Sustainable Urban Drainage Modelling in InfoWorks ICM

Introduction

Sustainable drainage systems (SUDS), also referred to as Low Impact Development (LID) tools, are drainage solutions that provide an alternative to the direct drainage of surface flow through networks of pipes to nearby watercourses. They work on the basis of temporarily storing or slowing the drainage of surface water. Within InfoWorks ICM, SUDS have always been represented using network objects such as ponds, lateral inflows to conduits, infiltration loss from conduits and manholes and permeable conduits. These have been described in the following blogs:-

- Modelling of SUDs/BMPs/LIDs in InfoWorks ICM and CS (overview)  

- Modelling of Swales in InfoWorks ICM and CS  

These objects, together with other 2D features, allowed the detailed modelling of structures such as swales, permeable pavements and ponds. Through time, further SUDS techniques have been developed such as the use of rain barrels, bio-retention cells, rain gardens and infiltration trenches. InfoWorks ICM version 6.5 sees the release of exciting functionality which will allow the user better representation of these features using an approach which would be familiar to Storm Water Management Model (SWMM) users.

Within this new approach, SUDS controls are represented by a combination of vertical layers whose properties are defined on a per-unit-area basis. This allows SUDS of the same design but different areal coverage to occur within different subcatchments within the model domain. During a simulation, ICM performs a moisture balance that keeps track of how much water moves between, and is stored within, each SUDS layer.

All of the SUDS controls provide some rainfall/runoff storage and evaporation of stored water (except for rain barrels). Infiltration into soil occurs in vegetative swales and can also occur in bio-retention cells, porous pavement systems, and infiltration trenches if those systems do not have an impermeable bottom liner. Infiltration trenches and porous pavement systems can also experience clogging over time which limits its hydraulic performance.

**SUDS Control Editor**

The SUDS Control Editor is used to define sustainable urban drainage feature that can be deployed to store, infiltrate, and evaporate. The design of the control is made on a per-unit-area basis so that it can be placed in any number of subcatchments at different sizes or number of features. The editor, available in the Subcatchment grid, contains the following data entry fields.
• **Control Name**
  A name used to identify the particular SUDS control.

• **SUDS Type**
  The generic type of SUDS being defined (bio-retention cell, rain garden, green roof, infiltration trench, permeable pavement, rain barrel, rooftop disconnection, vegetative swale).

• **SUDS Parameters**
  The SUDS parameters contain fields for the vertical layers that comprise a SUDS control. They include some combination of the following, depending on the type of SUDS being modelled:

  1. **Surface Layer**: Corresponds to the ground (or pavement) surface which receives direct rainfall and flow from adjacent areas, stored flow in depression storage and generates runoff that enters the drainage system.

  2. **Pavement Layer**: Layer of porous concrete or asphalt used in permeable pavement systems.

  3. **Soil Layer**: Engineered soil mixture used in bio-retention cells to support vegetative growth.

  4. **Storage Layer**: Bed of crushed rock or gravel that provides storage in bio-retention cells, permeable pavements and infiltration trenches. For rain barrels it is the simply the barrel itself.

  5. **Underdrain System**: Drains water from the storage layer of bio-retention cells, permeable pavements and infiltration trenches.

  6. **Drainage Mat**: Used for green roofs to represent the mat or plate that lies beneath the soil and above the roof structure. The drainage mat conveys any water that drains through the soil layer off the roof.
Figure 2: Conceptual Model of a Bio-Retention Cell as represented in Infoworks ICM

Table 1 provides some common SUDS features and the Infoworks ICM SUDS layers of which they commonly comprise.

