

SWMM tutorial for urban rainfall-runoff and LID modelling

WAT-E2030 HYDROLOGICAL MODELLING

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SWMM TUTORIAL FOR URBAN RAINFALL-RUNOFF AND LID SIMULATIONS

This document contains the basics of using SWMM in urban hydrological modelling and LID design for the Hydrological Modelling Course. SWMM is a freely available software with easy-to-read, up-to-date manuals, therefore it is easy to gain a deeper understanding about the model on your own. During the course, the examples given in this document are detailed enough for students to conduct their own urban hydrology/LID exercises to pass the course. Further information can be found in the SWMM manuals:

SWMM user's manual: *This manual includes the basic information and step-by-step guidance on how to use the model:*

Rossman, L.A. 2015. Storm Water Management Model User's Manual Version 5.1. EPA-600/R-14/413b. Available online: <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100N3J6.TXT>

SWMM hydrology reference manual: *This reference manual includes detailed information about the computation of hydrological processes in SWMM:*

Rossman, L.A., Huber, W.C. 2016a. Storm Water Management Model Reference Manual Volume I – Hydrology (revised January 2016). EPA/600/R-16/093. Available online: <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100NYRA.txt>

SWMM water quality reference manual: *This reference manual includes detailed information about the LID modelling with SWMM and provides e.g. example parameter values for different LID units:*

Rossman, L.A., Huber, W.C. 2016b. Storm Water Management Model Reference Manual Volume III – Water Quality. EPA/600/R-16/093. Available online: <https://nepis.epa.gov/Exe/ZyPDF.cgi/P100P2NY.PDF?Dockey=P100P2NY.PDF>

SWMM hydraulics' reference manual: *This reference manual includes detailed information about the hydraulic modelling with SWMM:*

Rossman, L.A., Huber, W.C. 2017. Storm Water Management Model Reference Manual Volume II – Hydraulics. EPA/600/R-16/093. Available online: <https://nepis.epa.gov/Exe/ZyPDF.cgi/P100S9AS.PDF?Dockey=P100S9AS.PDF>

TEMPLATE FILES FOR THIS TUTORIAL AND THE WEEK'S ASSIGNMENT

To start working, download the model and data files described below from the MyCourses/Assignments-page and save them to your computer:

- [Urban_hydrology_example.inp](#) (an example model file for traditional development)
- [Urban_hydrology_example.ini](#) (a settings file)
- [Urban_hydrology_example_LID.inp](#) (an example model file added with LID examples)
- [Urban_hydrology_example_LID.ini](#) (a settings file)
- [climate2005.dat](#) (a climate file for summer 2005)
- [climate2006.dat](#) (a climate file for summer 2006)
- [storms2005_10MIN.dat](#) (rainfall data for June-August 2005 with 10-min time interval)
- [storms2006_2MIN.dat](#) (rainfall data for June-August 2006 with 2-min time interval)

The examples of this tutorial are based on the SWMM files [Urban_hydrology_example.inp](#) and [Urban_hydrology_example_LID.inp](#). These files include SWMM-models of a residential area with a traditional pipe sewer system for surface runoff. The latter file, [Urban_hydrology_example_LID.inp](#), includes examples of *Low Impact Development* (LID) units implemented in the existing urban area. Their *.ini*-files (the same file name except its extension is *.ini*) include saved settings for the SWMM's

graphical user interface. The model can be run without an *ini*-file; however, it will use the default graphical settings.

In addition to the above model and data files, you will need to download a template file for your own design exercise. Guidance on how to select your catchment file will be given during the lecture or in MyCourses. There will be three catchments available: **Catchment1.inp**, **Catchment2.inp**, or **Catchment3.inp**. Remember to download the associated *.ini*-file, too.

PART 1: RAINFALL-RUNOFF MODELLING IN SWMM

STUDY AREA

Vallikallio is a medium-density residential area in Espoo. An illustration of the catchment's land cover, sewer network and the catchment outlet are shown in Figure 1. Vallikallio's landscape is characterised by three to four storey apartment buildings with asphalt streets and parking areas. A subsurface pipe sewer network covers the whole catchment being the only route for the conveyance of surface runoff away from the catchment area. Traffic-related areas and the majority of the rooftops are directly connected to the pipe sewer system. Total area of the catchment is 11.4 ha, of which 34% is covered by asphalt surfaces (Table 1). Vegetated areas mainly consist of lawns and shrubs near the buildings and natural pine forest. Some scattered gravel/sand surfaces are located within building yards, e.g., playgrounds. Soils within the catchment mainly consist of sandy till including areas with only a thin (<1 m) soil layer on top of the bedrock and areas with steeper layers of sandy till.





Figure 1. Surface types in Vallikallio and the locations of the sewer network and the catchment outlet. This map was obtained from the MSc thesis of Raudaskoski (2016) (available at: <https://aaltodoc.aalto.fi/handle/123456789/19943>, in Finnish). More recently, Tuomela (2017) built a water quality model for the same study catchment (available at: <https://aaltodoc.aalto.fi/handle/123456789/28476>, in English).

Table 1. Proportions of different surface types of the total catchment area and some key parameter values in SWMM used in the example model files.

Surface type	Area (ha)	Area (%)	Imperviousness (%)	Depression storage (mm)	Manning's roughness (-)
Asphalt	3.94	34.6	95	0.5	0.014
- vehicular streets	0.73	6.4	95	0.5	0.014
- walkways	1.66	14.6	95	0.5	0.014
- parking lots	1.55	13.6	95	0.5	0.014
Roof	2.15	18.9	100	0.3	0.01
Gravel/sand	0.73	6.4	33	1.5	0.03
Paving (tiles, stones)	0.24	2.1	85	0.7	0.02
Vegetation	4.30	37.7	0	2.45	0.5
Open rock	0.04	0.004	100	3.16	0.05
Total catchment area	11.4	100			

OPENING THE MODEL

- Open SWMM: find EPA SWMM 5.1 folder in your computer's Start Menu, select  EPA SWMM 5.1
- After the program opens: from the top-left corner of the Main Menu, select *File* -> *Open* and browse the location of the *Urban_hydrology_example.inp*. Open it.
- When working with SWMM, remember to save your work regularly: from the top-left corner, select *File* -> *Save* or click the  button.

MODIFYING THE MAP VIEW

After opening the *Urban_hydrology_example.inp*, adjust map settings using the *Map Browser* panel. Select *Map* -> select a theme from *Subcatchments* menu -> *Imperviousness*. For the design assignment, there are two useful subcatchment themes: *Imperviousness* and *LID usage*. The *Imperviousness* theme visualizes the different surface types according to their imperviousness (Figure 2). The *LID usage* theme helps to identify subcatchments with LID units.

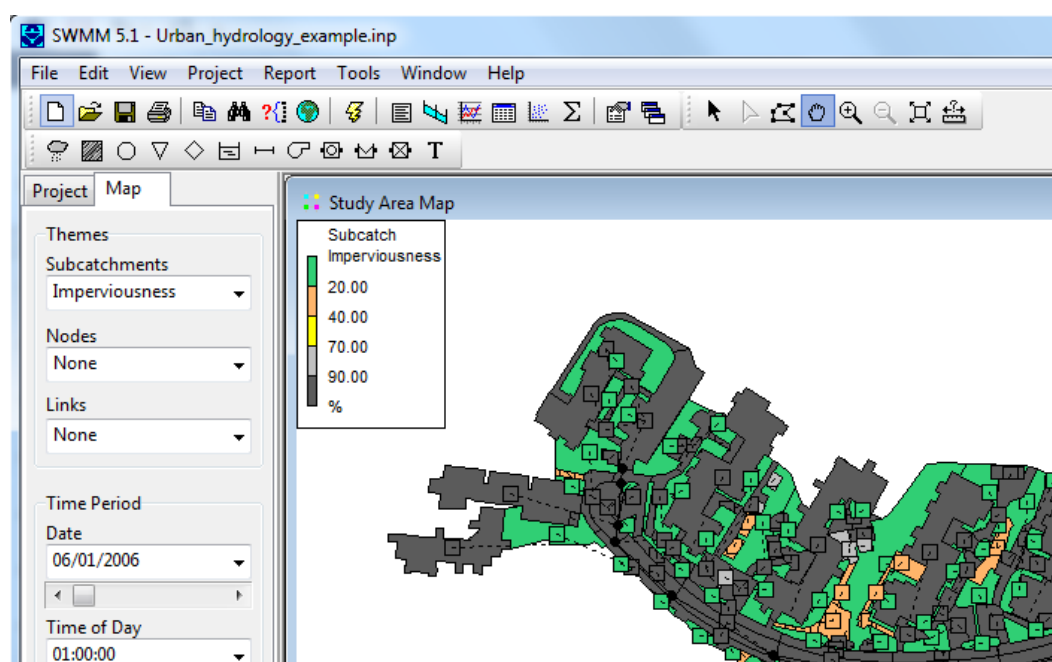


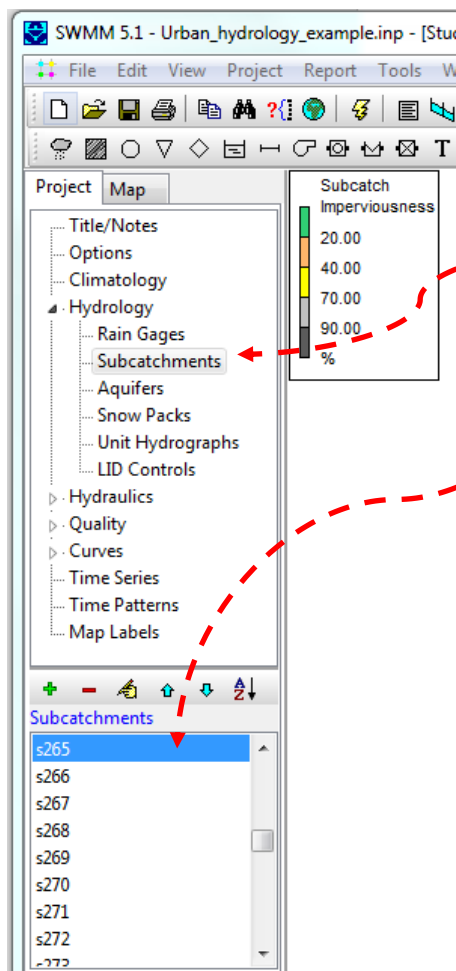
Figure 2. When you open a SWMM file (.inp file), you'll see a completely black map. Use Map Browser Panel to select different themes to illustrate your study area (no theme is selected as default). In the current exercise, choose *Subcatchments* -> *Imperviousness*.

SUBCATCHMENT PROPERTIES

In the example model files, each subcatchment represents one land cover type: asphalt surface, roof, tile/concrete paving, gravel/sand surface, open rock or vegetation. Each land cover type is defined with several parameters, for which the key parameters are as follows:

- **Imperviousness (%)**: the percent imperviousness of the subcatchment – rainfall falling on the impervious proportion of the catchment generates surface runoff. Infiltration only occurs from pervious areas. *Affects the volume of surface runoff.*
- **Manning's roughness (-)**: the value of n (i.e., roughness parameter) in Manning's equation for surface runoff. Another important variable is the Manning's roughness coefficient for sewer pipes. *Affects the shape of the runoff hydrograph.*
- **Depression storage (mm)**: The depth of depression storage on impervious and pervious surfaces, includes the initial abstractions (surface wetting and ponding, interception) that must be filled before surface runoff occurs. When the depth of water exceeds this storage, any excess rainfall will produce surface runoff with an outflow rate given by Manning's equation. *Affects the volume of surface runoff.*
- **Infiltration**: infiltration to the unsaturated soil zone of pervious subcatchment areas. In the template files, the Green-Ampt method is chosen for modelling infiltration. *Affects the volume of surface runoff.*

The parameter values for different land cover types in the template models are shown in Table 1. Typical parameter values can also be found from the SWMM's User manual (Rossman, 2015). It is not necessary to change the subcatchment properties when working with the course assignment.

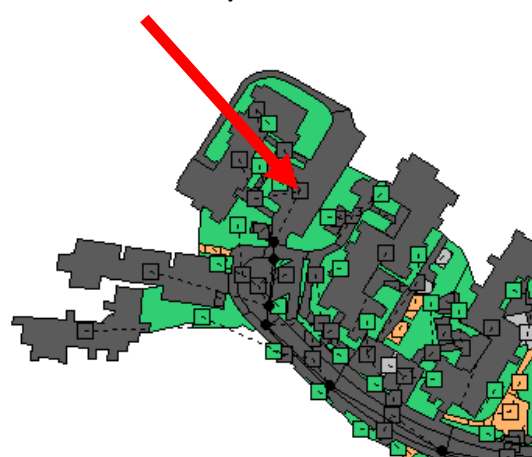


There are two ways to select a subcatchment and explore its properties:

→ From *Project Browser* panel: select **Project** -> **Hydrology** -> **Subcatchments** -> select the subcatchment from **Subcatchments** list, press



→ OR: From the map view: select a subcatchment by right-clicking its square symbol and select **Properties**



The Subcatchment Editor window for the Subcatchment s265

Property	Value
Name	s265
X-Coordinate	378526.396
Y-Coordinate	6678966.391
Description	41
Tag	parking
Rain Gage	r1
Outlet	j38
Area	0.06342
Width	12.28327
% Slope	3.23947
% Imperv	95
N-Imperv	0.014
N-Perv	0.014
Dstore-Imperv	0.5
Dstore-Perv	0.5
%Zero-Imperv	0
Subarea Routing	OUTLET
Percent Routed	100
Infiltration	GREEN_AMPT
Groundwater	NO
Snow Pack	
LID Controls	0
Land Uses	0
Initial Buildup	NONE
Curb Length	51.63

Name: Name of the subcatchment

Tag: Subcatchment's surface type

Outlet: Outlet for the subcatchments surface runoff: it can be another subcatchment or a sewer node/junction (here the sewer junction j38)

% Imperv: Subcatchment imperviousness

N-Imperv/N-Perv: Manning's n for impervious and pervious surfaces

Dstore-Imperv/Dstore-Perv: The depth (mm) of depression storage

Infiltration: The method for the calculation of infiltration: by selecting this, you can access the parameter values used for the calculation of infiltration

LID Controls: The number of LID units assigned to this subcatchment

RUNNING A SIMULATION

To run a simulation, go through the following steps:

[STEP 1. Provide rainfall data.](#)

[STEP 2. Provide climate data.](#)

[STEP 3. Set simulation options.](#)

[STEP 4. Run a simulation.](#)

[STEP 5. View the simulation results.](#)

STEP 1. PROVIDE RAINFALL DATA

In SWMM, a user-defined time series is a good option for event-scale simulation with short-term rainfall data whereas an external data file is better for long-term continuous simulation. For the week's assignment, rainfall data is given both as external files (3-month continuous rainfall data *storms2005_10MIN.dat* and *storms2006_2MIN.dat*) and as separate time series created using SWMM's *Time Series Editor*. In the template files, there are four ready-made time series (as shown in Figure below) that represent typical 10-minute design storms for sewer design with different recurrence intervals (the recurrence intervals of 2, 5, 10 and 50 years). Of the time series given, the 5-year design storm represents the common design storm in sewer sizing in Finland (about 10 mm of rainfall within a 10-minute period).

