E²STORMED Decision Support Tool Guidelines

Version 1.2.1

E²STORMED PROJECT
Improvement of energy efficiency in the water cycle by the use of innovative storm water management in smart Mediterranean cities
www.iiama.upv.es/iiama/en/research/european-projects.html

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

L'Europe en Méditerranée
Europe in the Mediterranean

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1. E²STORMED DECISION SUPPORT TOOL: QUICK GUIDE

1.1. INTRODUCTION

The E²STORMED Decision Support Tool is software which supports the decision-making process in urban stormwater management. Using this tool, the advantages and disadvantages of different drainage scenarios can be compared and different decision criteria can be defined to choose the best option for urban stormwater management. The E²STORMED DST encourages making decisions based not only on financial criteria, but also on energy, environmental and social criteria.

This software has been developed by the Polytechnic University of Valencia (Spain) with the assistance of the University of Abertay Dundee within the E²STORMED project: *Improvement of energy efficiency in the water cycle by the use of innovative storm water management in smart Mediterranean cities*. This project aims to improve energy efficiency in the urban water cycle and in buildings by promoting the use of innovative storm water solutions such as Sustainable Drainage Systems (SuDS) in Mediterranean cities.

The main objective of this project is to develop this Decision-Support Tool to encourage local authorities to take better informed decisions. This tool can be used to compare financial, energy and environmental criteria to improve the urban stormwater management.

E²STORMED project is funded by the MED Programme of the European Union and co-financed by the European Regional Development Fund (ERDF). It is led by the Polytechnic University of Valencia (Spain) and other eight project partners are involved from Spain, Italy, United Kingdom, Croatia, Montenegro, Greece and Malta.

In 2019, the E²STORMED DST has been improved thanks to the funding provided by the TRIG-EAU project (http://interreg-maritime.eu/fr/web/T.R.I.G-Eau) as part of the Interreg Programme of the European Union.

1.2. SUSTAINABLE STORMWATER MANAGEMENT

Sustainable Drainage Systems (SuDS) are stormwater systems designed both to manage the risks resulting from urban runoff and to contribute to environmental and landscape improvement. SuDS objectives are, therefore, to minimize the impacts from the urban development on stormwater quantity and quality and maximize amenity and biodiversity opportunities (Woods-Ballard et al., 2007), as shown in Figure 1.1. This type of system can contribute to flood control, pollution control and provide an alternative source of water.

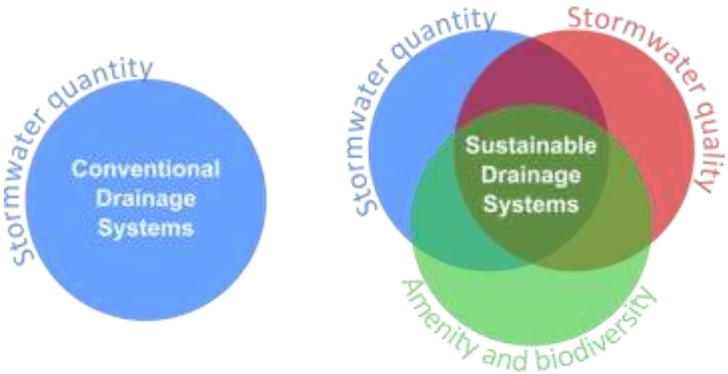


Figure 1.1. Comparison of objectives between Conventional Drainage Systems and Sustainable Drainage Systems.

As explained in the Report on stormwater management of the E²STORMED project, sustainable solutions for stormwater management can achieve one or many of the following benefits (Philip, Module 4. Stormwater- Exploring the options. SWITCH Training Kit. Integrated urban water management in the city of the future, 2011b):

- Flood control: The attenuation and infiltration of stormwater during heavy rainfall events reduces the peak runoff, which reduces the risk of overflows locally and downstream.
- Pollution control: Natural systems such as soils, vegetation and wetlands have different treatment capabilities that can be exploited in SuDS.
- Protection against erosion: SuDS reduce runoff velocity, avoiding erosion of riverbanks.
- Alternative source of water: Stormwater can be collected and reused either directly for non-potable purposes or, following treatment, for potable use.
- Amenity value: The construction of ponds and wetlands has the advantage of creating natural habitats, increasing biodiversity and providing recreational opportunities.
- Climate change adaptation: The use of natural systems to attenuate runoff provides greater flexibility to cope with flows from unexpectedly heavy rainfall.
- Economic efficiency: Many decentralized stormwater solutions are cheap to construct and maintain in comparison to conventional technologies.

International recommendations (EC, 2012; USEPA, 2008) have been developed to encourage the implementation of more sustainable, flexible and efficient drainage systems.

Water and wastewater facilities are often the largest and most energy-intensive loads owned and operated by local governments, representing up to 35% of municipal energy use. SuDS benefits can reduce energy consumption in cities by:

- Reducing use of potable water, hence, energy consumed by acquisition -frequently by pumping- and treatment of drinking water, even higher where desalination is used and/or water imported.

- Reducing stormwater inflow into sewer systems, hence, energy consumed by treatment of wastewater and pumping of surface and foul water.

- Reducing local temperatures and shading building surfaces, hence lessen the cooling and heating demand for buildings, reducing energy needs and decreasing emissions from power plants.

This tool allows the exploration of the relationships between stormwater management and other parts of urban water and energy management.

1.3. General description of Decision Support Tool (DST)

After reviewing different Decision Support tools, as shown in the Report on Management and decision assessment of the E²STORMED Project, it was concluded that none of the decision tools reviewed included energy efficiency criteria. For this reason, the E²STORMED Decision Support Tool (DST) has been developed to support the decision-making process not only based on financial and hydraulic criteria, but also on energy, environment and social criteria, in order to ensure stormwater management sustainability.

The main purpose of the E²STORMED DST is to compare and evaluate different drainage options for stormwater management. It has not been developed to design in detail the hydraulic and water quality process of stormwater infrastructures for which numerous tools and software are available. The E²STORMED DST is used to evaluate drainage scenarios that have been previously designed with these tools and different levels of detail can be used to obtain decision-making results with the E²STORMED DST, as explained in Section 1.6. For a low level of detail, the data of a preliminary design can be introduced and evaluated with very few site specific data using the estimation panels included in the E²STORMED DST. For drainage scenarios which have already been designed, this tool can be used to introduce the hydraulic and financial data obtained in the detailed design and to compare them with the multi-decision criteria analysis.

This tool has been created to:

1. Define different drainage system scenarios. Each scenario is defined by different drainage components (a catalogue of types of drainage infrastructures is included in this tool).

2. Define the advantages and disadvantages of each scenario analyzed. Different methods and equations are proposed to analyse:

   - Construction and maintenance costs, energy consumption and CO_2 emissions.

   - Costs, energy consumption and CO_2 emissions produced by stormwater treatment and pumping.

   - Rainwater reuse benefits and energy savings.

   - Flood protection benefits.

- Building insulation benefits and energy savings.
- Advantages delivered by ecosystem services.

This analysis of advantages and disadvantages includes the estimation of costs, energy consumption and CO_2 emissions of the main urban water management processes.

3. Compute and represent for each scenario the variation of costs, energy consumed, and CO_2 emissions during an analysis period.
4. Use these results to develop decision criteria based on energy efficiency, costs and proper water management. They can be complemented by other social and environmental criteria to support the decision-making process. These criteria are used in a multi-criteria analysis to choose between different drainage scenarios.

The general structure of the tool is shown in Figure 1.2.

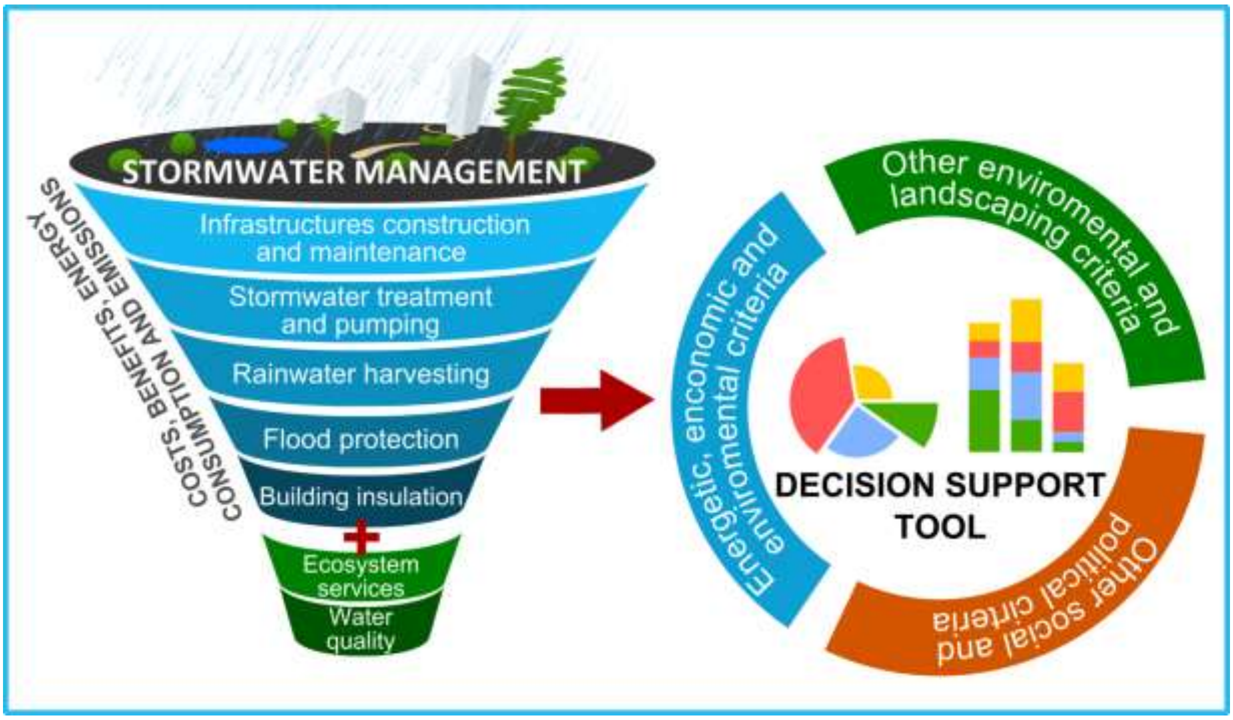
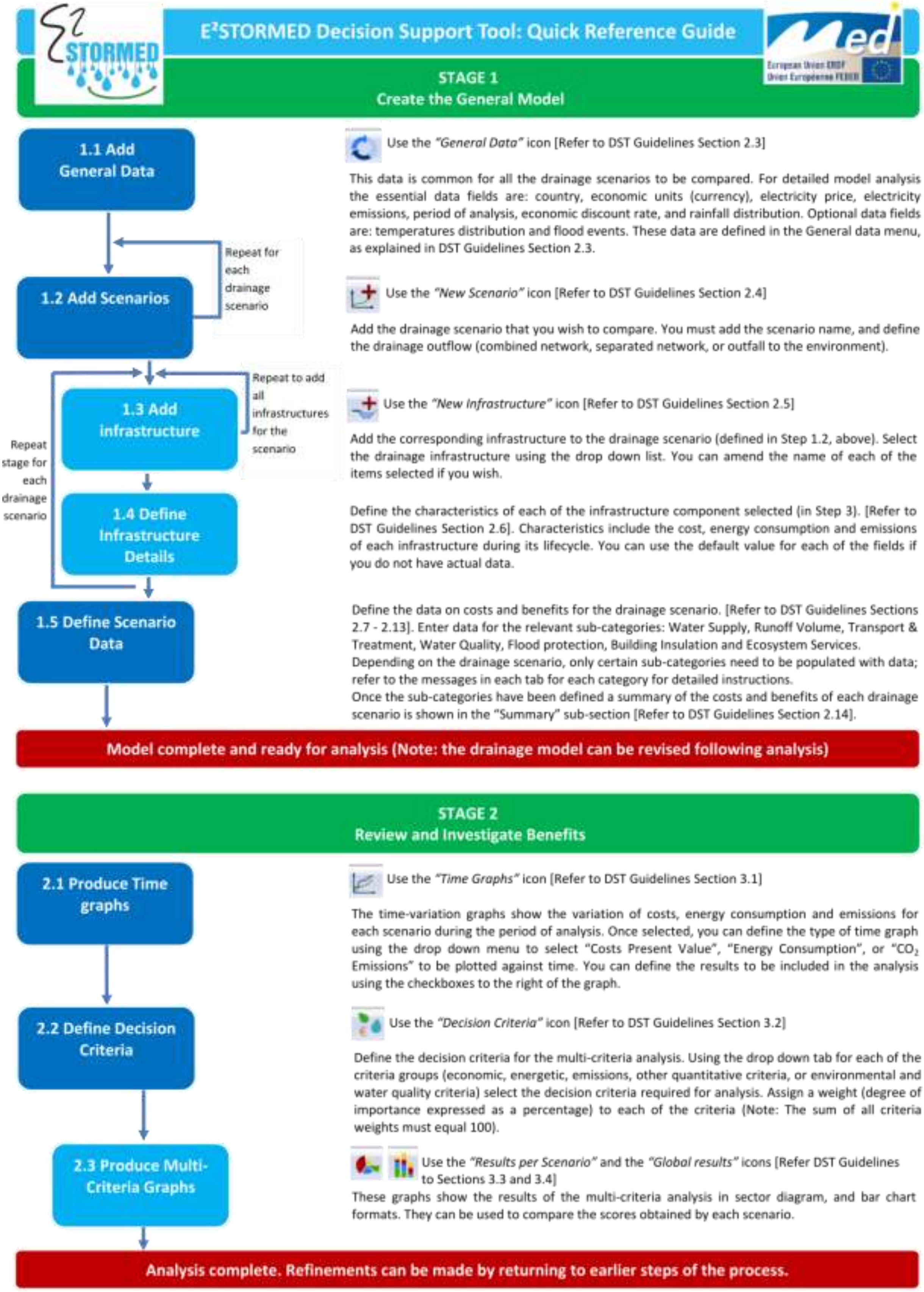


Figure 1.2. General structure of the E²STORMED DST.

Results obtained can be used to support the decision-making process, since different energy, financial and social criteria are compared in a multi-criteria analysis. The decision-making process is complex since different stakeholders are involved and numerous social, political and environmental factors can influence the decisions. The process to be followed to perform this analysis is explained in the following section.

1.4. Quick Reference Guide



E²STORMED Decision Support Tool: Quick Reference Guide

STAGE 1
Create the General Model

1.1 Add General Data

Use the *"General Data"* icon [Refer to DST Guidelines Section 2.3]

This data is common for all the drainage scenarios to be compared. For detailed model analysis the essential data fields are: country, economic units (currency), electricity price, electricity emissions, period of analysis, economic discount rate, and rainfall distribution. Optional data fields are: temperatures distribution and flood events. These data are defined in the General data menu, as explained in DST Guidelines Section 2.3.

Repeat for each drainage scenario

1.2 Add Scenarios

Use the *"New Scenario"* icon [Refer to DST Guidelines Section 2.4]

Add the drainage scenario that you wish to compare. You must add the scenario name, and define the drainage outflow (combined network, separated network, or outfall to the environment).

Repeat stage for each drainage scenario

Repeat to add all infrastructures for the scenario

1.3 Add infrastructure

Use the *"New Infrastructure"* icon [Refer to DST Guidelines Section 2.5]

Add the corresponding infrastructure to the drainage scenario (defined in Step 1.2, above). Select the drainage infrastructure using the drop down list. You can amend the name of each of the items selected if you wish.

1.4 Define Infrastructure Details

Define the characteristics of each of the infrastructure component selected (in Step 3). [Refer to DST Guidelines Section 2.6]. Characteristics include the cost, energy consumption and emissions of each infrastructure during its lifecycle. You can use the default value for each of the fields if you do not have actual data.

1.5 Define Scenario Data

Define the data on costs and benefits for the drainage scenario. [Refer to DST Guidelines Sections 2.7 - 2.13]. Enter data for the relevant sub-categories: Water Supply, Runoff Volume, Transport & Treatment, Water Quality, Flood protection, Building Insulation and Ecosystem Services.
Depending on the drainage scenario, only certain sub-categories need to be populated with data; refer to the messages in each tab for each category for detailed instructions.
Once the sub-categories have been defined a summary of the costs and benefits of each drainage scenario is shown in the "Summary" sub-section [Refer to DST Guidelines Section 2.14].

Model complete and ready for analysis (Note: the drainage model can be revised following analysis)

STAGE 2
Review and Investigate Benefits

2.1 Produce Time graphs

Use the *"Time Graphs"* icon [Refer to DST Guidelines Section 3.1]

The time-variation graphs show the variation of costs, energy consumption and emissions for each scenario during the period of analysis. Once selected, you can define the type of time graph using the drop down menu to select "Costs Present Value", "Energy Consumption", or "CO_2 Emissions" to be plotted against time. You can define the results to be included in the analysis using the checkboxes to the right of the graph.

2.2 Define Decision Criteria

Use the *"Decision Criteria"* icon [Refer to DST Guidelines Section 3.2]

Define the decision criteria for the multi-criteria analysis. Using the drop down tab for each of the criteria groups (economic, energetic, emissions, other quantitative criteria, or environmental and water quality criteria) select the decision criteria required for analysis. Assign a weight (degree of importance expressed as a percentage) to each of the criteria (Note: The sum of all criteria weights must equal 100).

2.3 Produce Multi-Criteria Graphs

Use the *"Results per Scenario"* and the *"Global results"* icons [Refer DST Guidelines to Sections 3.3 and 3.4]
These graphs show the results of the multi-criteria analysis in sector diagram, and bar chart formats. They can be used to compare the scores obtained by each scenario.

Analysis complete. Refinements can be made by returning to earlier steps of the process.

1.5. Parts of the graphical interface

The graphical user interface of E²STORMED DST is divided into four main parts (Figure 1.3):

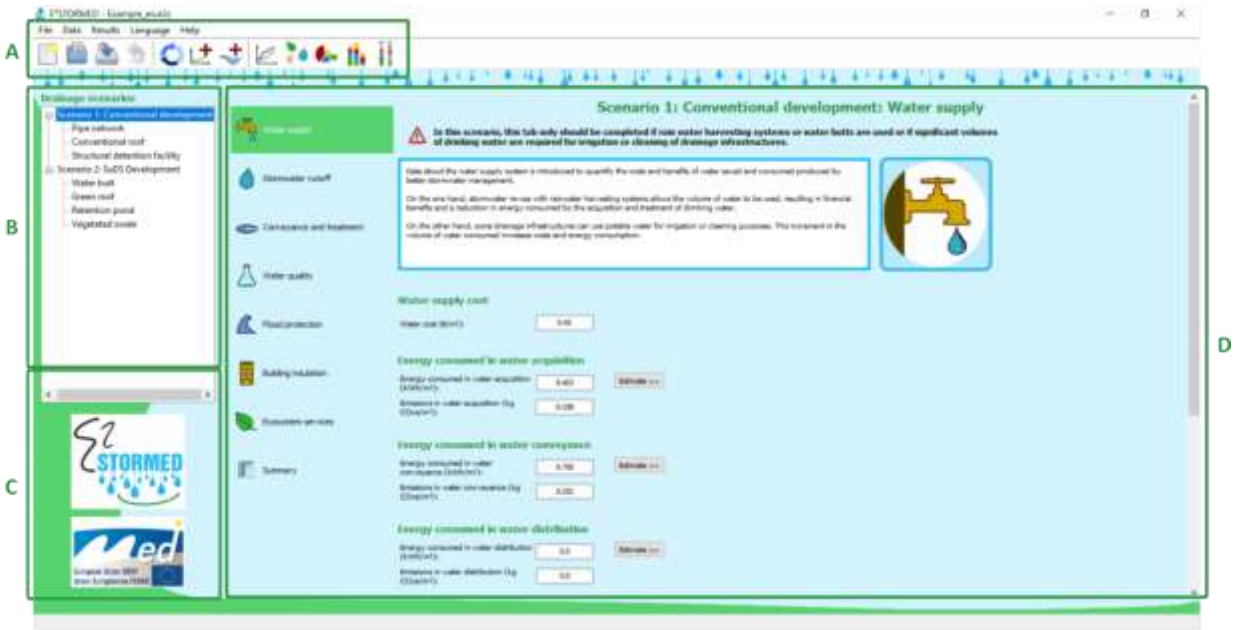


Figure 1.3. Main parts of the graphical user interface in scenarios mode.

A. Menu and toolbar: Contain the different options to create, save and open E²STORMED files. They also allow computing and obtaining the desired results. The main menu has the following options:

- File menu: To create, open and save an E²STORMED file. These files have extension .e2s. The options of this menu are addressed in Section 2.1.
- Data menu: To define the general model data, to add new drainage scenarios and to add new drainage infrastructure components in each scenario. The options of this menu are explained in Sections 2.3. , 2.4. and 2.5.
- Results menu: To obtain graphs to compare different drainage scenarios and to make a multi-criteria analysis. The options of this menu are addressed in Sections 3.1. - 3.4.
- Language menu: This menu allows the user to choose the software language. Currently, the available languages are English, Spanish, Italian, French, Croatian, Montenegrin and Greek.
- Help menu: Detailed information about this software including a digital version of these guidelines and the quick reference guide. It can also be used to open the example described in these guidelines.

B. Drainage scenarios window: This window is used to observe and edit the different scenarios that are being compared. Each scenario comprises different drainage components, which are shown in this tree. When a scenario is selected in this tree, the data window is in scenario mode (Figure 1.3), where as if an infrastructure is selected, this window is in infrastructure mode (Figure 1.4). The options of this tree are explained in Section 2.2.

C. Logos: E²STORMED project logo, within this software has been developed, and MED programme logo of European Union, which funds the E²STORMED project.

D. Data window: This window is used to introduce the data for each scenario and component. The appearance of this window changes when an element is selected in the drainage scenarios window. The data that must be introduced in this window is explained in Sections 2.6. - 2.14.

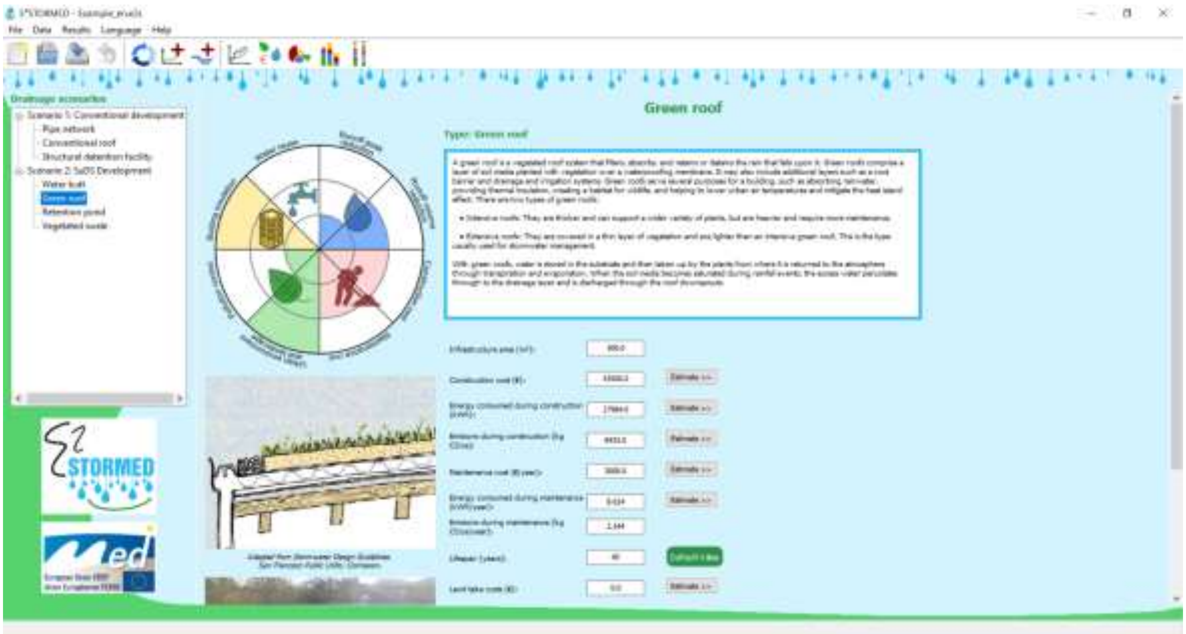


Figure 1.4. Graphical user interface in infrastructure mode.

1.6. LEVELS OF DETAIL

The E²STORMED DST has been designed to be used for analysis with different levels of detail. In all parts of these guidelines that deal with costs, hydraulic performance or energy consumption estimation, there are two different sections:

→ **Detailed analysis:** When data are available. In this section, the detailed analysis to obtain the desired results is explained. In general, these procedures require specific local data about water management and/or detailed models on drainage infrastructures performance. These procedures must be followed to analyse in detail the different advantages and disadvantages of each scenario.

→ **Estimation:** When using default values. In each part of the DST, an estimation panel is included to estimate costs, hydraulic performance or energy consumption of drainage components with few local data and a preliminary design of infrastructures. Furthermore, default values of required data are provided for most of the estimation panels based on the literature review that was undertaken. These default values should be modified if local data are available. These panels allow the user to compare different drainage scenarios without great effort. This preliminary analysis can be very useful to modify the design of the drainage scenarios and to evaluate what costs and benefits of stormwater management are more significant and require more detailed analysis.