<table>
<thead>
<tr>
<th>LID type</th>
<th>Surface</th>
<th>Pavement</th>
<th>Soil</th>
<th>Storage</th>
<th>Underdrain</th>
<th>Drainage mat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio-retention cell</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>o</td>
<td></td>
</tr>
<tr>
<td>Rain garden</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green roof</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Infiltration trench</td>
<td>x</td>
<td></td>
<td></td>
<td>o</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Permeable pavement</td>
<td>x</td>
<td>x</td>
<td></td>
<td>o</td>
<td>x</td>
<td>o</td>
</tr>
<tr>
<td>Rain barrel</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rooftop disconnection</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetative swale</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Conceptual Representations of common SUDS features in Infoworks ICM (x is required, o is optional).

**Surface Layer Parameters**

The Surface Layer parameters of the SUDS Control Editor is used to describe the surface properties of bio-retention cells, porous pavement, infiltration trenches, and vegetative swales.
These properties are as follows:

- **Berm Height**
  When confining walls or berms are present this is the maximum depth (mm) to which water can pond above the surface of the SUDS unit before overflow occurs. For SUDS that experience overland flow, it is the height of any surface depression storage. For swales, it is the height of the trapezoidal cross section.

- **Storage Depth**
  Only active for rooftop disconnections.

- **Vegetative Volume Fraction**
  The fraction of the storage area above the surface that is filled with vegetation.

- **Roughness (Manning’s n)**
  Manning’s $n$ for overland flow over the surface of porous pavement or a vegetative swale. Use 0 for other types of SUDS.

- **Slope**
  Slope of porous pavement surface or vegetative swale (m/m). Use 0 for other types of SUDS.

- **Side Slope**
  Slope of the side walls of a vegetative swale’s cross section. This value is ignored for other types of SUDS.

If either Surface Roughness or Surface Slope values are 0 then any ponded water that exceeds the storage depth is assumed to completely overflow the SUDS control within a single time step.

**Pavement Layer Parameters**
The Pavement Layer page of the SUDS Control Editor supplies values for the following properties of a porous pavement SUDS.

![Figure 4: SUDS Control Pavement Layer Parameters](image)

- **Thickness**
  The thickness of the pavement layer (mm). Typical values are 100 to 150mm.

- **Void Ratio**
  The volume of void space relative to the volume of solids in the pavement for continuous systems or for the fill material used in modular systems. Typical values for pavements are 0.12 to 0.21. Note that porosity = void ratio / (1 + void ratio).
- **Impervious Surface Fraction**
  Ratio of impervious paver material to total area for modular systems; 0 for continuous porous pavement systems.

- **Permeability**
  Permeability of the material used in continuous systems or hydraulic conductivity of the fill material (gravel or sand) used in modular systems (mm/hr). The permeability of new porous concrete or asphalt is very high but can drop off over time due to clogging by fine particulates in the runoff (see below).

- **Clogging Factor**
  Number of pavement layer void volumes of runoff treated it takes to completely clog the pavement. Use a value of 0 to ignore clogging. Clogging progressively reduces the pavement's permeability in direct proportion to the cumulative volume of runoff treated.

Using an estimate of the number of years it takes to fully clog the system (Y\text{clog}), the Clogging Factor can be computed as:

\[ Y_{\text{clog}} \times Pa \times CR \times (1 + VR) \times (1 - ISF) / (T \times VR) \]

Where:-
- \( Pa \) is the annual rainfall amount over the site,
- \( CR \) is the pavement's capture ratio (area that contributes runoff to the pavement divided by area of the pavement itself),
- \( VR \) is the Void Ratio,
- \( ISF \) is the Impervious Surface Fraction, and
- \( T \) is the pavement layer Thickness.

As an example, it may take 5 years to clog a continuous porous pavement system that serves an area where the annual rainfall is 360 mm/year. If the pavement is 60mm thick, has a void ratio of 0.2 and captures runoff only from its own surface, then the Clogging Factor is:-

\[ 5 \times 360 \times (1 + 0.2) / 60 / 0.2 = 180. \]

**Soil Layer Parameters**
The Soil Layer parameters of the SUDS Control Editor describes the properties of the engineered soil mixture used in bio-retention types of SUDS.