TO ADD RAINFALL DATA FOR A SIMULATION:

From the *Project Browser* panel, select **Hydrology** -> **Rain Gages** to open *Rain Gage Editor*.

In the *Rain Gage Editor*, set the properties for a rain gage named *r1* as follows:

- **Rain Format** VOLUME
- **Station ID** STA01
- **Rain Units** MM

Selecting a data source:



- ➔ Select **TIMESERIES** from the **Data Source** dropdown menu
- ➔ Use **Series Name** field to select the name of the time series

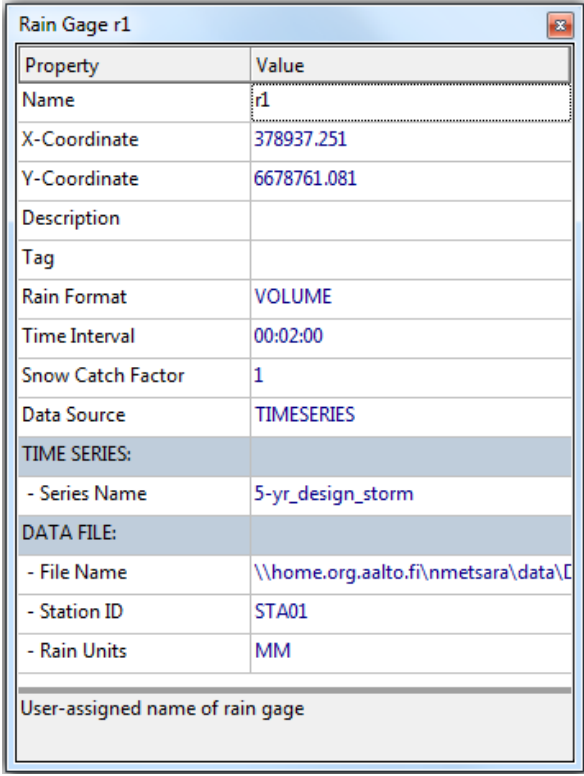
OR:

- ➔ Select **FILE** from the Data Source dropdown menu
- ➔ Select the File Name data field and search the right file using the standard Windows File Selection dialog
- ➔ Click open to select the file and close the dialog.

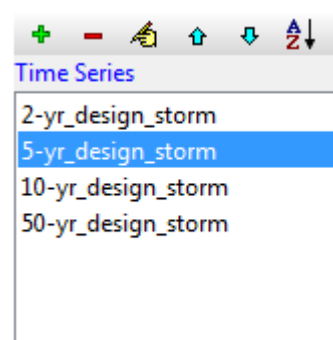
Finally, set **Time Interval** equal to the time step of the rainfall data used: 2 minutes (00:02:00) for the time series and the file *storms2006_2MIN.dat*, 10 minutes (00:10:00) for the file *storms2005_10MIN.dat*.

To modify or create time series:

- ➔ select **Time series** from the **Project** panel
- ➔ press  to modify an existing time series
- ➔ press  to add a new time series.



Property	Value
Name	r1
X-Coordinate	378937.251
Y-Coordinate	6678761.081
Description	
Tag	
Rain Format	VOLUME
Time Interval	00:02:00
Snow Catch Factor	1
Data Source	TIMESERIES
TIME SERIES:	
- Series Name	5-yr_design_storm
DATA FILE:	
- File Name	\\home.org.aalto.fi\nmetsara\data\
- Station ID	STA01
- Rain Units	MM
User-assigned name of rain gage	




STEP 2. PROVIDE CLIMATE DATA

For the course assignment, the climate data for the calculation of evaporation is given as external files that can be downloaded from the MyCourses/*Assignments*-page. Use ***climate2006.dat*** with the 2006 rainfall data and ***climate2005.dat*** with the 2005 rainfall data. The climate files include minimum and maximum daily temperatures that SWMM uses to estimate potential daily evaporation rates. If you are simulating the design storm time series, you can choose either one of the climate files.

ADDING CLIMATE DATA FOR A SIMULATION:

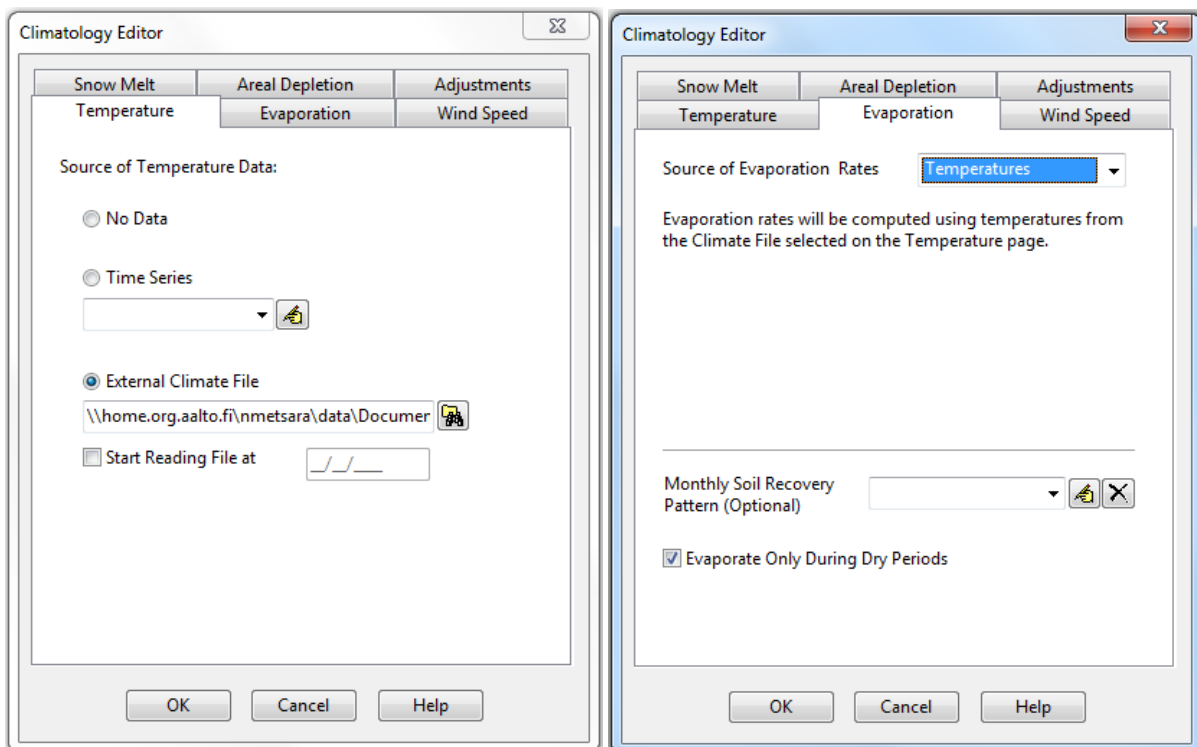
From the *Project* panel, select ***Climatology*** -> ***Temperature*** and press  to open *Climatology Editor*

On the ***Temperature*** page:


- ➔ select ***External Climate File***
- ➔ press  and search the right file using the standard Windows File Selection dialog
- ➔ click *open* to select the climate file.

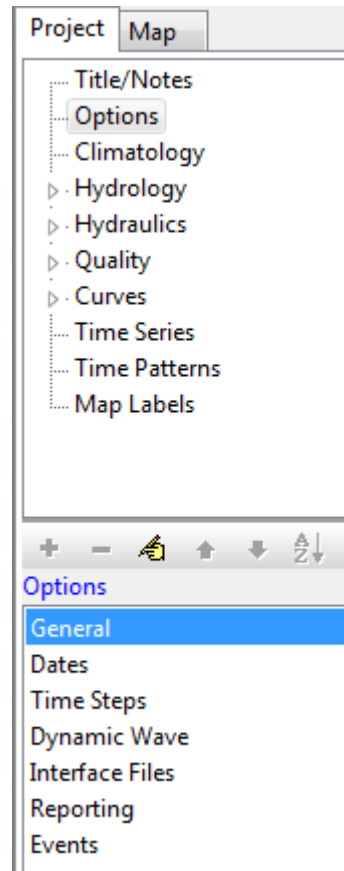
On the ***Evaporation*** page:

- ➔ select ***Temperatures as a Source of Evaporation Rates***
- ➔ check that ***Evaporate Only During Dry Periods*** box is selected
- ➔ select *ok* to close the editor.



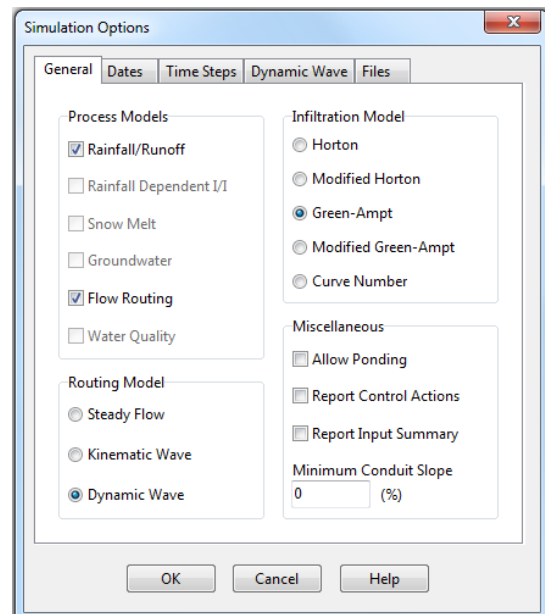
STEP 3. SET SIMULATION OPTIONS

From the *Project* panel, select **Options** -> **General** and press  to open *Simulation Options Editor*



Check the following settings on the **General** page:

- ➔ Process Models: **Rainfall/Runoff** and **Flow Routing** selected
- ➔ Routing Model: **Dynamic Wave** selected
- ➔ Infiltration Model: **Green-Ampt** selected



Set the simulation time on the **Dates** page according to your rainfall data file and the purpose of the simulation. Below the only difference between the design storm simulation (A) and the simulation with the long-term rainfall data (B) is the end date in the **End Analysis on** field: 06/02/2006 for a design storm and 08/31/2006 for the summer 2006 rainfall data. If you are running a simulation with the summer 2005 data, remember to change the year to 2005.

A) Simulation with a design storm

Simulation Options dialog box, Dates tab. The 'End Analysis on' field is set to 06/02/2006 at 23:58. Other fields include Start Analysis on (06/01/2006 00:00), Start Reporting on (06/01/2006 00:00), Start Sweeping on (01/01), End Sweeping on (12/31), and Antecedent Dry Days (0).

B) Long-term simulation with rainfall data

Simulation Options dialog box, Dates tab. The 'End Analysis on' field is set to 08/31/2006 at 23:58. Other fields include Start Analysis on (06/01/2006 00:00), Start Reporting on (06/01/2006 00:00), Start Sweeping on (01/01), End Sweeping on (12/31), and Antecedent Dry Days (0).


Check the following settings on the **Time Steps** page:

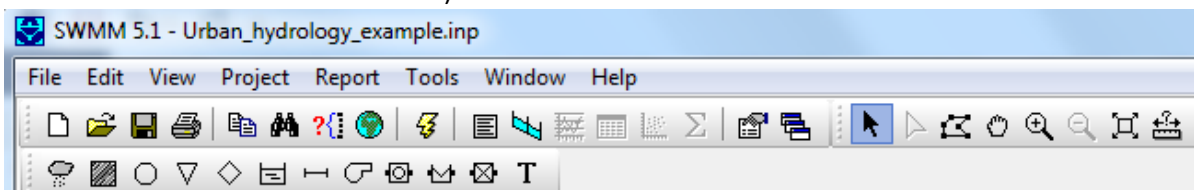
- ➔ **Reporting** time step depends on the purpose of the analysis. The basic setup is to set it equal to the time step of the rainfall data used: *2 minutes* for 2006 data and the design storm time series, *10 minutes* for the year 2005 rainfall data. If the purpose is to determine water balance components for long-term time periods, larger reporting time steps (e.g. 1 h or 1 day) can be used. For the analysis of short-term peak flow rates, small reporting time step is required.
- ➔ **Runoff: Dry Weather** 01:00:00 (1 hour)
- ➔ **Runoff: Wet Weather** 00:00:05 (5 sec)
- ➔ **Routing**: 5 seconds
- ➔ Press *ok* to close the Editor.

Simulation Options dialog box, Time Steps tab. Reporting is set to 0 days and 00:02:00. Runoff: Dry Weather is 0 days and 01:00:00. Runoff: Wet Weather is 0 days and 00:00:05. Routing is 5 seconds. Steady Flow Periods: Skip Steady Flow Periods (unchecked), System Flow Tolerance (%) is 5, Lateral Flow Tolerance (%) is 5.