The level of detail used to compare different scenarios should relate to the decision to be made. If a final decision involves important stormwater infrastructure, detailed data should be introduced in the DST to compare different options.

1.7. Example description

The software includes an example of decision-making in an urban area. This example is used in the different sections of these guidelines to explain how the DST can be applied. At the end of each section, the data introduced for the example are highlighted with a green rectangle. This example compares two scenarios of stormwater management for a new urban development in Spain. The area of this urban development is 51,200 m² with has 66 households and a school. This example has been analysed using the estimation panels of each part of the E²STORMED DST. Thanks to these panels, an analysis to compare two drainage scenarios has been made with few local data and a preliminary stormwater design.

1.7.1. Scenario 1: Conventional development

This storm water network is a combined system and water is discharge into a Wastewater Treatment Plant. Three stormwater infrastructures are used:

- Conventional roof in school: Area 300 m² (it is introduced to be compared with the green roof of Scenario 2).
- Conventional drainage network: 900 m.
- Structural detention facility: 650 m³.

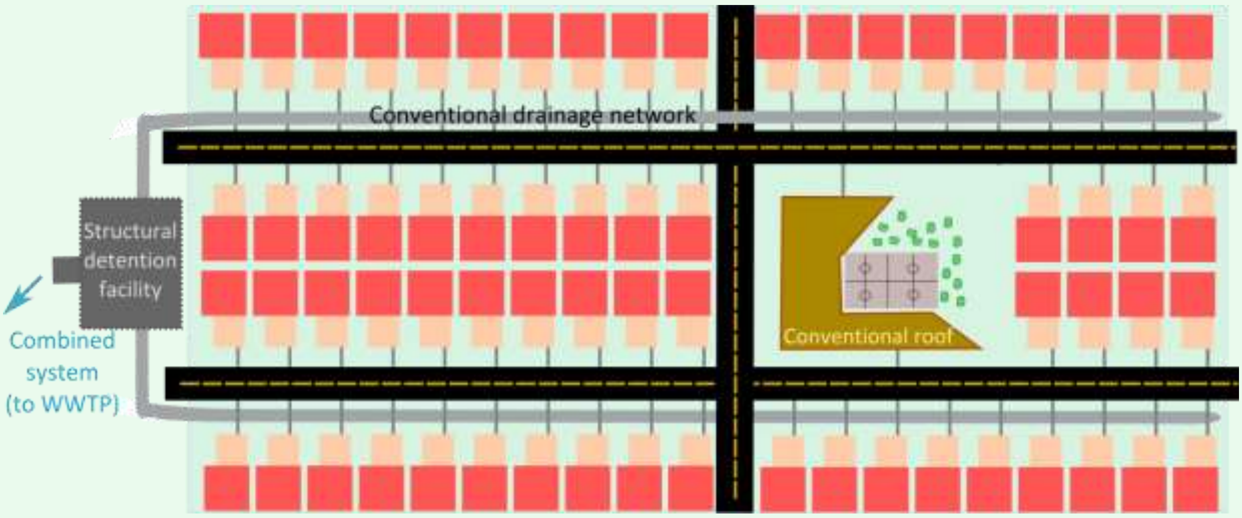


Figure 1.5. Schematic of scenario 1: conventional development.

1.7.2. Scenario 2: Development with SuDS

In this case, stormwater is directly discharged into the environment. This scenario consists of four drainage infrastructures:

- Green roof in school: Area 300 m².
- 2 vegetated swales: Area 850 m² each one. Land take: 970 m² each.
- Retention pond: 650 m³. Land take: 875 m².
- Water butts (one per household): 0.7 m³ each.

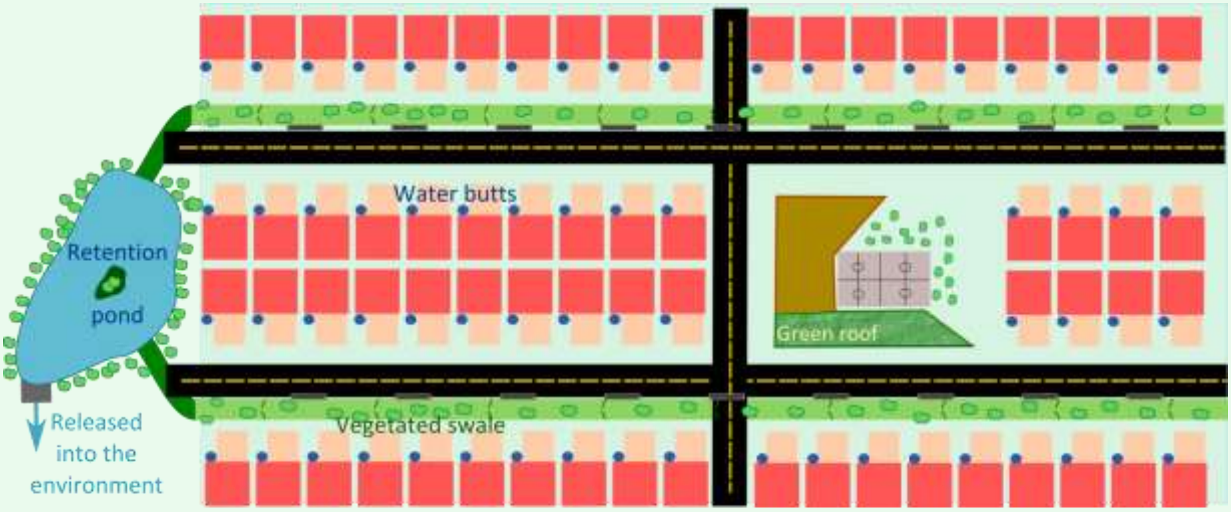


Figure 1.6. Schematic of scenario 2: SuDS development.

2. DATA INPUT

2.1. FILE MENU

The file menu has the structure shown in Figure 2.1.

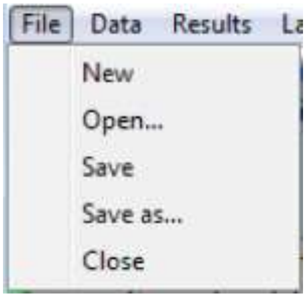


Figure 2.1. File menu.

The options of this menu are:

- New: Create a new comparison of drainage scenarios. This action can also be performed with the corresponding toolbar button.
- Open...: Open a previously created E²STORMED file. E²STORMED files created with this software have the extension .e2s. This action can also be performed with the corresponding toolbar button.
- Save: Using this option, changes in the scenarios comparison can be saved in the current working file. E²STORMED files created with this software have the extension .e2s. This action can also be performed with the corresponding toolbar button.
- Save as: With this option changes in the comparison of scenarios can be saved in a different file. E²STORMED files created with this software have the extension .e2s.
- Close: With this option the main software window is closed.

These options can also be chosen with the corresponding toolbar buttons, shown in Figure 2.2.

Figure 2.2. Toolbar buttons to create, open and save a file and undo button.

Finally, undo button in the toolbar can be used to recover previous results after clicking in an Estimate Button in any tab.

2.2. DRAINAGE SCENARIOS WINDOW

This window shows all the scenarios and infrastructure components that have been added into the model. The appearance of this window is shown in Figure 2.3. The first tree level shows the drainage scenarios that are being compared defined by their name. The second tree level shows the different drainage infrastructure components that make up each scenario also defined by name.

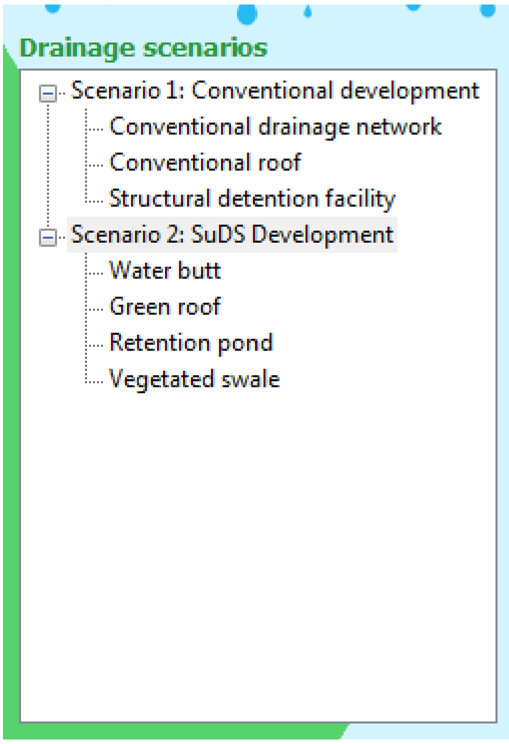


Figure 2.3. Drainage scenarios window.

When a scenario is selected in this tree, the data window shows the data of this scenario in scenarios mode (Figure 1.3), whereas if an infrastructure component is selected, the data window shows the data corresponding to this component in infrastructure mode (Figure 1.4).

When a first level element (scenario) is right-clicked, a menu is shown with the following options:

- Add new scenario…: This option allows a new drainage system scenario to be added to the comparison. This is explained further in Section 2.4.
- Add new infrastructure…: This option allows a new drainage infrastructure component to be added to the selected scenario. This is explained further in Section 2.5.
- Redefine scenario…: This option allows the user to change the name and the type of drainage outflow of the selected scenario. This is explained further in Section 2.4.
- Copy scenario…: This option can be chosen to create a new scenario with the same data as that of a scenario that has already been completed. When this option is chosen, the name of the new scenario should be defined.

- Remove scenario: This option removes the selected scenario and its data from the comparison.

When a second level element (drainage infrastructure component) is right-clicked, the available options are:

- Add new infrastructure...: This option allows adding a new drainage infrastructure in the scenario of the selected infrastructure. This is explained further in Section 2.5.

- Edit infrastructure…: This option allows the name and type of a selected infrastructure to be changed. This is explained further in Section 2.5.

- Copy infrastructure…: This option allows copying an infrastructure that has already been introduced. This menu is explained further in Section 2.5.

- Remove infrastructure...: This option removes the selected infrastructure and its data from the scenario.

2.3. GENERAL DATA MENU

This menu is used to define the data that is common for all the drainage scenarios to be compared (for instance location, electricity price, rainfall distribution…). This menu is shown with the corresponding toolbar button (Figure 2.4) or with the menu option *Data → General data.*

Figure 2.4. Toolbar button to show the general data menu.

The options of this menu are:

A. Country: Country where the urban area is located. This is used to estimate the default values for the electricity emissions in this menu and the thermal transmittance of conventional roofs in Section 0

B. Currency: Monetary units used to compute and represent costs and benefits. All the parts of this tool use euros, so data should be introduced in this currency.

C. Electricity price: Cost of electricity in the urban area. This cost is used to estimate the cost of energy consumption in the water cycle and the benefits of energy savings.

D. Electricity emissions: Equivalent CO_2 emissions produced by electricity consumed depening on the energy resources mix of each country or region. The default values of emissions per kWh of electricity consumed in each European country are shown in Table 2.1 (values of 2010). In the rest of countries, these values are obtained from other sources, as explained in the Report on energy in the urban water cycle of E²STORMED project.

E. Period of analysis: Number of years used to compute the costs, energy consumptions and emissions of stormwater management infrastructures. Short periods of analysis will produce results more focused or implementation and construction costs, whereas with long periods of analysis, maintenance costs are more important.

F. Economic discount rate: It is the rate at which economic units in the future are brought back to the present. This rate takes into account the money depreciation and the loss of opportunities for not using this money in other investments.

G. Rainfall distribution: Monthly average rainfall in the urban area. These data are used to compute water reuse and runoff volumes. The data are introduced in the menu shown in Figure 2.6.

H. Temperature distribution: Average daily temperature variation in summer and in winter in the urban area. This information only needs to be completed if green roof building insulation benefits are to be estimated in any scenario. The data is introduced in the menu shown in Figure 2.8.

I. Flood events: This menu is used to introduce the return period of the flood events that are used to estimate flood protection benefits in all the drainage scenarios. If flood protection benefits are not to be considered, these data are not needed. This menu (Figure 2.7) includes:

- Add flood event return period button: This button is used to add a new return period.
- Remove return period button (-): This button can be used to eliminate and added return period.

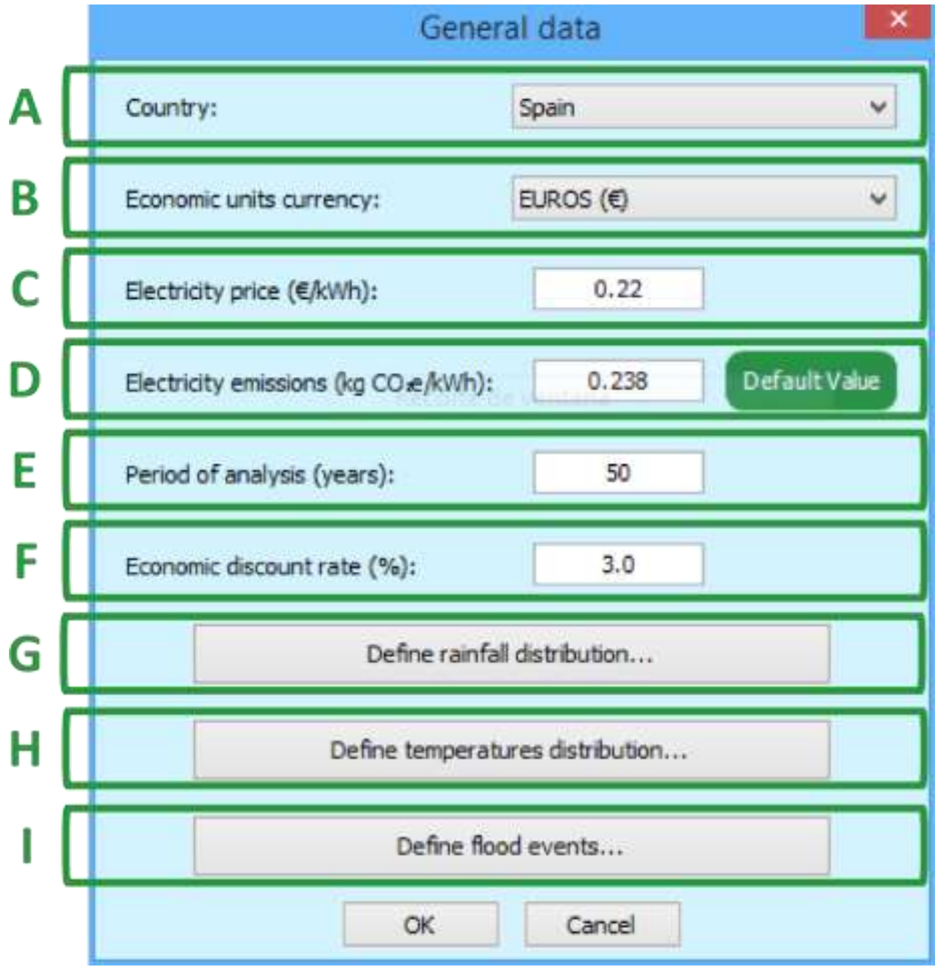


Figure 2.5. General data menu.

Country	2004	2005	2006	2007	2008	2009	2010
Albania	30	26	26	31	0	1	2
Armenia	114	131	130	157	159	102	92
Austria	224	218	217	204	187	158	188
Azerbaijan	677	650	671	570	534	499	439
Belarus	463	459	461	452	465	466	449
Belgium	285	275	263	254	254	218	220
Bosnia and Herzegovina	772	797	852	1007	830	806	723
Bulgaria	537	502	490	592	565	537	535
Croatia	314	331	337	422	367	291	236
Cyprus	772	788	758	761	759	743	697
Czech Republic	617	614	606	636	621	588	589
Denmark	403	369	459	425	398	398	360
Estonia	1029	1048	965	1048	1084	1078	1014
Finland	258	164	265	238	177	190	229
France	67	79	72	76	72	78	79
FYR of Macedonia	797	791	783	871	905	799	685
Georgia	89	101	147	161	79	123	69
Germany	503	486	483	504	476	467	461
Gibraltar	766	761	751	751	757	757	762
Greece	780	779	731	752	748	725	718
Hungary	448	372	373	368	351	313	317
Iceland	0	0	0	1	1	0	0
Ireland	575	584	537	510	471	452	458
Italy	497	486	509	475	452	411	406
Kazakhstan	584	570	839	658	541	433	403
Kosovo	1297	1121	1127	1089	1088	1286	1287
Kyrgyzstan	68	58	56	61	57	57	59
Latvia	97	89	113	107	114	96	120
Lithuania	68	101	100	88	83	84	337
Luxembourg	393	389	387	381	385	376	410
Malta	913	1034	954	1012	849	850	872
Montenegro	..	341	386	352	456	274	405
Netherlands	467	454	452	455	442	420	415
Norway	3	2	3	4	3	11	17
Poland	833	818	821	820	815	799	781
Portugal	465	521	431	396	394	379	255
Republic of Moldova	526	529	506	530	510	526	517
Romania	528	493	521	542	512	472	413
Russian Federation	402	436	445	428	426	402	384
Serbia	883	764	817	750	772	766	718
Slovak Republic	233	221	214	220	207	210	197
Slovenia	345	349	362	375	332	318	325
Spain	382	397	369	387	327	297	238
Sweden	23	19	23	17	18	19	30
Switzerland	28	32	33	30	29	26	27
Tajikistan	22	21	21	20	20	17	14
Turkey	426	438	452	494	511	496	460
Turkmenistan	872	872	872	872	927	865	954
Ukraine	360	397	430	440	447	390	392
United Kingdom	491	491	515	506	499	453	457
Uzbekistan	588	588	583	609	543	566	550
European Union (27)	391	387	391	395	374	357	347

Table 2.1. Equivalent CO_2 Emissions (g CO_2e per kWh) per country due to electricity consumption (IEA, 2012).

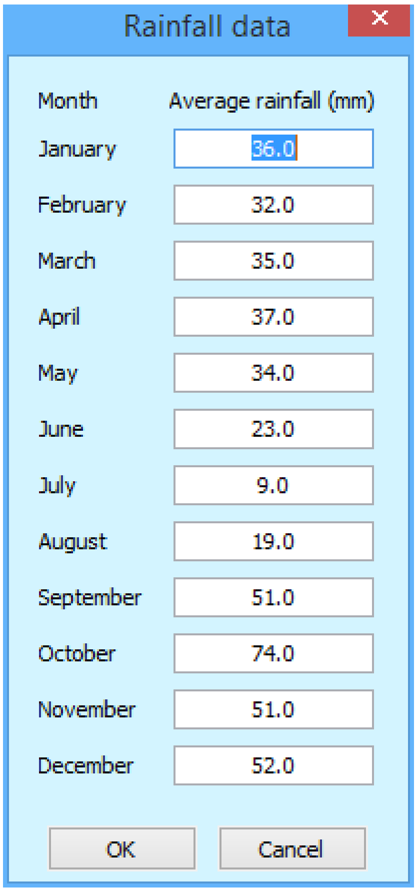


Figure 2.6. Rainfall distribution menu.

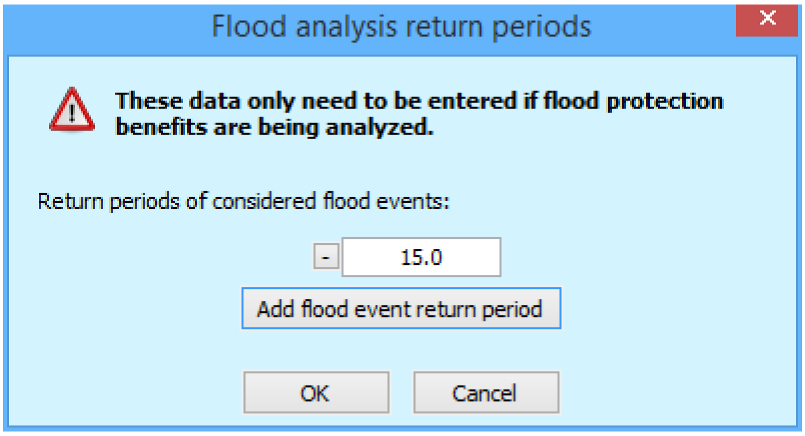


Figure 2.7. Flood events menu.

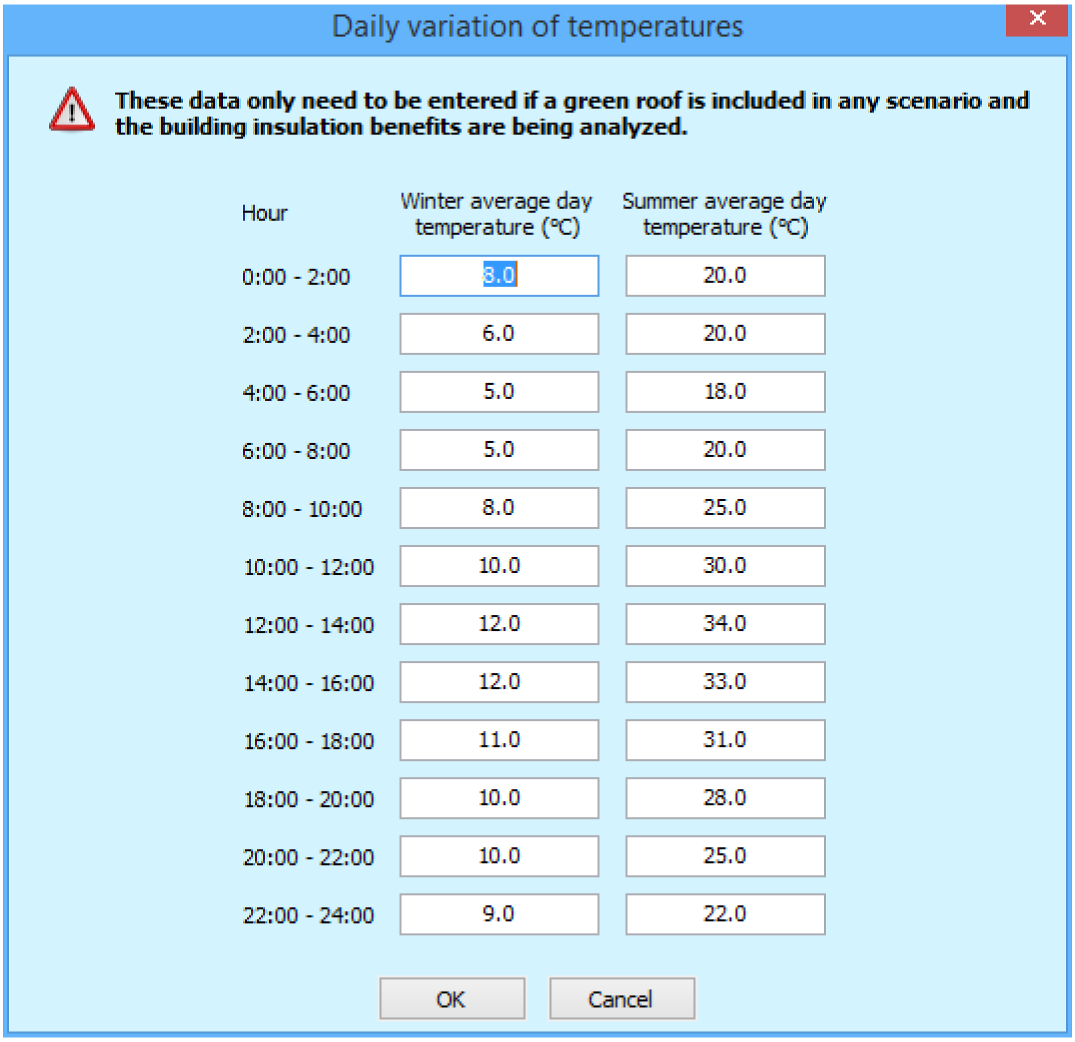


Figure 2.8. Temperature distribution menu.

EXAMPLE

General data about the example described in Section 1.7. are introduced in this menu:

- Electricity price: 0.22 €/kWh.
- Default value of electricity emissions for Spain: 0.238 kg CO_2/kWh.
- Period of analysis: 50 years.
- Discount rate: 3%.
- Annual rainfall distribution in the urban area is introduced as shown in Figure 2.6.
- Daily temperatures distribution in the urban area is introduced as shown in Figure 2.8.
- A flood event with return period of 15 years is used for flood protection benefits estimation.

2.4. ADD NEW DRAINAGE SYSTEM SCENARIO

This menu is used to add a new drainage system scenario in the analysis. The scenarios are compared to support the decision-making process, as explained in Section 1.3. A scenario can be added with the corresponding toolbar button (Figure 2.9) or with the menu option *Data → New scenario…*

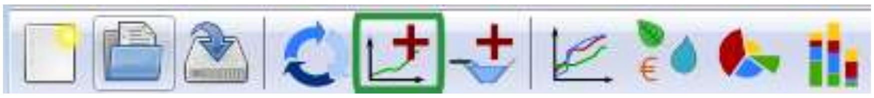


Figure 2.9. Toolbar button to add a new drainage system scenario.

The options that must be completed in this menu (Figure 2.9) are:

A. Scenario name: Name of the scenario that will be used in the results graphs.

B. Drainage outflow: Type of drainage outflow for each scenario. There are three options:

- Combined network: When the runoff produced in the study area discharges to a combined drainage network. Stormwater is mixed with wastewater.
- Directly into the environment: When, after going through the drainage system in the area of study, water is directly discharge in a stream or a river into the environment.
- Separate network: When the runoff produced in the area of study discharges in a separate drainage network (only for stormwater).