**Figure 5: SUDS Control Soil Layer Parameters**

These properties are the following:-
- **Class**
  Use this to choose the type of soil that is being represented. When the #D flag is used for the other soil layer parameters, choosing a soil class will populate the soil parameters with appropriate defaults for that particular soil type. The default parameters for each soil type are shown below in Table 2.

<table>
<thead>
<tr>
<th>Soil Class</th>
<th>Porosity</th>
<th>Field Capacity</th>
<th>Wilting Point</th>
<th>Conductivity (mm/hr)</th>
<th>Suction Head (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>0.437</td>
<td>0.062</td>
<td>0.024</td>
<td>120.396</td>
<td>49.022</td>
</tr>
<tr>
<td>Loamy Sand</td>
<td>0.437</td>
<td>0.105</td>
<td>0.047</td>
<td>39.972</td>
<td>60.96</td>
</tr>
<tr>
<td>Sandy Loam</td>
<td>0.453</td>
<td>0.19</td>
<td>0.085</td>
<td>10.922</td>
<td>109.982</td>
</tr>
<tr>
<td>Loam</td>
<td>0.463</td>
<td>0.232</td>
<td>0.116</td>
<td>3.302</td>
<td>88.9</td>
</tr>
<tr>
<td>Silt Loam</td>
<td>0.501</td>
<td>0.284</td>
<td>0.135</td>
<td>6.604</td>
<td>169.926</td>
</tr>
<tr>
<td>Sandy Clay Loam</td>
<td>0.398</td>
<td>0.244</td>
<td>0.136</td>
<td>1.524</td>
<td>219.964</td>
</tr>
<tr>
<td>Clay Loam</td>
<td>0.464</td>
<td>0.31</td>
<td>0.187</td>
<td>10.016</td>
<td>210.058</td>
</tr>
<tr>
<td>Silty Clay Loam</td>
<td>0.471</td>
<td>0.342</td>
<td>0.21</td>
<td>1.016</td>
<td>270.002</td>
</tr>
<tr>
<td>Sandy Clay</td>
<td>0.43</td>
<td>0.321</td>
<td>0.221</td>
<td>0.508</td>
<td>240.030</td>
</tr>
<tr>
<td>Silty Clay</td>
<td>0.479</td>
<td>0.371</td>
<td>0.251</td>
<td>0.508</td>
<td>290.068</td>
</tr>
<tr>
<td>Clay</td>
<td>0.475</td>
<td>0.378</td>
<td>0.265</td>
<td>0.254</td>
<td>320.04</td>
</tr>
</tbody>
</table>


- **Thickness**
  The thickness of the soil layer (mm). Typical values range from 450 to 900 mm for rain gardens, street planters and other types of land-based bio-retention units, but only 75 to 150 mm for green roofs.

- **Porosity**
  The ratio of volume of pore space to total volume of soil.

- **Field Capacity**
  Ratio of Volume of pore water to total volume after the soil has been allowed to drain fully. Below this value, vertical drainage of water through the soil layer does not occur.

- **Wilting Point**
  Ratio of pore water volume to total volume for a well dried soil where only bound water. The moisture content of the soil cannot fall below this limit.

- **Conductivity**
  Hydraulic conductivity for the fully saturated soil (mm/hr).

- **Conductivity Slope**
  Slope of the curve of log (conductivity) versus soil moisture content (dimensionless). Typical values range from 5 for sands to 15 for silty clay.

- **Suction Head**
  The average value of soil capillary suction along the wetting front (mm). This is the same parameter as used in the Green-Ampt infiltration model.
**Storage Layer Parameters**
The Storage Layer parameters of the SUDS Control Editor describes the properties of the crushed stone or gravel layer used in bio-retention cells, porous pavement systems, and infiltration trenches as a bottom storage/drainage layer. It is also used to specify the height of a rain barrel.

