process removing mass.

4.3.2 Exponential build-up

When the exponential build-up equation for pollutants is applied. The equation for build-up of pollutant is:

$$B = C_{1b}(1 - e^{-C_{2b}t})$$

Where:

- B is the build-up mass (kg/ha);
- C_{1b} is the maximum build-up possible (kg/ha);

- C_{2b} is the build-up rate constant (days^{-1});
- t is time (days).

When pollutants are partially washed off the surface, the reverse of the equation is used to calculate an effective value of t for the number of days it would have taken to build-up the remaining mass.

4.4 Pollutant wash-off model

A wash-off model describes the rate of mass of a pollutant washed off the surface of a land use when rain occurs. The Event Mean Concentration (EMC) pollutant wash-off model is applied as it provides the simplest and is considered to be the most robust way of reflecting the wash-off of the various pollutants from different land use types.

The EMC represents the average pollutant concentration for a stormwater event, expressed in units of mass per volume (e.g. mg/L). This rate should include both dissolved and suspended fractions of the pollutant.

Pollutants are removed from the surface at a rate to produce the target concentration of pollutant in the runoff (e.g. if the runoff was 5 l/s and the EMC was 40 mg/l, the mass load washed off would be 200 mg/s). The concentration of runoff is fixed and continues during a wet weather event until either the rainfall stops, or if there is isn't enough mass on the surface.

The equation for the EMC wash-off function is:

$$w = K_w Q$$

Where:

- w is the wash-off mass (mg/s);
- K_w is the EMC concentration expressed in the same units as the flow rate Q (mg/m^3);
- Q is the total runoff rate which applies to the land use being analysed (m^3/s). (This is the flow rate entering the SuDS so after the effects of depression storage and runoff routing delays).

The default surface wash-off EMC for each pollutant is provided in Appendix B. The parameters have been derived from literature (Clary et al., 2020). The parameters are editable by advanced users by exporting/importing the pollutant profile CSV file.

After the mass has been washed off the surface, a fraction of it enters the system to be modelled as dissolved pollutants, with the remainder being modelled as being adsorbed onto suspended sediments. This fraction can be adjusted in the pollutant profile.

4.5 SuDS pollutant removal and reduction

Pollutants are 'removed' by SuDS in one of two ways: they are either retained within SuDS components (e.g. via sedimentation or adsorption) or reduced in concentration via treatment processes that occur as they pass through the component (e.g. degradation via the action of sunlight, or uptake by plants).

The process is shown in Figure 4.1.

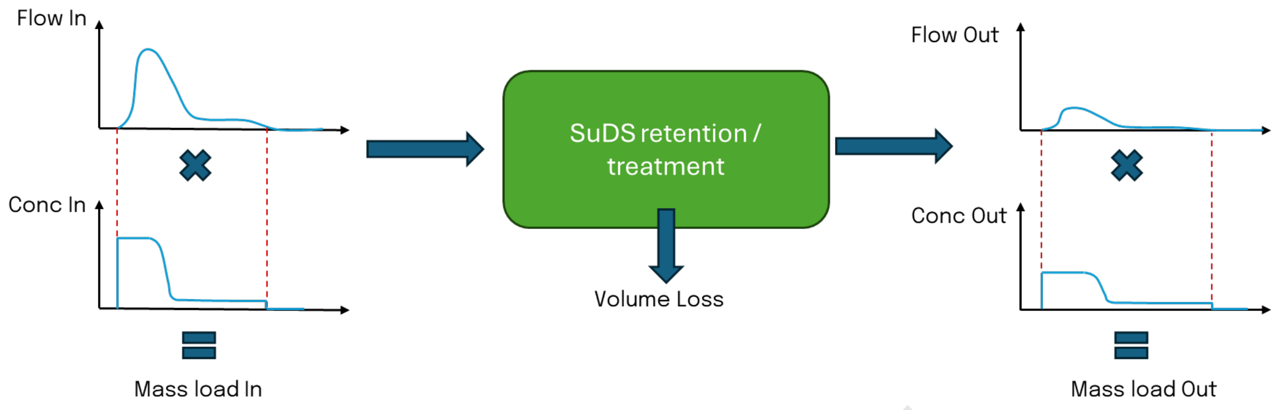

Figure 4.1: SuDS pollutant removal and load reduction schematic

Source: HR Wallingford

The tool uses a simple data-driven approach to represent the removal of pollutants by SuDS instead of a physically based approach which would be much more complex and not necessarily any more accurate.

Concentration of pollutants in the SuDS outflow is directly related to the concentration in the inflow for each timestep in the simulation. The greater the number of SuDS components in series will act to further reduce concentrations.

As the pollutant removal approach is based on reduction in outflow concentration compared to the inflow concentration, the model does not conserve mass. The pollutant load out is calculated from the fixed outflow concentration and the flow out. The 'lost' mass is not modelled and represents the sum of all the possible processes e.g. absorbed in the soils, infiltrated, broken down by UV etc.

The International BMP database (www.bmpdatabase.org) holds a significant body of monitoring data for SuDS that is fully interrogable. The outflow and inflow EMCs from the BMP database for each SuDS component were evaluated to arrive at a SuDS "efficiency" value which represents any process that reduces concentration in the SuDS unit. Removal efficiency is a decimal number representing how large a change in pollutant concentration occurs through the SuDS unit. This is typically a number between 0 (no removal) and 1 (complete removal). Values below 0 may be possible in some cases, based on observed figures and indicate an increase in pollutant concentration. The equation to calculate the pollutant reduction efficiency is:

$$Reduction\ efficiency = 1 - \frac{EMC_{out}}{EMC_{in}}$$

The EMC percentage reductions are provided in Appendix B.3. The parameters have been derived from literature (Clary et al., 2020). These parameters are currently fixed and not editable by the user.

4.6 Timestep calculations

The order of the calculations controlling the movement of pollutant mass is done separately for each pollutant, with suspended and dissolved loads being calculated separately. The modelled process is as follows for each timestep:

1. Sum the total pollutant load (mg/s) entering the SuDS unit from each of the contributing surface areas and upstream SuDS.
2. Calculate the inflow concentration at this timestep (mg/m^3) = pollutant load (mg/s)/incoming flow (m^3/s).

3. The inflow concentration is averaged over a 1 hour window. This means that when the pollutant mass load on the surface is depleted the concentrated in tails off rather than dropping to 0 immediately. Inflow concentration only drops to 0 when flow in is 0.
4. Ascertain the efficiency of this SuDS node for the modelled pollutant (decimal value, typically 0-1).
5. Calculate the outflow concentration from the rolling average inflow concentration and the SuDS efficiency. Outflow concentration (mg/m³) = inflow concentration (mg/m³) – ([inflow concentration (mg/m³)] x efficiency). Therefore the outflow concentration is zero only when the inflow concentration is zero.
6. Calculate the pollutant load out (mg/s) = outflow concentration (mg/m³) x outgoing flow (m³/s). Therefore the outflow pollutant load is zero only when the inflow concentration is zero or when there is no flow out.