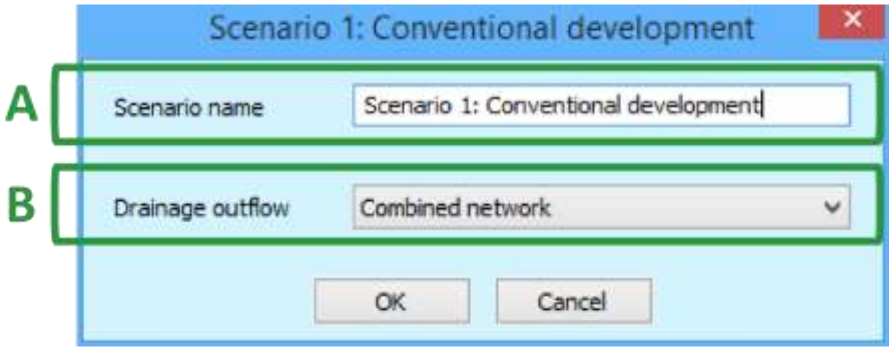


Figure 2.10. Add a new drainage system scenario menu.

2.5. ADD NEW INFRASTRUCTURE

2.5.1. Add infrastructure menu

This menu is used to add a new drainage infrastructure component in a drainage system scenario. An infrastructure component can be added with the corresponding toolbar button (Figure 2.11) or with the menu option *Data → New infrastructure…*

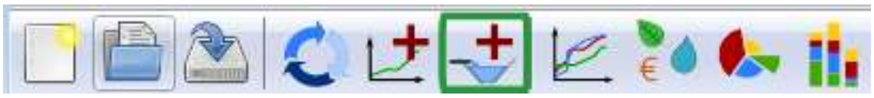


Figure 2.11. Toolbar button to add a new infrastructure component.

The options that must be completed in this menu (Figure 2.12) are:

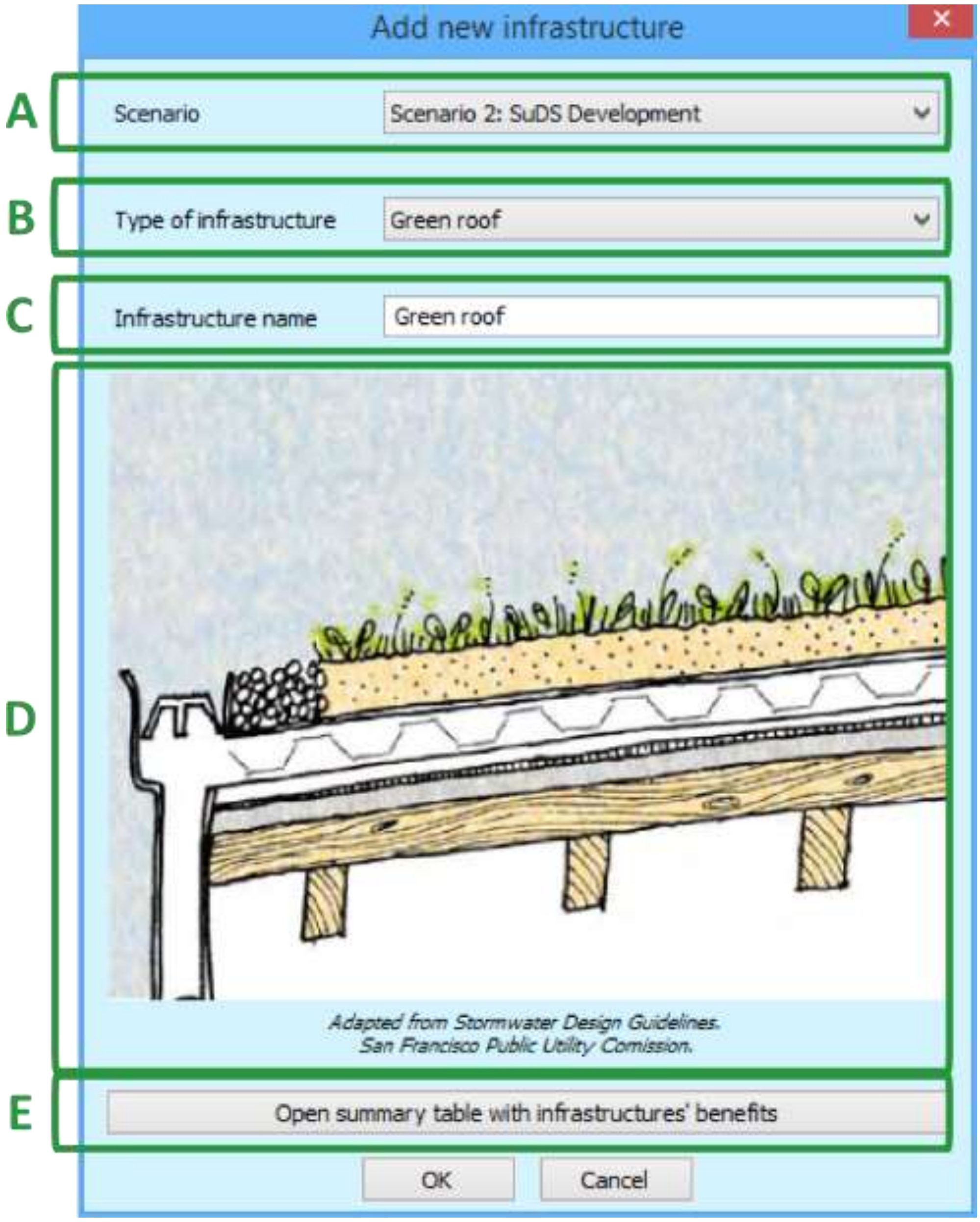


Figure 2.12. Add new infrastructure menu.

A. Scenario: This choice is used to select the scenario where the infrastructure is added.

B. Type of infrastructure: A pre-defined catalogue of types of drainage infrastructure components is included. The characteristics of these types are defined in Annex 1. In this section, the different types are divided between conventional and sustainable systems. If an infrastructure component that is not found in the pre-defined infrastructures' types is going to be added, the "other drainage infrastructure" option should be selected.

C. Infrastructure name: Name of the infrastructure component that will be shown in the Drainage scenarios window.

D. Infrastructure schematic: This drawing shows the general arrangement of the infrastructure selected. It is changed automatically when the selected infrastructure component changes.

E. Summary table with infrastructure's benefits: This option opens a summary table with the ecosystem services provided for each of infrastructure. The purpose of this table is helping to choose between the different types of infrastructures. This table has been obtained from different sources as explained in the E²STORMED Report on Ecosystem services and it is shown in the Annex 2. Furthermore, in this Annex a detailed table is included to describe the benefits of different drainage options that can help urban planners and stormwater managers.

2.6. Introduce stormwater infrastructures data

2.6.1. Introduction

In order to compare different drainage options, E²STORMED DST analyses costs and energy consumption during the period of analysis (defined in the General data menu). The analysis of costs during the entire period allows a homogenous comparison between different options. These costs and energy consumption should include installation, land take and on-going operation and maintenance.

For each drainage infrastructure component of each scenario, E²STORMED DST analyses lifecycle costs and energy consumption on the basis of the following assumptions (as shown in Figure 2.13):

- Construction cost, energy consumed and emissions are used to introduce the needs for installing the infrastructure. This cost includes detailed design and development costs.

- Land take cost introduces the cost of occupying a zone in the urban area. This cost only needs to be introduced if the drainage infrastructure requires land take.

- In each infrastructure component, actions are required to maintain them to ensure continued performance. The cost, energy consumed and emissions of these actions are introduced with an average annual maintenance cost, energy consumption and emissions.

- Each infrastructure component has a lifespan, after which a major restoration may be need to ensure continued good performance. It is assumed that the cost and energy consumption of this restoration is equal to the construction cost and energy consumed. This is a common assumption in lifecycle costs analysis.

- All costs are discounted to the base date using the discount rate introduced in the General data menu. The formulations used to obtain costs present value are explained in Section 3.1.

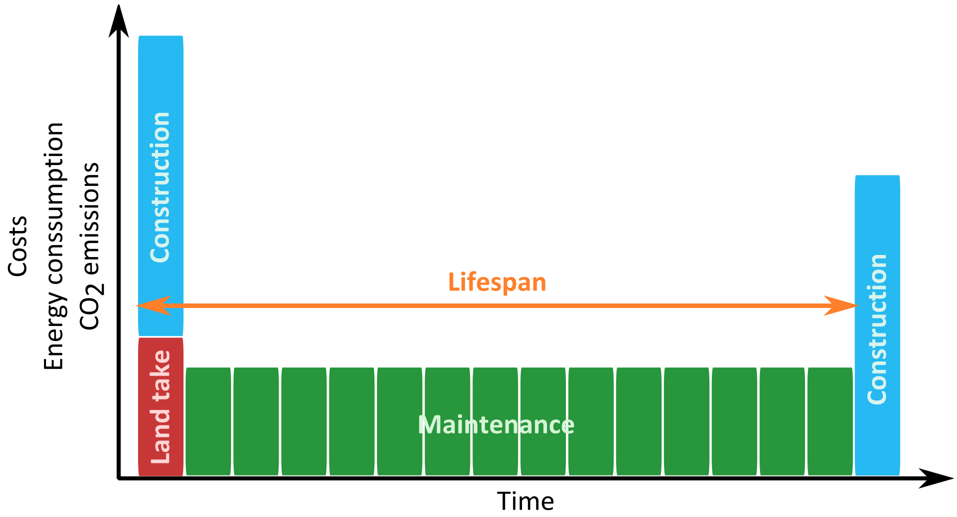


Figure 2.13. Distribution of costs and energy consumption for a drainage infrastructure component during its lifecycle.

2.6.2. Stormwater infrastructures tab

In the infrastructures tab, the different costs, energy consumptions and emissions of each infrastructure component during its lifecycle should be introduced. This tab is shown when a component is selected in the Drainage scenarios window (Section 2.1.). The data that must be introduced in this tab is (Figure 2.14):

A. Main size characteristic: This defines the size of the infrastructure component and is be used to estimate costs and energy consumption. In each type, the characteristic used (length, area or volume) to define the size of the component is different, depending on the properties of each. Table 2.2 shows the main dimensions used in each type of infrastructure component.

B. Construction cost: Costs of design and installation. The process to estimate this cost is explained in Section 2.6.3.

C. Energy consumed during construction. The process to estimate this energy consumption is explained in Section 0

D. Emissions during construction: Equivalent CO_2 emissions produced during the construction. The process to estimate these emissions is explained in Section 0

E. Maintenance cost: Average annual maintenance costs. The process to estimate this cost is explained in Section 2.6.3.

F. Energy consumed during maintenance: Average annual energy consumed during the maintenance. The process to estimate this energy consumption is explained in Section 0

G. Emissions during maintenance: Average annual equivalent CO_2 emissions produced during the maintenance. The process to estimate these emissions is explained in Section 0

H. Lifespan: Expected lifespan for each drainage infrastructure component. The E²STORMED DST proposes a default value for this lifespan (Obtained when the Default Value button is clicked).

This value is based on literature references as explained in the E²STORMED Report on Stormwater Management. The value proposed for each type of infrastructure is detailed in Section 2.5. In a detailed analysis, the lifespan should be estimated for each infrastructure component based on its characteristics, expected maintenance, construction standards and lifespan of similar projects in the region.

I. Land take costs: Cost of occupying a zone in the urban area. This cost only needs to be introduced if the drainage infrastructure requires land take. The process to estimate this cost is explained in Section 2.6.3.

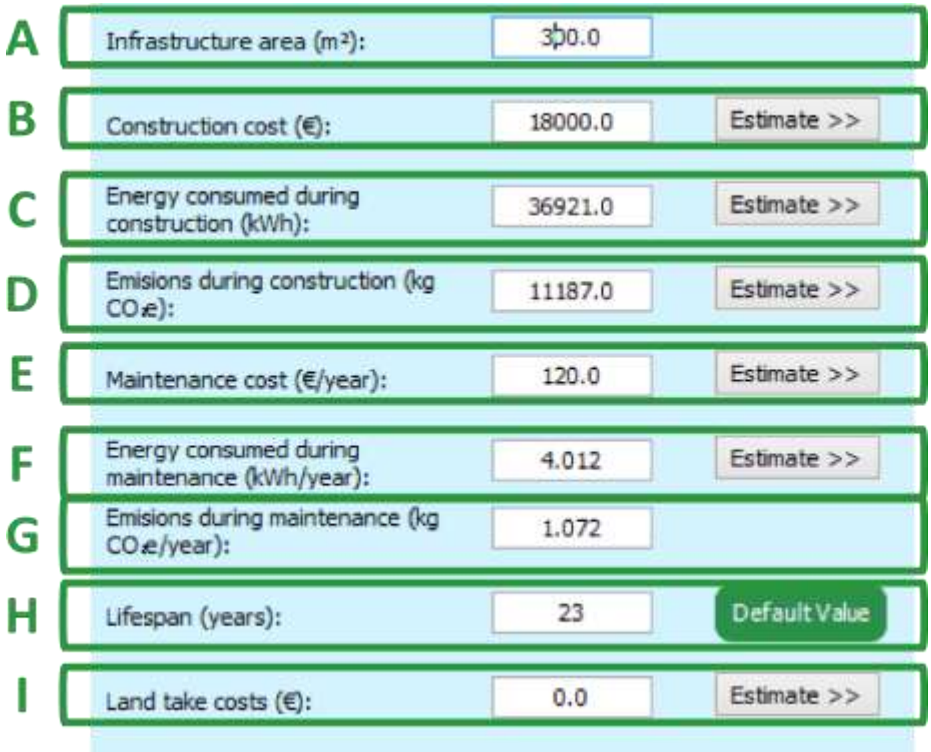


Figure 2.14. Stormwater infrastructure costs tab.

2.6.3. Estimation of lifecycle costs

→ Detailed analysis

In general, project the **construction cost** should be calculated with a detailed budget of the construction tasks and costs, based on the detailed design. A construction budget must be adapted to material and labor costs in the region for all construction stages.

In a similar way, the average annual **maintenance cost** should be based on a detailed maintenance plan. This plan should be set out at the design stage and must detail all the activities needed to make sure that the system continues to function as designed. There is also a relationship between construction and maintenance costs: better construction standards will produce lower maintenance costs.

Various manuals provide guidelines to design stormwater systems and each SuDS type. They provide some formulae and procedures to easily define its size and characteristics. Some examples are:

(CLADPW, 2010; CSQA, 2003; CP, 2008; NYSDEC, 2010; Puertas-Aguado, Suárez-López, & Anta-Álvarez, 2008; Woods-Ballard, y otros, 2007). These manuals can also be very useful to support construction and maintenance cost estimation. More details about tools and criteria for stormwater systems design are explained in the E²STORMED Report on stormwater management.

Finally, **land take costs** are based on the cost of the terrain that each infrastructure will occupy. Some drainage infrastructures are underground, so this cost can be assumed to be zero.

→ Cost Estimation

For a preliminary analysis, the E²STORMED DST proposes that lifecycle costs should be estimated using unit construction and maintenance costs. These costs are multiplied by each main size characteristic in each component. The main size characteristic used in each type depends on its properties and they are detailed in Table 2.2. Unit costs rates are introduced in the estimation panel (shown when the Estimate button is clicked).

Type of drainage infrastructure	Main dimension	Units
Conventional drainage networks	Length	m
Conventional roof	Area	m^2
Standard pavement	Area	m^2
Structural detention facilities	Volume	m^3
Rain harvesting systems	Volume	m^3
Water butts	Volume	m^3
Green roofs	Area	m^2
Permeable pavements	Area	m^2
Soakaways	Volume	m^3
Infiltration trenches	Volume	m^3
Geocellular systems	Volume	m^3
Bioretention areas	Area	m^2
Rain gardens	Area	m^2
Filter strips	Area	m^2
Filter drains	Volume	m^3
Vegetated swales	Area	m^2
Infiltration basins	Volume	m^3
Detention basins	Volume	m^3
Retention ponds	Volume	m^3
Constructed wetlands	Volume	m^3

Table 2.2. Main dimension used for each type of infrastructure.

The parts of the **construction cost** estimation panel are (Figure 2.15):

A. Collapse button: Used to hide the construction cost panel.

B. Unit construction cost: Costs of designing and installing a drainage infrastructure component based on each main size characteristic. A default value of this cost rate for each type is shown when the Default Value button is clicked. The proposed default values of construction unit costs are shown in Table 2.3 and detailed in Annex 1. They are obtained from international literature and guidelines, as shown in the E²STORMED Report on stormwater management. Construction costs are very site specific and therefore, general rate only be used for a first approximation and cannot be considered as definitive values.

C. Estimate button: Estimates construction costs multiplying the construction cost rates by the main size characteristic of the infrastructure.

Figure 2.15. Construction cost estimation panel.

The **Maintenance cost** estimation panel is similar to the construction cost estimation panel with maintenance costs rates. The proposed default values of maintenance cost rates are shown in Table 2.3 and detailed in Annex 1. They are obtained from international literature and guidelines, as shown in the E²STORMED Report on stormwater management. In the same way, maintenance costs are also very site specific and therefore, general rates can only be used for a first approximation and cannot be considered as definitive values.

The **Land take** costs estimate panel (Figure 2.16) can be used to estimate the land take costs as a product of land cost rates in this urban area by the area occupied. In this case, no default values are proposed since the land cost varies so widely in the different urban areas and the area occupied depends on the infrastructure size and design.

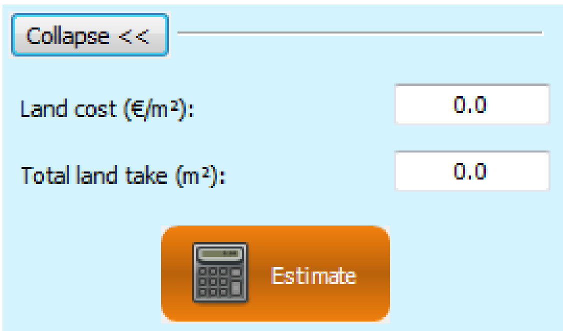


Figure 2.16. Land take cost estimation panel.

Type of drainage infrastructure	Unitary construction cost	Unitary maintenance annual cost
Conventional drainage networks	200.00 €	1.00 €
Conventional roof	60.00 €	0.40 €
Standard pavement	50.00 €	0.45 €
Structural detention facilities	400.00 €	1.50 €
Rain harvesting systems	250.00 €	70.00 €
Water butts	320.00 €	1.00 €
Green roofs	120.00 €	15.00 €
Permeable pavements	30.00 €	1.00 €
Soakaways	40.00 €	4.00 €
Infiltration trenches	40.00 €	4.00 €
Geocellular systems	150.00 €	0.80 €
Bioretention areas	75.00 €	8.00 €
Rain gardens	65.00 €	2.50 €
Filter strips	6.00 €	0.10 €
Filter drains	35.00 €	0.90 €
Vegetated swales	20.00 €	0.10 €
Infiltration basins	65.00 €	5.00 €
Detention basins	22.00 €	0.50 €
Retention ponds	45.00 €	1.50 €
Constructed wetlands	40.00 €	1.30 €

Table 2.3. Default values for unitary construction and maintenance costs.

EXAMPLE

In the proposed example, construction and maintenance costs are estimated using the unit costs proposed in the E²STORMED DST, multiplying them by the main characteristic for each infrastructure. These characteristics are defined in Section 1.7. The results for each component of each scenario are shown in Table 2.4.

As can be seen in this table, construction costs are higher for scenario 1 although in the scenario 2, land take costs are much higher. Therefore, in total, drainage implementation costs will be higher in scenario 2.

Infrastructure	Construction cost (€)	Maintenace cost (€/year)	Land take cost (€)	Lifespan (years)
Scenario 1				
Conventional drainage network	180000	900	-	35
Conventional roof	18000	120	-	23
Structural detention facility	260000	975	-	50
Scenario 2				
Water butt	11550	46.2	-	30
Green roof	43500	3000	-	40
Retention pond	29250	975	118125	50
Vegetated swale	25500	170	261900	30

Table 2.4. Lifecycle costs in the example.

2.6.4. Estimation of lifecycle energy consumptions and emissions

→ Detailed analysis

The construction, operation and maintenance of drainage systems involves energy consumption which must be considered in order to determine the energy efficiency of the Urban Water Cycle. Furthermore, an environmental impact statement requires the assessment of energy consumption which is usually estimated by calculating the associated equivalent CO_2 emissions as they express the potential effect on global warming. Thus, both energy consumption and environmental impact need to be evaluated.

The construction of water urban infrastructure systems involves a significant consumption of different resources (water, energy, etc.). Energy demand for conventional and sustainable urban drainage systems requires energy mainly in the form of electricity and fuel. Some examples include: energy to modify the topography and for the production of building materials, etc.

Construction energy consumption and emissions are estimated based on the construction project of each infrastructure. The unit energy consumption of machinery and materials can be obtained from international guidelines and recommendations, and the total construction energy consumption and emissions can be estimated by adding the consumption and emissions of each process necessary for construction. This process is detailed in the E²STORMED Report on energy in the urban water which has been followed to obtain the values used in the E²STORMED DST.

In the same way, **maintenance energy consumption and emissions** can be estimated with the consumption and emissions of each maintenance activity. In general, inspection and monitoring are the most energy intensive activities as staff transport is involved. This process is also detailed in the E²STORMED Report on energy in the urban water cycle which has been followed to obtain unit energy consumption and emission values for the maintenance of each type.

→ Estimative analysis

Construction energy consumption and emissions are estimated in the E²STORMED DST using unit energy consumption and emissions. These unit values are multiplied in each infrastructure by the main size characteristics which depend on the properties of each and are detailed in Table 2.2. Unit values are introduced in the estimation panel (shown when the Estimate button is clicked).

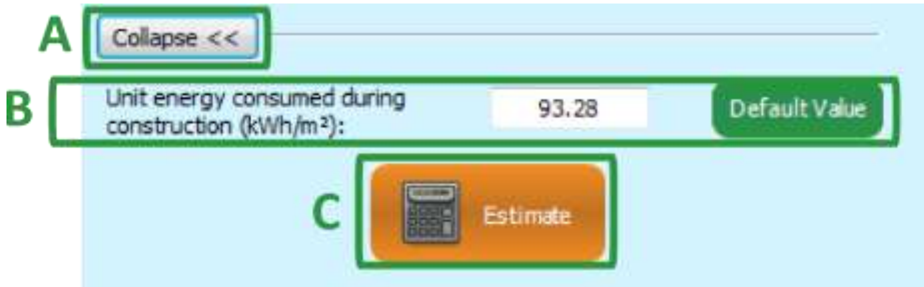


Figure 2.17. Construction energy consumption estimation panel.

The parts of the **construction energy consumption** estimation panel are (Figure 2.17):

- **A.** Collapse button: Used to hide the construction energy consumption panel.
- **B.** Unit energy consumed during construction: Construction energy consumed based on its main size characteristic. A default value for each type is shown when the Default Value button is clicked. Proposed default values are shown in the E²STORMED Report on energy in the urban water cycle. Values obtained are shown in Table 2.5. Energy consumption for this type of activity is very site specific and therefore, general values can only be used for a first approximation and cannot be considered as being definitive.
- **C.** Estimate button: Estimates the construction energy consumption by multiplying the unit energy consumption cost by its main size characteristic.

Equivalent CO_2 emissions during construction are also estimated using unit values. The options of the emissions estimation panels are the same as the options in the energy estimation panels. Suggested default values are shown in the E²STORMED Report on energy in the urban water cycle and are shown in Table 2.5. Drainage infrastructures emissions are very site specific and therefore, general values can only be used for a first approximation and cannot be considered to be definitive.

The **Maintenance energy consumed** has been estimated dividing maintenance in two parts, as explained in the E²STORMED Report on energy in the urban water cycle:

- Annual maintenance: It refers to all activities carried out over the period of one year. These activities are simple and easy to execute. Inspection and monitoring are common for all drainage systems while other annual maintenance activities depend on each system characteristics. Some typical maintenance activities are: grass mowing and cuttings, litter removal, scrub clearance, weed control, vacuum sweeping of paving, top-up mulched areas / re-mulch beds as required, etc. The energy required and emissions for this maintenance are estimated with the energy consumption and emissions associated to the transport, which is the fuel consumed by the vehicle when visiting the site.

- Periodic maintenance: It refers to all those activities carried out every several years. Examples of scheduled periodic maintenance activities include: clear vegetation, de-silting, de-silting of main area, install new geotextile, remove and reinstall block pavement, and remove, dispose and replace gravel layer. These activities are (generally) more difficult to execute than the annual maintenance activities and are, consequently, more energetically intensive. The energy consumption and emissions of periodic maintenance are estimated based on unit values

As shown in the following formula, energy required is estimated adding energy consumed during annual maintenance (first term) and during periodic maintenance (second term):

$$ENE = n \cdot c \cdot d \cdot NCV + S \cdot Uen_{mant} \qquad \text{Equation 2.1}$$

Where *n* is the number of trips for annual maintenance (recommended values provided by the Decision Support Tool are shown in Table 2.5.), *c* is the fuel consumption of the vehicle (DST considers 8 l /100 km), *d* is the average distance to visit the site for annual maintenance (default value is 5 km), *NCV* (net calorific value of the fuel, DST considers 10.03 kWh/l), *S* is the main size characteristic of the infrastructure (length, area or volume) and Uen_{mant} is the unit value for energy consumption in periodic maintenance (suggested unit values for each type of infrastructure are shown in Table 2.5).