<table>
<thead>
<tr>
<th>Grid [SUDS control] - S</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Barrel height (Storage (mm))</strong></td>
</tr>
<tr>
<td><strong>Thickness (Storage (mm))</strong></td>
</tr>
<tr>
<td><strong>Void ratio (Storage)</strong></td>
</tr>
<tr>
<td><strong>Seepage Rate (Storage (mm/hr))</strong></td>
</tr>
<tr>
<td><strong>Clogging factor (Storage)</strong></td>
</tr>
<tr>
<td>1.00</td>
</tr>
<tr>
<td>12.000</td>
</tr>
<tr>
<td>12.000</td>
</tr>
<tr>
<td>36.000</td>
</tr>
<tr>
<td>48.000</td>
</tr>
<tr>
<td>0.010</td>
</tr>
<tr>
<td>0.010</td>
</tr>
<tr>
<td>0.000</td>
</tr>
</tbody>
</table>

**Figure 6: SUDS Control Storage Layer Parameters**

The following data fields are displayed:-
- **Barrel Height**
  This is the height of a rain barrel, domestic rain barrels range in height from 600 to 900 mm.
- **Thickness**
  This is the thickness of a gravel layer (mm). Crushed stone and gravel layers are typically 150 to 450 mm thick.

The following data fields do not apply to Rain Barrels.
- **Void Ratio**
  The volume of void space relative to the volume of solids in the layer. Typical values range from 0.5 to 0.75 for gravel beds. Note that porosity = void ratio / (1+ void ratio).
- **Seepage Rate**
  The maximum rate at which water can flow out the bottom of the layer after it is first constructed (mm/hr). Typical values for gravels are 250 to 750 mm/hr. If the layer contains a sand bed beneath it then the conductivity of the sand should be used. If there is an impermeable floor or liner below the layer then use a value of 0. The actual exfiltration rate through the bottom will be the smaller of this limiting rate and the normal infiltration rate into the soil below the layer.
- **Clogging Factor**
  Total volume of treated runoff it takes to completely clog the bottom of the layer divided by the void volume of the layer. Use a value of 0 to ignore clogging. Clogging progressively reduces the Filtration Rate in direct proportion to the cumulative volume of runoff treated and may only be of concern for infiltration trenches with permeable bottoms and no under drains.

**Underdrain Parameters**
SUDS storage layers can contain an optional underdrain system that collects stored water from the bottom of the storage layer and conveys it to a conventional storm drain. The Underdrain page of the SUDS Control Editor describes the properties of this system.
Figure 7: SUDS Control Underdrain Layer Parameters

It contains the following data entry fields:

- **Flow Coefficient and Flow Exponent**
  Coefficient $C$ and exponent $n$ that determines the rate of flow through the underdrain as a function of height of stored water above the drain height.

- **Offset Height**
  Height $H_d$ of any underdrain piping above the bottom of a storage layer or rain barrel (mm).

- **Drain Delay** (for Rain Barrels only)
  The number of dry weather hours that must elapse before the drain in a rain barrel is opened (the drain is assumed to be closed once rainfall begins). This parameter is ignored for other types of SUDS.

- **Flow Capacity Underdrain**
  The flow capacity of the storage layer or rain barrel.

**Drainage Mat Parameters**

Used for green roofs to represent the mat of plate that lies beneath the soil and above the roof structure. The drainage mat conveys any water that drains through the soil layer off the roof.

Figure 8: SUDS Control Drainage Mat Layer Parameters
- **Thickness**
  Thickness of the mat or plate (mm). Typically ranges from 25-50mm.

- **Void Fraction**
  The ratio of void volume to total volume in the mat. Typically ranges from 0.5-0.6.

- **Roughness**
  Manning’s n used to compute the horizontal flow rate of drained water through the mat. Previous modelling studies have suggested using a relatively high value such as from 0.1 to 0.4.

Once the various SUDS features have been added then they can be used in the subcatchment properties page under the SUDS Controls.

**Subcatchment SUDS Control**

The Subcatchment SUDS Control Editor is invoked from a subcatchment property sheet to specify how a particular SUDS control will be deployed within the subcatchment.