Note: the computational time steps will affect both the time it takes to run the model and the magnitude of continuity errors. **5 secs** for wet weather runoff and routing work well with short design storms, but can make the computation too slow, when the long-term rainfall data is used. Hence, you may use **15 sec** time step for long-term simulation to speed up the process.

STEP 4. RUN A SIMULATION

To run a model, click the lightning button  on the SWMM's Standard toolbar (or select **Project -> Run simulation** from the Main Menu).



STEP 5. VIEW THE SIMULATION RESULTS

After the model run is completed, SWMM displays a Run Status stating whether the run was successful or not. For a successful model run, also the mass continuity errors for both surface runoff (the hydrological catchment model) and flow routing (routing of runoff through the pipe sewer system to the catchment outlet) are shown. Continuity errors simply show the percent difference between the initial storage + total inflow and the final storage + total outflow for the total catchment area and drainage system. Large continuity errors (for example errors larger than 5%) require checking the validity of the analysis results.

There are several ways to view the simulation results. More information about viewing the results can be found in the SWMM's user manual (Rossman, 2015), Chapter 2.5, Chapter 2.7, and Chapter 9.

VIEWING THE STATUS REPORT

To view the status report, select Report -> Status from the Main Menu. The status report shows the basic information about the quality of the model run and e.g. the mass balance components for the complete model run (Figure 3 and Figure 4). Based on the status report extracts, there was a considerable difference in total rainfall between the summers 2005 and 2006: it rained only 52.4 mm during the summer 2006 (Figure 3), which is only 15% of the total rainfall in the summer 2005, 347.6 mm (Figure 4). In the 2006, 34.1 mm of rainfall was lost through evaporation and infiltration, resulting in 18.2 mm of surface runoff. This comprises 35% of the total rainfall during that period. However, during the wet summer 2005, 49% of the rainfall produced surface runoff. This surface runoff volume, 169.2 mm, is ninefold compared with the surface runoff volume in the summer 2006.

```

*****
Runoff Quantity Continuity      Volume      Depth
*****                          hectare-m    mm
*****                          -----
Total Precipitation .....      0.598      52.400
Evaporation Loss .....         0.107      9.400
Infiltration Loss .....        0.282     24.713
Surface Runoff .....           0.208     18.227
Final Storage .....           0.001      0.062
Continuity Error (%) .....     -0.004
    
```

Figure 3. An extract of the status report (select Report -> Status) when using the rainfall data from the dry summer 2006.

```

*****
Runoff Quantity Continuity      Volume      Depth
*****                          hectare-m    mm
*****                          -----
Total Precipitation .....      3.965     347.600
Evaporation Loss .....         0.292     25.632
Infiltration Loss .....        1.742    152.729
Surface Runoff .....           1.931    169.243
Final Storage .....           0.000      0.000
Continuity Error (%) .....     -0.001
    
```

Figure 4. A status report extract when using the 10-min rainfall data from the wet summer 2005.

VIEWING THE SUMMARY REPORT

To view the Summary Report, select **Report -> Summary** from the Main Menu. The Summary Report displays summary results for each subcatchment, node and link in the drainage system. When using the example model files, summary results are available for the subcatchments *s3-s612*, individual sewer pipes as links (*Conduits c1-c43*), and for each node including junctions representing the sewer manholes (*Junctions j1-j44*) and one catchment outlet node (*o1*). By changing the **Topic** in the Summary Report window, various results for different variables can be shown.

In Figure 5, a view of the summary report for *Subcatchment Runoff* is shown. In Figure 5, *Total Runoff* exceeds total precipitation for some subcatchments. This is because these subcatchments receive runoff from other neighbouring subcatchments: the amount of this additional runoff is shown as *Total Runon*. The table also shows important details about the catchment hydrology: the total amounts of evaporation (*Total Evap*, mm) and infiltration (*Total Infil*, mm) and the highest peak flow rate (*Peak Runoff*, l/s) during the simulation period.

The screenshot shows a window titled "Summary Results" with a dropdown menu set to "Subcatchment Runoff". Below the menu is a table with the following data:

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10 ^{^6} ltr	Peak Runoff LPS	Runoff Coeff
s265	52.40	8.47	16.78	2.95	41.00	0.03	9.52	0.674
s266	52.40	0.86	16.82	2.63	33.68	0.03	8.92	0.632
s267	52.40	5.23	15.71	2.81	39.05	0.01	2.55	0.678
s268	52.40	55.96	16.68	4.58	86.97	0.02	7.85	0.803
s269	52.40	8.50	16.06	2.95	41.80	0.01	2.45	0.686
s270	52.40	50.71	17.33	4.38	81.23	0.02	6.97	0.788
s271	52.40	19.82	15.79	3.41	52.95	0.01	3.71	0.733

Figure 5. An extract of a model summary report (select Report -> Summary) for Subcatchment runoff.

Figure 6 illustrates another example of the summary report for Node Flooding. This lists all nodes that flooded during the simulation period. SWMM reports flooding when the water depth in the node exceeds the maximum assigned depth, hence, there is not enough capacity in the pipe system but water raises to the ground surface level. In Figure 6, the duration and magnitude of such flooding is rather small during the simulation period. By default, SWMM excludes the flooded water from the system. This can be changed by allowing ponding in the Simulation Options Editor, so that the water is stored atop the node and released back into the sewer system when capacity exists to do so.

The screenshot shows a window titled "Summary Results" with a dropdown menu set to "Node Flooding". Below the menu is a table with the following data:

Node	Hours Flooded	Maximum Rate LPS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood Volume 10 ^{^6} ltr	Maximum Pondered Depth Meters
j13	0.01	93.19	88	17:09	0.000	0.000
j17	0.01	66.55	88	17:09	0.000	0.000
j18	0.04	61.36	88	17:09	0.003	0.000
j19	0.01	44.83	88	17:10	0.000	0.000
j24	0.01	53.13	88	17:09	0.000	0.000
j25	0.01	45.72	88	17:09	0.000	0.000

Figure 6. An extract of a model summary report (select Report -> Summary) for Node Flooding when using the 2-min rainfall data for the summer 2006


COPYING THE SUMMARY REPORT DATA TO EXCEL

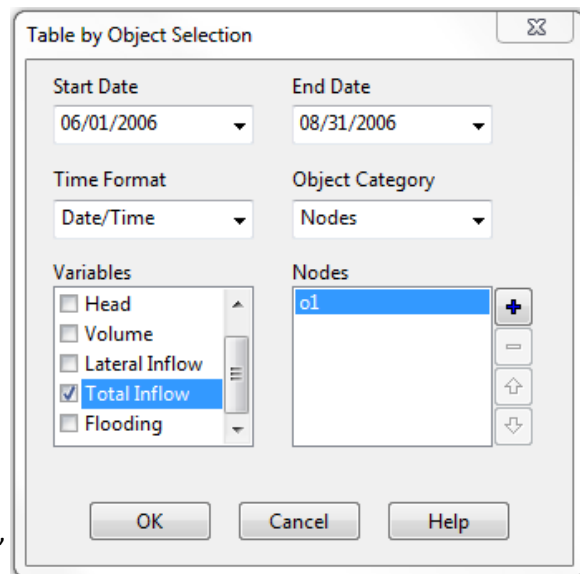
To copy data from a summary report, select **Edit -> Copy to -> Clipboard** from the Main Menu. Open an Excel file, select a cell and paste the data on a worksheet.

COPYING THE DETAILED CONTINUOUS DATA TO EXCEL

It is possible to copy detailed continuous simulation data for any subcatchment, node or link to Excel for further viewing and analysis. First, select **Report -> Table -> By Object** from the Main Menu.

- In the **Table by Object Selection** window, adjust the **Start Date** and the **End Date** for the wanted time series.
- For **Time Format**, select either the **Elapsed Time** from the start of the simulation or the **Date/Time** format. *Elapsed time* is quite appropriate for short design storms, whereas *Date/Time* may suite the long-term simulation better.
- From the **Object Category**, choose the object type: in the Figure on the right, *Nodes* are selected. The easiest way to select a node is to left-click it on the map window and then

click the  button. Here the time series of Total Inflow to the Node *o1* is selected, hence, we will obtain a data table containing the continous time series of flow rate (l/s) at the catchment outlet.



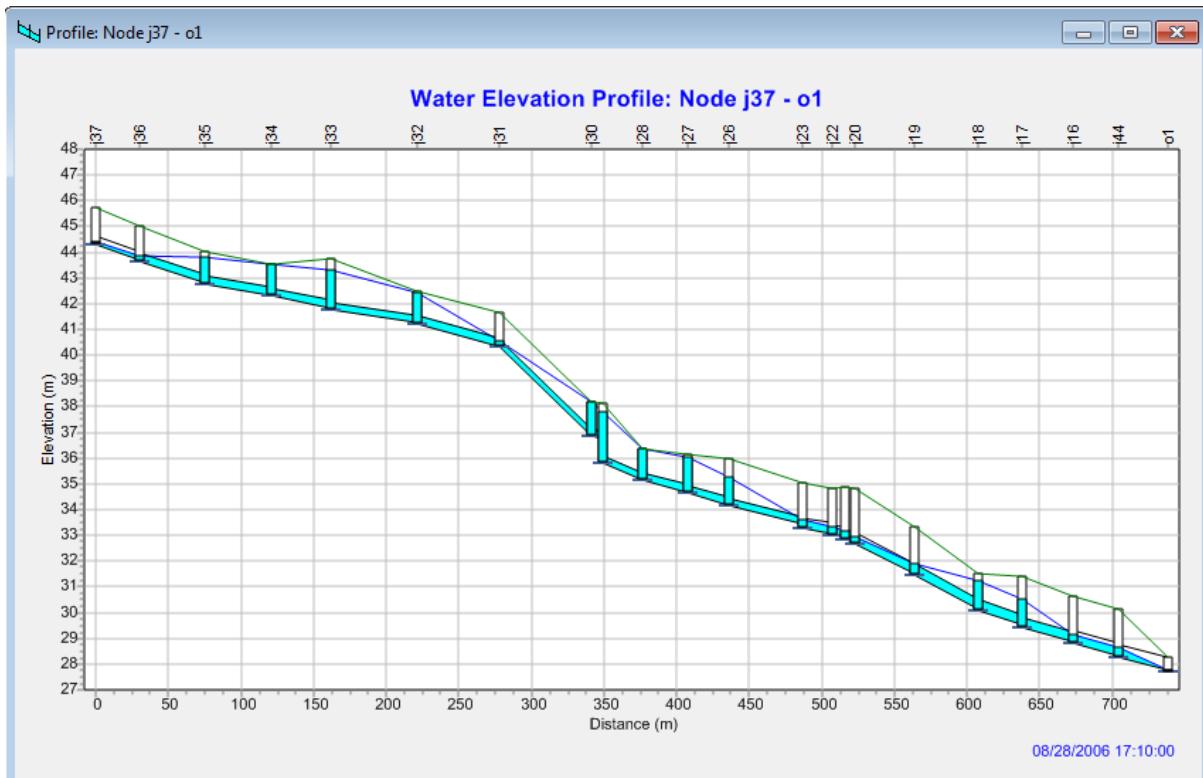
After the data table is created, select **Edit -> Copy to -> Clipboard** and paste the data to an Excel file.

Date	Time	Total Inflow (LPS)
06/01/2006	01:00:00	0.00
06/01/2006	02:00:00	0.00
06/01/2006	03:00:00	0.00
06/01/2006	04:00:00	0.00
06/01/2006	05:00:00	0.00
06/01/2006	06:00:00	0.00
06/01/2006	07:00:00	0.00
06/01/2006	08:00:00	0.00
06/01/2006	09:00:00	0.00
06/01/2006	10:00:00	0.00
06/01/2006	11:00:00	0.00
06/01/2006	12:00:00	0.00

CREATING GRAPHS

You can always create graphs from your data by copying it to Excel and by adding and editing graphs using the Excel's plotting tools. However, it is also possible to create time series plots in SWMM. For this, choose **Report -> Graph -> Time Series** from the Main Menu. It is also possible to create profile scatter plots or profile plots of the sewer system. Profile plots are particularly useful when illustrating node flooding (example of a profile plot in Figure 7). Instructions on how to utilize SWMM's graph tools see the SWMM's user manual (Rossman, 2015), Chapter 9.

Figure 7. A profile plot of the sewer system at the time of the worst flooding based on the results in Fig. 6. Instructions for creating a profile plot in the SWMM's user manual (Rossman, 2015), Section 9.5.



PART 2: MODELLING LOW IMPACT DEVELOPMENT (LID) SYSTEMS

Low Impact Development (LID) systems refer to small-scale decentralized urban runoff management units of which the primary purpose is to reduce runoff volumes, flow rates and pollutant loads by mimicking natural catchment processes. LID systems reduce runoff by decreasing the amount of impervious surfaces, by increasing infiltration and evaporation, and by delaying runoff before conveying it to the receiving water bodies or drainage systems. In SWMM, several LID options are available, including a bioretention cell, a rain garden, a green roof, a rain barrel, a permeable pavement, an infiltration trench, a vegetative swale and a rooftop disconnection.

Creating and simulating LID systems in SWMM includes three phases:

- [Phase 1: Create a scale-independent LID unit using the LID Editor \(Project -> Hydrology -> LID Controls\).](#)
- [Phase 2: Add a LID unit to a subcatchment with appropriate sizing \(select a subcatchment by clicking the Map Window or from the Project panel -> Hydrology -> Subcatchments -> select a subcatchment, select LID Controls from the Subcatchment Editor\).](#)
- [Phase 3: Run the LID model with rainfall data, interpret the runoff results.](#)

An example model file for the LID modelling, *Urban_hydrology_example_LID.inp*, can be downloaded from the MyCourses/Assignments-page.