Following the same procedure, emissions during maintenance are estimated with the following equation:

$$EMI = n \cdot c \cdot d \cdot EF + S \cdot Uem_{mant} \qquad \text{Equation 2.2}$$

Where *EF* (emissions factor of the fuel, DST considers 2.68 CO_2e/l) and Uem_{mant} is the unit value for emissions in periodic maintenance (suggested unit values for each type of infrastructure are shown in Table 2.5). The justification of these proposed unit values is explained in the E²STORMED Report on energy in the urban water cycle.

In order to compute estimate energy consumptions and emissions during maintenance, these values should be introduced ion the DST as shown in the following figure:

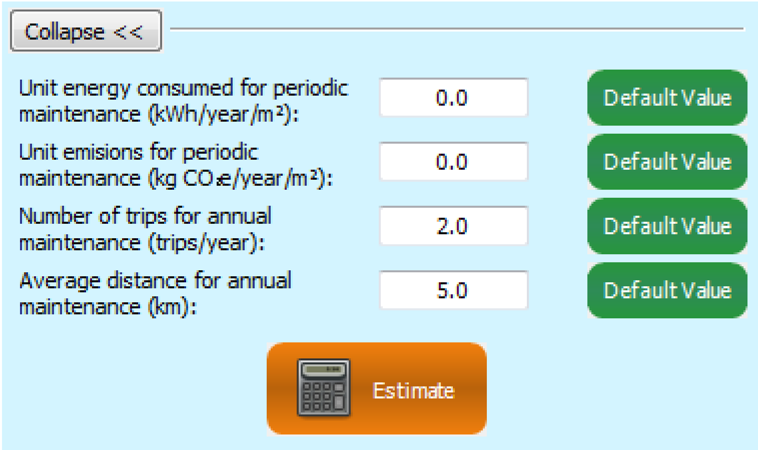


Figure 2.18. Maintenance energy consumption and emissions estimation panel.

Type of drainage infrastructure	Unit	Construction		Periodic Maintenance		Number of trips
		Energy kWh/unit	*Emissions* kgCO2e/unit	*Energy* kWh/unit	*Emissions* kgCO2e/unit	
Sewer Pipes	m	32.32	9.56	0	0	1
Standard Pavement	m^2	164.68	52.11	0.0004	0.0001	1
Structural Detention Facilities	m^3	849.29	269.02	0	0	2
Conventional Roof	m^2	123.07	37.29	0	0	1
Vegetated Swales	m^2	42.82	13.41	0.1853	0.0488	6
Filter Drains	m^3	101.28	31.99	6.8836	1.8136	2
Infiltration trenches	m^3	55.74	17.13	6.8836	1.8136	2
Soakaways	m^3	52.10	16.06	5.4993	1.4489	2
Filter Strips	m^2	11.58	3.40	0	0	12
Permeable Pavement	m^2	92.18	29.17	0.0014	0.0004	2
Retention Ponds	m^3	36.84	11.10	0.0063	0.0017	2
Detention Basins	m^3	25.52	7.50	0.0039	0.001	2
Infiltration Basins	m^3	15.66	4.25	0.0039	0.001	2
Rain gardens	m^2	117.99	35.98	0.0987	0.026	12
Bioretention Areas	m^2	137.13	42.32	0.0987	0.026	12
Constructed Wetlands	m^2	71.87	10.77	0.0126	0.0033	2
Rainwater Harvesting System	m^3	245.42	80.61	0	0	2
Water butts	m^3	241.96	79.88	0	0	2
Green Roof	m^2	93.28	28.11	0	0	2
Geocellular Systems	m^3	1011.93	328.59	0	0	2

Table 2.5. Energy consumed and equivalent CO_2 Emissions unit values for each type of drainage infrastructure construction and periodic maintenance.

EXAMPLE

In the proposed example, construction and maintenance energy consumption and emissions are determined by the unit values in the E²STORMED DST, multiplying them by the main characteristic of each infrastructure. These characteristics are defined in Section 1.7. The results for each component of each scenario are shown in Table 2.6.

Infrastructure	Construction energy consumed (kWh)	Maintenance energy consumed (kWh/year)	Construction emissions (kg CO_2)	Maintenance emissions (kg CO_2/year)
Scenario 1				
Conventional drainage network	29088	4.012	8604	1.072
Conventional roof	36921	4.012	11187	1.072
Structural detention facility	552038.5	8.024	174863	2.144
Scenario 2				
Water butt	11178.55	8.024	3690.46	2.144
Green roof	27984	8.024	8433	2.144
Retention pond	23946	12.119	7215	3.249
Vegetated swale	72794	339.082	22797	89.392

Table 2.6. Lifecycle energy consumed and emissions in the example.

2.7. WATER SUPPLY

2.7.1. Introduction

Linkages within the different components of the urban water cycle are numerous and complex. In this section data about the water supply system is introduced to help quantify the costs and benefits of water saved and consumed through better stormwater management.

On the one hand, stormwater reutilization with rainwater harvesting systems is an ancient technique enjoying a revival in popularity due to the inherent quality of rainwater and the current interest in reducing consumption of treated water. With these systems, collected water is used for non-potable purposes such as flushing toilets, washing machines and irrigation. Rainwater harvesting systems can also be used to provide potable water, but a sophisticated water treatment system may be necessary to ensure compliance with potable water quality standards. Water butts are the simplest type of rainwater harvesting systems and are typically used for irrigation purposes.

Stormwater re-use with rainwater harvesting systems allows the volume of water used to be used, resulting in economic benefits and a reduction in energy consumed by the acquisition and treatment of drinking water. These energy savings are especially high where desalination is used for water supply.

On the other hand, some drainage infrastructures can use potable water for irrigation or cleaning purposes. This addition in the volume of water consumed also increases costs and energy consumption.

2.7.2. Water supply tab

In each scenario, this tab only should be completed if rain water harvesting systems or water butts are used, or if significant volumes of drinking water are consumed for irrigation or cleaning (for example for keeping grass green). Data to be introduced in this tab is as follows (Figure 2.19):

A. Water cost: Value of cubic metre of water supplied. This value can easily be obtained from water bills and it is highly dependent on local conditions. This value is used to estimate the benefit of water reutilization and the potential water consumption cost reduction.

B. Energy consumption and emissions in water acquisition: Energy consumed and CO_2 emissions per cubic metre to obtain and treat water in the water supply system. This value can be obtained from measurements of local energy consumed. There may be significant differences in energy consumed depending on the water source; usually desalinated water has the highest energy needs. In the acquisition panel (shown when the Estimate button is clicked) a procedure is suggested to estimate the unit energy consumption costs and emissions. This panel is explained in Section 2.7.3.

C. Energy consumed and emissions in water conveyance: Energy consumed and CO_2 emissions per cubic metre to convey water from the acquisition point to the urban distribution tank. This value can be obtained from measurements of energy consumed locally. Energy consumed mainly depends on the amount of pumping needed to convey this water. In the conveyance panel (shown when the Estimate button is clicked) a procedure is suggested to estimate these unit energy consumptions and emissions. This panel is explained in Section 0

D. Energy consumed and emissions in water distribution: Energy consumed and CO_2 emissions per cubic metre to distribute water in the urban area. This value can be obtained from measurements of energy consumed locally. The energy consumed mainly depends on the amount of pumping needed to distribute this water. In the distribution panel (shown when the Estimate button is clicked) a procedure is proposed to estimate these unit energy consumptions and emissions. This panel is explained in 2.7.5.

E. Water losses in the network: Percentage of water that is lost in the water supply network. The higher these losses are, the more energy is needed to get water in the water supply point, as shown in Equation 2.4.

F. Volume of water consumed: Annual volume of potable water consumed for irrigation and cleaning purposes for the systems defined in the drainage scenario. This volume of water consumed produces an increment on stormwater management costs and energy consumed.

G. Volume of water reused: Annual volume of water reused from rain harvesting systems and water butts. The process to estimate this volume is explained in 2.7.6.

H. Results for water supply: Annual costs or benefits, energy consumed or saved and emissions saved or avoided in the water supply system produced by stormwater management. These values are estimated when the Estimate button is clicked.

Annual costs or benefits of water reused and consumption is estimated with the following equation:

$$FIN = c \cdot (V_{cons} - V_{reu}) \qquad \textit{Equation 2.3}$$

Where *FIN* is the financial cost (positive) or benefit (negative) of water reused and consumption (econ. units/year), *c* is the water cost (econ. units/m³), V_{cons} is the volume of water consumed (m³/year) and V_{reu} is the volume of water reused in the rain harvesting systems and water butts (m³/year).

Annual energy consumed or saved of water reused and consumption is estimated with the following equation:

$$ENE = (ene_a + ene_t + ene_d) \cdot (V_{cons} - V_{reu}) \cdot \frac{100}{100-l} \qquad \textit{Equation 2.4}$$

Where *ENE* is the energy consumed (positive) or saved (negative) of water reused and consumption (kWh/year), ene_a is the energy consumed in water acquisition (kWh/m³), ene_t is the energy consumed in water conveyance (kWh/m³), ene_d is the energy consumed in water distribution (kWh/m³) and *l* are the percentage of water losses in the network (%).

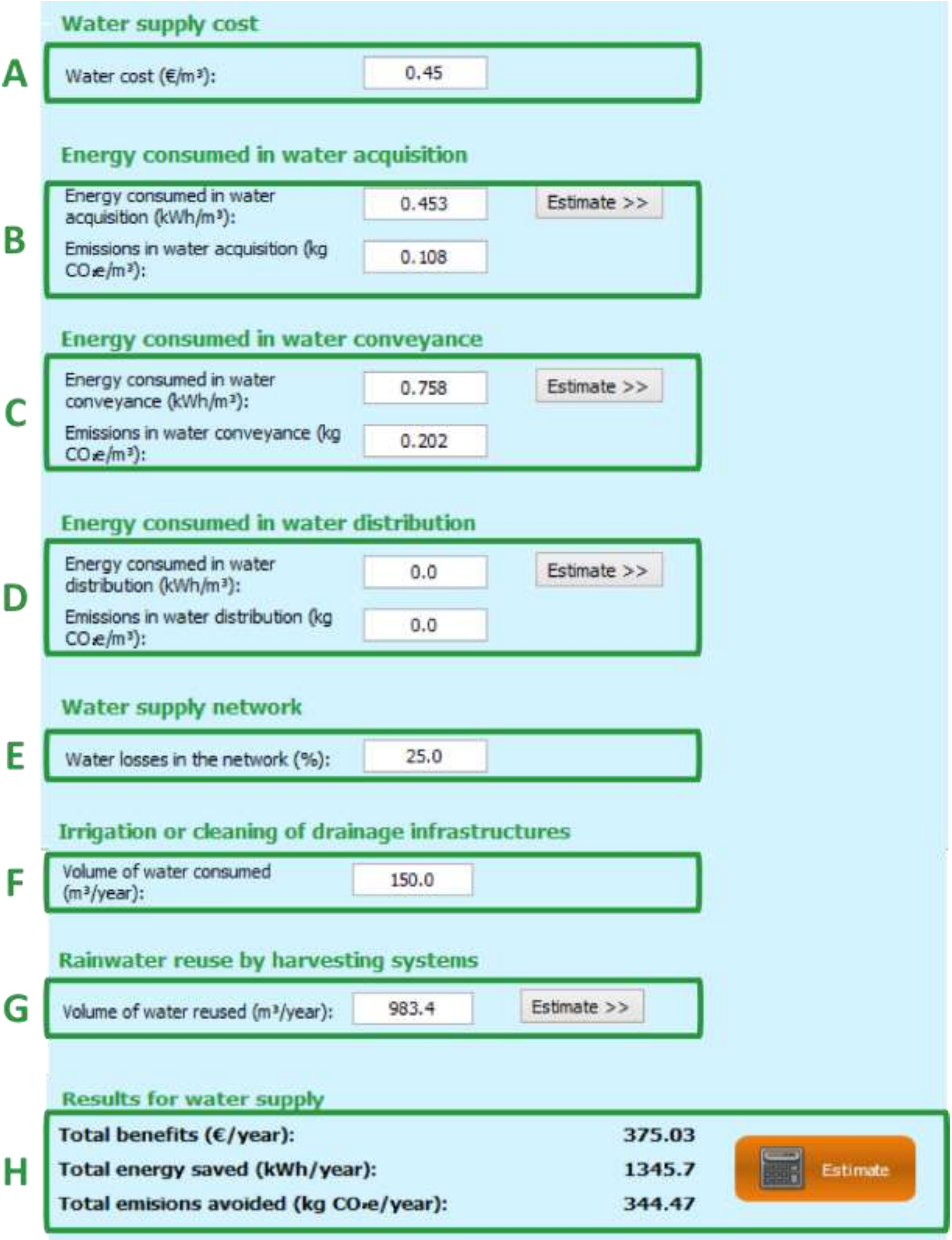


Figure 2.19. Water supply tab.

Finally, annual emissions or emissions avoided of water reused and consumption is estimated with the following equation:

$$EMI = (emi_a + emi_t + emi_d) \cdot (V_{cons} - V_{reu}) \cdot \frac{100}{100-l} \qquad \textit{Equation 2.5}$$

Where *EMI* are the emissions produced (positive) or avoided (negative) of water reused and consumption (kg CO_2/year), emi_a are the emissions produced in water acquisition (kg CO_2/m^3), emi_t are the emissions produced in water conveyance (kg CO_2/m^3) and emi_d are the emissions produced in water distribution (kg CO_2/m^3).

EXAMPLE

Water supply benefits and costs of stormwater management have been calculated for the example with the following data:

- Water cost: 0.45 €/m³.
- The energy consumed and emissions of each part of the water supply system are estimated as indicated in the following sections.
- Water losses in the network are 25%.
- In scenario 1, 100 m³/year are consumed to clean the structural detention facility.
- In scenario 2, 150 m³/year are consumed to irrigate the green roof.
- In scenario 2, stormwater volume reused in water butts is estimate as explained in 2.7.6.

The results obtained in this tab are shown in Table 2.7.

Scenario	Water consumed (m³/year)	Water reused (m³/year)	Costs (€/year)	Energy consumed (kWh/year)	Emissions (kg CO_2/year)
Scenario 1	100	0	45	161.47	41.33
Scenario 2	150	983.4	-375.03	-1345.7	-344.47

Table 2.7. Water supply results in the example.

2.7.3. Estimation of energy consumed in water acquisition

→ Detailed analysis

Energy estimation in water acquisition includes the energy consumed and CO_2 emissions produced per cubic metre of water obtained and treated.

In general, the best method to obtain the **energy consumed** is to measure it directly in the water acquisition system, since it depends on local conditions, equipment and methods. It should include the energy needed to obtain the water from its source and to treat this water. In the next part, an estimation method is proposed (shown in the water acquisition panel) to be used when these data are not available.

When the energy consumed has been obtained, the equivalent CO_2 emissions can be obtained using the electricity emissions factor (if the main energy vector used is electricity) or the fuel emissions factor (if other fuel is used). The electricity emissions factor is defined in Section 2.3. The emissions factor of the most important type of fuels used in urban water systems are shown in Table 2.8.

	Emissions factor kg CO_2/kWh
Natural gas	0.202
Liquefied Petroleum Gases	0.227
Gasoline	0.249
Diesel	0.267
Other petroleum products	0.264
Biofuels	0.255
Coal	0.340
Wood/wood waste	0.403

Table 2.8. Emission factors of the most important type of fuels used in urban water systems.

→ Estimation

This method is based on pumping equations and international values of energy consumed in water acquisition. Energy consumption from two different sources of water can be combined in this tab. For each source of water, two different methods can be used to estimate energy consumption and emissions depending on the water source.

If treated water comes from **desalination**, the energy consumed per cubic metre is obtained directly from international values. Desalination removes high concentrations of minerals and salts from seawater consuming high rates of energy in the process. The E²STORMED Report on energy in the urban water cycle includes a report on data on the energy consumed in desalination from different international cases. In the E²STORMED DST, an average value of 3 kWh/m³ is proposed. Electricity is the main energy vector for desalination so the CO_2 emissions per cubic metre are estimated using the electricity emissions factor, as explained in Section 2.3.

If water is obtained from **surface water** bodies or **groundwater**, the energy consumed depends on pumping requirements and the type of water treatment needed. In this case, the water acquisition panel has the appearance shown in Figure 2.20.

In this panel, the pumping energy needs per cubic metre are estimated using the following equation:

$$ENE = \Delta H \cdot \frac{9810}{3600 \cdot 1000} \cdot \frac{100}{\eta_{mec}} \cdot \frac{100}{\eta_{ener}} \qquad \text{Equation 2.6}$$

Where *ENE* is the energy consumed per cubic metre in pumping (kWh/m³), ΔH is the height different between the outflow point and the water source point (m), η_{mec} is the mechanical efficiency of the pump to transmit the energy to the water (a recommended value is 75%) and η_{ener} is the energy efficiency of the energy system to transmit the energy from the pump (recommended values are 85% for electric systems and 35% for fuel systems). This equation is based on the Bernoulli equation set up to compute the energy necessary to pump a cubic metre of water. This is explained in detail in the E²STORMED Report on energy in the urban water cycle.

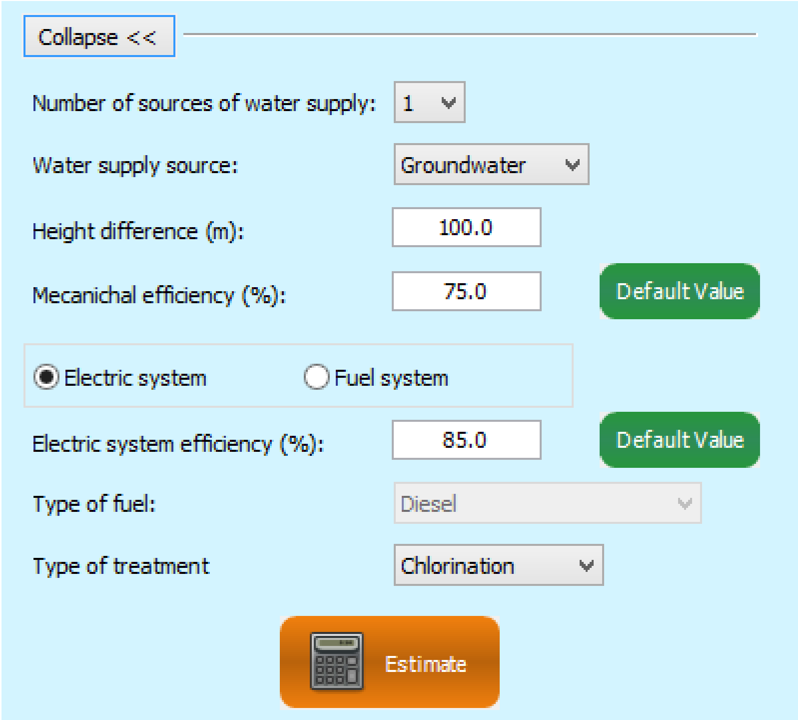


Figure 2.20. Water acquisition panel.

Pumping emissions are estimated using the electricity emissions factor for electric pumping systems or the fuel emissions factor for fuel pumping systems. The electricity emissions factor is defined in Section 2.3. The emissions factor of the most important type of fuels used in the urban water system are shown in Table 2.8.

In order to estimate the energy consumed in water treatment, different treatment possibilities can be selected:

- No treatment: Water is not treated in the water supply network.
- Basic treatment: When water only has a basic quality treatment such asflocculation, filtration and sedimentation.
- Chlorination: Potable water is chlorinated to eliminate microbial contamination.
- Ozonation: Basic treatment is complemented with an ozonation process.
- UV Radiation: Basic treatment is complemented with a UV Radiation process.

The energy consumed in each treatment technique has been estimated using average values obtained from the literature and international case studies, as explained in the E²STORMED Report on energy in the urban water cycle. Typical values used in each type of water treatment are shown in Table 2.9

Type of treatment	Average energy consumed (kWh/m³)
No treatment	0
Basic treatment	0.0052
Chlorination	0.025
Ozonation	0.055
UV Radiation	0.112

Table 2.9. Average energy consumed in each type of treatment.

Treatment emissions are estimated on the basis that the main energy source is electricity, so the energy consumed values are multiplied by the electricity emissions factor, explained in Section 2.3.

The total energy needs and emissions per cubic metre are computed when the Estimate button is clicked as are the sum of pumping and treatment energy consumed and emissions. If two different sources of water are combined, these values are estimated based on the percentage of water from each source.

EXAMPLE

In the example, water is obtained only from groundwater (100 m depth), with electric pumps and the only treatment is chlorination. These data are introduced in the water acquisition panel, as shown in Figure 2.20. Default values are used for pumping efficiencies, and chlorination is included to improve water quality. With these data, the estimated energy consumed for water acquisition is 0.453 kWh/m³ and emissions are 0.108 kg CO_2/m³.

2.7.4. Estimation of energy consumed in water conveyance

→ Detailed analysis

The energy required to be estimated in water conveyance is the energy needed to move the water from the acquisition point to the distribution tank from where water is supplied to the urban area.

In general the best method of obtaining this energy consumed is to measure it directly in the water conveyance system, since it depends on local conditions, equipment and methods. In the next section, an estimation method is proposed (shown in the water conveyance panel) to be used when these data are not available.

When the energy consumed has been obtained, equivalent CO_2 emissions can be obtained using the electricity emissions factor (if the main energy vector used in pumping is electricity) or the fuel emissions factor (if fuel is used for pumping). The electricity emissions factor is defined in Section 2.3. The emissions factor of the most important type of fuels used in the urban water system are shown in Table 2.8.

→ Estimation

This method is based on hydraulic equations for pumping needs estimation. In this panel, pumping energy needs per cubic metre are computed with the following equation:

$$ENE = (\Delta H + \Delta P) \cdot \frac{9810}{3600 \cdot 1000} \cdot \frac{100}{\eta_{mec}} \cdot \frac{100}{\eta_{ener}} \qquad \textit{Equation 2.7}$$

Where *ENE* is the energy consumed per cubic metre in pumping (kWh/m³), *ΔH* is the height difference between the distribution tank and the acquisition point (m), *ΔP* are the pressure losses along the pipe produced by friction (m), η_{mec} is the mechanical efficiency of the pump to transmit the energy to the water (a recommended value is 75%) and η_{ener} is the energy efficiency of the energy system to transmit the energy from the pump (recommended value are 85% for electric systems and 35% for fuel systems). This equation is based on Bernoulli equation particularized to compute the energy necessary to pump a cubic metre of water. This is further explained in detail in the E²STORMED Report on energy in the urban water.

Pressure losses (*ΔP)* are estimated with the following equation:

$$\Delta P = f \cdot \frac{L}{D/_{1000}} \cdot \frac{v^2}{2 \cdot 9.81} \cdot \left(1 + \frac{\%_{LOC}}{100}\right) \qquad \textit{Equation 2.8}$$

Where *f* is the friction factor that represents the frictional losses in the pipe, *L* is the pipe length (m) and it can be estimated like the distance between the water source and the distribution tank, *D* is the pipe internal diametre of the pipe (mm), *v* is the average water velocity in the pipe (m/s) and $\%_{LOC}$ are the minor losses in the pipe, represented as a percentage of friction losses (a representative value is 10%).

The friction factor *f* is estimated with the Colebrook White´s equation for turbulent flow:

$$\frac{1}{\sqrt{f}} = -2\, log_{10}\left(\frac{k/D}{3.7 \cdot D/_{1000}} + \frac{2.51}{v/_{\vartheta} \cdot D/_{1000} \sqrt{f}}\right) \qquad \textit{Equation 2.9}$$

Where ϑ is the kinematic water viscosity (taken as 10^{-6} m²/s) and *k* is the average roughness height of the pipe and it mainly depends on the pipe material (mm). Table 2.10 shows proposed values for this parametre for the most common pipe materials.

Type of material	Average roughness height (mm)
Cast iron	0.255
Concrete or concreted lined	0.3-3
Galvanized iron	0.150
Plastic	0.002
Steel	0.045

Table 2.10. Proposed values of average roughness height for different pipe materials (USEPA, 2000).

In the water conveyance panel, the different data needed to compute these equations are introduced. Default values are proposed for most of these data to estimate the energy consumed when no data are available. It has the appearance shown in Figure 2.20.

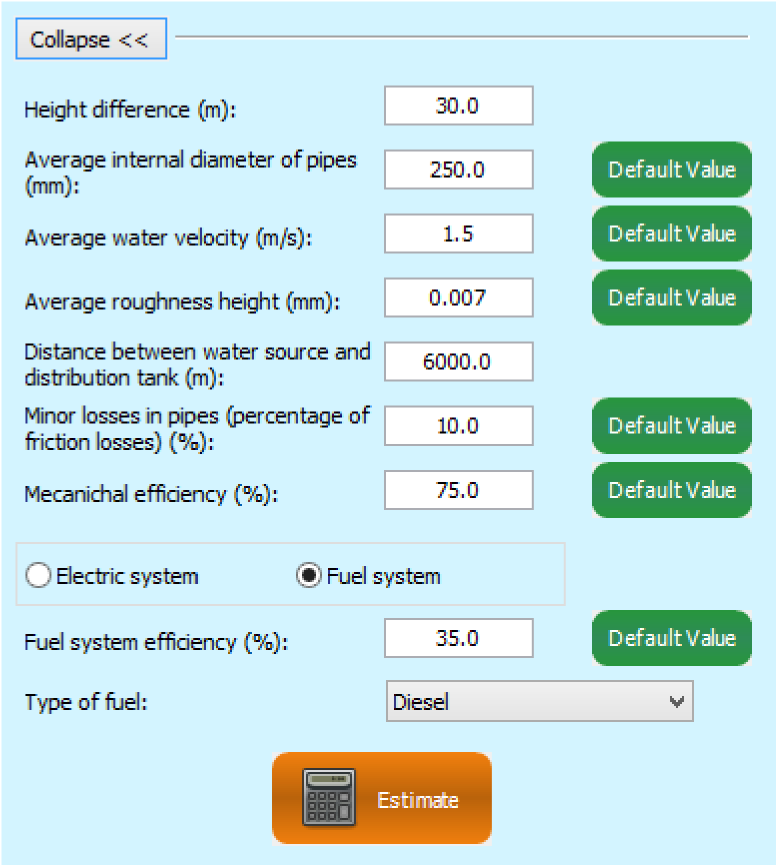


Figure 2.21. Water conveyance panel.