![Subcatchment SUDS Control Editor](image)

**Figure 9: Subcatchment SUDS Control Editor**

It contains the following data entry fields.

- **SUDS Structure**
  The name of a previously defined SUDS control to be used in the subcatchment.

- **Number of Units**
  The number of equal size units of the SUDS practice (e.g., the number of rain barrels) deployed within the subcatchment.

- **Area**
  The surface area devoted to each replicate SUDS unit (m²). The **Area of Subcatchment (%)** field indicates how much of the total subcatchment area is devoted to the particular SUDS being deployed.

- **Unit Surface Width**
  The width of the outflow face of each identical SUDS unit (m). This parameter only applies to SUDS processes that use overland flow (e.g. Porous Pavement, Vegetative Swales) to convey surface runoff off of the unit. The other SUDS processes (e.g. Bio-Retention Cells and Infiltration Trenches) simply spill any excess captured runoff over their berms.

- **Initial Saturation**
  For Bio-Retention Cells this is the degree to which the unit’s soil is initially filled with water (0% saturation corresponds to the wilting point moisture content, 100% has the moisture content equal to the porosity). The storage zone beneath the soil zone of the cell is assumed to be completely dry. For other types of SUDS it corresponds to the degree to which their storage zone is initially filled with water.

- **Impervious Area Treated**
  The percent of the impervious portion of the subcatchment’s non-SUDS area whose runoff is treated by the SUDS practice. (E.g. if rain barrels are used to capture roof runoff and roofs represent 60% of the impervious area, then the impervious area treated is 60%). If the SUDS unit treats only direct
rainfall, such as with a green roof, then this value should be 0. If the SUDS takes up the entire subcatchment then this field is ignored.

- **Outflow to... Outlet/Pervious/Impervious**
  Select an option to specify where the outflow from the SUDS is returned to. It can be returned to the subcatchment's pervious or impervious area rather than going to the subcatchment's outlet. An example of where this might apply is a rain barrel whose contents are used to irrigate a lawn area. This field is ignored if the SUDS takes up the entire subcatchment. Pervious surfaces can drain fully or partially to impervious surfaces in the same subcatchment, and vice-versa, the remaining runoff being sent directly to the outlet.

- **Drain to Subcatchment**
  Select this option to have the outflow from the SUDS to return to a separate subcatchment defined in the subcatchment properties. This is useful to the representation of a SUDS feature draining to a subcatchment. For example you could route the surface runoff from a roof top to buffer around the house and then runoff from the buffer around the house to the lawn (with all 3 areas represented separately as subcatchments draining to each other).

- **Drain to Node**
  Select this option to have the outflow from the SUDS to return to a defined node. If this field and the above field are blank then the drain flow is sent to the same place as the outflow.

The SUDS features in ICM will influence runoff and so after placement of SUDS within the subcatchment, the impervious area values may require adjustment to compensate for the amount of original subcatchment area that been replaced by SUDS. For example, suppose that a subcatchment which is 40% impermeable has 75% of that area converted to a permeable pavement LID. After the SUDS feature is added the subcatchment's percent impermeable should be changed to the percent of impermeable area remaining divided by the percent of non-SUDS area remaining. This is \((1 - 0.75)\times 40 \div (100 - 0.75\times 40)\) or 14.3 %.

**Initial conditions**

It is possible to set the initial saturation for a SUDS control in the SUDS Control editor but it is possible to specify the initial saturation on the SUDS Subcatchment tab of a Rainfall event. The value in the rainfall event takes precedence over the value defined on a subcatchment in the Model network.

**Hydraulic Calculations**

The Infoworks ICM SUDS functionality uses components of the SWMM 5 approach (EPA, 2010) within the ICM simulation engine. This section describes how the calculations are conducted.

**The SUDS model**

If we consider a SUDS feature such as a bio-retention cell shown in Figure 10. Conceptually it can be represented by a series of three separate layers.
The surface layer receives both direct rainfall and runoff from adjacent surfaces. Water is lost via infiltration into the soil layer located below it, by evapotranspiration of any water stored in depression storage and vegetative capture, and through runoff.