As described in Section 4.5, this methodology is a simple approach where the outflow concentration is based on the inflow concentration and the SuDS removal 'efficiency'. As such, the model does not preserve pollutant mass through the system.

5 Hydraulic and water quality performance reporting

5.1 User interface

The tool provides selected results on the results tab for the user to check before viewing and downloading the planning report (Section 5.2).

The selected results are focussed at providing a summary of the performance of the whole SuDS network.

The hydraulic metrics provided for the time series rainfall simulations are:

- Average annual[6] **rainfall and runoff volumes** on the site.
- Average annual[6] summary of the **surface water runoff destination** (i.e. losses at source[7], SuDS infiltration, SuDS reuse, SuDS evapotranspiration or leaves the site via the site outfall) as a **total volume and a proportion of the rainfall volume**. This shows how much of the surface water volume is retained on site or used for rainwater harvesting.
- A breakdown of the **number of events that result in zero runoff from the site** (i.e. meet the Interception criteria) by annual, summer[8] and winter[9] average and storm depth.

The hydraulic metrics provided for the design storm simulations are:

- **Peak flow rate at the site outfall** for the critical duration storm for each return period simulated.
- Peak flow rate at the site outfall for all storms simulated.
- **Total flood volume from the drainage system** for the critical duration storm for each return period simulated.

[6] The average annual totals are calculated as the total simulation value divided by the total number of years including part/decimal years simulated. Therefore it is recommended that whole years are simulated so that the results aren't skewed towards a particular season
[7] Losses at source represents the proportion of rainfall that does not runoff from the surface and therefore does not enter the drainage system network. It also includes evaporation from depression storage (see Section 2.2 and 2.3)
[8] Summer is defined as 1st May to 31st October inclusive
[9] Winter is defined as 1st November to 30th April inclusive

The water quality metrics provided for the time series rainfall simulations are:

- A comparison of the max influent concentration to the network (i.e. the concentration from the highest polluting land surface connected to the network) and max effluent concentration at the outfall (i.e. after all the SuDS treatment). A **percentage reduction in pollutant concentration** is therefore estimated.
- A comparison of pollutant wash-off annual average mass from the land use surfaces to the average annual mass leaving the outfall and therefore an **indicative percentage reduction in mass load** which might be removed by the system. Note the model does not conserve mass and therefore these results are indicative only (see Section 4.5).

A more thorough description of these metrics is provided in Section 5.2 below.

5.2 Planning (hydraulic) and water quality report

The “planning” and water quality reports are downloadable outputs from the tool. They are aimed at providing all the hydraulic and water quality summary information required for the SuDS components to be submitted as part of a planning application. There are three separate reports, a planning (hydraulic) report for both time series and design storms and a water quality report for time series.

The reports are focussed at the hydraulic and water quality performance of the SuDS at the outfall from the proposed development. For more detailed information on each individual SuDS unit a more detailed evaluation report will be developed in due course (Section 5.2).

The planning and water quality reports include the following summary of the model and input data:

- User information;
- Model run information;
- Site information including total areas drained by the drainage network;
- Number and types of SuDS;
- SuDS network schematic and connectivity;
- SuDS infiltration rate;
- Rainfall, runoff and evapotranspiration input data;
- Climate change information;
- Water quality model parameters (for the water quality report only).

The reports also include the results of the same metrics as on the user interface described in Section 5.1 and more description on each of these is provided below.

Surface water runoff volume and destination

This metric is provided for the planning (hydraulic) time series report.

Retaining as much surface water runoff volume on the site as possible mimics the natural environment and reduces the impact on receiving systems; sewers in terms of flood risk and CSO spills. As such some countries have metrics whereby a certain proportion of the rainfall volume must be retained on site.

The volumes are broken down by the following categories:

- Rainfall volume;
- Runoff volume;

- Volume losses at source[10];
- Volume infiltrated by SuDS;
- Volume reused by rainwater harvesting;
- Volume evapotranspired by SuDS;
- Volume leaving the site via the site outfall.

Number of events with zero runoff from the site

This metric is provided for the planning (hydraulic) time series report.

Interception describes the prevention of runoff from the site for small rainfall events or the start of larger rainfall events. It aims to mimic natural catchment runoff conditions where rainwater would normally evapotranspire or infiltrate into the ground to replenish aquifers and river base flows.

To calculate this metric the continuous rainfall time series needs to be split into events. How this is done and the user editable inter event dry period parameter is explained in Appendix C.

The tool reports on the number and percentage of rainfall events for which "no outflow" from the site (the most downstream SuDS) is reported i.e. the event rainfall is captured on the site, no discharge off the site occurs.

The criteria used to define whether an event is considered to result in zero runoff from the site is whether the flow rate at the outfall exceeds a threshold of 0.01 l/s per hectare of impervious surfaces upstream of the outfall at any point throughout the rainfall event.

As shown in Figure 5.1, events which clearly exceed the threshold do not meet the zero runoff criteria (blue solid line), whilst a low threshold of 0.01 l/s per hectare allows for events with very small amounts of runoff to still be considered zero runoff (green solid line). There is the possibility that some rainfall events will follow another rainfall event where the drain down of the system is not complete (blue and green dashed lines); more likely where the system is large or throttle rates are tight. As a result, even if the response from the current rainfall event is small the preceding event's drawdown response results in the event failing the zero runoff criteria (blue dashed line). The number of events that are affected by this reporting criteria is small although will be greater for larger networks where throttle rates are tight. In these cases it is possible to reduce this affect by increasing the inter-event dry period parameter in the model (see Appendix C), although this will results in fewer larger events.

[10] Losses at source represents the proportion of rainfall that does not runoff from the surface and therefore does not enter the drainage system network. It also includes evaporation from depression storage (see Section 2.2 and 2.3). It is equivalent to the rainfall volume minus the runoff volume