Water conveyance emissions are estimated using the electricity emissions factor for electric pumping systems or the fuel emissions factor for fuel pumping systems. The electricity emissions factor is defined in Section 2.3. The emissions factor of the most important type of fuels used in the urban water system are shown in Table 2.8.

EXAMPLE

In the example, the distance between the water source and the distribution tank is 6 000 m and the height difference between these two points is 30 meters. These data are introduced in the water conveyance panel, as shown in Figure 2.20. Default values are used for all the other data needed to compute pumping energy needs. With these data, the estimated energy consumed for water conveyance is 0.453 kWh/m^3 and emissions are 0.108 kg CO_2/m^3.

2.7.5. Estimation of energy consumed in water distribution

→ Detailed analysis

The energy required to be estimated in water distribution is the energy needed to distribute the water in the urban area from the distribution tank.

In general, the best method of obtaining this energy consumed is to measure it directly in the water distribution system, since it depends on local conditions, equipment and methods. In the next section an estimation method is proposed (shown in the water distribution panel) to be used when this data is not available.

When the energy consumed has been obtained, the equivalent CO_2 emissions can be obtained using the electricity emissions factor (if the main energy vector used in pumping is electricity) or the fuel emissions factor (if fuel is used for pumping). The electricity emissions factor is defined in Section 2.3. The emissions factor of the most important type of fuels used in the urban water system are shown in Table 2.8.

→ Estimation

This method is based on hydraulic equations for pumping. In this panel, the pumping energy needs per cubic metre are computed with the following equation:

$$ENE = (\Delta H + \Delta P + 0.102 \cdot P_{sup}) \cdot \frac{9810}{3600 \cdot 1000} \cdot \frac{100}{\eta_{mec}} \cdot \frac{100}{\eta_{ener}} \qquad \textit{Equation 2.10}$$

Where *ENE* is the energy consumed per cubic metre in pumping (kWh/m³), *ΔH* is the height different between the supply points and the distribution tank (m), *ΔP* are the pressure losses along the pipe produced by friction (m), P_{SUP} is the pressure that must be supplied to the houses (a recommended value is 300 kPa), η_{mec} is the mechanical efficiency of the pump to transmit the energy to the water (a recommended value is 75%) and η_{ener} is the energy efficiency of the energy system to transmit the energy from the pump (recommended value are 85% for electric systems and 35% for fuel systems). This equation is based on Bernoulli equation particularized to compute the energy necessary to pump a cubic metre of water. This is further explained in the Report on energy in the urban water cycle of the E²STORMED project.

Pressure losses (*ΔP)* are estimated with the following equation:

$$\Delta P = f \cdot \frac{L}{D/_{1000}} \cdot \frac{v^2}{2 \cdot 9.81} \cdot \left(1 + \frac{\%_{LOC}}{100}\right) \qquad \textit{Equation 2.11}$$

Where *f* is the friction factor that represents the frictional losses in the pipe, *L* is the pipe length (m) and it can be estimated like the distance between the distribution tank and the supplied houses, *D* is the pipe internal diametre of the pipe (mm), *v* is the average water velocity in the pipe (m/s) and $\%_{LOC}$ are the minor losses in the pipe, represented as a percentage of friction losses (a representative value is for distribution is 15%).

The friction factor *f* is estimated with the Colebrook White´s equation for turbulent flow:

$$\frac{1}{\sqrt{f}} = -2\, log_{10}\left(\frac{k/D}{3.7 \cdot D/_{1000}} + \frac{2.51}{v/_{\vartheta} \cdot D/_{1000}\sqrt{f}}\right) \qquad \textit{Equation 2.12}$$

Where ϑ is the kinematic water viscosity (taken as 10^{-6} m²/s) and *k* is the average roughness height of the pipe and it mainly depends on the pipe material (mm). Table 2.10 shows proposed values for this parametre for the most common pipe materials.

In the water distribution panel, the different data needed to compute these equations are introduced. Default values are proposed for most of these data to estimate energy consumed when no data are available. It has the appearance shown in Figure 2.22.

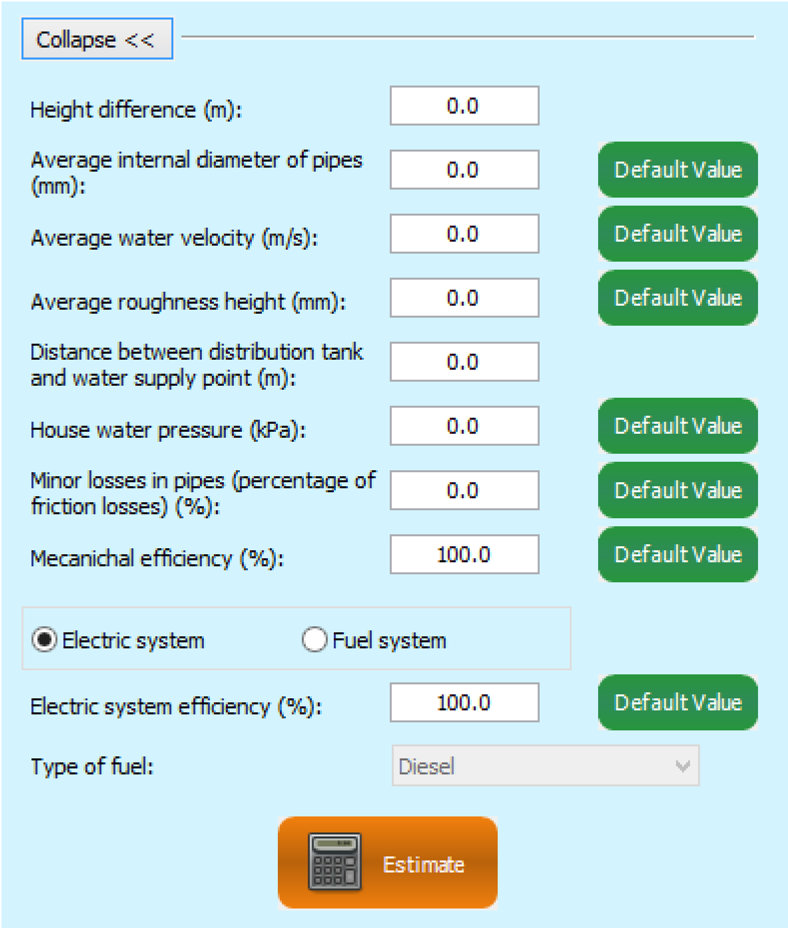


Figure 2.22. Water distribution panel.

Water distribution emissions are estimated using the electricity emissions factor for electric pumping systems or the fuel emissions factor for fuel pumping systems. The electricity emissions factor is defined in Section 2.3. The emissions factor of the most important type of fuels used in the urban water system are shown in Table 2.8.

EXAMPLE

In the example, water is distributed directly from the distribution tank by gravity. Therefore, the estimated energy consumed for water conveyance is 0 kWh/m³ and emissions are 0 kg CO_2/m³.

2.7.6. Estimation of the volume of rainwater available for reuse volume by harvesting systems

→ Detailed analysis

Stormwater reutilization with rainwater harvesting systems is an ancient technique enjoying a revival in popularity due to the inherent quality of rainwater and interest in reducing consumed of treated water (TWDB, 2005). With these systems, the water collected is used for non-potable purposes such as flushing toilets, washing machines and irrigation. Rainwater harvesting systems can also be used to provide potable water, but a sophisticated water treatment system may be necessary to ensure compliance with potable water quality standards. Water butts are the simplest type of rainwater harvesting systems and are typically used for irrigation purposes.

In order to estimate the annual volume of water reused with rain harvesting system and water butts, detailed water balances must be made. This water balance must be made with a rainfall series long enough to be representative of the annual variations and with a time-step short enough (one day should be a good option for a detailed analysis). The water balance is based on the inflows (depending on precipitation and drainage area characteristics) and outflows (water demands) in the storage. The following tools and manuals can be used for this detailed analysis:

- Rain harvesting manuals: Several manuals provide guidelines to design and maintain rain harvesting systems. Some examples are (CBC, 2007) and (TWDB, 2005).

- NCSU Rainwater Harvesting Model (NCSU, 2013): This computer model is available online to assist in determining the appropriate cistern size for a given situation. The model uses rainfall data and anticipated usage to establish cistern inputs and outputs.

- Rainwater Harvesting Calculators: Spreadsheets developed by public entities to estimate the annual performance of a rainwater harvesting cistern based on the estimation of the runoff to the cistern, cistern size and the site's non-potable demand. Some examples are the spreadsheets for San Francisco (SFPUC, 2012) and for Texas (TWDB, 2010).

If data are not available for a detailed water balance for each rain harvesting system, a global monthly water balance can be made with the E²STORMED DST, as explained in the next section.

→ Estimation

In the E²STORMED DST, a first approximation of water volume available for reuse can be based on a monthly water balance, as shown in Figure 2.23.

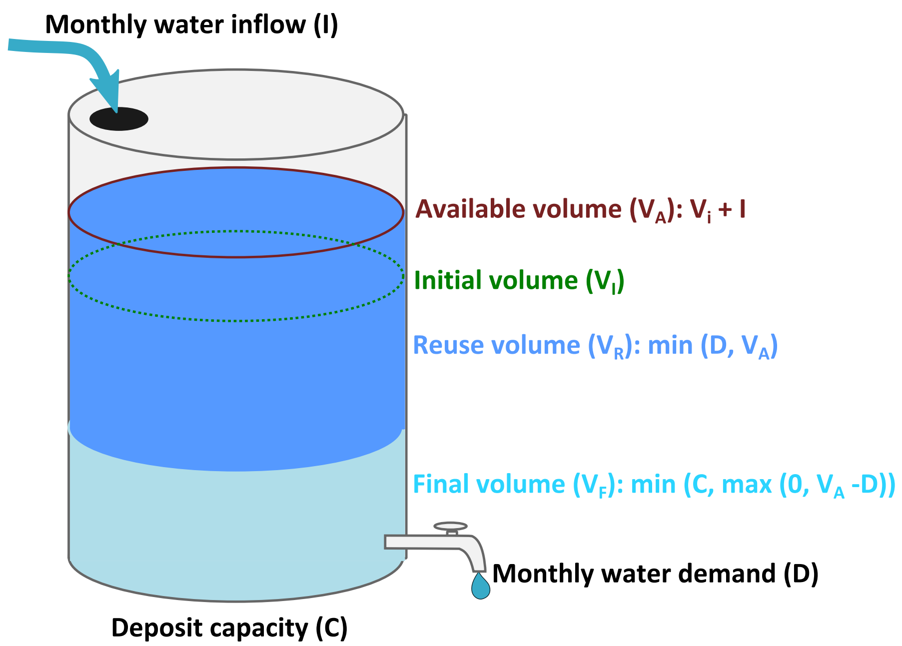


Figure 2.23. Monthly water balance in rain harvesting systems.

In this balance, monthly water inflow (*I*) can be estimated with the following formula (Woods-Ballard, y otros, 2007):

$$I = R \cdot A \cdot C \cdot e \qquad \textit{Equation 2.13}$$

Where *I* is the monthly water inflow (m^3), *R* is the monthly average rainfall (m), A is the catchment area of the rain harvesting system (m^2), *C* is the runoff coefficient, which indicates the proportion of the runoff that reaches the collection tank (recommended values is 0.9 for conventional roofs) and *e* is the filter efficiency, which represents the proportion of the collected water that is available for use (recommended value of 90%). The drainage coefficient and filter efficiency will depend on the details of each rain harvesting system and the mechanism in place to collect the water from the roof.

The monthly water demand (*D*) should be estimated for irrigation and household uses that will reuse this rainwater. Household water demand is more stable and depends on the number of inhabitants of the house. The volume of water needed will also depend on its use, for instance, for toilets use, 5-10 toilet flushes can be considered per person and per day (SFPUC, 2012).

Irrigation demand is usually more seasonal and can be estimated using evapotranspiration formulae (Allen, Pereira, Raes, & Smith, 1998; UCCE, 2000). These estimates multiply the potential evapotranspiration (which depends on local meteorological conditions) by an irrigated vegetation factor and by the irrigation system efficiency.

The data needed to compute this water balance with the E²STORMED DST are (Figure 2.24):

A. Collapse button: Used to hide the water reuse estimation panel.

B. Storage capacity: Sum of the storage capacity of all the rain harvesting systems and water butts introduced in the scenario. This capacity is used to compute the water balance shown in Figure 2.23.

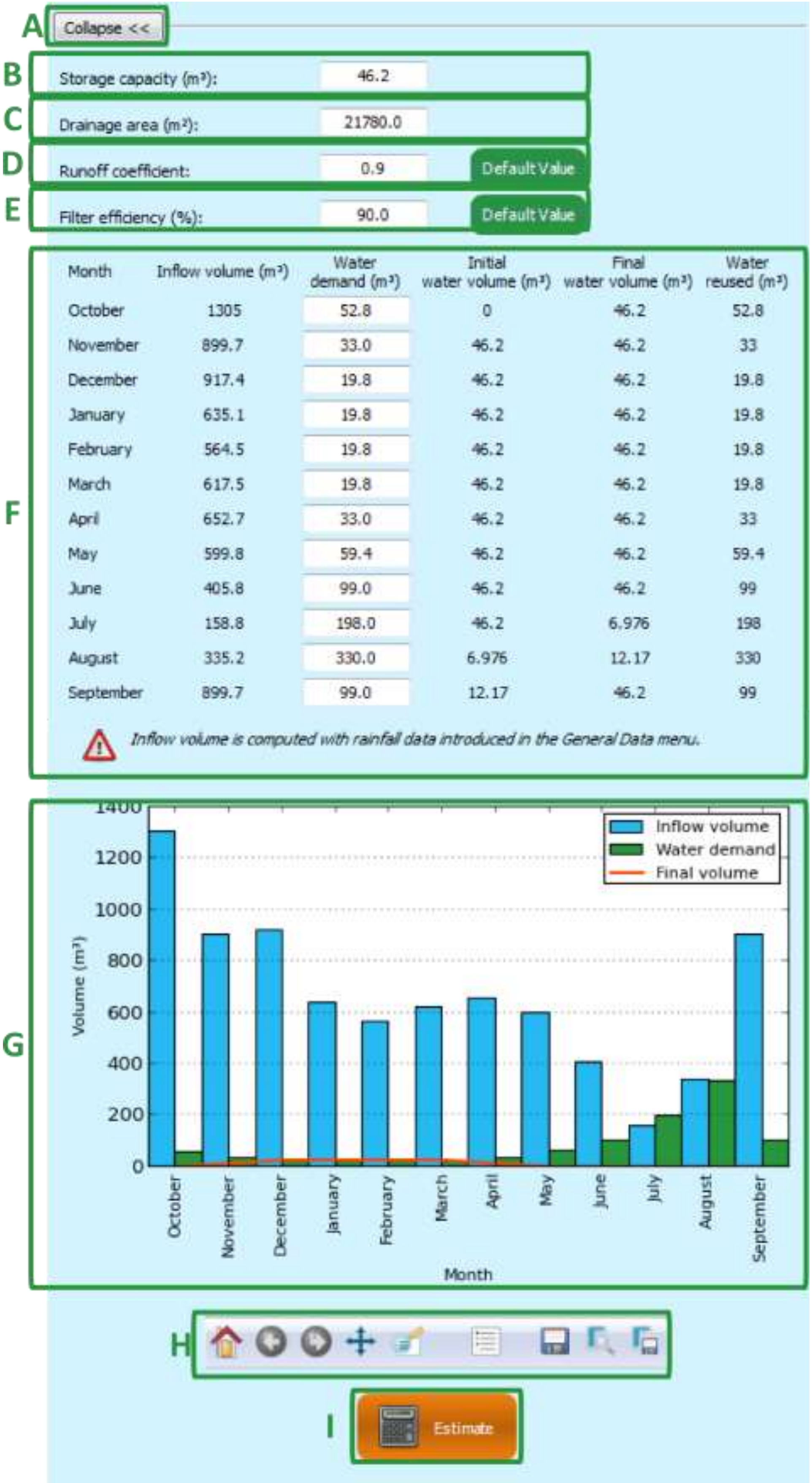
C. Drainage area: Sum of catchment areas of the rain harvesting systems to be used in Equation 2.11.

D. Runoff coefficient: Drainage coefficient of each catchment area for the rain harvesting systems to be used in Equation 2.11.

E. Filter efficiency: Proportion of the collected water that is available for use (default value is 90%).

F. Monthly water balance: Results of the water balance for the rain harvesting systems on the basis of the equations of Figure 2.23. Monthly average rainfall is introduced in the General data menu and water demand must be introduced by the user. In this balance, it is assumed that the storage volume is empty at the end of the summer.

G. Water balance graph: Represents graphically the water balance results. The blue bars show the inflow volume each month in the deposit and green bars show the water demands. The red line shows the annual variation of the water volume in the storage at the end of each month.



Month	Inflow volume (m³)	Water demand (m³)	Initial water volume (m³)	Final water volume (m³)	Water reused (m³)
October	1305	52.8	0	46.2	52.8
November	899.7	33.0	46.2	46.2	33
December	917.4	19.8	46.2	46.2	19.8
January	635.1	19.8	46.2	46.2	19.8
February	564.5	19.8	46.2	46.2	19.8
March	617.5	19.8	46.2	46.2	19.8
April	652.7	33.0	46.2	46.2	33
May	599.8	59.4	46.2	46.2	59.4
June	405.8	99.0	46.2	46.2	99
July	158.8	198.0	46.2	6.976	198
August	335.2	330.0	6.976	12.17	330
September	899.7	99.0	12.17	46.2	99

Inflow volume is computed with rainfall data introduced in the General Data menu.

Figure 2.24. Water reuse estimation panel.

H. Graph toolbar: Allows the user to move the view, zoom it and return to the initial graph view. These options can also be used to show or hide a legend, to export the graph and to view the graph results in a table.

I. Estimate button: When all the data has been input, this button computes the monthly water balance and estimates the annual volume of water reused in the storage volume.

EXAMPLE

In scenario 2 of the example, water to be reused from all of the water butts is estimated using the water reuse estimation panel. To estimate water reuse volume, all water butts have been considered as a single entity. The global capacity is 46.2 m³ (66 water butts x 0.7 m³) and the global drainage area is 21780 (66 water butts x 330 m² each). Water demands per water butt are shown in Table 2.11. These demands are multiplied by 66 (number of water butts) to estimate the global water demand and they are introduced in the water reuse estimation panel as shown in Figure 2.24.

Month	10	11	12	1	2	3	4	5	6	7	8	9
Water demand (m³)	0.8	0.5	0.3	0.3	0.3	0.3	0.5	0.9	1.5	3	5	1.5

Table 2.11. Water demands per water butt in the example.

With these data, the water reuse volume is estimated, obtaining a volume of water reused of 983.4 m³/year for scenario 2. Figure 2.25 shows the water balance results.

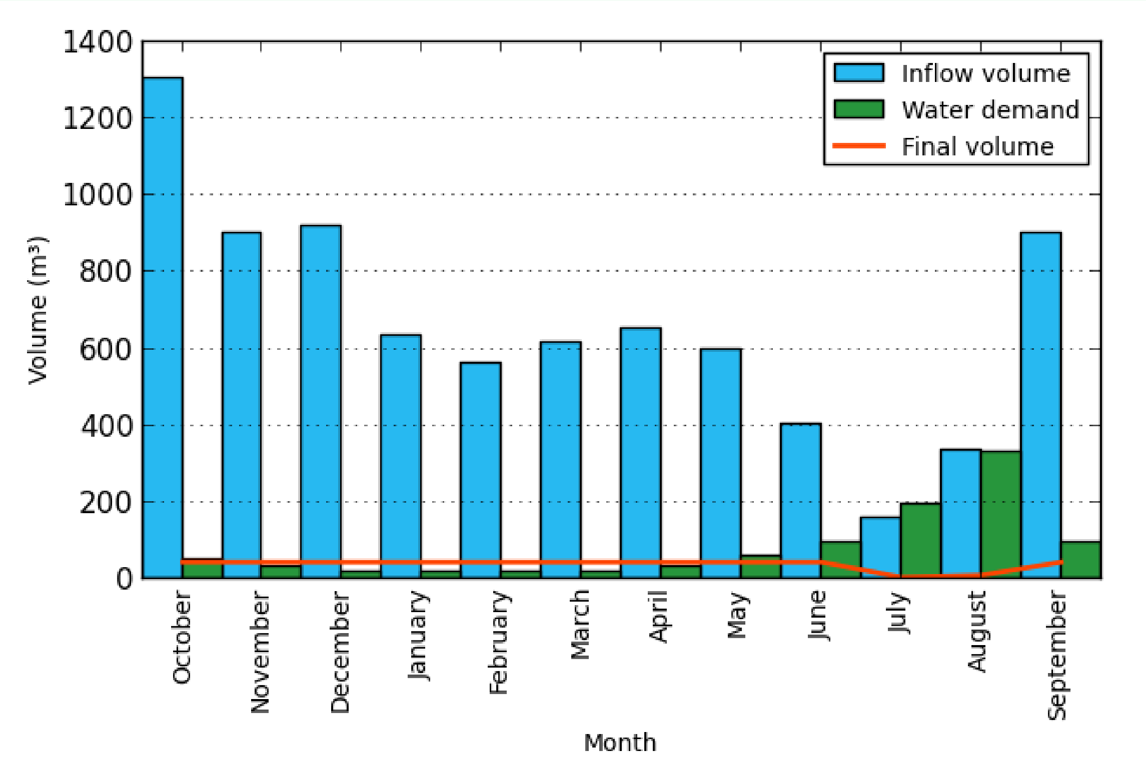


Figure 2.25. Example water reuse graph in scenario 2.

2.8. STORMWATER RUNOFF

2.8.1. Introduction

In this part of the E^{2}STORMED DST, the runoff produced in each drainage scenario is introduced. Some drainage arrangements produce a significant reduction of runoff volumes and rates, especially during small storm events. Volume reduction can lead to reduced frequency of discharges or much smaller discharge volumes, which produces lower water conveyance and treatment costs in both combined and separate networks.

The results from this section are used in the Conveyance ant treatment section (Section 2.9) to estimate the costs and energy consumed of treating and conveying all this runoff in each scenario.

2.8.2. Stormwater runoff

In this tab the runoff produced in each scenario is introduced. The parts of this tab are (Figure 2.26):

A. Runoff volume produced: Annual volume of runoff produced in the urban area for each scenario. The process to estimate this runoff is explained in Section 2.8.3. The simplified methodology described later in this section can be used to estimate runoff. The data need to estimate runoff are introduced in the runoff estimation panel (shown when the estimate button is clicked).

B. Aquifer recharge and evapotranspiration: Annual volume of aquifer recharge and evapotranspiration produced in the drainage infrastructures. The process to analyze runoff urban processes is explained in Section 2.8.3. The simplified methodology described later in this section can be used to estimate this volume. The data need to estimate this volume are introduced in the runoff estimation panel (shown when the estimate button is clicked).

C. Peak outflow rate for design storm: Maximum outflow rate obtained using a hydraulic model of the drainage system with the design storm. A simplified procedure to estimate this outflow rate is not provided in this tool, since it is a complex process and is not used in the DST financial, energy and emissions calculations. Only general guidance is given in Section 2.8.3. In general, this value is usually obtained when a stormwater system is designed with an hydraulic model. In this tool, these data should only be introduced if the outflow rate is an important criterion for the decision making process. If it is introduced, it can be used as decision criterion in the multi-criteria analysis as explained in Section 3.2.

D. Combined Sewer Overflows: Annual volume of discharge from Combined Sewer Overflows (CSO) produced in each scenario. This part is only shown in the scenarios where stormwater is discharged into a combined network (as defined in the Add scenario menu). The process to estimate this volume is explained in Section 2.8.4. The data needed to estimate CSO volume are introduced in the CSO estimation panel (shown when the estimate button is clicked).