The soil layer receives infiltration from the surface layer and loses water through evapotranspiration and by percolation into the storage layer below it.

The storage layer consists of coarse crushed material or gravel. It receives percolation from the soil layer above it and water is lost water by either infiltration into the underlying soil or outflow through a perforated pipe underdrain system.

The hydrologic performance of the Bio retention cell SUDS feature can be modelled by calculating the mass balance equations that express the change in water volume in each layer over time as the difference between the inflow water rate and the outflow rate. The equations for the surface layer, soil layer, and storage layer can be written as below, respectively.

\[
\frac{\partial d_1}{\partial t} = i + q_0 - e_1 - f_1 - q_1
\]

\[
L_2 \frac{\partial \theta_2}{\partial t} = f_1 - e_2 - f_2
\]

\[
\phi_3 \frac{\partial d_3}{\partial t} = f_2 - f_3 - q_3
\]

where:-

\(d_1\) = depth of ponded surface water,

\(\theta_2\) = soil layer moisture content,
\( d_3 \) = depth of water in the storage layer,

\( i \) = rainfall rate,

\( q_0 \) = upstream flow on to surface,

\( q_1 \) = surface runoff flow rate,

\( q_2 \) = underdrain outflow rate,

\( e_1 \) = surface evaporation rate,

\( e_2 \) = soil layer evaporation rate,

\( f_1 \) = surface infiltration rate,

\( f_2 \) = soil percolation rate,

\( f_3 \) = soil infiltration rate,

\( L_2 \) = depth of the soil layer, and

\( \phi \) = porosity of the storage layer.

The flux terms (\( q, e, \) and \( f \)) in these equations are functions of the current water content in the various layers (\( d_1, \theta_2, \) and \( d_3 \)) and the specific characteristics of the site and soil. The soil percolation rate decreases exponentially from \( K_s \) with decreasing soil moisture:

\[
f_2 = k_s \exp\left(-\rho(\phi - \theta_2)\right)
\]

where \( \rho \) is a percolation constant typically in the range of 5 to 15.

The under drain outflow rate (per unit area of the SUDS control) is modelled with the following equation:

\[
Q = C(h - H_d)^n
\]

where \( C \) and \( n \) are constants and \( h \) is the height of stored water (mm) and \( H_d \) is the offset distance of the drain from the bottom of the unit. If the layer does not have an underdrain then the user can set \( C \) to 0. A typical value for \( n \) would be 0.5 (making the drain act like an orifice). A rough estimate for \( C \) can be based on the time \( T \) required to drain a depth \( D \) of stored water. For \( n = 0.5 \), \( C = 2D^{1/2}/T \).

This set of equations is calculated at each time step to determine how an inflow hydrograph to the SUDS feature is converted into some combination of runoff hydrograph, sub-surface storage, sub-surface drainage, and infiltration into the surrounding soil. SWMM 5 offers a choice of three different methods for computing soil infiltration rates – the Horton, Green-Ampt and Curve Number models. SWMM only offers a single infiltration model in a model network, although ICM can allow many. The simulation engine will set the infiltration model based on the first surface it finds that has a runoff volume which matches those in SWMM (Horton, Modified Horton, Green-Ampt or SCS). If none is specified then ICM will use the Horton model.
A Few Examples

Bio-Retention Cell

Biological retention cells/facilities are landscaped depressions used for the storage and infiltration of storm water through plants, soil and micro-organisms in areas with relatively lower ground level before draining to a drainage bed usually comprised of gravel.

Figure 11: An example of a biological retention cell. Photo from Susdrain website (www.susdrain.org)

To represent a Biological Retention Cell within Infoworks ICM, we would use the following 4 surface layers:

- Surface
- Soil
- Storage
- Underdrain

The schematisation of the bio-retention cell is shown in figure 12.
Figure 12: A Schematic representation of a biological retention cell within ICM.