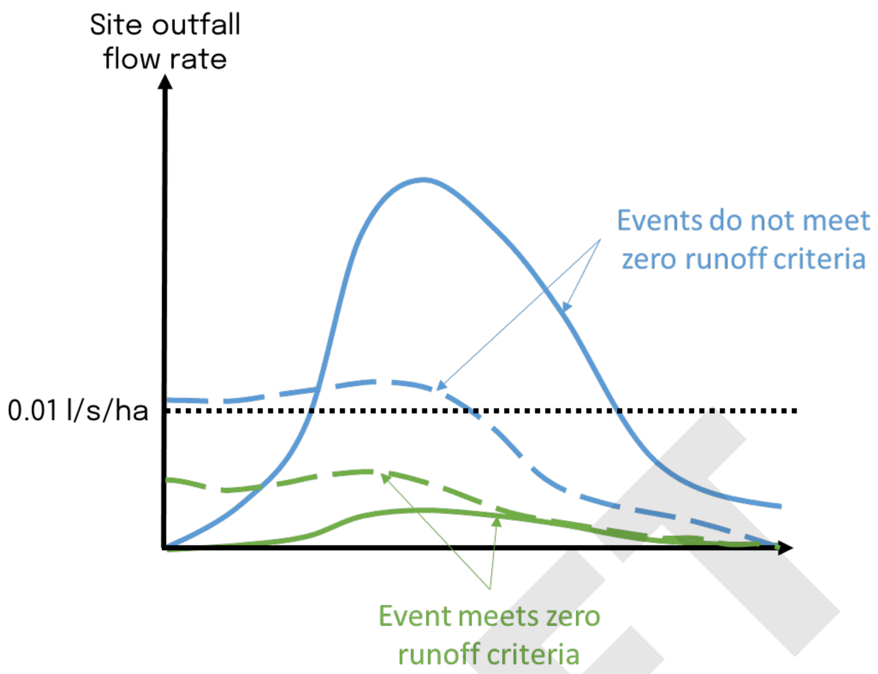

Figure 5.1: Criteria for defining whether an event results in zero runoff from the site

Source: HR Wallingford

The number and percentage of events complying with the zero runoff (interception) criteria is reported for events of rainfall depth in bands of 0-2 mm, 2-5 mm, 5-10 mm and 10 mm+, and reported for annual average[11], summer[12] and winter[13] average.

It would be anticipated that nearly all rainfall events less than 2 mm will meet the zero runoff criteria as depression storage largely prevents runoff occurring for smaller events. Events greater than 10 mm are likely to be outside the range of events which are likely to be wholly retained on site. As such, the 2-5 mm and 5-10 mm bands may be of greater interest in terms of identifying whether the SuDS system delivers effective interception.

Peak flow rate

This metric is provided for the planning (hydraulic) design storm report.

Developments generally have to limit peak flow rates from the site in order to mimic more natural catchments and protect downstream systems from flood risk or erosion of small watercourses.

The peak flow rate describes the maximum flow rate through the outfall from the site. The flow rate is provided for all design storm events simulated and the critical duration for each return period.

Surface water flood volume

This metric is provided for the planning (hydraulic) design storm report.

Developments need to demonstrate the drainage system is designed to a sufficient return period to manage flood risk.

[11] The average annual totals are calculated as the total simulation value divided by the total number of years including part/decimal years simulated. Therefore it is recommended that whole years are simulated so that the results aren't skewed towards a particular season/month
[12] Summer is defined as 1st May to 31st October inclusive
[13] Winter is defined as 1st November to 30th April inclusive

The total volume of flooding from the drainage system is reported for all design storm events simulated and the critical duration for each return period.

Water quality performance

These two metrics are provided for the water quality time series report.

To minimise the potential pollution risk posed by the surface water runoff to the receiving water body the drainage system should incorporate appropriate SuDS to treat the surface water runoff.

Reporting is on a per pollutant basis with separate values for suspended and dissolved pollutants. Reporting is of the pollutant mass washed off the various surfaces in the catchment and the mass leaving the main outfall. From this an indicative percentage reduction in mass load which might be removed by the system is provided. Note the model does not conserve mass and therefore these results are indicative only (see Section 4.5).

Reporting is also given of the maximum influent concentrations (i.e. the concentration from the highest polluting land surface connected to the network) and the maximum effluent concentration at the site outfall (i.e. after all the SuDS treatment). A percentage reduction in pollutant concentration is therefore estimated.

5.3 Evaluation reporting

This report describes the Tool functionality at month 18 of the StopUP SuDS project. Over months 18-30 further evaluative functionality to be added.

This will include:

- A review of key design characteristics of the proposed SuDS network against good practice; and
- A report commenting on likely performance and risks posed by the proposed network, with recommendations on potential mitigation options and improvements.

6 References

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Appendices

A Swale surface layer geometry

The swale SuDS unit is unique from the other SuDS units because the surface layer is represented with side slopes, a longitudinal slope and a longitudinal length. The longitudinal gradient and length effects the storage capacity and the depth at the overflow structure. Note, no travel time or velocities are calculated; the surface layer continues to act as a simple reservoir that stores water from the bottom up.

The geometry equation for the relationship between water depth and storage volume is:

$$V = \frac{L_w}{2}\big(H(B + HX) + h(B + hX)\big)$$

Where:

- V = Volume of water in swale surface layer (m³);
- L_w = Length of water in swale (m). (If $HY \geq L, L_w = L$. If $HY < L, L_w = HY$);
- B = Base width of swale (m);
- H = Water depth in swale surface layer from downstream end (m);
- h = Water depth in swale surface layer from upstream end (m) ($h = H - \frac{L}{Y}$ where Y = swale longitudinal slope (m/m). If $H - \frac{L}{Y} < 0$, set $h = 0$);
- X = Side slope in units of 1 in X (m/m).

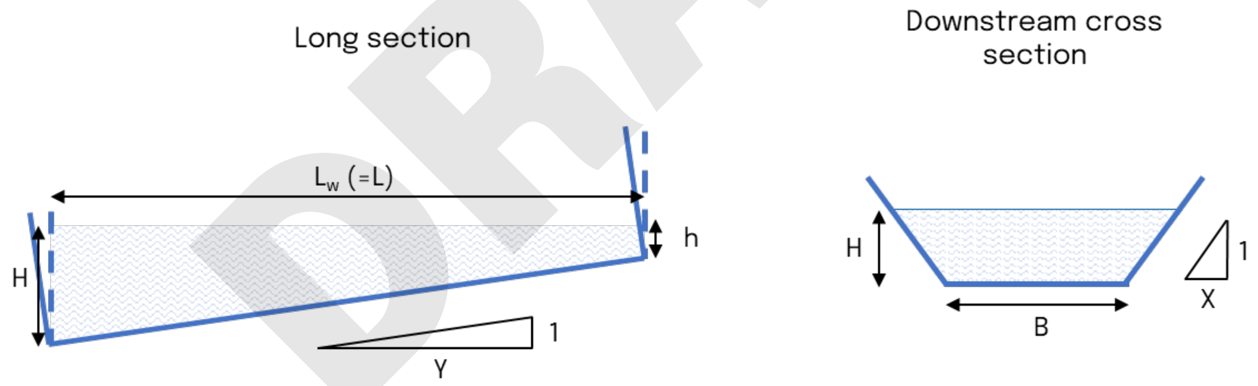

Figure A.1: Swale geometry schematic

Source: HR Wallingford

Rearranging the above equation to find the depth in the swale as a function of volume results in a cubic equation. When the water level in the swale means the swale does not reach the upstream end of the swale ($h = 0$ and $L_w = HY$), the equation can be solved empirically by the model. However when the water level does reach the upstream end of the swale ($h > 0$ and $L_w = L$) the cubic equation is difficult to solve therefore in these circumstances to reduce computational effort, the volume-depth equation has been implemented into the model by using an 'estimator' to determine the water depth for a time-step. The estimator works by passing different water depths to the depth-volume equation until the target volume for that time-step water depth is arrived at.