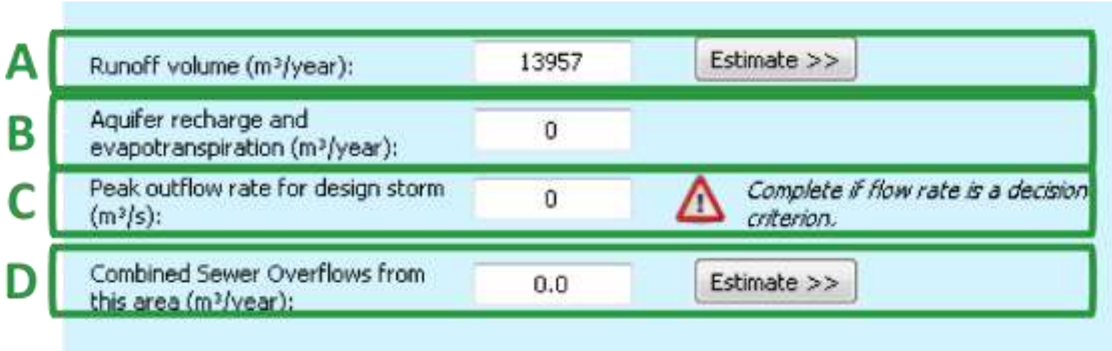


Figure 2.26. Stormwater runoff tab.

2.8.3. Estimation of runoff characteristics

→ Detailed analysis

Estimation of the annual runoff volume produced in an urban area should use accurate rainfall data and modeling of the urban flow processes both on the urban surface and through the drainage system. A water balance must be made for the total system including interception, evapotranspiration and infiltration processes. These computations can be made with specialized models and tools.

Hydraulic models can also be very useful to estimate peak outflow rate for the design storm. In this case, is necessary to evaluate the drainage system behaviour for this storm, obtaining the outflow hydrograph produced in each system component.

The following tools and guides can be useful to estimate the runoff characteristics according to the drainage system infrastructures in each scenario:

- Urban Hydrology for Small Watersheds (USDA, 1986): Presents simplified procedures to calculate storm runoff volume, peak rate of discharge, hydrographs, and storage volumes to design stormwater management systems. These procedures are applicable to small watersheds, especially urbanized watersheds.

- Storm Water Management Model (SWMM) (USEPA, 2013a): Free dynamic rainfall-runoff simulation model used for single event or long-term simulation of runoff quantity and quality from primarily urban areas. New releases allow modeling the hydrological performance of SuDS such as permeable pavements, green roofs, infiltration trenches and vegetated swales.

- Integrated Urban Drainage Modeling Guide (WAPUG, 2009): Detailed technical guidance that explains how to choose and use integrated urban drainage models.

- Stormwater and SuDS Manuals: Different manuals provide guidelines to design stormwater systems and each kind of SUDS. They also provide some formulae and procedures to easily define its size and characteristics. Some examples are: (CLADPW, 2010; CSQA, 2003; CP, 2008; NYSDEC, 2010; Puertas-Aguado, Suárez-López, & Anta-Álvarez, 2008; Woods-Ballard, y otros, 2007).

→ Estimation

In the E²STORMED DST runoff is estimated by selecting the downstream infrastructure of each infrastructure component introduced. Therefore, the drainage linkages between infrastructures are defined. The following rules must be followed:

- Drainage systems cannot create a loop. If the system A drains into system B, B cannot drain back into A.

- At least one component must drain into the combined network (in combined drainage system scenarios), into the separate network (in separate drainage system scenarios) or directly into the environment (in this type of scenario). The outflow from the lowest component will be the runoff produced from the urban area.

The annual runoff volume produced in each drainage infrastructure is estimated with the following formula:

$$V = (I + {}^{R}/_{1000} \cdot A \cdot C) \cdot \frac{(100 - \%_{red})}{100} \qquad \textit{Equation 2.14}$$

Where *V* is the annual runoff volume that flows from this infrastructure (m^3/year), *I* is the sum of the runoff volumes of the upstream infrastructures (m^3/year) and it is computed with the drainage linkages between infrastructures, *R* is the annual rainfall (mm/year), *A* is the tributary drainage area in each infrastructure (m^2), *C* is the runoff coefficient of this drainage area and $\%_{red}$ is the percentage of runoff volume reduced in the drainage infrastructure.

Annual aquifer recharge and evapotranspiration produced in the drainage infrastructures is estimated with the percentage of runoff volume reduction, since it is the difference between the inflow and the outflow. The total volume is obtained adding the volume of aquifer recharge and evapotranspiration for each infrastructure.

This formula is computed for each drainage infrastructure to compute the total runoff produced in the area. The data that should be introduced in this panel (Figure 2.27) is:

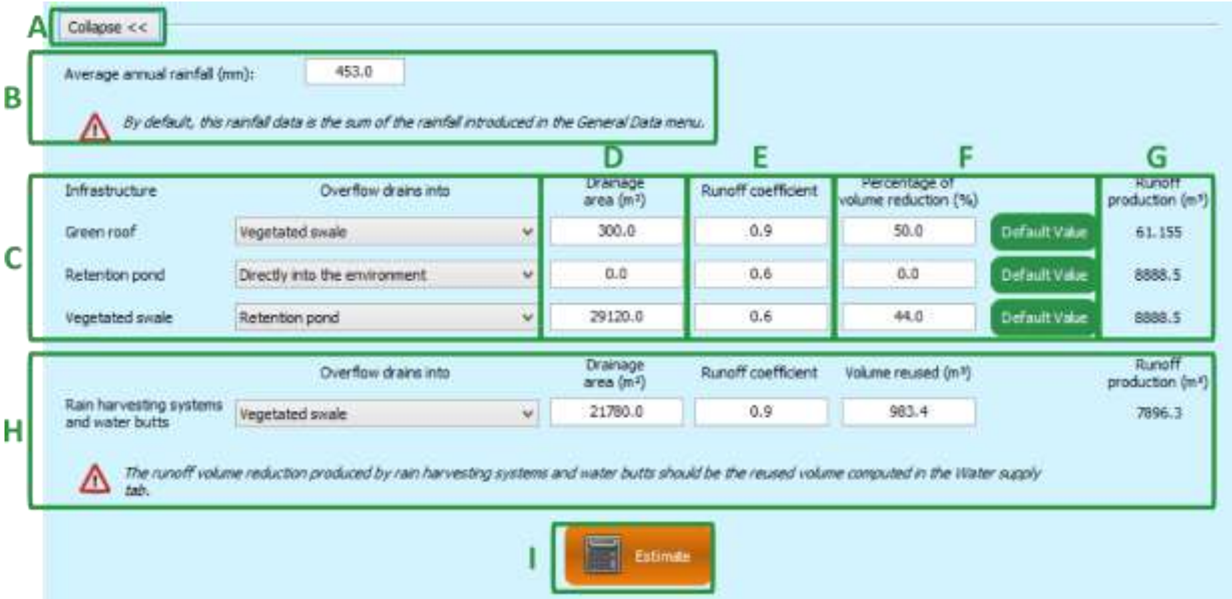


Figure 2.27. Runoff estimation panel.

- **A.** Collapse button: Used to hide the runoff estimation panel.
- **B.** Average annual rainfall: Average rainfall used to compute annual runoff volume in the urban area. By default, this value is the sum of monthly average rainfall data input in the General data menu.
- **C.** Infrastructures drainage linkages: In this part of the panel, the downstream infrastructure for each scenario's component parts is defined. With these data, the drainage linkages are computed to estimate the runoff produced.
- **D.** Drainage area: Upstream area of each drainage component. It should not include the drainage area upstream, only the area whose water flows directly into this component. In some infrastructures, initial values shown for drainage area are taken from the infrastructure area, even though they can be modified.
- **E.** Runoff coefficient: Represents the part of the runoff produced in the drainage area that reaches the component. It depends on the permeability of the drainage area and the land use. Table 2.13 shows recommended values of this coefficient for different land uses. In green roofs, an impermeable surface runoff coefficient should be considered (0.9-1) since the runoff volume reduction is considered within the percentage volume reduction applied. If there are different land uses upstream, a weighted runoff coefficient can be introduced.
- **F.** Percentage of volume reduction: Some stormwater components reduce the volume of runoff produced through infiltration, interception and/or evapotranspiration. Proposed default values of volume reduction for each type are presented in Table 2.12. These values can be used to obtain a first approximation for annual runoff volume reduction. They are highly dependent on component design and weather conditions. The more torrential the climate, the lower annual volume reductions will be achieved. In order to obtain an accurate estimation of runoff volume reduction, a continuous model is needed. It must represent water balance

during a representative period, analyzing interception, evapotranspiration and infiltration processes. Therefore, the annual evaporation and aquifer recharge produced in the drainage infrastructures is computed based on this coefficient.

G. Runoff production: Annual volume of runoff produced in each component obtained using Equation 2.12.

H. Runoff production in rainwater harvesting systems: In rainwater harvesting systems and water butts, the volume reduction should be equal to the reused volume estimated in the Water supply tab, explained in 2.7.6. These types of systems are joined in one group, where runoff production is estimated by subtracting the stormwater reused volume.

I. Estimate button: When this button is clicked, annual runoff volume is estimated for this scenario.

Type of drainage infrastructure	% Runoff volume reduction	Source
Conventional drainage networks	Not substantial reduction	Estimation
Structural detention facilities	Not substantial reduction	Estimation
Rain harvesting systems	[1]	-
Water butts	[1]	-
Green roofs	50 %	(USEPA, 2012)
Permeable pavements	Clay: 60% Sandy soils: 99%	(USEPA, 2012)
Soakaways	85%[2]	Estimation
Infiltration trenches	85%[2]	Estimation
Geocellular systems	[3]	-
Bioretention areas	50%	(ISBMPD, 2011)
Rain gardens	85%[2]	Estimation
Filter strips	Not substantial reduction	Estimation
Filter drains	Not substantial reduction	Estimation
Vegetated swales	40%	(ISBMPD, 2011)
Infiltration basins	85%[2]	Estimation
Detention basins	30%	(ISBMPD, 2011)
Retention ponds	Not substantial reduction	(ISBMPD, 2011)
Constructed wetlands	Not substantial reduction	(ISBMPD, 2011)

[1]Depending on water reused in each system.
[2]If they are correctly designed, they should infiltrate all runoff volume except during very heavy rainfall events.
[3]Only volume reduction when is designed for infiltration. Volume reduction is very dependent on detention volume and infiltration capacity.

Table 2.12. Approximated annual runoff volume reduction for each type of drainage infrastructure.

Type of surface	Runoff coefficients	
	Typical range	Recommended value
Asphalt	0.7-0.95	0.8
Concrete	0.8-0.95	0.9
Brick	0.7-0.85	0.8
Roofs	0.75-0.9	0.85
Pervious Concrete	0.1-0.3	0.2
Paving Stones	0.1-0.7	0.4
Grass Pavers	0.15-0.6	0.35
Lawns and grass:		
sandy soil, slope < 2%	0.05-0.1	0.08
sandy soil, slope > 2%	0.15-0.2	0.17
heavy soil, slope < 2%	0.13-0.17	0.15
heavy soil, slope > 2%	0.25-0.35	0.3
Landscaping	0.15-0.3	0.2
Crushed Aggregate	0.15-0.3	0.25

Table 2.13. Typical values of runoff coefficients for different land uses (SFPUC, 2009).

EXAMPLE

In order to estimate the runoff produced in each scenario of the example, the following data are input:

- Runoff coefficient of conventional roofs and green roofs: 0.9.
- Runoff coefficient of remaining urban area: 0.6.
- Drainage area in conventional drainage network: 51 200 m² – 300 m²(conventional roof)
- Drainage area in water butts: 21 780 m² (66 water butts · 330 m²).
- Drainage area in vegetated swales: 51 200 m² (total) – 300 m² (green roof) – 21 780 m² (water butts).
- Default values are used to estimate runoff volume reduction.

The annual runoff volume obtained is 13 957 m³ in scenario 1 and 8 888.5 m³ in the scenario 2. There is only aquifer recharge and evapotranspiration in scenario 2, which is equal to 7045 m³/year.

In this example, the peak outflow has not been included as a criterion in the multi-criteria analysis; therefore this information has not been completed.

2.8.4. Estimation of Combined Sewer Overflow Discharges

→ Detailed analysis

In combined networks, discharges from Combined Sewer Overflows (CSO) to the environment are occasionally produced during rainfall events. These volumes are not treated in the wastewater treatment plants so they should not be considered to estimate runoff conveyance and treatment costs. On the other hand, this stormwater is mixed with wastewater so its quality is usually poor and produce environmental problems when released to natural water bodies.

The best data about CSO annual spill volume is obtained when these discharges are recorded and measured. If measurement data are not available, a hydraulic model can be used to estimate the runoff hydrographs produced to find the maximum CSO spill volumes. For this analysis, the tools outlined in the previous section can be used.

→ Estimation

In the E^{2}STORMED DST, a first estimation of Combined Sewer Overflows (CSO) annual spill volume can be obtained multiplying:

- Average number of Combined Sewer Overflow spills per year: This information is usually available in the wastewater network register.
- Average volume of Combined Sewer Overflow spills: This value can be estimated with an average rainfall event and the wastewater network capacity.

These data are introduced in the CSO estimation panel (Figure 2.28) to obtain the CSO annual volume.

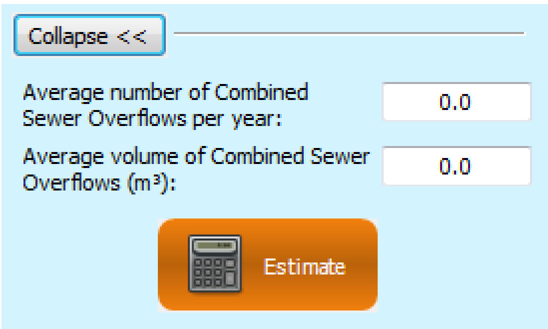


Figure 2.28. CSO estimation panel.

EXAMPLE

In the example presented, Combined Sewer Overflow spills are not produced in any scenario.

2.9. Conveyance and Treatment

2.9.1. Introduction

Some drainage systems (especially SuDS) reduce the volume of volumes entering the drainage network and improve its quality, thus decreasing water treatment and conveyance cost and energy consumption. These benefits can be very significant and must be taken into account in the decision-making process. This part of the E²STORMED DST is used to estimate the cost and energy consumption of treating and pumping the runoff produced in each drainage scenario. When they are estimated, costs and energy consumed by runoff estimated in different scenarios can be compared.

The highest **stormwater conveyance** costs and energy consumptions are usually produced when pumping is needed. The energy consumed by pumping depends on several factors such as distance, height difference, water volume pumped, pump and pipes characteristics and pumping time. Reducing runoff volumes to be pumped will significantly reduce pumping energy needs. This reduction will result in less costs and CO_2 emissions.

Stormwater treatment costs and energy consumption is different if this water is treated jointly with wastewater (combined systems) or not (separate systems). In **combined systems**, wastewater is usually treated in wastewater treatment plants with intensive techniques to remove organic matter and nutrients. In **separate systems**, stormwater is usually discharged directly at high volumes to receiving water bodies with little or no treatment. In some cases, stormwater is treated with primary techniques such as mesh screens, sedimentation tanks and debris booms. The most significant treatment techniques in both cases are explained in the E²STORMED Report on Stormwater management.

2.9.2. Conveyance and treatment tab

This tab is used to estimate the cost and energy consumption of treating and pumping the runoff produced in each drainage scenario. These costs are computed by multiplying the runoff produced (estimated in the Stormwater runoff tab) by the costs and energy consumption of treating and pumping runoff water (introduced in this tab). The data introduced in this tab are shown in (Figure 2.19):

A. Storm water pumping cost and energy consumption: Costs, energy consumed and CO_2 emissions per cubic metre to pump stormwater to the treatment or discharge point. These values can be obtained from local cost and energy consumption measurements. In the stormwater pumping panel (shown when the Estimate button is clicked) a procedure is proposed to estimate the unit costs of energy consumption and emissions. When pumping is not required, this option should be deselected.

B. Waste water treatment cost and energy consumption: Costs, energy consumed and CO_2 emissions per cubic metre to treat wastewater or stormwater. These values can be obtained from local cost and energy consumption measurements. When there is no wastewater treatment, this option should be deselected. Treatment costs are different if this water is treated jointly with wastewater (combined systems) or not (separate systems):

- In combined systems, a procedure is proposed to estimate these unit costs, energy consumption and emissions in the wastewater treatment panel (shown when the Estimate button is clicked). This panel is explained in Section 2.9.4.

- In separate systems, a default value is proposed for these unit costs and energy consumptions since there is very little international data about treatment costs in separate systems. The proposed values of 0.0185 €/m³ and 0.01 kWh/m³ have been obtained from international data, as explained in the E²STORMED Reports on Stormwater management and on Energy in the urban water cycle. Treatment emissions are estimated on the assumption that the main energy source is electricity, so energy consumption values are multiplied by the electricity emissions factor, explained in Section 2.2.

C. Percentage of water losses: A small amount of stormwater/wastewater is lost in the network that conveys it to the treatment plant. It is considered that the volume lost in the network is not treated.

D. Volume of water conveyed: Volume of water used to compute pumping cost and energy consumption. This is equal to the runoff produced minus the CSO spill volume. These values are obtained in the Stormwater runoff tab.

E. Volume of water treated: Volume of water used to compute treatment cost and energy consumption. It is obtained subtracting the volume of water lost from the volume of water conveyed in each scenario.

F. Conveyance and treatment results: Annual cost, energy consumption and emissions from the conveyance and treatment of stormwater are obtained using Equations 2.13, 2.14 and 2.15.

G. Estimate button: When this button is clicked, the conveyance and treatment results are obtained based on introduced unit costs and energy and runoff data.

Annual costs of runoff pumping and treatment are estimated with the following equation:

$$FIN = c_{tra} \cdot (V_R - V_{CSO}) + c_{tre} \cdot (V_R - V_{CSO}) \cdot \frac{100-\%_l}{100}$$ *Equation 2.15*

Where *FIN* is the financial cost of water conveyance and treatment (econ. units/year), c_{tra} is the water pumping cost (econ. units/m³), c_{tre} is the water treatment cost (econ. units/m³), V_R is the annual runoff volume (m³/year)³), V_{CSO} is the annual Combined Sewer Overflows volume (m³/year) and $\%_l$ is the percentage of water losses in the network.

Annual energy consumed of pumping and treatment is estimated with the following equation:

$$ENE = ene_{tra} \cdot (V_R - V_{CSO}) + ene_{tre} \cdot (V_R - V_{CSO}) \cdot \frac{100-\%_l}{100}$$ *Equation 2.16*

Where *ENE* is the energy consumed in water conveyance and treatment (kWh/year), ene_{tra} is the energy consumed in water conveyance (kWh/m³) and ene_{tre} is the energy consumed in water treatment. (kWh/m³).

Finally, annual emissions of pumping and treatment are estimated with the following equation:

$$ENE = emi_{tra} \cdot (V_R - V_{CSO}) + emi_{tre} \cdot (V_R - V_{CSO}) \cdot \frac{100 - \%_l}{100} \qquad \textit{Equation 2.17}$$

Where *EMI* are the emissions produced in water conveyance and treatment (kg CO_2/year), emi_{tra} are the emissions produced in water conveyance (kg CO_2/m^3) and emi_{tre} are the emissions produced in water treatment (kg CO_2/m^3).

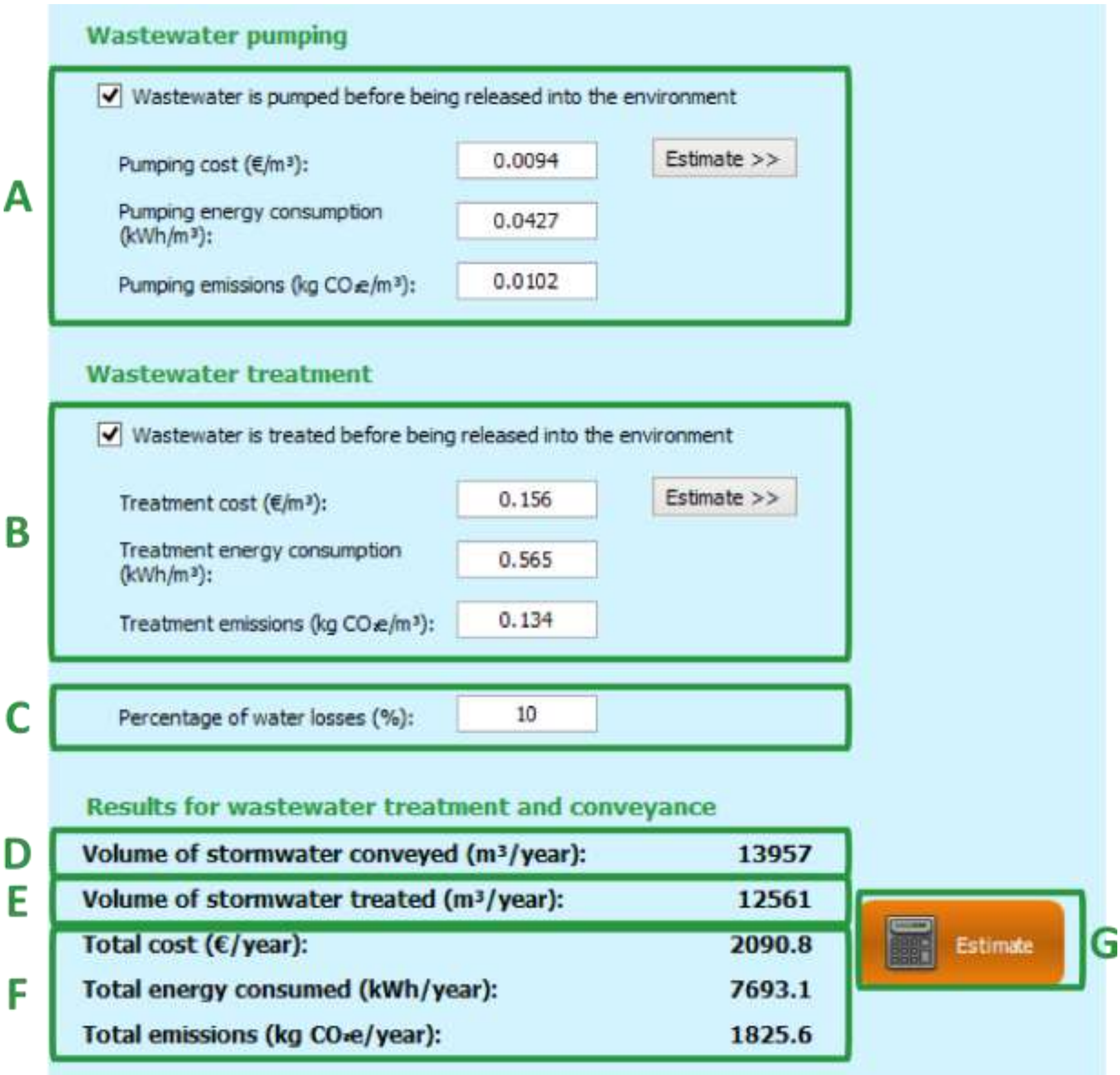


Figure 2.29. Conveyance and treatment tab.

EXAMPLE

Stormwater treatment and costs of stormwater management have been calculated for the example using the following data:

- In scenario 1, costs, energy consumption and emissions of conveyance and treatment are estimated as shown in the following sections.
- Percentage of water losses in the drainage network: 10%.
- In scenario 2, stormwater is discharged directly into the environment without pumping or treatment. In this case, conveyance and treatment cost and energy consumptions are zero.

In scenario 1, a conveyance and treatment cost of 2 090.8 €/year has been obtained. Furthermore, energy consumption is 7 693.1 kWh/year and emissions are 1 825.6 kg CO_2/year.

2.9.3. Estimation of water pumping cost and energy consumption

→ Detailed analysis

In general, the best method of obtaining this energy consumption is to measure it directly in the pumping system, since it depends on local conditions, equipment and methods. In the following section, an estimation method is outlined (shown in the stormwater pumping panel) to be used when these data are not available.

The financial cost of the energy consumed can be converted with the electricity price in electric systems or with the fuel price and net calorific value (Table 2.14) in fuel systems.

When energy consumption has been obtained, equivalent CO_2 emissions can be estimated using the electricity emissions factor (if the main energy vector used is electricity) or the fuel emissions factor (if fuel is used). The electricity emissions factor is defined in Section 2.3. The emissions factor of the most important type of fuels used in the urban water system are shown in Table 2.14.

	Units	Net calorific value kWh/unit	Emissions factor kg CO_2/kWh
Natural gas	m^3	9.34	0.202
Liquefied Petroleum Gases	kg	13.15	0.227
Gasoline	l	9.11	0.249
Diesel	l	10.04	0.267
Other petroleum products	kg	11.18	0.264
Biofuels	l	6.61	0.255
Coal	kg	7.84	0.340
Wood/wood waste	kg	4.34	0.403

Table 2.14. Emissions factor and net calorific value of the most important type of fuels used in the urban water system.

→ Estimation

This method is based on energy estimation with pumping equations. In this panel, pumping energy needs per cubic meter are computed with the following equation:

$$ENE = \Delta H \cdot \frac{9810}{3600 \cdot 1000} \cdot \frac{100}{\eta_{mec}} \cdot \frac{100}{\eta_{ener}} \qquad \textit{Equation 2.18}$$

Where *ENE* is the energy consumed per cubic meter in pumping (kWh/m^3), ΔH is the height different between the water collection point in the urban area and the water outflow point (m), η_{mec} is the mechanical efficiency of the pump to transmit the energy to the water (a recommended value is 75%) and η_{ener} is the energy efficiency of the energy system to transmit the energy from the pump (recommended value are 85% for electric systems and 35% for fuel systems). This equation is based on Bernoulli equation particularized to compute the energy necessary to pump a cubic meter of water. This is further explained in the E²STORMED Report on energy in the urban water cycle.