Essentially with a bio-retention cell, the significant part is the soil store which receives flow from the surface through infiltration and controls the rate at which water filters through the system, and can percolate to a separate storage facility. In this case an underdrain is also simulated to represent the drainage from the bio-retention cell.

The surface layer, has a berm height of 6mm. Flow exfiltrates into a sandy clay loam with a thickness of 12mm. The default soil parameters for the sandy clay loam soil type have been used. Beneath the soil layer is a 12mm thick gravel layer which allows storage of water with a void ratio of 0.5 and a seepage rate of 0.2. This is then drained via an underdrain with an offset height of 0.5mm which conveys flow out of the SUDS feature.
Green Roof Layers

Green roofs are essentially a vegetated surface which provide retention and attenuation of flow and encourage evapo-transpiration. In some ways, they are a variation of the bio-retention cell that have a soil store on top of a geotextile sub-storage layer, which in this case is represented using a drainage mat, that allows excess percolated flow to drain off the roof. Outflow from a green roof (down-pipes) are rarely designed to be a constraint.

The following surfaces have been used to represent a green roof:

- Surface,
- Soil
- Drainage Mat

And shown schematically in figure 14.
The green roof has been represented with a surface layer with a height of 5mm and a high slope and vegetation fraction, indicating a sloping roof and the vegetated nature of a green roof. Infiltration from this layer then drains into a sandy soil layer before any flow that works its way through the soil layer ends up at a thin drainage mat which allows water to drain from the roof top.

Rain Gardens

A rain-garden can be considered similar to a bio-retention cell albeit on a smaller scale, they tend to be a small shallow depression which is designed to overflow into a piped drainage system. It is often a flat depression of 100mm to 300mm deep, similar to a bio-retention cell but without the gravel bed. Beneath it flow can percolate through to the underlying soil.
Figure 16: Example of a Rain Garden. Photo from Susdrain website (www.susdrain.org)

They can be schematised with the following layers:

- Surface
- Soil

Figure 17: A schematic of the representation of a rain garden within InfoWorks ICM.
Figure 18: Rain garden parameters within InfoWorks ICM.

The surface layer has a low berm height and a high vegetation volume fraction which represents the surface storage. There is then an underlying soil layer comprising of sandy clay material.

**Rain Barrel**

Rain barrels are an enclosed overground or underground stormwater collection facility that collect roof runoff during storm events. They can either slowly release flow into the system or allow the reuse of rainwater during dry weather periods.

They consist of just 2 layers:

- **Storage**
- **Underdrain**

![Diagram of rain barrel parameters](image)

Figure 19: A schematic of the representation of a rain barrel within InfoWorks ICM.

In this instance the storage layer is the same as the barrel height (480mm). There is then the underdrain component which represents the drainage component of the rain barrel.
Figure 20: The rain barrel parameters within InfoWorks ICM.

Infiltration Trench

Infiltration trenches are linear excavations filled with stone aggregate or other void-forming material used to capture runoff from upstream impermeable areas and encourage infiltration for underground water recharge.

They can be represented using 3 layers:

- Surface
- Storage
- Underdrain

Figure 21: A schematic of the representation of an infiltration trench within InfoWorks ICM.
The layers include a sloping surface with a relative high roughness value to represent hydraulic retardation due to the presence of vegetation. Flow can infiltrate through the surface into a small storage layer (36mm) with flow then drained via the underdrain to the subcatchment outlet.

**Permeable Pavement**

Permeable Pavements are block paving or permeable asphalt on top, high voids geo-grid in the middle or stone media, and the base can be lined or soil. A large majority of rainfall will pass through the pavement into a storage layer below where it can infiltrate into the soil below. The outlet is usually a form of hydraulic control.
Figure 23: A typical permeable pavement. Photo from Susdrain website (www.susdrain.org)

Figure 24: A schematic of the representation of a permeable pavement within InfoWorks ICM.