The plan area of the soil and drainage layers are calculated from the length of the swale and setting the base width of the swale equal to the width of the surface layer at 100 mm water depth. 100 mm is used in order to represent how the soils extend beyond the base width of a swale and partly up the sides. The soil and drainage layers continue to be represented as vertical sided, flat bottomed reservoirs. The SuDS perimeter and plan area are used to determine the infiltration from the soil layer. These are calculated as follows:

$$SuDS\ perimeter\ (m) = 2L + 2\big(B + \ 2(0.1X)\big)$$

$$Below\ ground\ plan\ area\ (m^2) = L\big(B + \ 2(0.1X)\big)$$

Where:

- $L =$ Length of swale (m);
- $B =$ Base width of swale (m);
- $X =$ Side slope in units of 1 in X (m/m).

B Water quality parameters

B.1 Pollutant profile CSV file

The CSV file pollutants.csv can be downloaded to view or edit the pollutant and land use parameters. There are 3 blank “User Defined” profiles for paved and roof provided to allow advanced users to model additional runoff surfaces.

land_use_name	pollutant	washoff_emc_mg_l	proportion_dissolved	buildup_model	linear_buildup_mg_ha_day	exponential_c1b	exponential_c2b
Commercial Road / Car Park (High Use)	Cr	0.007	0.255	exponential		0.00418	0.059
Commercial Road / Car Park (High Use)	Cu	0.08	0.502	exponential		0.0173	0.0284
Commercial Road / Car Park (High Use)	Ni	0.05	0.562	linear	0.00025		
Commercial Road / Car Park (High Use)	TSS	200	0	exponential		98.6	0.0915
Commercial Road / Car Park (High Use)	Zn	0.15	0.409	exponential		0.07398	0.10266
Commercial Road / Car Park (Medium Use)	Cr	0.005	0.255	exponential		0.003135	0.04425
Commercial Road / Car Park (Medium Use)	Cu	0.025	0.502	exponential		0.0173	0.0284
Commercial Road / Car Park (Medium Use)	Ni	0.01	0.562	linear	0.000125		
Commercial Road / Car Park (Medium Use)	TSS	100	0	exponential		69.02	0.06405
Commercial Road / Car Park (Medium Use)	Zn	0.1	0.409	exponential		0.04932	0.06844
Commercial Roofs	Cr			none			
Commercial Roofs	Cu			none			
Commercial Roofs	Ni			none			
Commercial Roofs	TSS	20	0	exponential		24.65	0.022875
Commercial Roofs	Zn			none			
Commercial Roofs (Zinc)	Cr			none			
Commercial Roofs (Zinc)	Cu			none			
Commercial Roofs (Zinc)	Ni			none			
Commercial Roofs (Zinc)	TSS	20	0	exponential		24.65	0.022875
Commercial Roofs (Zinc)	Zn	0.15	0.409	infinite			
Pervious Surface	Cr			none			
Pervious Surface	Cu			none			
Pervious Surface	Ni			none			
Pervious Surface	TSS			none			
Pervious Surface	Zn			none			
Residential Road / Car Park	Cr	0.002	0.255	exponential		0.00209	0.0295
Residential Road / Car Park	Cu	0.01	0.502	exponential		0.01211	0.01988
Residential Road / Car Park	Ni	0.002	0.562	linear	0.000075		
Residential Road / Car Park	TSS	50	0	exponential		44.37	0.041175
Residential Road / Car Park	Zn	0.05	0.409	exponential		0.030825	0.042775
Residential Roofs	Cr			none			
Residential Roofs	Cu			none			
Residential Roofs	Ni			none			
Residential Roofs	TSS	20	0	exponential		24.65	0.022875
Residential Roofs	Zn			none			
User Defined Paved 1	Cr			none			
User Defined Paved 1	Cu			none			
User Defined Paved 1	Ni			none			
User Defined Paved 1	TSS			none			
User Defined Paved 1	Zn			none			
User Defined Paved 2	Cr			none			
User Defined Paved 2	Cu			none			
User Defined Paved 2	Ni			none			
User Defined Paved 2	TSS			none			
User Defined Paved 2	Zn			none			
User Defined Paved 3	Cr			none			
User Defined Paved 3	Cu			none			
User Defined Paved 3	Ni			none			
User Defined Paved 3	TSS			none			
User Defined Paved 3	Zn			none			
User Defined Roof 1	Cr			none			
User Defined Roof 1	Cu			none			
User Defined Roof 1	Ni			none			
User Defined Roof 1	TSS			none			
User Defined Roof 1	Zn			none			
User Defined Roof 2	Cr			none			
User Defined Roof 2	Cu			none			
User Defined Roof 2	Ni			none			
User Defined Roof 2	TSS			none			
User Defined Roof 2	Zn			none			
User Defined Roof 3	Cr			none			
User Defined Roof 3	Cu			none			
User Defined Roof 3	Ni			none			
User Defined Roof 3	TSS			none			
User Defined Roof 3	Zn			none			

pollutants

Figure B.1: Pollutant profile CSV file

B.2 Pollutant and land use parameters

Table B.1: Water quality default parameters

Land Use	Pollutant	Wash-off EMC (mg/l)	Fraction Dissolved	Build-up Model	Linear Build-up Rate (mg/ha/day)	Exponential C1b (kg/ha)	Exponential C2b (days^{-1})
Commercial Road/Car Park (High Use)	Cr	0.007	26%	exponential		0.00418	0.059
Commercial Road/Car Park (High Use)	Cu	0.08	50%	exponential		0.0173	0.0284
Commercial Road/Car Park (High Use)	Ni	0.05	56%	linear	0.00025		
Commercial Road/Car Park (High Use)	TSS	200	0%	exponential		98.6	0.0915
Commercial Road/Car Park (High Use)	Zn	0.15	41%	exponential		0.07398	0.10266
Commercial Road/Car Park (Medium Use)	Cr	0.005	26%	exponential		0.003135	0.04425
Commercial Road/Car Park (Medium Use)	Cu	0.025	50%	exponential		0.0173	0.0284
Commercial Road/Car Park (Medium Use)	Ni	0.01	56%	linear	0.000125		
Commercial Road/Car Park (Medium Use)	TSS	100	0%	exponential		69.02	0.06405
Commercial Road/Car Park (Medium Use)	Zn	0.1	41%	exponential		0.04932	0.06844
Commercial Roofs	Cr			none			
Commercial Roofs	Cu			none			
Commercial Roofs	Ni			none			
Commercial Roofs	TSS	20	0%	exponential		24.65	0.022875
Commercial Roofs	Zn			none			
Commercial Roofs (Zinc)	Cr			none			
Commercial Roofs (Zinc)	Cu			none			