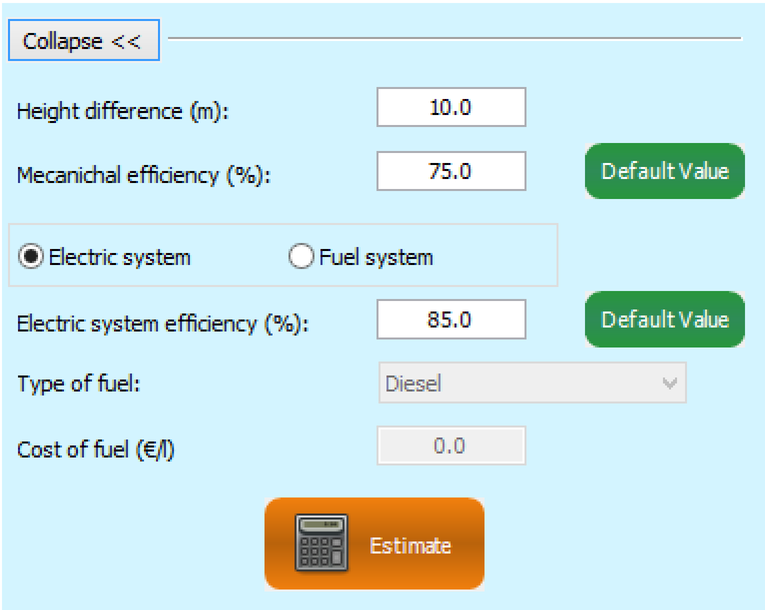


Figure 2.30. Stormwater pumping panel.

The cost of pumping water is estimated using the electricity price in electric systems or with the fuel price and energy production (Table 2.14) in fuel systems.

Pumping emissions are estimated using the electricity emissions factor for electric pumping systems or the fuel emissions factor for fuel pumping systems. The electricity emissions factor is defined in Section 2.3. The emissions factor of the most important type of fuels used in the urban water system are shown in Table 2.14.

EXAMPLE

In scenario 1, water is pumped through a head of 10 metres with electric pumps. This data are introduced in the stormwater pumping panel, as shown in Figure 2.30. Default values are used for pumping efficiencies. With this data, estimated energy consumption for water pumping is 0.0427 kWh/m^3, cost is 0.0094 €/m^3 and emissions are 0.0102 kg CO_2/m^3.

2.9.4. Estimation of wastewater treatment cost and energy consumption

→ Detailed analysis

The unit wastewater treatment cost can be provided by the wastewater management department or company, although sometimes this data is not public and may be very dependent on local management. Operation and maintenance costs for Wastewater Treatment Plants (WWTP) include labor, electricity, chemicals, laboratory analysis, repairs, equipment replacement, and administrative costs, including insurance and sludge disposal (CAPE COD Commission, 2013). When this cost is estimated, the following aspects must be taken into account:

- Treatment processes used in the wastewater management plant.
- Treatment plant capacity, a higher volume of water treated shall produce lower unit costs.
- Year of construction, newer plants and technologies tend to be more efficient.

In general, the best method of obtaining wastewater energy consumption is to measure it directly in the wastewater treatment system, since it depends on local conditions, equipment and methods. In the following section, an estimation method is suggested (shown in the wastewater treatment panel) to estimate costs and energy consumption when these data are not available.

When energy consumption has been obtained, equivalent CO_2 emissions can be estimated using the electricity emissions factor (if the main energy vector used is electricity) or the fuel emissions factor (if fuel is used). The electricity emissions factor is defined in Section 2.3. The emissions factor of the most important type of fuels used in the urban water system are shown in Table 2.14.

→ Estimation

In order to obtain an approximate **treatment** cost for a first analysis, the results of a study made in the Mediterranean (Molinos Senante, 2012) are used in the wastewater treatment panel, as explained in the E²STORMED Report on Stormwater Management. According to the results of this study, the unit treatment cost can be obtained from the annual volume of water treated in the plant, the type of treatment processes and the plant age, as shown in the following equation:

$$c_{trea} = A \cdot {V_{WWTP}}^{B} \cdot e^{C \cdot t + D} \qquad \textit{Equation 2.19}$$

Where c_{trea} is the unit cost of wastewater treatment (€/m^3), V_{WWTP} is the annual capacity of the Wastewater Treatment Plant (WWTP) (m^3/year), t is the WWTP age (years), A, B, C and D are constants obtained directly from data adjustment. The value of these constants is shown in Table 2.15.

These constants vary according to the type of wastewater treatment. The following options are available (USEPA, 2013c):

- Aerated basin: Treatment pond provided with artificial aeration to promote the biochemical oxidation of wastewaters

- Activated sludge without nutrient removal: Reactor where microorganisms are cultivated and are in contact with the wastewater to eliminate the organic pollutants.

- Activated sludge with nutrient removal: Activated sludge process that includes microorganism to eliminate nitrogen and phosphorus.

- Trickling filter: Aerobic treatment system that utilizes microorganisms attached to a medium to remove organic matter from wastewater. They are also called biofilters.

- Rotating biological contactors: A variation of trickling filters. Consists of parallel discs where microorganisms grow in the surface and produce the biological degradation of wastewater pollutants.

- Tertiary treatment: When the previous treatments are completed with an advanced treatment. In general, the purpose of these treatments is to eliminate nutrients like nitrogen and phosphorus. The costs obtained for tertiary treatment are added to the primary and secondary costs.

Type of main treatment	A	B	C	D
Primary and secondary treatments				
Aerated basin	169.48	-0.546	0.0009	0.5483
Activated sludge without nutrients removal	2.1165	-0.2872	0.0174	1.4396
Activated sludge with nutrients removal	2.518	-0.2847	0.007	1.6534
Trickling filter	17.361	-0.4229	0.1006	0.5650
Rotating biological contactors	28.952	-0.5507	0	2.1679
Tertiary treatments				
General tertiary treatment	3.7732	-0.2777	0	0.5733

Table 2.15. Constants to compute WWTP unit costs.

The **energy consumed** in wastewater treatments is calculated by interpolating the data from Table 2.16, which relates energy consumption to plant size. These values are obtained from literature, as explained in the Report on E²STORMED Energy in the water cycle.

Treatment Plant Size categories (m^3/day)	Unit Electricity Consumption (kWh/m^3)				
	Aerated basins	Activated Sludge *without* nutrients removal	Activated Sludge *with* nutrients removal	Trickling Filter	Rotating biological contactors
x ≤ 3785	0.02	0.59	0.59	0.48	0.48
3785 < x ≤ 18925	0.02	0.36	0.36	0.26	0.26
18925 < x ≤ 37850	0.02	0.32	0.32	0.23	0.23
37850 < x ≤ 75700	0.02	0.29	0.29	0.20	0.20
75700 < x ≤ 189250	0.02	0.28	0.28	0.18	0.18
X > 189250	0.02	0.27	0.27	0.18	0.18

Table 2.16. Unit Electricity Consumption for Wastewater Treatment by Size categories of Plant

If there is a tertiary treatment, 0.45 kWh/m^3 are added to these values. Treatment emissions are estimated assuming that the main energy source is electricity, so energy consumption values are multiplied by the electricity emissions factor as explained in Section 2.3.

These equations are used in the wastewater treatment panel to compute costs and energy consumption. Average default values are proposed for most of the data needed, in order to obtain a first result when no data are available. This panel is shown in Figure 2.31.

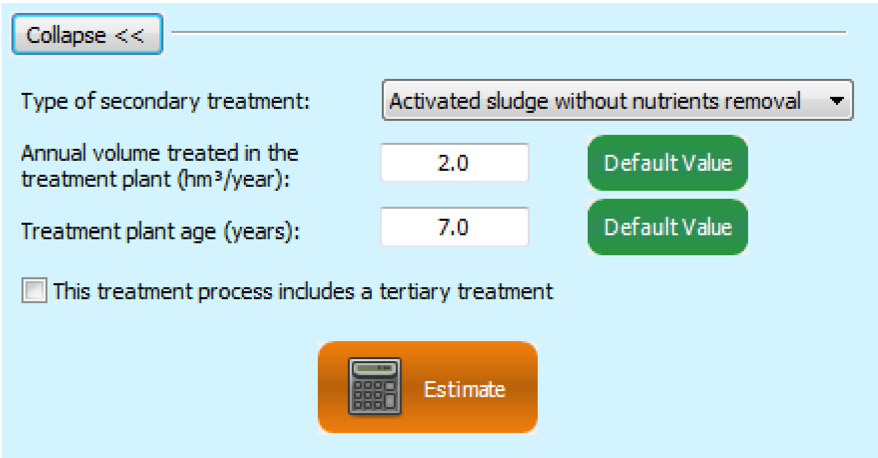


Figure 2.31. Wastewater treatment panel.

EXAMPLE

In scenario 1, water is treated in an activated sludge wastewater treatment plant without a tertiary treatment. Default values are used for the volume treated in the plant and its age, as shown in Figure 2.31. With these data, estimated cost for water treatment is 0.156 €/m^3, energy consumption is 0.565 kWh/m^3 and emissions are 0.283 kg CO_2/m^3.

2.10. Water quality

2.10.1. Introduction

Urbanization causes an increase in types and quantity of pollutants in surface and ground waters. Runoff from urban areas has been shown to contain many different types of pollutants, such as oils and grease, Polynuclear Aromatic Hydrocarbons (PAH's), heavy metals, sediments (soil particles) and agricultural pollutants including herbicides, pesticides and nutrients (WSDE, 2012). Rainwater mobilizes all of these pollutants which are washed into the drainage system and sometimes into rivers or into groundwater. All these contaminants can seriously damage the environment and beneficial uses of receiving waters.

To minimize the impacts of pollutants on receiving water bodies, a water quality management train is required. The main pollutant removal mechanisms that occur in stormwater infrastructures are (Woods-Ballard, y otros, 2007) (Figure 2.32):

- Filtration and biofiltration: The runoff is filtered using a variety of filtration media, for instance gravels (filter drains, permeable pavements, soakaways, infiltration trenches), soils (bioretention areas, rain gardens), surface vegetation (vegetated swales, filter strips) or aquatic vegetation (constructed wetlands).

- Sedimentation: Storing runoff volumes allows sediment particles to fall out of suspension. Most pollution in runoff is attached to sediment particles and therefore removal of sediments results in significant reduction in pollutant loads. Some examples of infrastructures where this process occur are detention basins, structural detention facilities, retention ponds and constructed wetlands.

- Adsorption: Occurs when pollutants attach or bind to the surface of soil or aggregate particles. Some examples where this process occurs are filter drains, permeable pavements, soakaways, infiltration trenches, constructed wetlands, retention ponds and rain gardens.

- Biodegradation: Retention ponds and wetlands promote macro and microbial plant activity to degrade organic pollutants such as oils and grease. This process will depend on environmental conditions such as temperature and the supply of oxygen and nutrients.

- Volatilization: Comprises the transfer of a compound from solution in water to the soil atmosphere and then to the general atmosphere. In SuDS, It occurs primarily with organic compounds petroleum products and pesticides. This process might be important in bioretention areas, green roofs and permeable pavements.

- Precipitation: Soluble metals react with the soil or aggregate and form suspension of insoluble precipitates.

- Uptake by plants: In ponds and wetlands, uptake by plants is an important removal mechanism for nutrients. Some metals can also be removed in this manner.

- Nitrification: Ammonia and ammonium ions can be oxidized by bacteria in the ground to form nitrate, which is a highly soluble form of nitrogen. Nitrate is readily used as a nutrient by plants.

- Photolysis: The breakdown of organic pollutants by exposure to ultra-violet light.

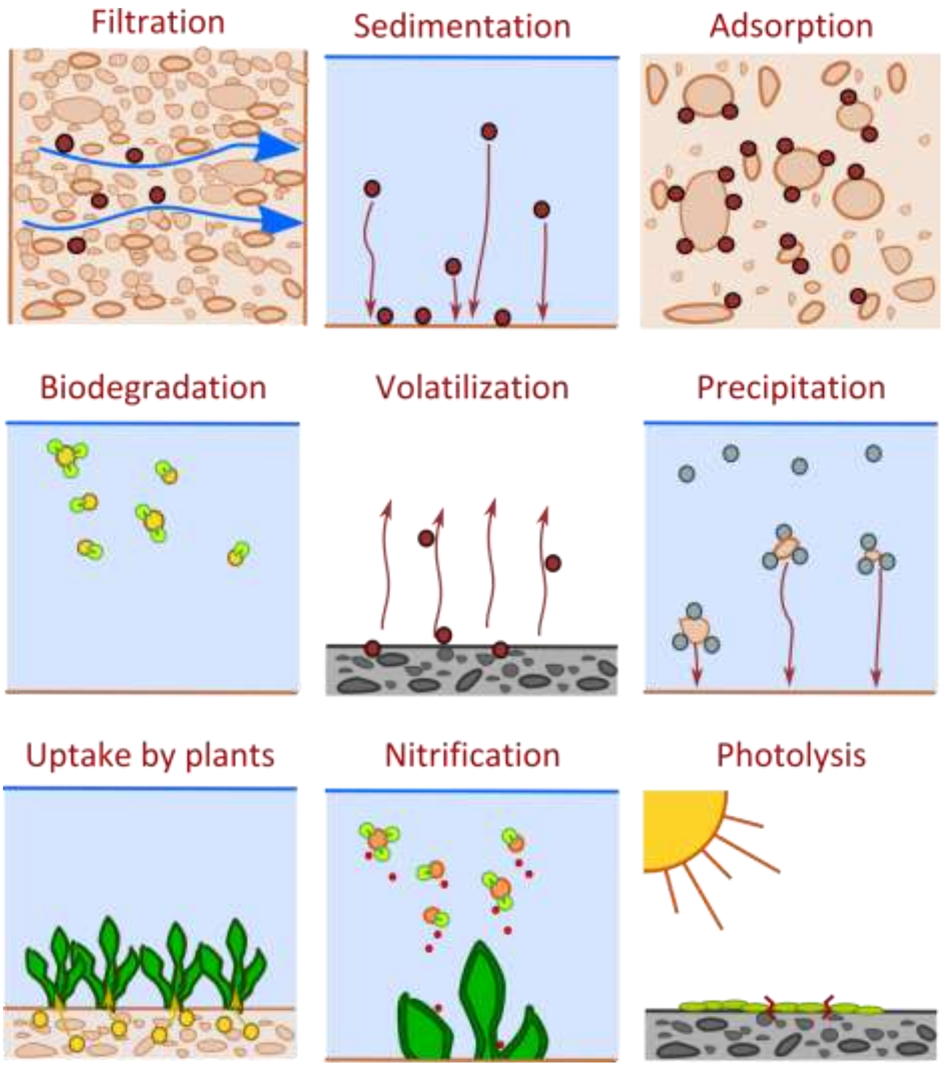


Figure 2.32. Schemes of the main pollutants removal mechanisms.

These water quality treatment options must influence the sizing and design of stormwater infrastructure, especially when SuDS are used. Some tools and manuals are available that can be useful to analyze water quality processes in detail and estimate outflow water quality after each treatment:

- CIRIA The SuDS Manual (Woods-Ballard, y otros, 2007): This manual provides general guidance to design stormwater management trains and explains how to take into account water quality processes in the design of each type of infrastructure.

- California Stormwater Best Management Practice Handbook (CSQA, 2003): It provides guidance to design stormwater infrastructures for water quality protection.

- Georgia Stormwater Management Manual (ARC, 2001): General guidance is provided to estimate pollutants removal efficiency of stormwater infrastructures in series.

- SUSTAIN model (USEPA, 2013b): Software that provides process-based simulation of flow and pollutant behavior for a wide range of structural SuDS. It provides guidance to optimize stormwater management trains.

In order to get proper quantitative results on quality performance of drainage systems it is important to analyze each case and storm in detail, since stormwater quality is highly variable during a storm, from storm to storm at a site, and between sites even of the same land use (NYSDEC, 2010). Furthermore, water quality processes are not linear, so a water treatment train will produce different results depending on the order of the treatment processes.

In the E²STORMED DST, runoff water quality is estimated in a qualitative way, since water quality processes are very complex and are not the main focus of this tool. Anyway, quantitative water quality results can be added as quantitative decision criteria in the Decision criteria menu, explained in Section 3.2.

2.10.2. Water quality tab

This tab only needs to be used if runoff water quality is qualitative decision criterion in the decision-making process. This tab provides a preliminary guidance about water quality processes, but these processes are complex and non-linear, so if water quality issues are important, and detailed analysis may be required with a different tool. In this tab, a qualitative estimation of runoff water quality should be made by the user for three different groups of pollutants (suspended soils, nutrients and heavy metals). This estimation is based on:

- The minimum number of infrastructures components with effective pollutant removal capacity likely to be appropriate for different contributing and receiving catchment characteristics. This minimum number of drainage components is calculated on the basis of the values shown in Table 2.17. In polluted catchment areas (such as highways and lorry parks) a higher number of drainage infrastructure components with effective pollutant removal is required.

- A qualitative estimate of the pollutant removal efficiency of each SuDS in the drainage scenario. This estimate should be made for each group of pollutants in Table 2.18. The qualitative information about each SuD and the minimum number should be a guide to estimate the outflow water quality in the scenario. These water quality values are a simplification of complex water quality processes. In a detailed analysis, water quality process should be quantified as explained in the previous section.

With these three estimates of the concentrations of three types of pollutants, a global runoff water quality value should be assigned as an average of the three values.

The water quality tab changes according to the type of drainage system. In combined drainage systems, the tab has the appearance shown in Figure 2.34. In other cases, it has the appearance shown in Figure 2.33.

Runoff catchment characteristics	Receiving water sensitivity		
	Low	Medium	High
Residential roofs only	1	1	1
Residential roads Parking areas Commercial zones	2	2	3
Industrial areas Highways Lorry parks	3	3	4

Table 2.17. Minimum number of components in the water quality management train for different contributing and receiving catchment characteristics. (Woods-Ballard, y otros, 2007).

Type of drainage infrastructure	Total suspended solids	Nutrients	Heavy metals
Conventional drainage networks	Low	None	Low
Convertional roofs	None	None	None
Standard pavement	None	None	None
Structural detention facilities	Medium	None	Low
Rain harvesting systems	High	Low	Medium
Water butts	Low	Low	Low
Green roofs	High	Low	Medium
Permeable pavements	High	High	High
Soakaways	Medium	Low	Medium
Infiltration trenches	High	Low	High
Geocellular systems	Low	None	Low
Bioretention areas	High	Low	High
Rain gardens	High	Low	High
Filter strips	Medium	Low	Medium
Filter drains	High	Low	High
Vegetated swales	High	Low	Medium
Infiltration basins	High	Medium	High
Detention basins	Medium	Low	Medium
Retention ponds	High	Medium	High
Constructed wetlands	High	Medium	High

Table 2.18. Quantitative evaluation of pollutants removal efficiency of each drainage infrastructure. Adapted from (Woods-Ballard, y otros, 2007).

The data that must be introduced in the water quality tab are:

- **A.** Minimum number of SuDS: In this part of the tab, the characteristics of the catchment area and the receiving water sensibility are introduced and the tool automatically computes the minimum number of components needed with effective pollutants removal according to Table 2.17. If different land uses are considered in the catchment area, the land use with the worst runoff quality should be chosen.
- **B.** Pollutant removal efficiency: Estimate of quality improvement for each drainage scenario for each group of pollutants (suspended soils, nutrients and heavy metals). These values are assigned according to Table 2.18.
- **C.** Combined Sewer Overflows water quality: User's estimation of water quality in Combined Sewer Overflows (CSO). This estimation should be based on data obtained in parts A and B. This part is only shown in scenarios with combined systems. In this part, it must be taken into account that in CSO, stormwater is mixed with wastewater.
- **D.** Water quality of treated water: User's estimation of water quality after being treated in a wastewater treatment plant. This estimation should be based on the knowledge about the treatment plant performance. This part is only shown in scenarios with combined systems.
- **E.** Global outflow water quality: User's estimation of runoff water quality when reaches the environment. This is a global score that must be done combining results of Section C and D. In separated systems, this estimation should be based on data obtained in parts A and B. In combined systems, this is a global score that should be estimated combining the CSO volumes and water quality (part C) with the treated water volumes and water quality (part D).

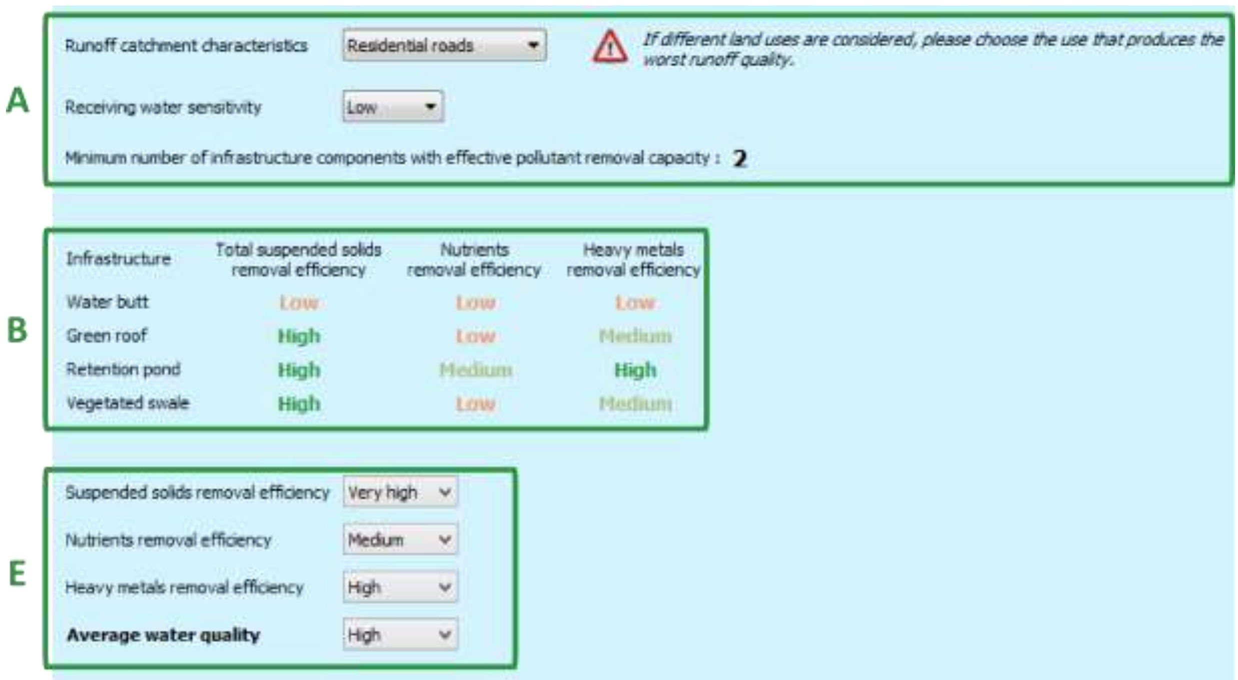


Figure 2.33. Water quality tab for separate systems.

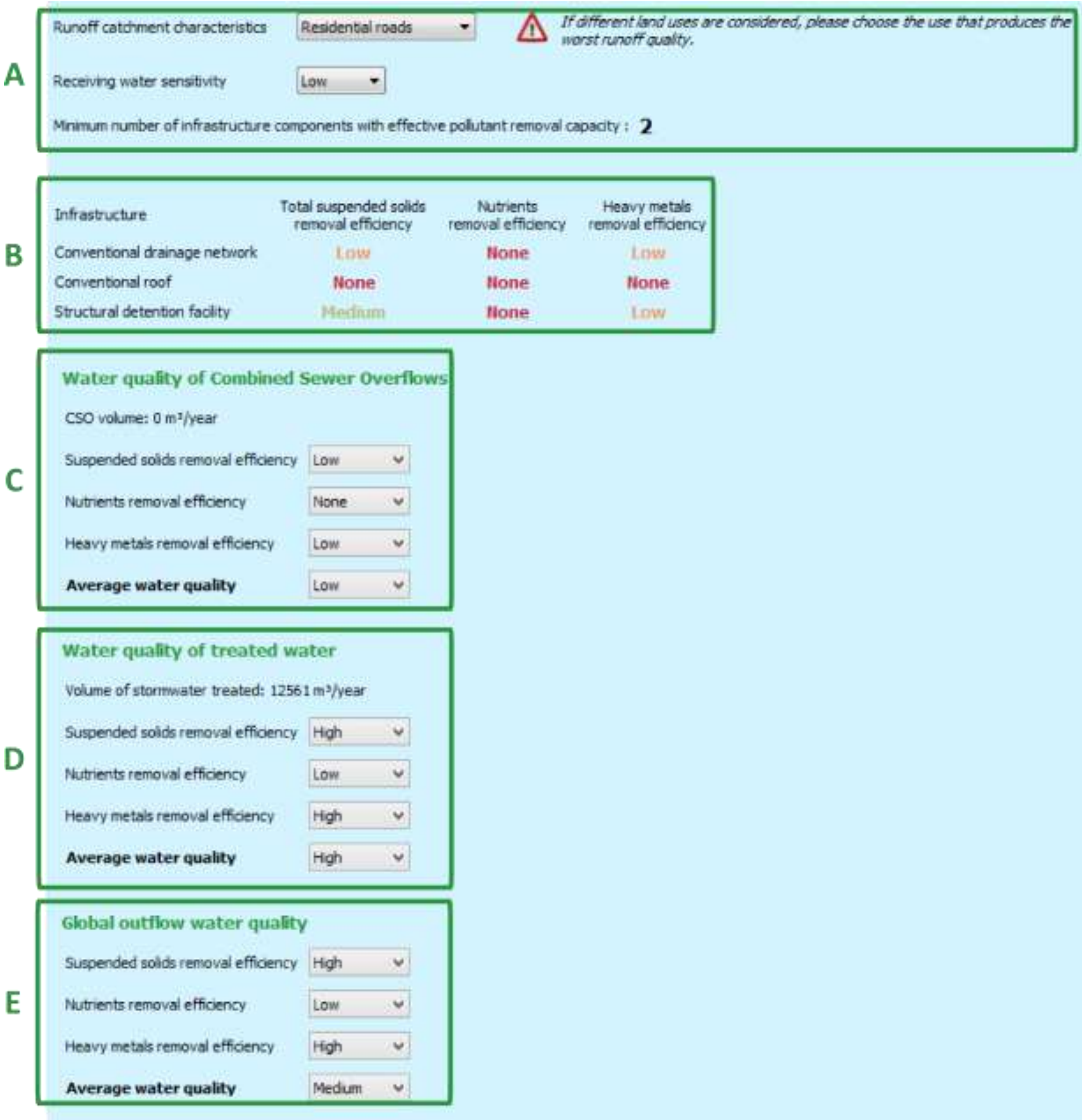


Figure 2.34. Water quality tab for combined systems.