DETAILS OF THE BIO-RETENTION CELL EXAMPLE

In SWMM, a typical bioretention cell is conceptualized by a number of horizontal layers (Figure 8). In the following, the bioretention cell is used as an example of how to add LID units to a SWMM model. Example parameterizations for [a green roof](#) and [a permeable pavement](#) are also included. For LID techniques not discussed here, example parameter values can be found in the SWMM's Water Quality Reference Manual (Rossman & Huber, 2016b). The bioretention cell is the most complex LID unit in SWMM in terms of its structure and sizing. Other LID units are more or less simplifications or modifications of the same basic components as included in a bioretention cell. For instance, LID units share similar features such as soil layers and storage layers with underdrains.

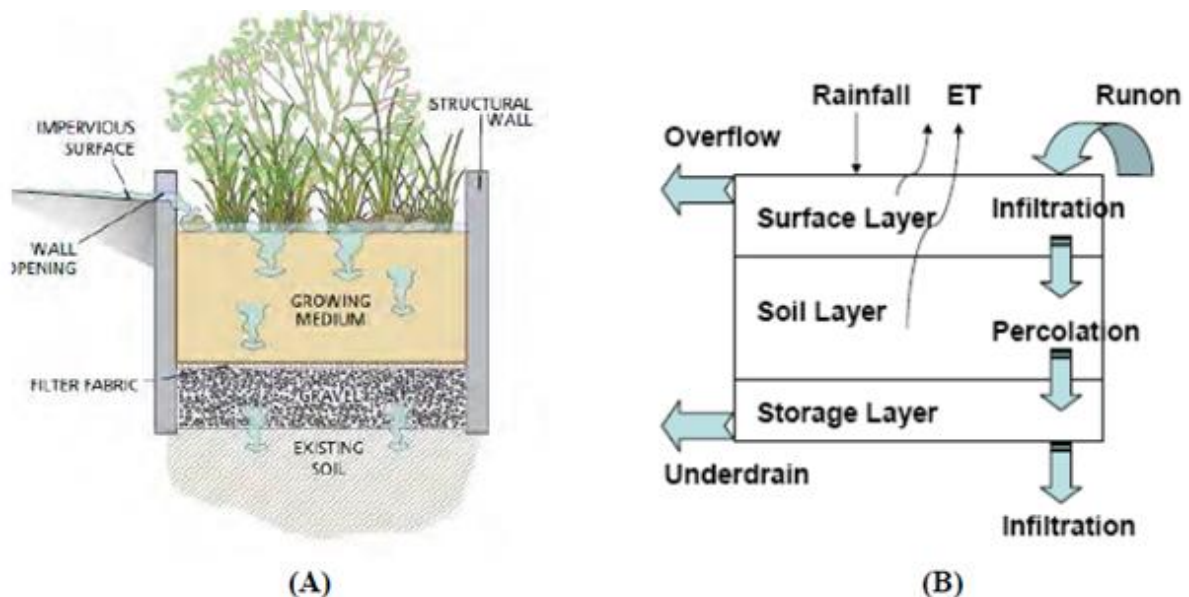
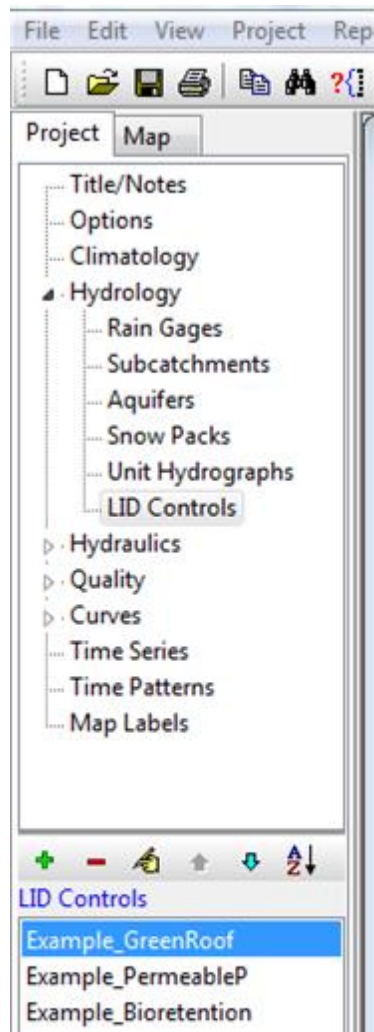


Figure 8. An illustration of a typical bioretention cell, adopted from the SWMM's Water Quality Reference Manual (Rossman & Huber, 2016b).

PHASE 1: USING THE LID EDITOR TO CREATE A LID UNIT (BIO-RETENTION CELL)

The first phase in LID design is to create scale-independent LID units.

Our example bioretention unit has a total depth of 1200 mm, consisting of a 700 mm soil layer with a berm height of 200 mm allowing some ponding to occur at the top of the structure. Underneath the soil layer there is a 300 mm gravel storage layer provided with an underdrain. The hydraulic conductivity of the underlying soil is rather moderate, 4.21 mm/h (set as loam), hence, an underdrain is used. It is noteworthy that in cold climatic conditions, the use of underdrain is always recommended in order to enhance wintertime operation.



From the *Project* panel:

→ select **Hydrology** -> **LID Controls**


If you want to add a new LID unit:

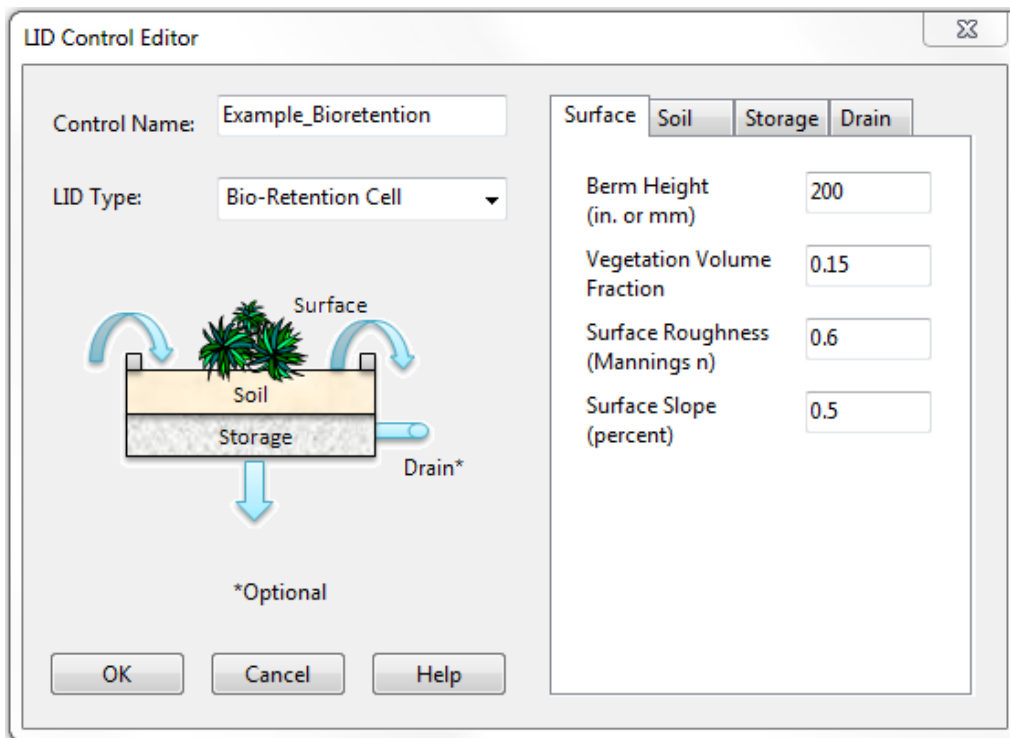
→ press **+** from *LID Controls* menu to add a new Object

in *LID Control Editor*, fill in a name for a new LID unit, select the LID type, and fill in the required parameter values. The name of the LID unit in the template file (*Urban_hydrology_example_LID.inp*) is *Example_Bioretention*.

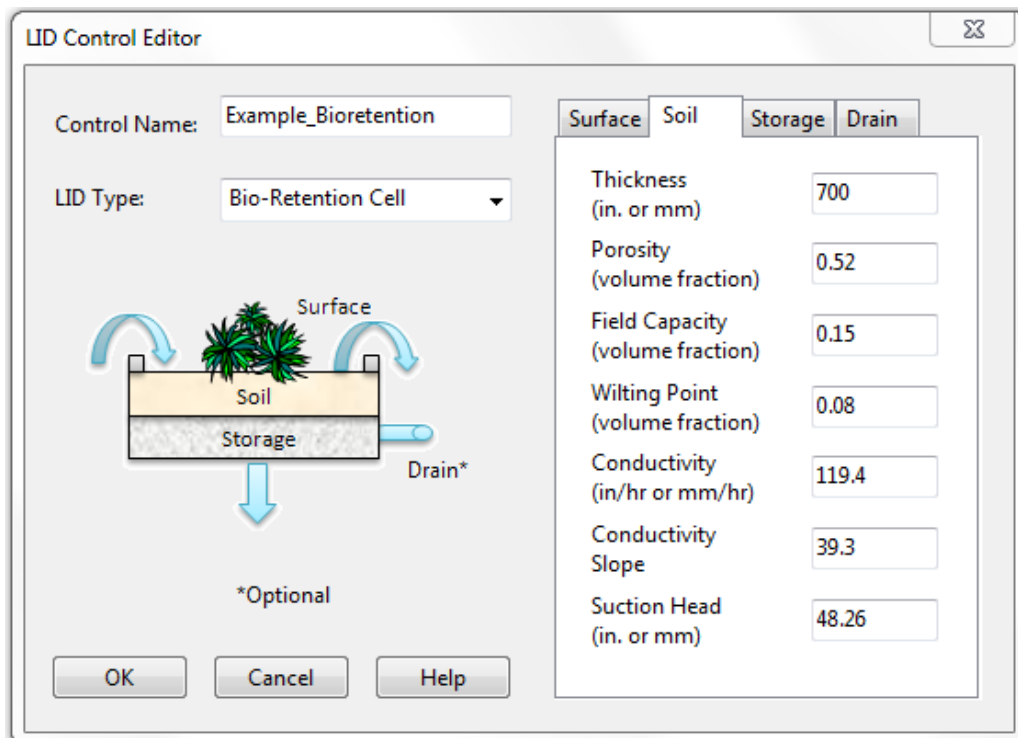
→ In *LID Control Editor*, parameter values are given separately for each LID layer on *Surface/Soil/Storage/Underdrain* -pages. Screen shots of the different *LID Control Editor* windows with example parameter values for a bioretention cell are shown on the following p. 17-18.

If you want to modify an existing LID unit:

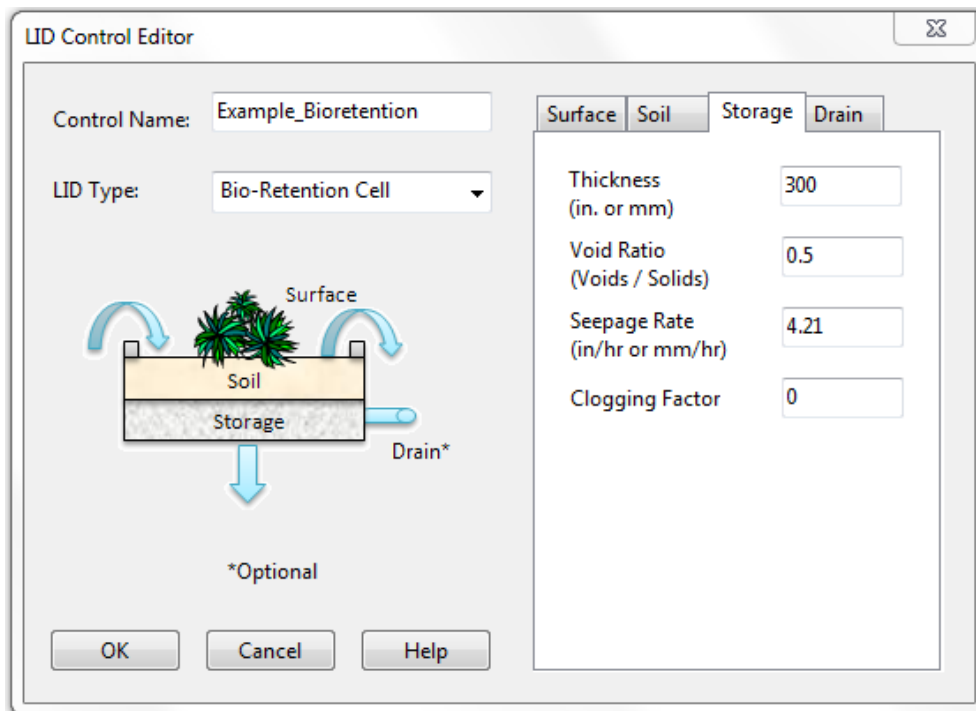
→ select the LID from the *LID Controls* list of existing LID units and press 



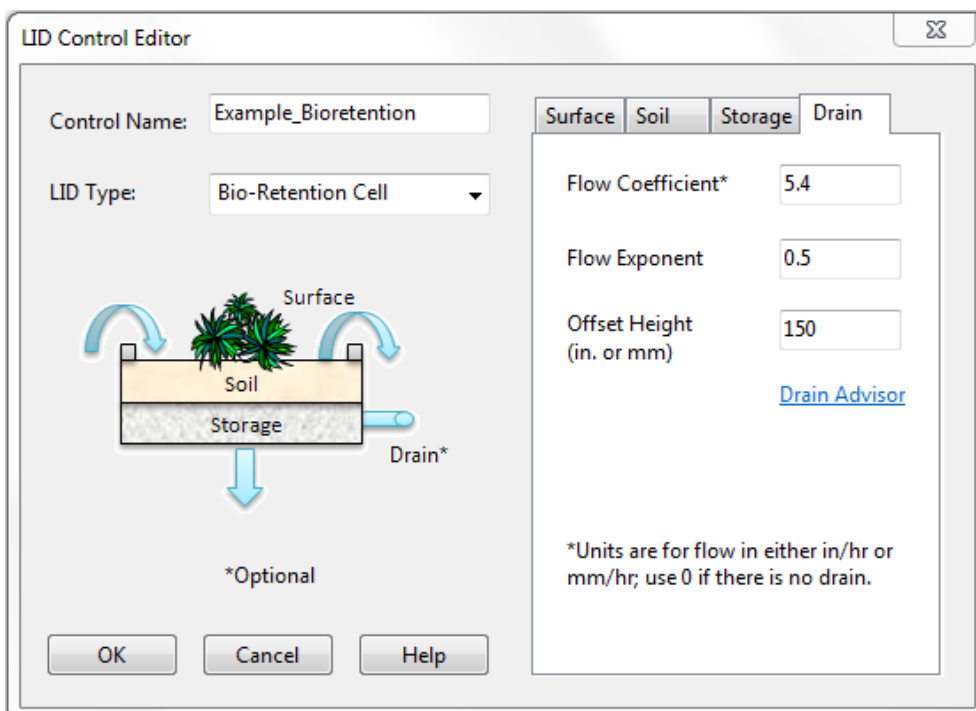
Vegetation is an essential part of a bioretention system, and in the current example it reduces the available space for ponding by 15% (**Vegetation Volume Fraction** 0.15).