Land Use	Pollutant	Wash-off EMC (mg/l)	Fraction Dissolved	Build-up Model	Linear Build-up Rate (mg/ha/day)	Exponential C1b (kg/ha)	Exponential C2b (days^{-1})
Commercial Roofs (Zinc)	Ni			none			
Commercial Roofs (Zinc)	TSS	20	0%	exponential		24.65	0.022875
Commercial Roofs (Zinc)	Zn	0.15	41%	infinite			
Pervious Surface	Cr			none			
Pervious Surface	Cu			none			
Pervious Surface	Ni			none			
Pervious Surface	TSS			none			
Pervious Surface	Zn			none			
Residential Road/Car Park	Cr	0.002	26%	exponential		0.00209	0.0295
Residential Road/Car Park	Cu	0.01	50%	exponential		0.01211	0.01988
Residential Road/Car Park	Ni	0.002	56%	linear	0.000075		
Residential Road/Car Park	TSS	50	0%	exponential		44.37	0.041175
Residential Road/Car Park	Zn	0.05	41%	exponential		0.030825	0.042775
Residential Roofs	Cr			none			
Residential Roofs	Cu			none			
Residential Roofs	Ni			none			
Residential Roofs	TSS	20	0%	exponential		24.65	0.022875
Residential Roofs	Zn			none			

Additionally 3 blank “User Defined” profiles for paved and roof are provided to allow advanced users to model additional runoff surfaces.

B.3 SuDS pollutant reduction

Table B.2: SuDS pollutant reduction efficiency

Node Type	Pollutant	Phase	Efficiency
bioretention	TSS	dissolved	n/a
bioretention	TSS	suspended	0.77273
bioretention	Cr	dissolved	0.23597
bioretention	Cr	suspended	0.8155
bioretention	Ni	dissolved	0.14191
bioretention	Ni	suspended	0.33333
bioretention	Zn	dissolved	0.39904
bioretention	Zn	suspended	0.79355
bioretention	Cu	dissolved	-0.10073
bioretention	Cu	suspended	0.45573
tree_pit	TSS	dissolved	n/a
tree_pit	TSS	suspended	0.60253
tree_pit	Cr	dissolved	-0.47453
tree_pit	Cr	suspended	0.26052
tree_pit	Ni	dissolved	0.14191
tree_pit	Ni	suspended	0.24796
tree_pit	Zn	dissolved	0.25381
tree_pit	Zn	suspended	0.52534
tree_pit	Cu	dissolved	0.23362
tree_pit	Cu	suspended	0.45573
drainage_basin	TSS	dissolved	n/a
drainage_basin	TSS	suspended	0.66206
drainage_basin	Cr	dissolved	0.2
drainage_basin	Cr	suspended	0.24757
drainage_basin	Ni	dissolved	0.13043
drainage_basin	Ni	suspended	0.4
drainage_basin	Zn	dissolved	0.22479
drainage_basin	Zn	suspended	0.66538
drainage_basin	Cu	dissolved	0.41944
drainage_basin	Cu	suspended	0.47657
rainwater_harvesting	TSS	dissolved	n/a
rainwater_harvesting	TSS	suspended	0
rainwater_harvesting	Cr	dissolved	0
rainwater_harvesting	Cr	suspended	0

Node Type	Pollutant	Phase	Efficiency
rainwater_harvesting	Ni	dissolved	0
rainwater_harvesting	Ni	suspended	0
rainwater_harvesting	Zn	dissolved	0
rainwater_harvesting	Zn	suspended	0
rainwater_harvesting	Cu	dissolved	0
rainwater_harvesting	Cu	suspended	0
rainwater_harvesting	TSS	dissolved	n/a
rainwater_harvesting	TSS	suspended	0
rainwater_harvesting	Cr	dissolved	0
rainwater_harvesting	Cr	suspended	0
rainwater_harvesting	Ni	dissolved	0
rainwater_harvesting	Ni	suspended	0
rainwater_harvesting	Zn	dissolved	0
rainwater_harvesting	Zn	suspended	0
rainwater_harvesting	Cu	dissolved	0
rainwater_harvesting	Cu	suspended	0
storage_tank	TSS	dissolved	n/a
storage_tank	TSS	suspended	0
storage_tank	Cr	dissolved	0
storage_tank	Cr	suspended	0
storage_tank	Ni	dissolved	0
storage_tank	Ni	suspended	0
storage_tank	Zn	dissolved	0
storage_tank	Zn	suspended	0
storage_tank	Cu	dissolved	0
storage_tank	Cu	suspended	0
pervious_pavement	TSS	dissolved	n/a
pervious_pavement	TSS	suspended	0.71429
pervious_pavement	Cr	dissolved	-4.6
pervious_pavement	Cr	suspended	-0.06667
pervious_pavement	Ni	dissolved	0.401
pervious_pavement	Ni	suspended	0.36986
pervious_pavement	Zn	dissolved	0.77022
pervious_pavement	Zn	suspended	0.66667
pervious_pavement	Cu	dissolved	0.23362
pervious_pavement	Cu	suspended	0.35659
soakaway	TSS	dissolved	n/a

Node Type	Pollutant	Phase	Efficiency
soakaway	TSS	suspended	0.60253
soakaway	Cr	dissolved	n/a
soakaway	Cr	suspended	0.26052
soakaway	Ni	dissolved	0.14191
soakaway	Ni	suspended	0.24796
soakaway	Zn	dissolved	0.25381
soakaway	Zn	suspended	0.52534
soakaway	Cu	dissolved	0.23362
soakaway	Cu	suspended	0.45573
swale	TSS	dissolved	n/a
swale	TSS	suspended	0.47308
swale	Cr	dissolved	0.2
swale	Cr	suspended	0.28
swale	Ni	dissolved	0.59184
swale	Ni	suspended	0.31034
swale	Zn	dissolved	0.42105
swale	Zn	suspended	0.43421
swale	Cu	dissolved	0.13385
swale	Cu	suspended	0.42975
swale_underdrained	TSS	dissolved	n/a
swale_underdrained	TSS	suspended	0.47308
swale_underdrained	Cr	dissolved	0.2
swale_underdrained	Cr	suspended	0.28
swale_underdrained	Ni	dissolved	0.59184
swale_underdrained	Ni	suspended	0.31034
swale_underdrained	Zn	dissolved	0.42105
swale_underdrained	Zn	suspended	0.43421
swale_underdrained	Cu	dissolved	0.13385
swale_underdrained	Cu	suspended	0.42975
pond	TSS	dissolved	n/a
pond	TSS	suspended	0.7551
pond	Cr	dissolved	0.01961
pond	Cr	suspended	0.5
pond	Ni	dissolved	-0.27778
pond	Ni	suspended	0.25816
pond	Zn	dissolved	0.576
pond	Zn	suspended	0.31624

Node Type	Pollutant	Phase	Efficiency
pond	Cu	dissolved	0.31102
pond	Cu	suspended	0.48905
green_roof	TSS	dissolved	n/a
green_roof	TSS	suspended	0.60253
green_roof	Cr	dissolved	-0.47453
green_roof	Cr	suspended	0.26052
green_roof	Ni	dissolved	0.14191
green_roof	Ni	suspended	0.24796
green_roof	Zn	dissolved	0.25381
green_roof	Zn	suspended	0.52534
green_roof	Cu	dissolved	0.23362
green_roof	Cu	suspended	0.45573

C Time series rainfall inter event dry period

The tool runs the model on a timestep basis for the continuous time series rainfall. However when processing the results to identify how many events result in zero runoff from the site the continuous time series needs to be separated into individual rainfall events.