The surface layer represent the pavement surface, the pavement layer the permeable pavement, which in this case is relatively thick at 150mm, within which flow can infiltrate and provide a small amount of storage, the storage the high voids geogrid and the underdrain the hydraulic control.
Swale
There are many variations in the design of swales. In general terms a swale is a vegetation covered overground channel, of any depth between 500mm to 2m or more. It can collect, transport and convey stormwater. Conveyance within the swale is usually restricted and allows more time for water to infiltrate into the soil below. It can be used as connection with other urban drainage facilities. When it is full it will spill from the surface at the bottom end and cause overland flow.

Following Layer:-

Surface
Figure 26: A typical swale feature. Photo from Susdrain website (www.susdrain.org)

Figure 26: A schematic of the representation of a rain barrel within InfoWorks ICM.

In this case the swale has a relatively high slow, high side slopes and a high roughness value to represent the presence of vegetation upon any surface flow.

Figure 27: The Swale parameters within InfoWorks ICM.
Results

There are 3 new results attributes available in the subcatchment results parameters. These are

- Total outflow, m³/s, this is the total outflow from the subcatchment (base flow + DWF + foul flow + runoff + infiltration + RDII + SUDS inflow and outflow).
- Impervious flow to SUDS, m³/s. The flow from the impervious area of the subcatchment to the SUDs control structure.
- SUDS Surface Outflow – surface outflow from SUDS controls, m³/s.

There is more detailed output for each particular control which can be obtained by checking the Timestep Log box in the Diagnostics dialog from the Run dialog. Also, ensure that Summary (PRN) results is checked in the Run dialog. This enables the generation of report files for each SUDS control. The report files should be found in the Results Folder for the current database (as set in the Options dialog). There will be one report file per SUDS control, the name will be sim<sim #>_<subcatchment_id>_<SUDS control name>.txt. Note that the units in the report file will always be mm/hr or mm, regardless of the setting of units in the UI.

Runoff reported by Simulation engine is the runoff from the non-SUDS area of the subcatchment i.e. total surface area – sum of area * number for each SUDS control. Thus subcatchments that are completely covered by SUDS controls will report zero runoff. The total outflow from the subcatchment will include the contribution from any SUDS controls.

Routing between Surfaces within a Subcatchment

An alternative method to modelling SUDS features, is to use internal routing between subcatchment surfaces. In earlier versions of InfoWorks ICM, the only option was for all surfaces of a subcatchment to drain to the outlet of the subcatchment. Now, pervious surfaces can drain fully or partly to impervious surfaces in the same subcatchment, and vice-versa, the remaining runoff being sent directly to the outlet.

On the Routing group of the Subcatchment Objects Properties there are two new fields:

- Internal routing: a drop down menu that allows you to choose “Direct (Direct to outlet)”, “To pervious (Impervious to pervious) “, or “To impervious (Pervious to impervious) “.
- Runoff routed internally (%): appears when Internal routing is not “Direct” only. Valid values are 0 ≤ Percent routed ≤ 100.

The value of surface type on runoff surfaces determines whether a surfaces is impervious or not. Surfaces with unknown surface type are considered to be pervious. The runoff volume is distributed amongst the receiving surfaces proportionally to their areas.

There are no new results, but note that the Runoff subcatchment result is no longer necessarily the sum of the runoff results from the individual surfaces. Where a surface’s runoff is routed wholly or partly to another surface, then that internally routed runoff is not included in the total runoff. When the runoff from the impervious surface is routed across the pervious surface, some of the runoff is lost to infiltration and depression storage in the pervious surface.
The *routing between subcatchment surfaces* option can be used to model SUDS features. This is done by representing the SUDs features as the permeable surface, setting the subcatchment’s permeable values to those of the SUDS feature, routing the runoff from the impermeable surface of the subcatchment to the pervious surface, and defining the *Percent Routed* to represent the percentage of impermeable surface connected to the SUDS feature.

**Further Reading**