The soil properties of the soil layer correspond to a typical engineered growth media for bioretention systems: 85% sand, 5% clay and 5% organic matter. Typical properties for this soil are given in Table 6-3 in the SWMM WQ manual: **Porosity** of 0.52, **Field Capacity** of 0.15, **Wilting Point** of 0.08, saturated hydraulic **Conductivity** of 119 mm/h, **Suction Head** of 48.3 mm/h.




Seepage rate corresponds to the hydraulic conductivity of the surrounding soil. If there is an impermeable liner at the bottom of the structure to prevent infiltration to the native soil (sometimes needed e.g. to prevent the pollution of the surrounding soil and groundwater), set **Seepage Rate** as 0.

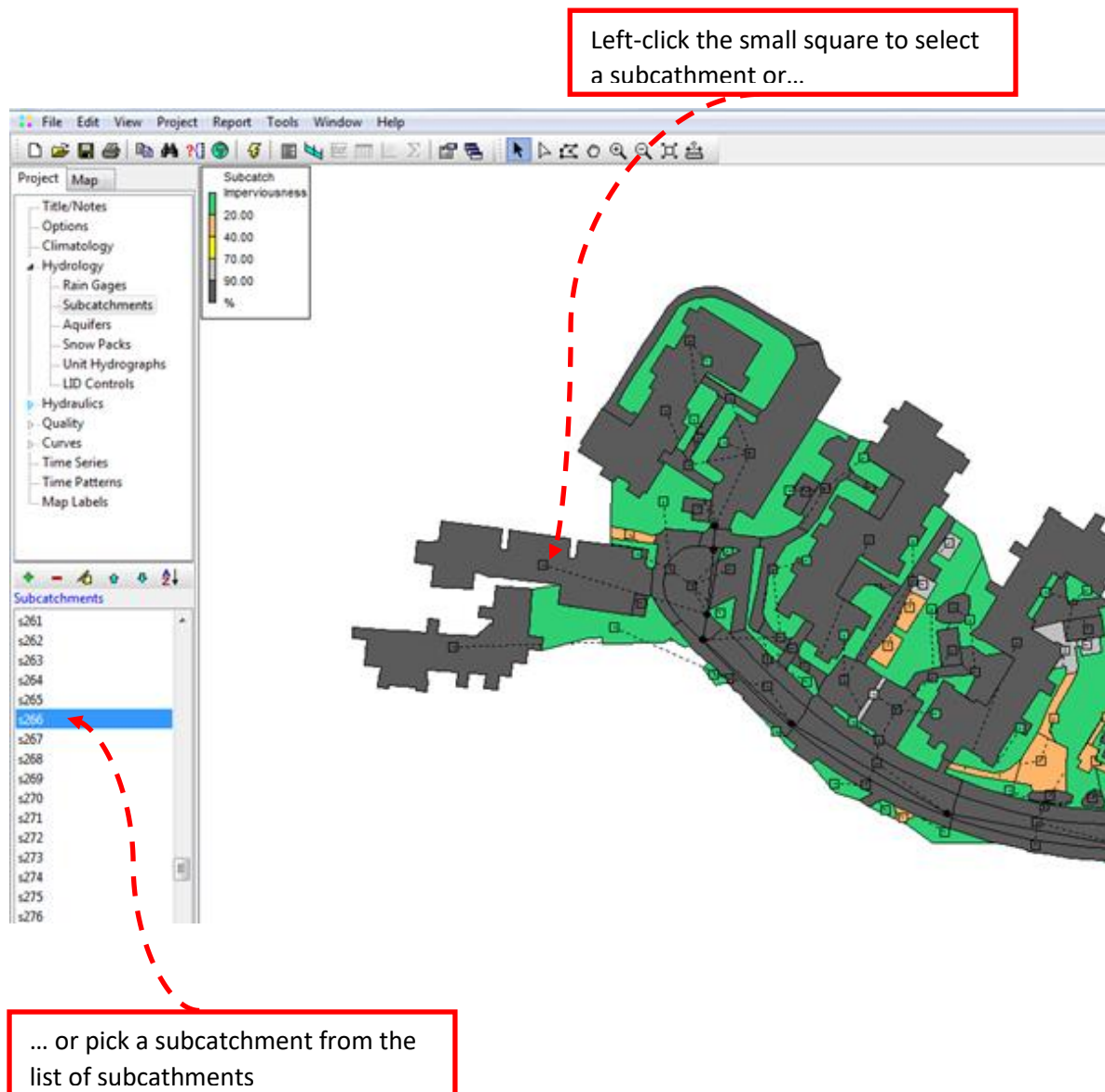


The simplest method of estimating the drain properties is to set **Flow Exponent** to 0.5 and to use the equation $2D^{0.5}/T$ to determine **Flow Coefficient**. D is the distance from the drain to the surface plus ponding depth (in mm) and T is the time in hours to drain (12 h). Hence, the flow coefficient for the current example is $2 * (200 \text{ mm} + 700 \text{ mm} + 300 \text{ mm} - 150 \text{ mm})^{0.5} / 12 \text{ h} = 5.4 \text{ mm/h}$. We can provide additional storage space at the bottom of the storage layer by adjusting the drain's offset height. With 0 mm offset height, the underdrain is located at the bottom of the storage layer. For more information about the drain properties, click the *Drain Advisor* link.

PHASE 2: ADDING A LID UNIT TO A SUBCATCHMENT (BIO-RETENTION CELL)

After creating scale-independent LID units, the next phase is to assign these units to a subcatchment with an appropriate sizing.

STEP 1. Left-click a subcatchment's symbol (a small square) on the map window or select the subcatchment's name from the list of subcatchments from the *Subcatchments* menu (*Subcatchment s266*). Press  to open the *Subcatchment Editor*.



STEP 2. Left-click the **LID Controls** value column to open the **LID Controls for Subcatchment** editor.

Property	Value
Name	s266
X-Coordinate	378475.153
Y-Coordinate	6678938.684
Description	41
Tag	parking
Rain Gage	r1
Outlet	j40
Area	0.07678
Width	13.03512
% Slope	3.25203
% Imperv	95
N-Imperv	0.014
N-Perv	0.014
Dstore-Imperv	0.5
Dstore-Perv	0.5
%Zero-Imperv	0
Subarea Routing	OUTLET
Percent Routed	100
Infiltration	GREEN_AMPT
Groundwater	NO
Snow Pack	
LID Controls	1 ...
Land Uses	0
Initial Buildup	NONE
Curb Length	58.9

LID controls (click to edit)

STEP 3. Left-click **Add** to open the **LID Usage Editor**.

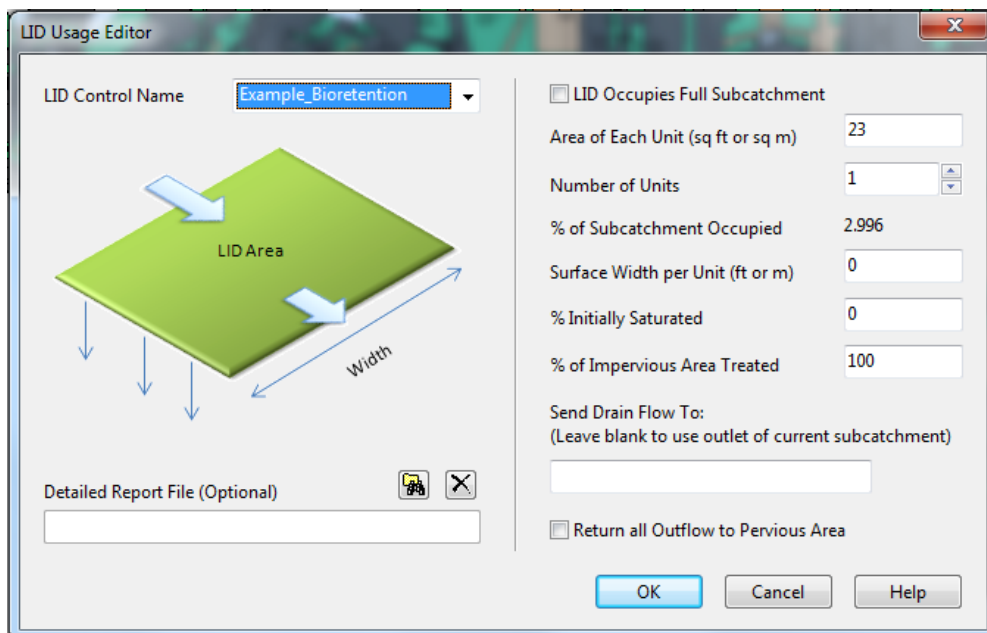
Control Name	LID Type	% of Area	% From Imperv	Report File

Buttons: Add, Edit, Delete, OK, Cancel, Help

STEP 4. Select the predetermined LID unit from the *LID Control Name* list.

STEP 5. Set the size of LID unit using the *LID Usage Editor*:

- ➔ **Area of Each Unit:** Add the surface area of the LID unit in m². SWMM will automatically update *% of Subcatchment Occupied*. For a bioretention cell, surface area of at least 2% of the total catchment area is recommended. In our example, 23 m² bioretention cell covers approximately 3% of the total catchment area.
- ➔ For a permeable pavement or a green roof, **LID Occupies Full Subcatchment** can be selected (if the LID covers the subcatchment area completely): in this case, SWMM will automatically set the area of the unit equal to the total subcatchment area.
- ➔ Set **% of Impervious Area Treated** to 100%, because the bioretention cell is going to capture all runoff from the non-LID area of the subcatchment that is completely paved with asphalt.
- ➔ In the current example, default values (0) for other parameters can be used. Explanations for all parameters in the *LID Usage Editor* are given in the SWMM's User Manual on p. 252-253 (Rossman, 2015).



As default, any surface overflow (i.e. runoff exceeding the capacity of the LID unit) or underdrain flow from the LID unit is sent to the subcatchment's outlet destination. By selecting *Return all Outflow to Pervious Area*, all runoff from the LID unit is conveyed to the pervious fraction of the subcatchment (might be useful in the case of rain barrels).

How to determine the capacity of the bioretention cell?

In the current example, the area of the bioretention cell, 23 m², comprises 3% of the total area of the parking lot (*Subcatchment s266*). Therefore, its Capture Ratio is $(1-0.03)/0.03=32.3$ (the impervious area that contributes runoff to the LID structure divided by the area of the LID itself). The total storage volume contained within the bioretention cell is $(1-0.15)*200$ mm (the ponding storage on top minus the vegetation fraction) plus $(0.52-0.08)*700$ mm (soil pore volume) plus $0.5*300$ mm (gravel storage volume) for a total of 628 mm. Considering the bioretention cell's capture ratio and its surface area, the capacity of the LID unit is $628 \text{ mm} / (32.3+1) = 18.9$ mm for the total catchment area. Hence the system should be able to capture storms up to a maximum depth of 18.9 mm.

PHASE 3: RUNNING A LID MODEL AND INTERPRETING THE RESULTS

➤ INTERPRETING LID RESULTS FROM A LONG-TERM CONTINUOUS SIMULATION

To run a model, set the rainfall data source (a file or a time series), the climate data file (2005 or 2006) and the simulation options as described earlier in [the Part 1 of this document](#). Also the results are obtained using the same tools [as earlier](#) (select *Report* from the Main Menu). In the following, we will take a look at the results for all LID units located in the template file: [the bioretention cell](#) at a parking lot (Subcatchment s266), [a permeable pavement](#) at a parking lot (Subcatchment 265) and [a green roof](#) in Subcatchment s113. The locations of the LID units are illustrated in Figure 9 using the [LID Usage theme](#). The LID subcatchments are directly connected to the sewer system: the junction j40 is the closest node in the sewer system that collects runoff from all of these subcatchments.