A rainfall "event" is defined in the tool based on splitting the continuous time series into individual events based on a duration which can be between 6 hours and 24 hours. The default setting is 9 hours. The event is defined as running through the rainfall period and the following dry period of network drawdown (which might be longer than the minimum inter-event period used). This is shown in Figure C.1.

Most users do not need to adjust the inter-event dry period parameter however advanced users could depending on their network.

Inter-event dry periods longer than 9 hours may be suitable for larger systems, or where drainage discharge rates are set low such that the drawdown takes more time. Similarly a shorter inter-event period might be suitable for systems with rapid drain down characteristics. Longer drain down between events tries to ensure that the system drains down before the next event takes place. A system which still has water discharging from it affects the network performance evaluation (see Section 5.1). It is not recommended to use values above 12 hours for the inter-event period to avoid aggregation of rainfall into much fewer but very long large events.

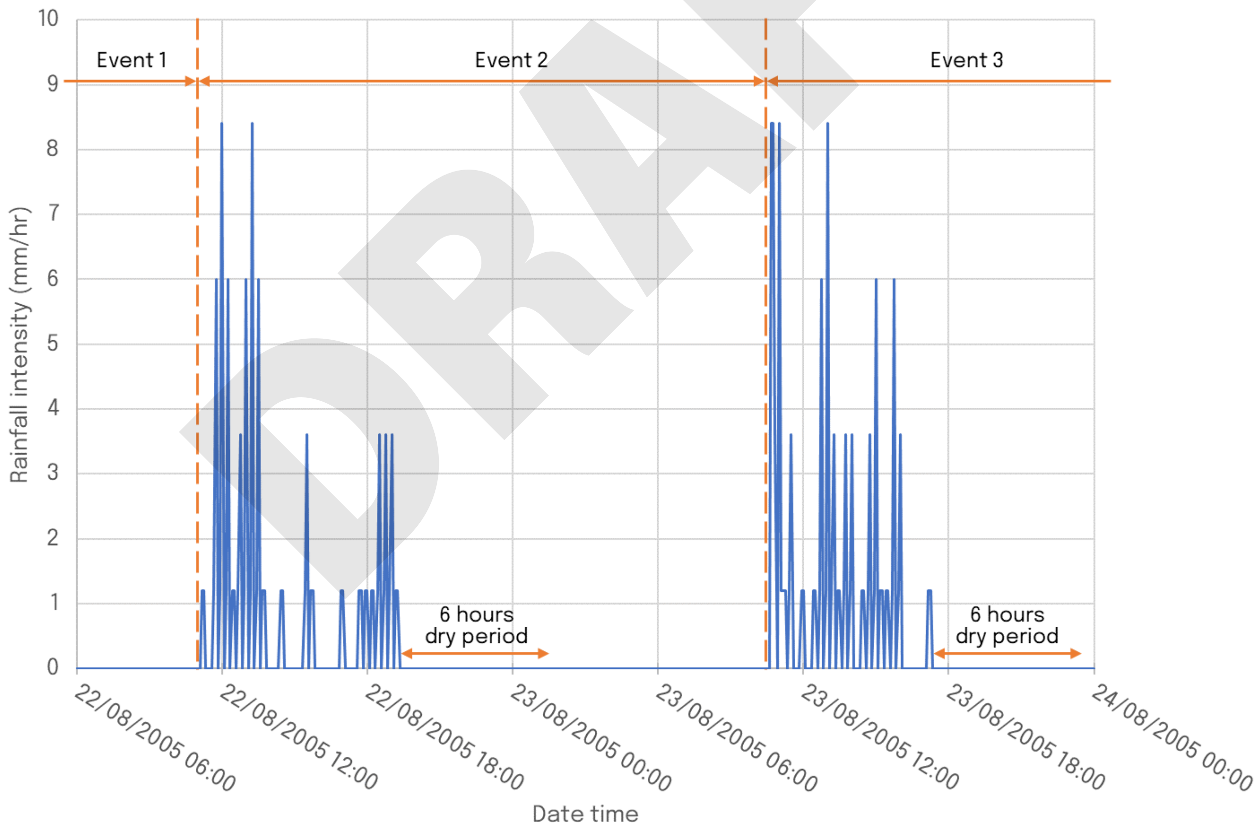

Figure C.1: Rainfall event definition

Source: HR Wallingford

D Pervious percentage runoff method

This appendix sets out the approach to pervious percentage runoff within the StopUP SuDS Tool. However, at present this is not fully implemented, and the Tool only models fixed percentage user specified runoff (see Section 2.2).

There are 3 methods to calculate the percentage runoff from catchment pervious surfaces. However, only 2 of methods are available for use for design storms and 2 for TSR. The user will select the chosen method from a drop down box on the "Runoff" tab in the Tool.

Table D.1 outlines the 3 runoff methods and which are available for use for design storms and/or TSR. Further details of these methods are given in the sections below.

Table D.1: Pervious runoff methods

Percentage runoff method	Description	Available for design storms?	Available for time series rainfall?
Fixed percentage – user specified	The user chooses a single percentage runoff value which is used as a constant for all of the event(s).	Yes (all events in a design storm duration-depth matrix will have the same percentage runoff)	Yes (all rainfall in the TSR will have the same percentage runoff)
Fixed percentage – based on rainfall event depth and soils	An equation is used to calculate a single percentage runoff value which is used as a constant throughout an event, but which is calculated for each event, based on the event depth.	Yes (each event in a design storm duration-depth matrix will have a different percentage runoff)	No
Variable runoff	The percentage runoff varies throughout all events based on the antecedent conditions and the rainfall taking place	No	Yes (percentage runoff varies with each timestep)

Fixed percentage – user specified

The user chooses a fixed percentage runoff value which is used throughout all of the event(s).

The following values are recommended:

- For design storms a value equal to 0.5 to 1.0 times the soil parameter SPR (standard percentage runoff[14]) is recommended. As SPR for soils range from 10 to 60%, a value in the range 5 to 60% is recommended.
- For TSR a value in the range of 0 to 0.2 times SPR is recommended. As SPR ranges from 10 to 60%, a value in the range of 0 to 12% is recommended.

Whilst the recommended ranges are narrower, the allowable values to be entered into the box are allowed to range between 0 and 100%.

SPR data is not provided although can be obtained from the following data sources:

- User defined (from UK FEH22 catchment data or UK WRAP soil maps).
- Converted from a BFIHOST value using the formula SPR=72 – 66.5*BFI from IH126 report (Boorman et al., 1995) (because FEH22 point data only provides BFIHOST not SPRHOST).

The percentage runoff value is applied once rainfall has filled the pervious depression storage. Depression storage is filled based on gross (100% factor) of initial rainfall.

[14] Standard Percentage Runoff (SPR) is the percentage of rainfall that falls onto a pervious surface/soil that contributes to surface water runoff and is a measure of different soil type's/catchments responses to rainfall

Fixed percentage - based on rainfall event depth and soils

An equation is used to calculate a single percentage runoff value which is used throughout an event but which varies between events. i.e. each event in a design storm duration-depth matrix will have different percentage runoff values.

The equation is based on the event rainfall depth (RD) and soil SPR parameter. The greater the rainfall depth and the higher the SPR value the greater the percentage runoff.

There is no influence of antecedent conditions on percentage runoff.

The equation[15] is:

$$if\ RD\ \leq 40mm;\ Percentage\ runoff\ (\%) = \frac{RD\ x\ SPR\ x\ 100}{40}$$

$$if\ RD\ > 40mm;\ Percentage\ runoff\ (\%) = (SPR\ x\ 100) + \ 0.45(RD - 40)^{0.7}$$

Where:

- RD is the total event rainfall depth (mm).
- SPR is the standard percentage runoff. This will be a user specified (see section above) value with lower and upper limits between 0.1 and 0.6.

The equation results in the curves shown on Figure D.1. Percentage runoff cannot exceed 100%.

The basis for the runoff equation is that up to 40 mm of rainfall, runoff is highly dependent on soil type. Above 40 mm of rainfall, additional runoff is largely independent of soil type. The part of the formula $0.45(RD - 40)^{0.7}$ comes from the Flood Studies Supplementary Report 16 (1985).

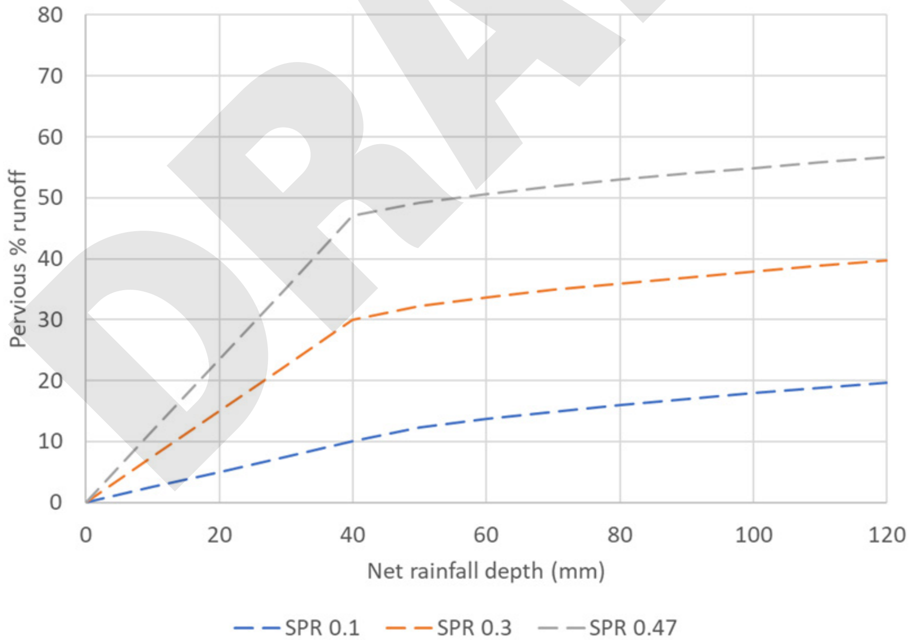

Figure D.1: Fixed percentage runoff based on rainfall event depth and soils

Source: HR Wallingford

Variable runoff

Variable runoff is only applied to continuous TSR only. Antecedent conditions are used to adjust the percentage runoff value at each timestep throughout an event. The parameter describing

[15] Note, this equation cannot be applied with an assessment of NAPI (the antecedent 30 days of rainfall) at the start of the event as the FSSR 16 equation was derived for the whole rainfall depth without decay or antecedent wetness influence

the antecedent conditions, $NAPI$, increases during/after recent rainfall and decays during dry spells and wet periods. A higher $NAPI$ value results in increased percentage runoff.

The antecedent conditions (NAPI, Normalised Antecedent Precipitation Index) is calculated for each timestep.

The equation[16], for percentage runoff at each timestep is:

$$if\ NAPI\ \leq 20mm;\ Percentage\ runoff\ (\%) = \frac{NAPI\ x\ SPR\ x\ 100}{20}$$

$$if\ NAPI\ is\ 20mm \leq 40mm;\ Percentage\ runoff\ (\%) = SPR\ x\ 100$$

$$if\ NAPI > 40mm;\ Percentage\ runoff\ (\%) = (SPR\ x\ 100) + 0.45(NAPI - 40)^{0.7}$$

The equation results in the curves shown on Figure D.2. Percentage runoff cannot exceed 100%.

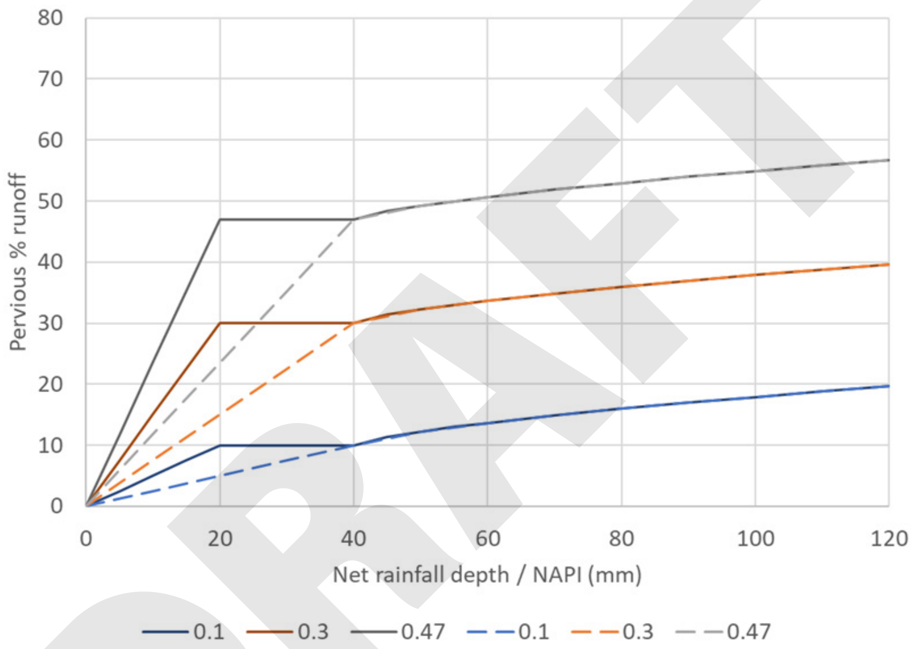

Figure D.2: "Variable runoff" equation (solid lines) compared to the "Fixed percentage runoff based on rainfall event depth and soils" equation (dashed lines)