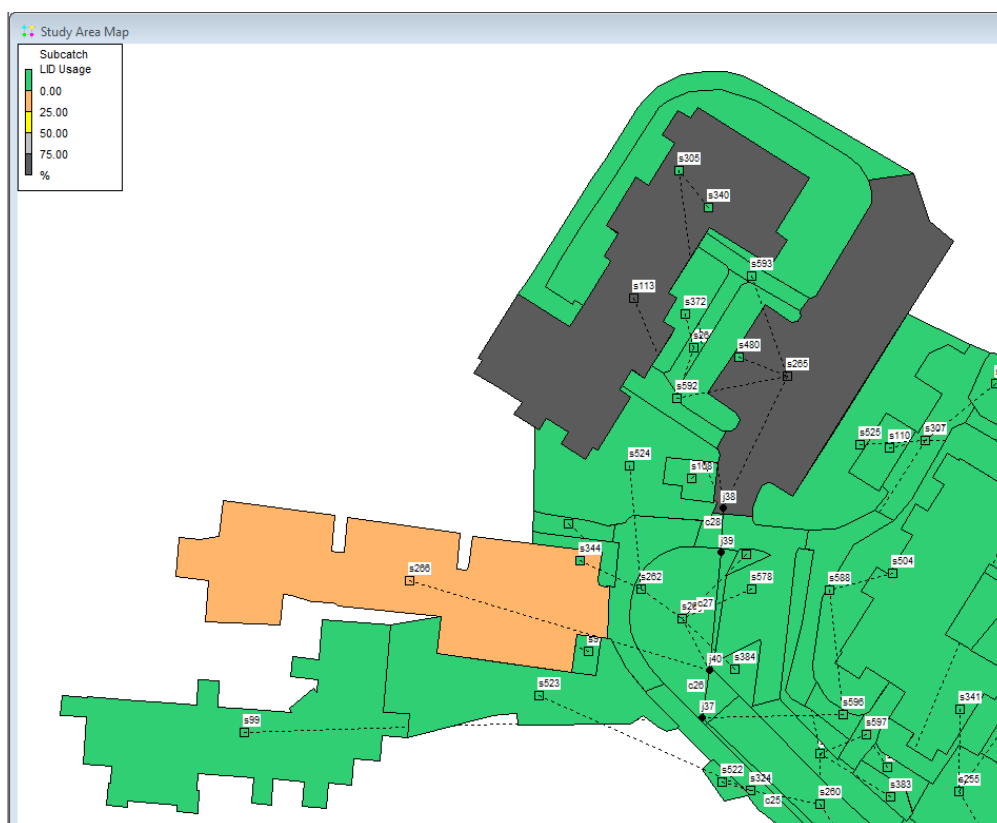


Figure 9. The locations of the LID units when using the LID Usage map theme (themes can be selected from [the Map panel](#)). The grey areas show the locations of the green roof and permeable pavement, because these LIDs cover the whole subcatchment area. The subcatchment with a bioretention cell is orange, because the bioretention cell covers only 3% of the subcatchment area. The dotted lines show the connections between the subcatchments and the sewer nodes.

After running the model using the rainfall data of the summer 2006 (*storms2006.dat*), the water balance components for the LID subcatchments can be seen from the Summary Report (select **Report -> Summary**). Based on the summary results, the subcatchment s265 produced no runoff during the three-month period because of the permeable pavement (Figure 10). In fact, it lost 60.17 mm as evaporation. The amount of evaporation exceeds the amount of precipitation (52.4 mm), because the subcatchment received 8.5 mm of surface runoff from neighbouring subcatchments (*Total Runon*). The subcatchment s266 with a bioretention cell produces 1.6 mm of runoff, which is still only 3% of the total precipitation. For comparison, the subcatchment summary reports for the template file without LID units were shown earlier in Figure 5: without LID units, the total runoff for the subcatchments S265 and s266 were 41.0 mm and 33.7 mm, respectively.

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10 ⁶ ltr	Peak Runoff LPS	Runoff Coeff
s265	52.40	8.47	60.17	0.00	0.00	0.00	0.00	0.000
s266	52.40	0.86	27.81	17.59	1.57	0.00	0.29	0.030

Figure 10. An extract of the summary results (Report -> Summary) for subcatchment runoff (the template file Urban_hydrology_example_LID.inp) when using the 2-min rainfall data for the summer 2006.

The summary results can also be obtained for a single LID structure by selecting **LID Performance** from the Topic list in the *Summary Results* window (Figure 11). In Figure 11, the total inflow equals the precipitation amount only for the green roof, which receives only the rainfall falling on the roof surface. Obviously, no infiltration can occur from the green roof (unless the roof leaks), therefore it can only reduce runoff through evapotranspiration. The total inflow is the largest for the bioretention cell, because it receives runoff from a much larger area than its own surface area. None of the LID units produced surface outflow showing that the capacity of the LID systems was large enough to capture all rainfall and runoff input during the summer 2006 conditions. Only the bioretention cell produced runoff through its underdrain to the sewer system.

The chosen structure of the LID unit may have significant impacts on the simulation results. Figure 12 shows how the results would change if the permeable pavement had no soil layer on top of the storage layer (the depth of the soil layer were set as 0 mm). In this case, the permeable pavement located in the subcatchment s265 would not produce any runoff to the sewer system, however, most runoff was reduced via infiltration and not through evaporation as was shown in Figure 11.

Subcatchment	LID Control	Total Inflow mm	Evap Loss mm	Infil Loss mm	Surface Outflow mm	Drain Outflow mm	Initial Storage mm	Final Storage mm	Continuity Error %
s113	Example_GreenRoof	52.40	51.83	0.00	0.00	0.00	2.00	2.57	-0.00
s265	Example_PermeableP	60.87	60.17	0.00	0.00	0.00	20.00	20.70	-0.00
s266	Example_Bioretention	1143.51	384.50	501.91	0.00	51.41	56.00	261.72	-0.00


Figure 11. The summary results for LID units alone for the summer 2006.

Subcatchment	LID Control	Total Inflow mm	Evap Loss mm	Infil Loss mm	Surface Outflow mm	Drain Outflow mm	Initial Storage mm	Final Storage mm	Continuity Error %
s113	Example_GreenRoof	52.40	51.83	0.00	0.00	0.00	2.00	2.57	-0.00
s265	Example_PermeableP	60.87	1.13	59.73	0.00	0.00	0.00	0.00	-0.00
s266	Example_Bioretention	1143.51	384.50	501.91	0.00	51.41	56.00	261.72	-0.00

Figure 12. The LID-specific summary results for permeable pavement without soil layer.

➤ INTERPRETING LID RESULTS FROM AN EVENT-SCALE DESIGN STORM SIMULATION

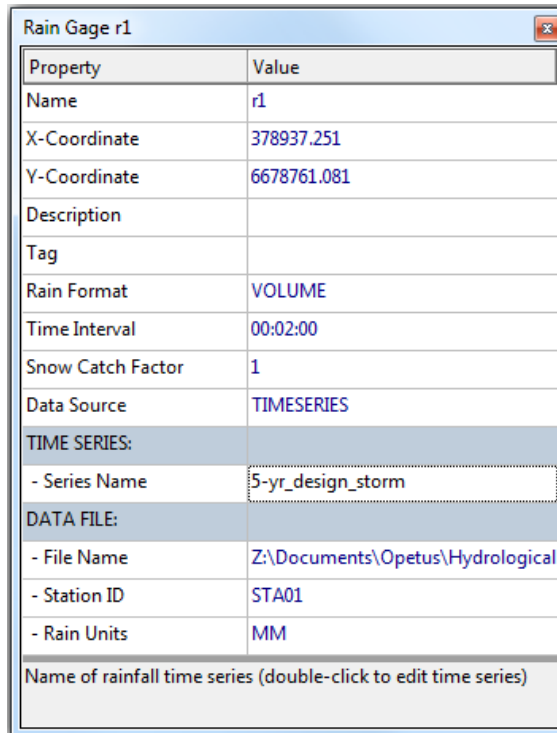
So far the examples of the results have only dealt with the long-term continuous simulations. However, comparisons using the design storm time series are important as the drainage design is often based on these events alone.


To run a simulation with a time series, change the source of rainfall data as was described in [the Part 1 of this document](#): from the *Project panel*, select **Hydrology -> Rain Gages** and press  to open the **Rain Gage Editor**.


Check the following settings:

- **Rain Format:** *VOLUME*
- **Time Interval:** *00:02:00*
- **Data Source:** *TIMESERIES*.
- **Series Name:** in the Figure on the right, once in every 5-years occurring design storm (*5-yr_design_storm*) is selected.

Close the window.



Before running a simulation, set the simulation time period using the **Simulation Options Editor** (see the figures below): from the **Project panel**, select **Options -> Date** and press . Set the duration of the analysis by changing the **End Analysis on** date to 06/02/2006. Also check the **Time Steps** page: set *2 minutes* as the **Reporting** time step and *5 seconds* as **Wet Weather** and **Routing** time steps.

Press *ok* to close the dialog. Run the model by selecting  symbol from the Main Toolbar.

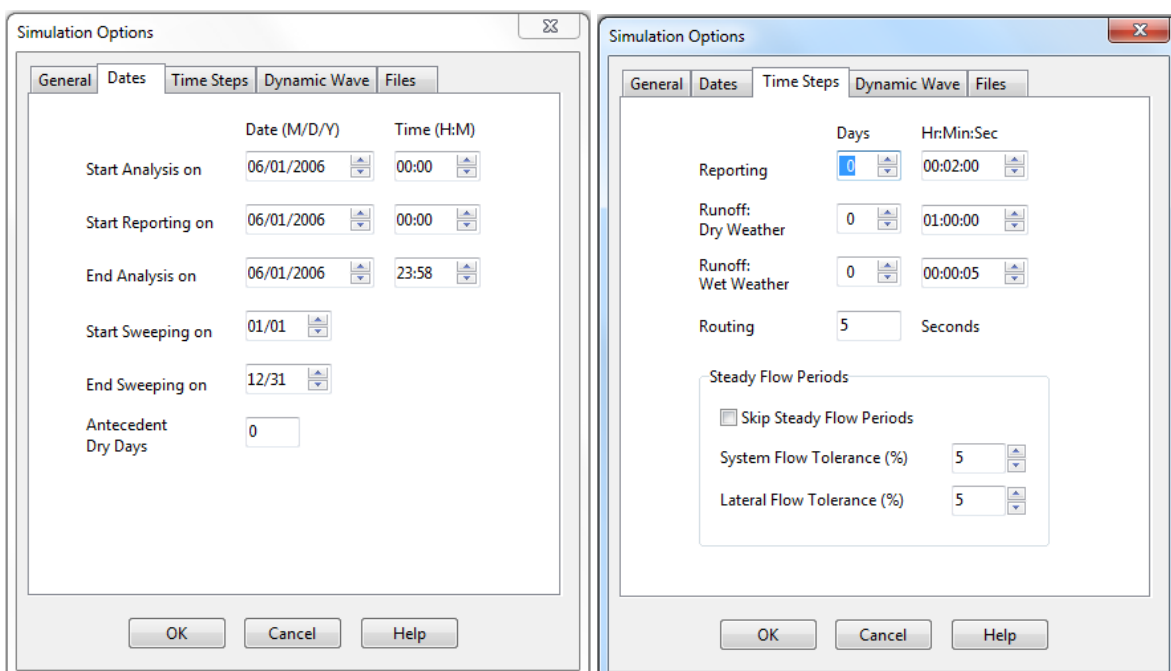


Figure 13 and Figure 14 illustrate the Summary results reports (select **Report** -> **Summary** from the Main Menu) for flow rates (*Node Inflow* selected as topic that reports flow rates in l/s for a particular node) in the junction *j40* that collects runoff from all of the three LID units in the LID model. The peak flow rate in the junction *j40* is 12.1 l/s for the LID model (Figure 13) whereas the peak flow rate for the traditional catchment without LID is more than double, 47.8 l/s (Figure 14). Hence, the LID units enabled a notable reduction in the peak flow rate during the 5-year design storm event. However, because the LID units only cover a rather small area in comparison to the total catchment area, there is no difference in the peak flow rate (436.5 l/s) at the catchment outlet (Node *o1*) with or without LID units.

Node	Type	Maximum Lateral Inflow LPS	Maximum Total Inflow LPS	Day of Maximum Inflow	Hour of Maximum Inflow	Lateral Inflow Volume 10 ⁶ ltr	Total Inflow Volume 10 ⁶ ltr	Flow Balance Error Percent
j40	JUNCTION	9.17	12.10	0	00:12	0.00518	0.0068	0.719
j41	JUNCTION	0.00	38.99	0	00:07	0	0.00814	-0.906
j42	JUNCTION	0.00	88.05	0	00:07	0	0.0216	0.949
j44	JUNCTION	10.94	438.77	0	00:12	0.00621	0.388	0.004
o1	OUTFALL	0.00	436.51	0	00:12	0	0.388	0.000

Figure 13. An extract of the Summary Results for Node Inflow when using 5-year design storm time series as rainfall data in the LID model.

Node	Type	Maximum Lateral Inflow LPS	Maximum Total Inflow LPS	Day of Maximum Inflow	Hour of Maximum Inflow	Lateral Inflow Volume 10 ⁶ ltr	Total Inflow Volume 10 ⁶ ltr	Flow Balance Error Percent
j40	JUNCTION	20.72	47.76	0	00:12	0.0115	0.0268	0.219
j41	JUNCTION	0.00	41.42	0	00:07	0	0.00814	-1.092
j42	JUNCTION	0.00	87.83	0	00:07	0	0.0215	0.604
j44	JUNCTION	10.94	438.83	0	00:12	0.00621	0.392	0.003
o1	OUTFALL	0.00	436.57	0	00:12	0	0.392	0.000

Figure 14. An extract of the Summary Results for Node Inflow when using 5-year design storm time series as rainfall data in the template model without LIDs..

In Figure 15 and Figure 16, time series plots for the 5-year design storm are shown for the junction *j40*. To obtain these graphs in SWMM, select **Report** -> **Graph** -> **Time Series** from the Main Menu, add *Node j40* as the Time series and *Total Inflow* as the variable.

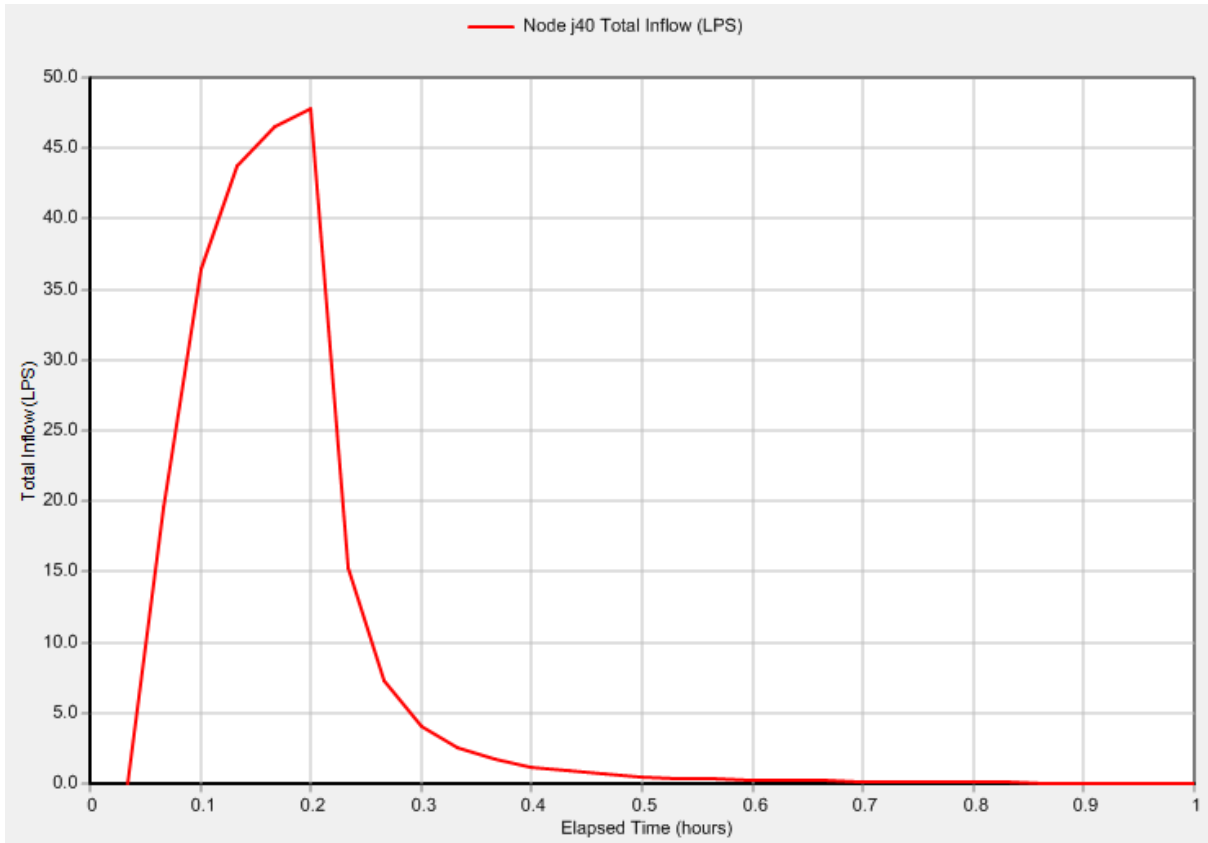


Figure 15. A time series plot for the 5-year design storm at the junction j40 without LID units.

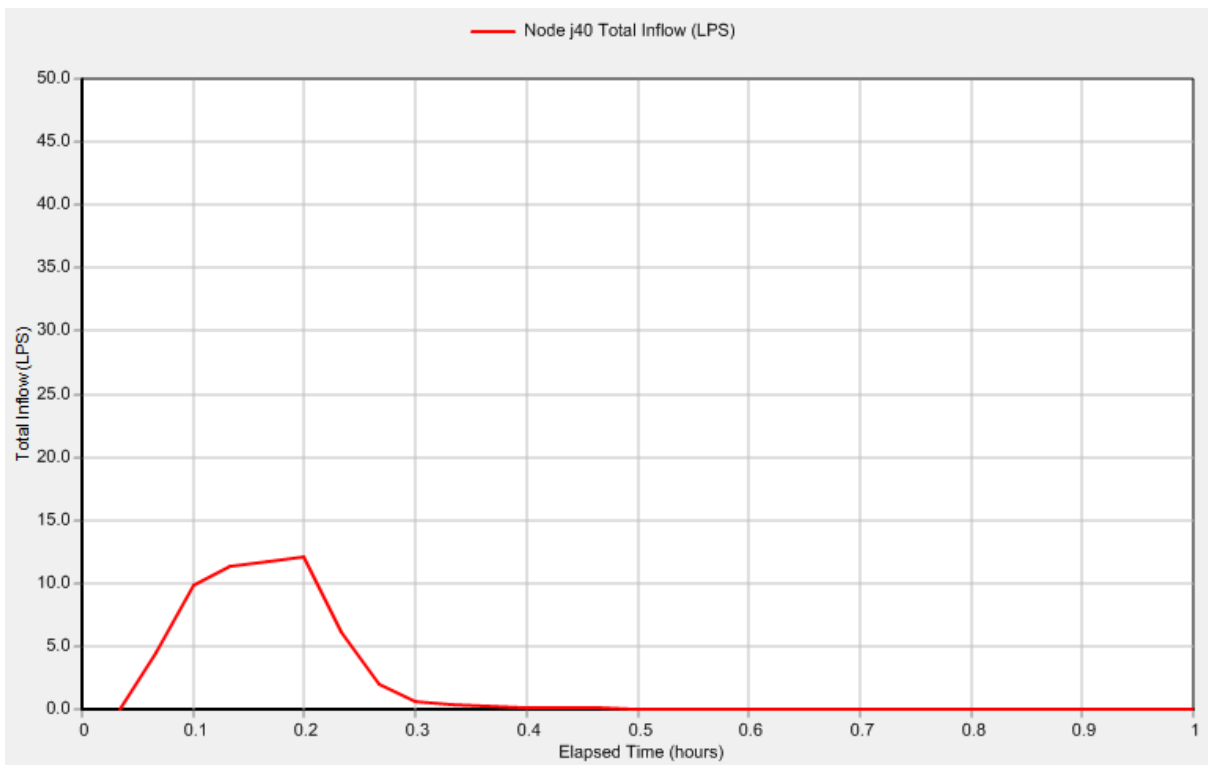


Figure 16. A time series plot for the 5-year design storm at the junction j40 with LID units.

EXAMPLE PARAMETER VALUES FOR SELECTED LID UNITS

➤ GREEN ROOF

Template file: *Urban_hydrology_example_LID.inp*

LID object name in the LID Editor: *Example_GreenRoof*

Location: *Subcatchment s113*

Parameter values for green roof were adopted from a Finnish green roof study (Krebs et al., 2015):
Krebs, G., Kuoppamäki, K., Kokkonen, T., Koivusalo, H. 2016. Simulation of green roof test bed runoff. Hydrological Processes, 30, 250-262.

LID Control Editor

Control Name:

LID Type:

Surface Soil Drainage Mat

Berm Height (in. or mm)

Vegetation Volume Fraction

Surface Roughness (Mannings n)

Surface Slope (percent)

OK Cancel Help

LID Control Editor

Control Name:

LID Type:

Surface Soil Drainage Mat

Thickness (in. or mm)

Porosity (volume fraction)

Field Capacity (volume fraction)

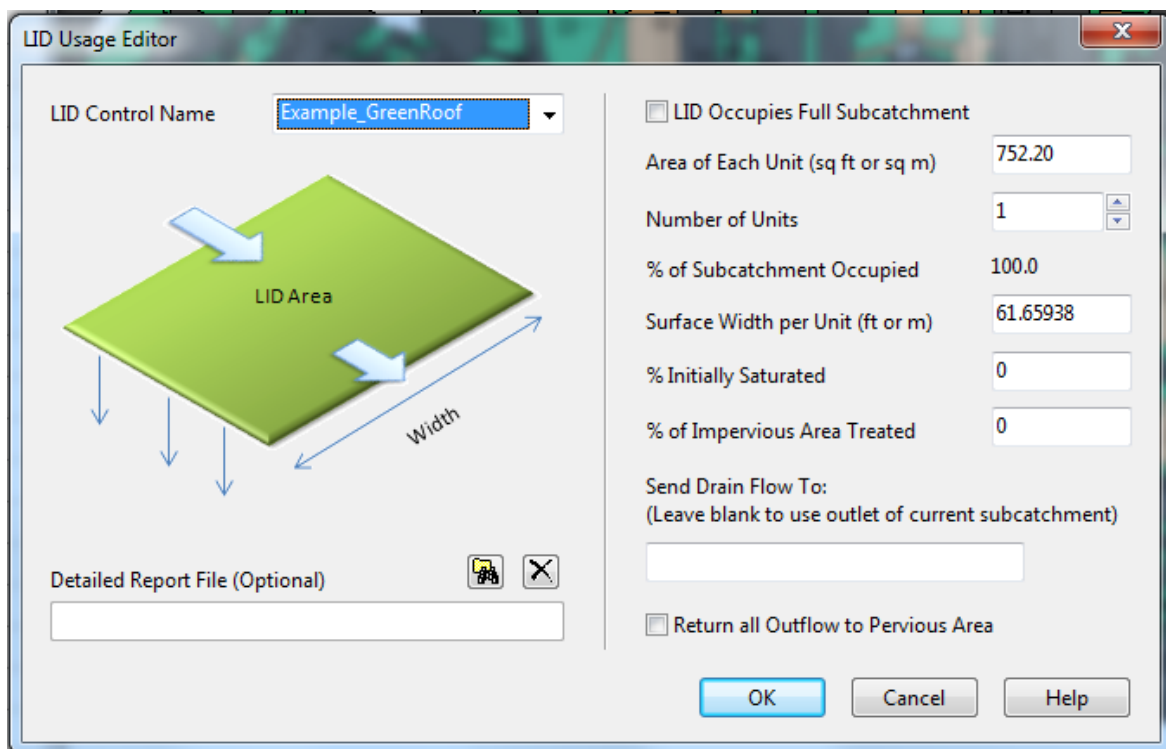
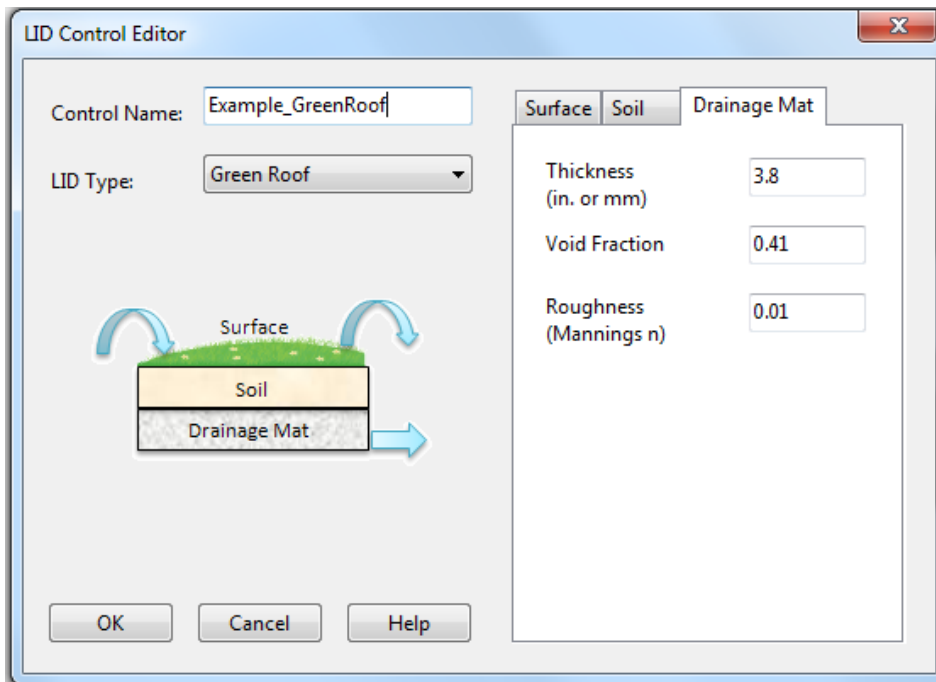
Wilting Point (volume fraction)

Conductivity (in/hr or mm/hr)

Conductivity Slope

Suction Head (in. or mm)

OK Cancel Help



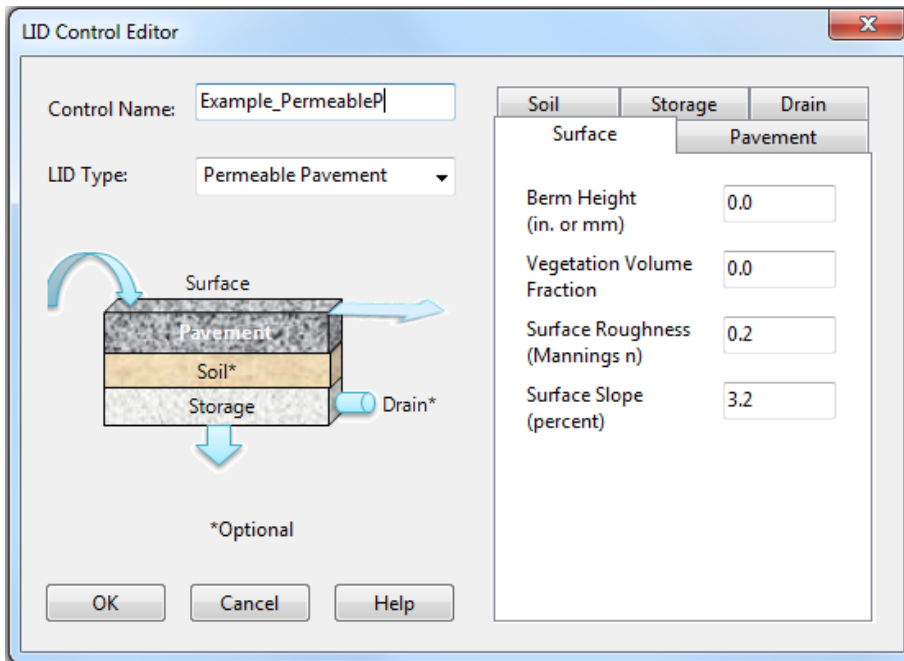
In the template file *Urban_hydrology_example_LID.inp*, the LID unit *Example_GreenRoof* is assigned to *Subcatchment s113*. When using *LID Usage Editor*, select **LID Occupies Full Subcatchment** (the green roof covers the whole roof) and adjust **Surface Width per Unit** equal to the **Width** value of the subcatchment (in this case the width of *Subcatchment s113*): you can check it by viewing the [Subcatchment Editor window](#), the 9th row from the top (*Width*). The *Width* applies to LID units that use overland flow to convey any excess surface runoff away from the LID unit (green roofs, permeable pavements, infiltration trenches and swales). It can be set 0 for other LID units that simply spill excess runoff over their berms (bioretention cells, rain gardens, rain barrels).