Source: HR Wallingford

The equation for NAPI on a sub-daily timestep is:

$$APIfactor = k^{\frac{\min(dt,86400)}{2\times 86400}}$$

$$NAPI(t + dt) = \big((NAPI(t) \times APIfactor) + (P - E)\big) \times APIfactor$$

Where:

- dt is the timestep in seconds;

[16] The linear part of the equation has increased in gradient compared to the "Fixed percentage – based on rainfall event depth and soils" equation (i.e. divide by 20 mm, not 40 mm). This is because it is not known what rainfall is coming and therefore if the event within a continuous event was 40 mm total, the average percentage runoff would have been 0.5*SPR, as opposed to 100%*SPR. Therefore a solution to match the "Fixed percentage – based on rainfall event depth and soils" equation where you know what rainfall depth you will achieve is to double the proposed linear component of the curve and then assume runoff percentage is SPR between 20 mm and 40 mm

- k is the decay factor which is set as 0.8[17];
- $NAPI(t)$ is NAPI at the current timestep;
- $NAPI(t+dt)$ is NAPI at the next timestep;
- P is the rainfall during the timestep;
- E is the evaporation during the timestep (see Section 2.3).

If $NAPI$ is calculated at less than -5 mm[18], the value is capped. There isn't a cap on the maximum value of NAPI.

[17] This is the same as used in the UKWIR rainfall runoff equation
[18] Note, negative NAPI and depression storage are slightly different things, one is wetting the soils, the other is minor depressions on the surface filling so it is OK to represent both. Additionally, the total of depression storage and negative NAPI should not make a large difference for large events

E Reporting parameters

This appendix describes each of the reporting parameters.

Time series rainfall results

Table E.1: What are the rainfall and runoff volumes on the site?

Parameter	Description
Total rainfall depth (mm)	Average annual rainfall depth. Total time series rainfall depth divided by the length of the time series rainfall in years
Contributing site area (ha)	Sum of the contributing areas and above ground SuDS plan areas draining to the SuDS network and connected to any of the river, sewer or to ground outfalls
Total rainfall volume (m^3)	Average annual total rainfall depth multiplied by the contributing site area
Total runoff volume (m^3)	Average annual total runoff volume from the contributing areas and the rainfall falling directly onto the SuDS (i.e. the rainfall volume minus any losses at source)

Table E.2: Where does the surface water runoff go?

Parameter	Description
Losses at source (i.e. rainfall that does not runoff the surface)	Average annual volume and proportion of rainfall volume that does not runoff from the surface and therefore does not enter the drainage system network. It also includes evaporation from depression storage. It is equivalent to the rainfall volume minus the runoff volume
Infiltration	Average annual volume and proportion of rainfall volume infiltrated by the SuDS units plus any volume that leaves via the 'to ground' outfall
Reuse	Average annual volume and proportion of rainfall volume used by the rainwater harvesting SuDS units
Evapotranspiration	Average annual volume and proportion of rainfall volume lost via evapotranspiration by the SuDS units
Leaves the site via the drainage outfall	Average annual volume and proportion of rainfall volume that leaves the site via the river or sewer outfall

Table E.3: How many rainfall events result in zero runoff from the site?

Parameter	Description
No. of events	Average annual number of events broken down by rainfall event depth and for the whole year and within the summer or winter season
No. of events with zero runoff from site	Average annual number of events which have resulted in zero runoff from the site (see Section 5.2 for method) broken down by rainfall event depth and for the whole year and within the summer or winter season
Percentage of events with zero runoff from site (%)	100 x No. of events with zero runoff from site/No. of events

Table E.4: How much pollution mass might be removed by the system?

Parameter	Description
Wash off Mass (mg)	The average annual wash-off mass of the pollutant from the contributing surfaces entering the surface water system
Mass leaving outfall (mg)	The average annual mass leaving the surface water system via the sewer or river outfall
Indicative mass load reduction (%)	100 x (Wash off mass – Mass leaving outfall)/Wash off mass

Table E.5: How much pollutant concentration might be reduced by the system?

Parameter	Description
Max influent concentration (mg/l)	The concentration of the highest polluting land surface connected to the SuDS network (connected to any of the river, sewer or to ground outfalls)
Max effluent concentration at outfall (mg/l)	The maximum effluent concentration at the site river or sewer outfall (i.e. after all the SuDS treatment). (The 'To ground' outfalls do not count towards water quality outputs)
% reduction in pollutant concentration	100 x (Max influent concentration – Max effluent concentration at outfall)/Max influent concentration

Design storm results

Table E.6: What is the peak flow rate at the site outfall for extreme events?

Parameter	Description
Storm durations run (minutes)	List of the storm durations simulated for each return period
Critical duration (minutes)	The storm duration which results in the maximum flow rate out of the SuDS, and if there is a tie, the duration which results in the maximum flood volume (and if a tie, then duration at peak flow rate)
Peak drainage flow rate at site outfall (l/s)	The maximum flow rate from the river/sewer outfall for the critical duration storm for each return period

Table E.7: What is the peak flow rate at the site outfall for all extreme events simulated?

Parameter	Description
Rainfall Depth (mm)	The rainfall depth of the design storm event by return period and duration
Peak drainage flow rate at site outfall (l/s)	The maximum flow rate from the river/sewer outfall for each design storm event

Table E.8: How much flooding occurs from the drainage system for extreme events?

Parameter	Description
Storm durations run (minutes)	List of the storm durations simulated for each return period
Critical duration (minutes)	The storm duration which results in the maximum flow rate out of the SuDS, and if there is a tie, the duration which results in the maximum flood volume (and if a tie, then duration at peak flow rate)
Total volume of flooding from the drainage system (m^3)	The maximum flood volume stored in the most downstream SuDS unit before the sewer/river outfall for the critical duration event for each return period

Table E.9: What is the total volume of flooding for all extreme events simulated?

Parameter	Description
Rainfall Depth (mm)	The rainfall depth of the design storm event by return period and duration
Total volume of flooding from the drainage system (m^3)	The maximum flood volume stored in the most downstream SuDS unit before the sewer/river outfall each design storm event

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