➤ PERMEABLE PAVEMENT

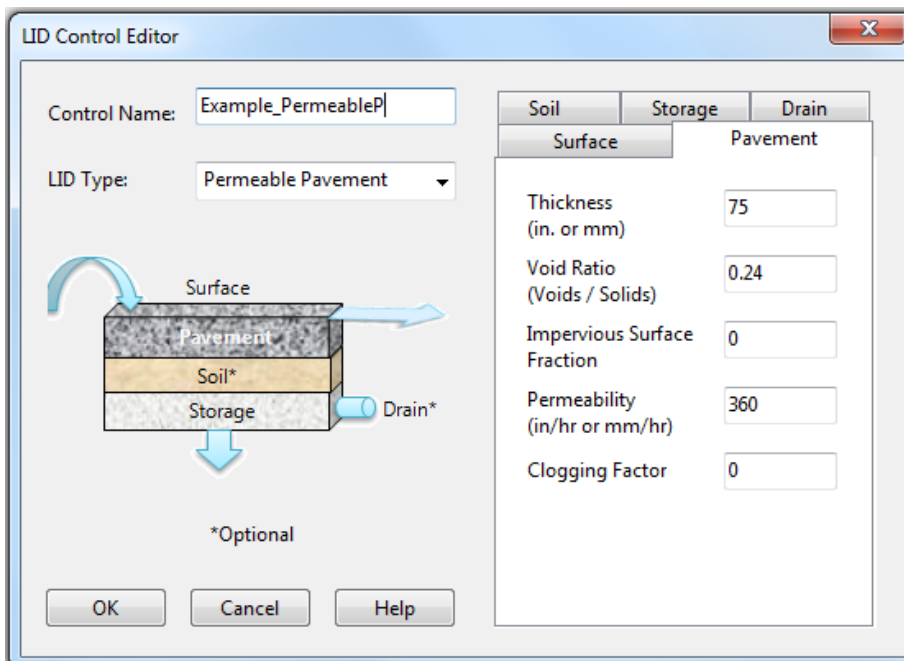
Model file: *Urban_hydrology_example_LID.inp*

LID object name in the LID Editor: *Example_PermeableP*

Location: *Subcatchment s265*

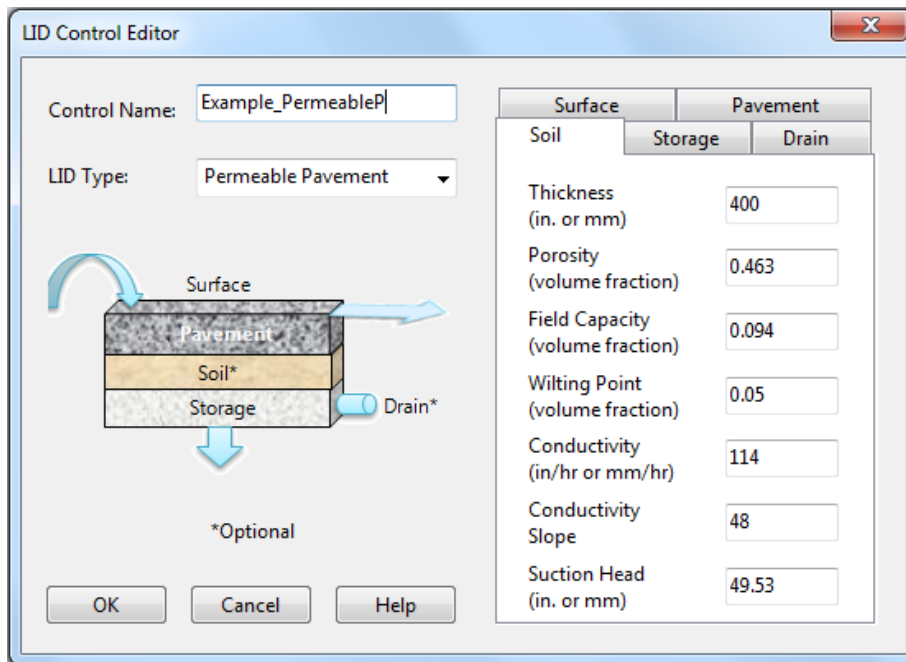


Set **Surface Slope** equal to the slope of the subcatchment. You can check it by viewing the [Subcatchment Editor window](#), the 10th row from the top (**% Slope**).

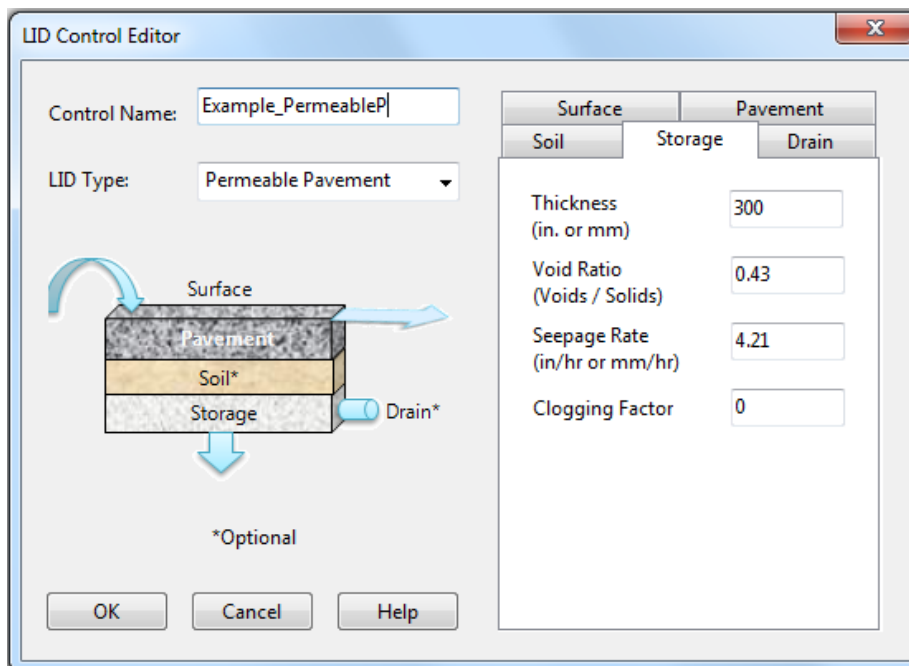


Note: It is useful to test different values for the pavement **permeability**. The permeability (360 mm/h) is a rather conservative value for permeability and much less than the values often reported in the SWMM manuals and literature abroad. In Finland, a design value of only 72 mm/h has been proposed (Kling, et al. 2015), which according to literature presents a clogged state.

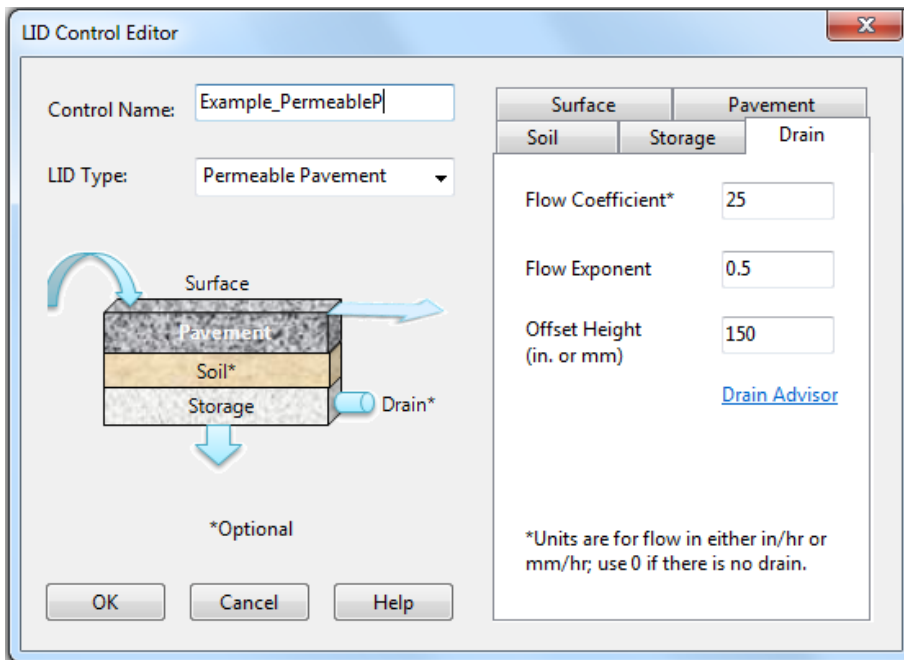
(Kling, T., Holt, E., Kivikoski, H., Korkealaakso, J., Kuosa, H., Loimula, K., Niemeläinen, E., Törnqvist J. 2015. Vettä läpäisevät päällysteet. Käsikirja suunnitteluun, rakentamiseen ja ylläpitoon, in Finnish).



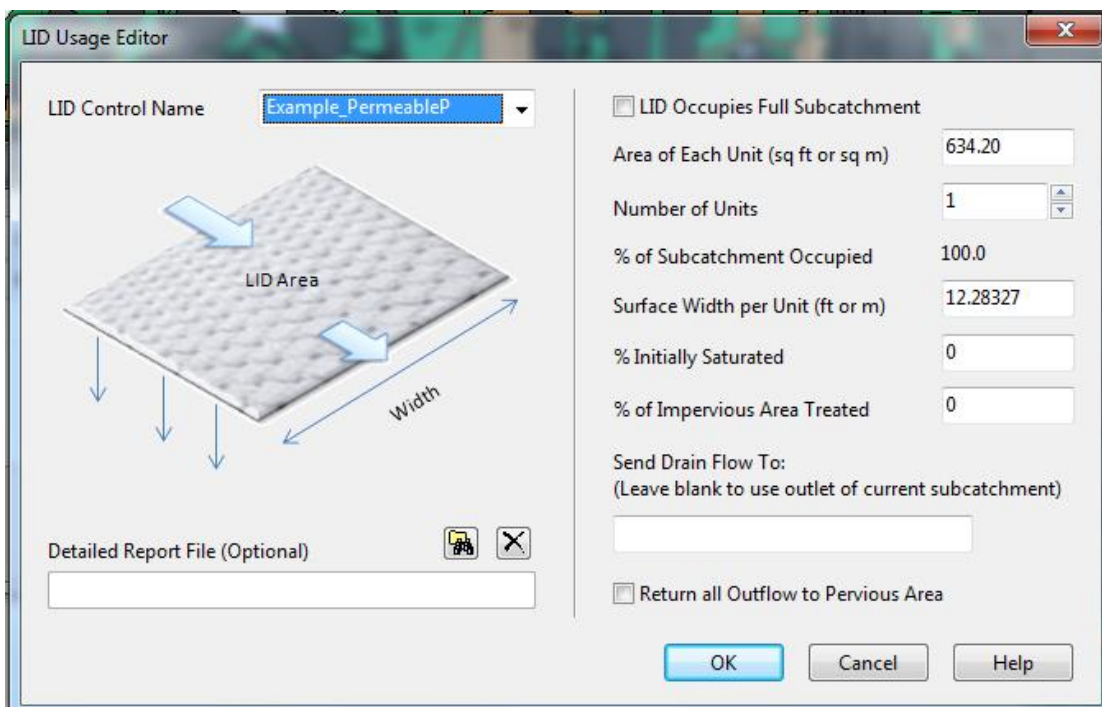
In permeable pavement, the **Soil** layer is optional. In the current example, a soil layer with a depth of 400 mm was included in order to promote better pollutant retention. **Thickness** of the soil layer can be set as 0 mm to ignore it. Here the soil layer parameters represent sand, adopted from the SWMM's Hydrology Reference Manual (Rossman and Huber, 2016a), p.151.



If the clogging of the system over time is included, instructions on how to determine the clogging factor are given in the SWMM 5.1 User's Manual on p. 247 (Rossman, 2015). Set **Seepage Rate** equal to the conductivity of the surrounding soil, if there is no need for preventing infiltration from the system to the soil below.



The drain properties were earlier described for bioretention cell on p. 18 and the same rules apply for any **Drain** layer. For permeable pavement in the current example, a time to drain of 2 h was used. Additional storage space at the bottom of the storage layer was provided with the 150 mm **Offset Height**. For more information about the drain properties, click the *Drain Advisor* link in the *LID Control Editor*.



In the template file *Urban_hydrology_example_LID.inp*, the LID unit *Example_PermeableP* is assigned to *Subcatchment s265*. When using the *LID Usage Editor*, select **LID Occupies Full Subcatchment** (the permeable pavement covers the whole asphalt surface) and adjust **Surface Width per Unit** equal to **Width** value of the subcatchment (in this case the width of *Subcatchment s265*). This parameter applies to LID units that use overland flow to convey any excess surface runoff off of the LID unit (green roofs, permeable pavements, infiltration trenches and swales). It can be set 0 for other LID units that simply spill excess runoff over their berms (bioretention cells, rain gardens, rain barrels).

PART 3: CHECK LIST FOR RUNNING A SIMULATION

STEP 1: Investigate the catchment area for suitable locations for different types of LIDs: green roofs for roofs, bioretention cells and permeable pavements for asphalt surfaces. You can try other LID techniques as well.

STEP 2: Create a LID unit using the [LID Editor](#).

STEP 3: Add the LID unit to a subcatchment using the [LID Usage Editor](#).

STEP 4: Add rainfall data: a data file or a time series, time interval 2 or 10 minutes?

STEP 5: Check the climate data file, the year 2005 or 2006?

STEP 6: Check the simulation options: the dates of the simulation period (3 months for long-term simulation, 2 days for a design storm), the time steps (Reporting, Wet Weather, Routing).

STEP 7: Run a simulation.

STEP 8: Interpret the results.