EXAMPLE

A qualitative estimate of outflow water quality has been made taking into account the following data:

- In both scenarios, receiving water sensitivity is low.
- In Scenario 1, outflow water quality has been estimated as shown in Figure 2.34. These results have been obtained assuming that all the runoff produced is treated in a wastewater treatment plant.
- In Scenario 2, outflow water quality has been estimated as shown in in Figure 2.33.

2.11. Flood protection

2.11.1. Introduction

A significant proportion of flooding is due to local problems which arise from sources such as surface stormwater runoff. Damage caused by local flooding is significant and includes: loss of life, damage to domestic and business premises, loss of livestock and damage to agriculture, infrastructural damage and loss of revenue (DEFRA, 2009). Therefore, well-designed drainage systems which incorporate storage contribute to reduced stormwater flood events and this in turn produces important social and economic benefits.

Although both conventional drainage systems and SuDS protect urban areas, they manage floods in a different way. SuDS manage more water above-ground than conventional drainage systems, keeping water out of sewers. Conventional systems are usually designed to move water downstream as quickly as possible. SuDS store surface water and allow it to infiltrate into the ground or gradually release it downstream where possible, to the natural drainage system (DEFRA, 2009).

2.11.2. Flood protection tab

This tab has been included to make an estimation of flood protection benefits in the case that hydraulic models have been elaborated to analyze flooded areas. If these hydraulic models are not available, the recommended approach is to compare scenarios with a similar level of protection, so this tab does not need to be completed. This tab is shown in Figure 2.35.

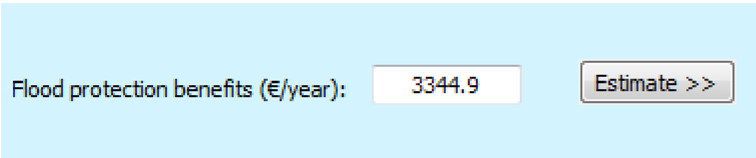


Figure 2.35. Flood protection tab.

As can be seen in this tab, only average flood protection benefits should be considered. In general, the flood protection benefits of a drainage scenario are computed comparing the situations with and without the drainage system. This estimate is explained in the following section. When the Estimate button is clicked, the flood protection estimation panel is shown. This panel includes a simplified methodology to estimate flood protection benefits, as explained in the following section.

2.11.3. Estimation of flood protection benefits

→ Detailed analysis

Flood protection benefits can be obtained using economic risks calculations for pluvial flooding. This risk is estimated by relating different pluvial flood events defined by a return period (inverse of probability of exceedance) with the estimated economic consequences of these events. In the case of urban stormwater flood risk, the most significant events are usually those with a relatively low return period (5-100 years), since these are the events that in general might be properly managed by the urban drainage system.

In order to estimate the expected economic consequences in each flood event, different methodologies can be used (Escuder-Bueno, Morales-Torres, Castillo-Rodríguez, & Perales-Momparler, 2011; QG, 2002) and the direct economic damage is usually estimated as a function of:

- Flood water depth.
- Reference cost (monetary units/m^2) for each urban land use and infrastructure. The estimate is based on the assumption that this land use is completely destroyed.
- Damages-depth curves: These define a relationship between water depth and percentage of damage for each urban land use.

The economic consequences should also include indirect costs resulting from the economic disruption caused by the flood, damages to economic activities, traffic stoppage and congestion… Results of the economic consequences of floods are used to represent flood risk by means of Frequency-Damages (FD) curves. These curves show the annual exceedance probability (inverse of return period) of each event versus its flood economic consequences. The area under the curve is the economic risk (monetary units per year) of pluvial flooding. If FD curves are computed for the cases with and without drainage, the economic benefits of flood protection are obtained directly from the difference between the two curves (Figure 2.36).

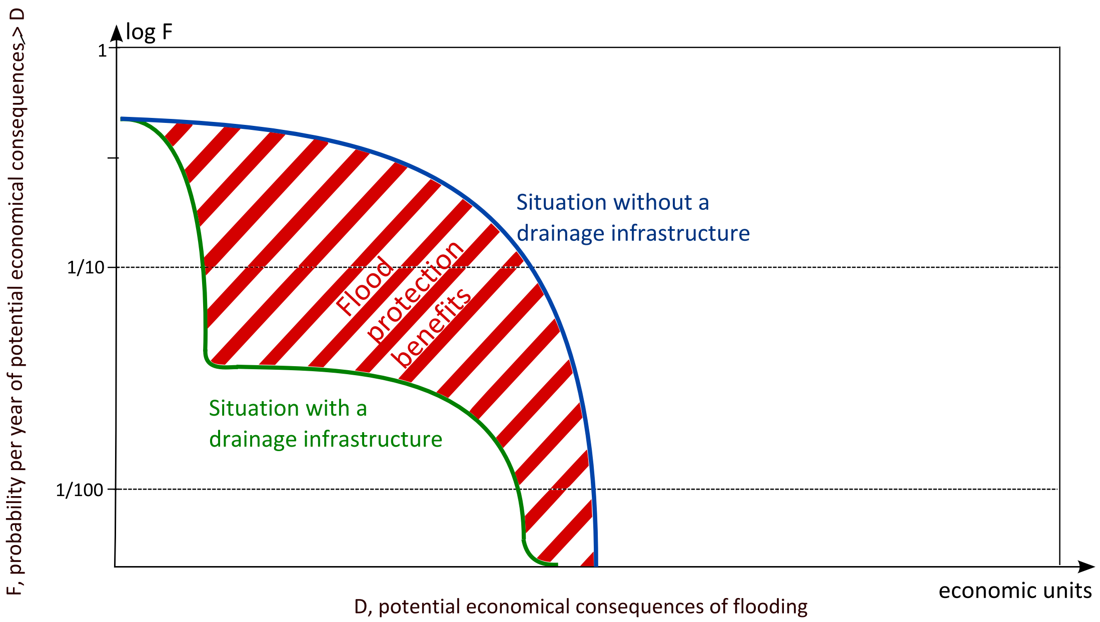


Figure 2.36. FD curves for representing flood economic risk. Adapted from (Escuder-Bueno, Morales-Torres, Castillo-Rodríguez, & Perales-Momparler, 2011).

Methodologies for the estimation of the consequences of pluvial flooding (Escuder-Bueno, Morales-Torres, Castillo-Rodríguez, & Perales-Momparler, 2011) also include other social consequences whose economic quantification is more complex such as loss of life. These consequences must be included in a detailed flood analysis, since they can be significant in high-magnitude flood events.

→ Estimation

In the E²STORMED DST, flood protection benefits can be estimated for each drainage scenario by introducing the Frequency-Damages (FD) curve for the two situations: with and without the drainage infrastructure, as explained previously. These curves define the economic consequences of different flood events and the return period of these events is defined in the General data menu (Section 2.2.). The higher the number of flood events analyzed, the more accurate the data of flood protection benefits is obtained. The economic consequences of each event can be introduced through two methods:

- Direct introduction of consequences: Economic consequences are estimated for each flood event in the two situations: with and without the drainage infrastructure. Some of the methodologies previously explained can be used to estimate these consequences.

- Households affected: As a simplification, the economic consequences can be estimated by estimating the number of properties affected during each event and multiplying this by the average economic damage per property. In a detailed analysis, other damages to infrastructures, public buildings… should also be included. The average economic damage per property is estimated using an online tool (NFIP, 2013) that estimates average economic damage per household as a function of water depth. The average economic damage per household is obtained by interpolating from data in Table 2.19.

Depth (m)	Average damages per household (€)
0.000	0
0.025	7939
0.051	7992
0.076	8576
0.102	11347
0.127	12965
0.152	15092
0.305	20335
0.610	25241
0.914	27413
1.219	29923

Table 2.19. Average economic damages per household as a function of water depth. Adapted from (NFIP, 2013) .

In order to estimate FD curves in the flood protection estimation panel (Figure 2.37), the following data are required:

A. Collapse button: Can be used to hide the flood protection estimation panel.

B. Method to estimate consequences: Used to introduce the economic consequences. As explained in the previous page, two different methods can be used.

C. Case without this drainage infrastructure: Data to define the FD curve in the case "without drainage infrastructure". Flood events are defined in the General data menu (Section 2.2.). When the default button is clicked to obtain a value for the average damage per household, average flood water depth is requested. The damage is estimated using the information in Table 2.19.

D. Flood events are defined in the General data menu (Section 2.2.). When the default button is clicked to obtain a value for the average damages per household, the average flood water depth is requested. These damages are estimated according to the values shown in Table 2.19.

E. FD graph: Represents graphically the two FD curves introduced above. The area between these curves is equivalent to the flood protection benefits.

F. Graph toolbar: The options of this toolbar allow the user to move the view, zoom it and return to the initial graph view. These options can also be used to show or hide a legend, to export the graph and to view the graph results in a table.

G. Estimate button: When all the data have been introduced, this button computes the flood protection benefits which are equal to the area between the two FD curves.

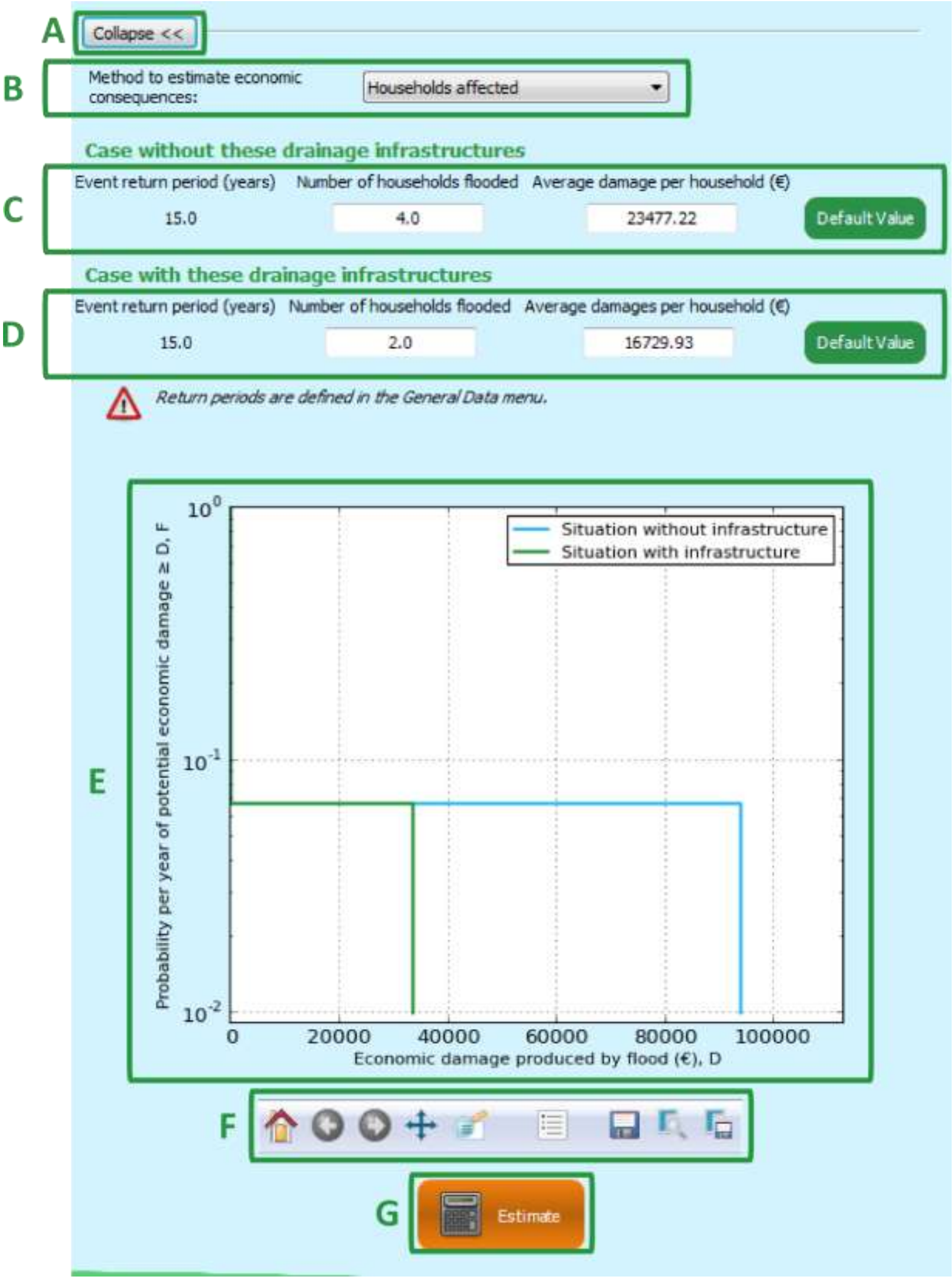


Figure 2.37. Flood protection estimation panel.

EXAMPLE

Flood protection benefits are estimated in both scenarios using the following data:

- For the 15 years return period flood, 4 houses would be flooded if there not were drainage infrastructure (average water depth=0.5 m) in both scenarios.
- In scenario 1, 2 houses would be flooded (average water depth=0.4 m).
- In scenario 2, 2 houses would also be flooded (average water depth=0.2 m).

With these data, the estimated flood protection benefits in scenario 1 are 3 344.9 €/year and in scenario 2 are 4 029.9 €/year. The FD curves obtained in both scenarios are shown in Figure 2.38.

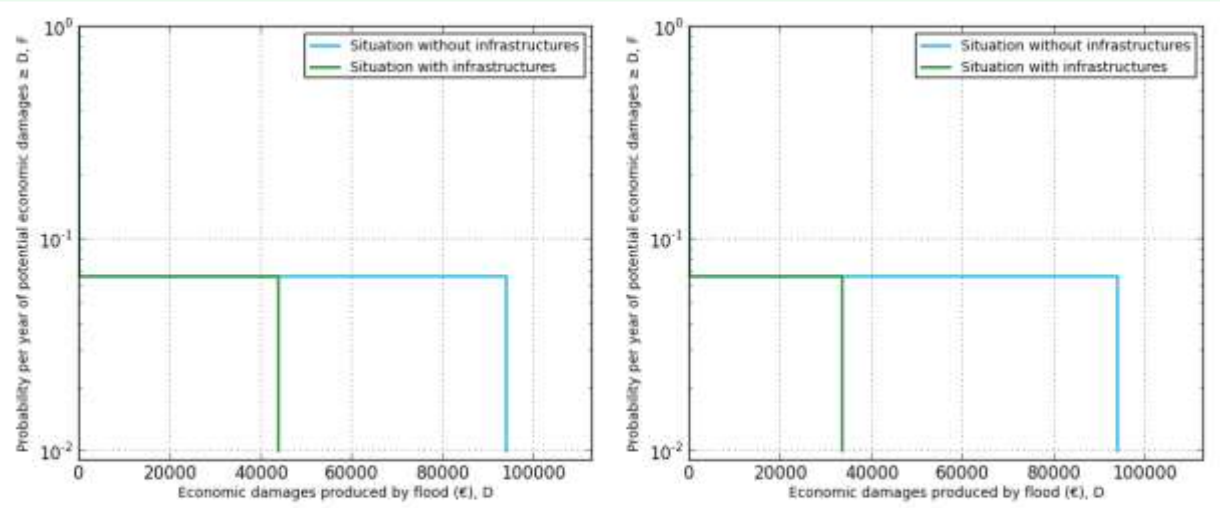


Figure 2.38. FD curves obtained in scenario 1 (left) and in the scenario 2 (right).

2.12. BUILDING INSULATION

2.12.1. Introduction

Buildings consumed about 40% of total end user energy requirements in Europe in 2010. It is the largest end use sector, followed by transport (32%), industry (24%) and agriculture (2%). Thus, the building sector is one of the key energy consumers in Europe, where energy use has increased a lot over the past 20 years. As shown in the E²STORMED Report on Energy in the urban water cycle, energy consumed in buildings relies mainly on non-renewable resources so it is important to find ways to save energy as a first step to mitigate environmental impacts and to preserve fuel resources.

Drainage infrastructure has no relationship with building insulation apart from green roofs which can block solar radiation, and reduce daily temperature variations and thermal range between summer and winter. The thermal effects of green roofs can be divided into two aspects (Sam C.M. Hui, 2009):

- Direct effect to the building (internal): Reduce the heat transfer through the roof to the building interior, reducing the energy use inside the building.

- Indirect effect on the surrounding environment (external): Reduces the heat transfer from the roof to the surrounding environment reducing the urban heat island effect. When the urban temperature is reduced, it will benefit all the buildings in the area or city and enhance energy conservation.

As explained in the following section, direct building insulation benefits can be quantified and included in the decision-making process.

2.12.2. Building insulation tab

This tab only needs to be used if a green roof is included in the scenario. As explained in the previous section, green roofs can improve buildings insulation which reduces the energy used for heating and air conditioning systems. This tab is shown in Figure 2.39.

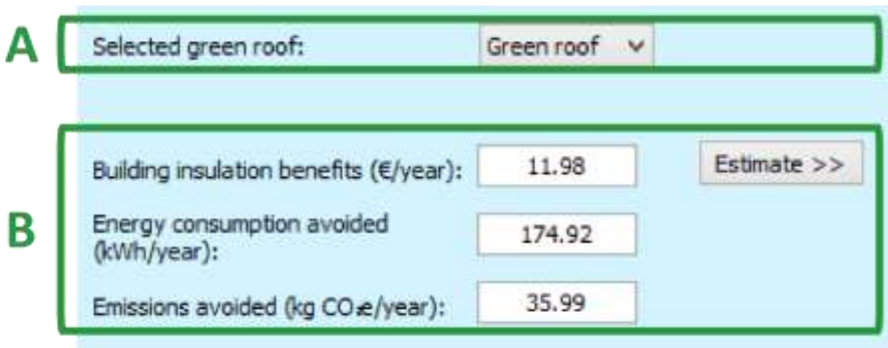


Figure 2.39. Building insulation tab.

The following data are required in this tab:

A. Selected green roof: This option is only shown when more than one green roof is added in a scenario allowing the introduction of different data to estimate building insulation benefits in each green roof.

B. The building insulation benefits, energy saved and emissions avoided are introduced in this section. In general, the financial and energy benefits of improved building insulation can be estimated through comparing green conventional roofs. This estimation is explained in the following section. When the Estimate button is clicked, the building insulation estimation panel is shown. This panel includes the simplified methodology to estimate building insulation benefits explained in the following section.

2.12.3. Estimation of building insulation benefits

→ Detailed analysis

Heat transfer in buildings is analyzed by subdividing the structure into different enclosures or elements (facade walls, openings, floors and roofs), to calculate heat loss separately.

This type of calculation is usually based on a one-dimensional model, which assumes that the elements are thermally homogeneous and composed of a number of parallel layers to the heat flow, as shown in the next figure.

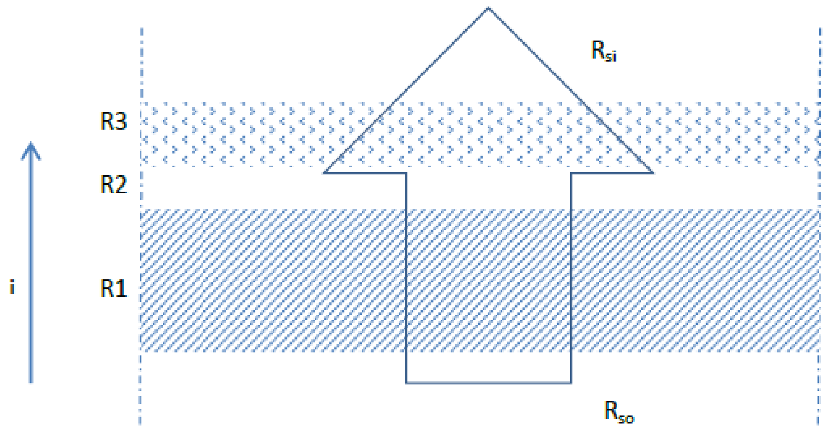


Figure 2.40. One-dimensional model of heat flux (M.I DÍAZ, 2005)

Heat transfer is defined as the Heat Transfer Coefficient (U), considered in a simplified, steady state. This value gives the heat loss through each building element per unit surface area and temperature difference of the considered element ($W/m^2/K$). Average values of the Heat Transfer Coefficient for different European countries are shown in Table 2.20. These values have been obtained from different references and guidelines, as explained in the Report on Energy in the urban water cycle of the E²STORMED project.

Heat flux transfer of green roofs is governed by four mechanisms: shading, thermal insulation, evapotranspiration and thermal mass. The thermal and energy performance of green roofs has been studied worldwide using three different approaches: field experimentation, numerical studies, and a combination of laboratory or field experiments with numerical models. In general, of total solar radiation absorbed by the green roof, about 27% is reflected, 60% is absorbed by the plants and the soil through evaporation and 13% is transmitted into the soil.

In order to evaluate the energy consumption of a green roof, a thermal study of the building can be made comparing the situation with a green roof and with a conventional roof. The difference between the energy consumed in these cases will produce the building insulation benefits. Different thermal analysis of green roofs has been made around the world, as explained in the Report on Energy in the urban water cycle of the E²STORMED project. A simplified estimation of building insulation benefits can be made with the E²STORMED DST in the building insulation estimation panel, as explained in the following part.

Country	U-value (W/m²/K)
Austria	0.22
Belgium	0.57
Bulgaria	0.3
Cyprus	0.55
Czech Rep.	0.24
Denmark	0.14
Estonia	0.18
Finland	0.18
France	0.22
Germany	0.22
Greece	0.39
Hungary	0.25
Ireland	0.31
Italy	1.2
Lithuania	0.18
Luxembourg	0.25
Malta	1.81
Netherlands	0.4
Poland	0.6
Portugal	1.33
Romania	1
Slovakia	0.3
Slovenia	0.2
Spain	0.54
Serbia	0.45
Croatia	0.29

Table 2.20. U-values of average conventional roofs in European countries (E²STORMED Report on Energy in the urban water cycle).

→ Estimation

In the E²STORMED DST, the benefits of building insulation are computed with the increment of the Heat Transfer Coefficient of a green roof in comparison with that of a conventional roof. The average variations of temperatures during summer and winter were introduced in the General data menu are used for this purpose. With these data, two different estimates are made:

- Cooling system: Summer days are used to estimate how hot the climate is and how much energy may be needed to keep buildings cool. Energy needs are calculated by subtracting the set point temperature from the mean daily temperature during summer (introduced in the General data menu), and summing only positive values over an entire year. It has been considered that cooling system uses electricity. Energy saved of green roof in the cooling system is computed with an energy balance per hour of a representative day of summer. This balance is made with the following equation:

$$ES_{cool}^{j} = \Delta U \cdot \left(T_{out}^{j} - T_{cset}\right) \cdot \frac{100}{\eta_C} \cdot A \cdot N_d \cdot N_{cm} \cdot 10^{-3}$$ *Equation 2.20*

  Where ES^{j}_{cool} is the energy saved in the hour j in the cooling system (kWh), ΔU is the difference in the heat transfer coefficient between a green roof and a conventional roof (W/m²·K), T^{j}_{out} is the average outside temperature for a summer day in the hour j (°C), T_{cset} is the building set point temperature for the cooling system (°C), η_C is the efficiency of the cooling system (a recommended value is 300%), A is the green roof area (m²), N_d is the average number of building uses per month and N_{cm} is the number of months that the cooling system is used. When the energy saved is added for all the hours of building use, the total energy saved for the cooling system is obtained.

- Heating system: Winter days are used to estimate how hot the climate is and how much energy may be needed to keep buildings warm. Energy saved is calculated by subtracting the mean daily temperature from the set point temperature, and summing only positive values over an entire year. Heating system energy vector can be electricity, fuel or both of them. Energy saved of green roof in the heating system is computed with an energy balance per hour of a representative day of winter. This balance is made with the following equation:

$$ES_{heat}^{j} = \Delta U \cdot \left(T_{hset} - T_{out}^{j}\right) \cdot \left(\frac{\%_{el}}{\eta_{He}} + \frac{100-\%_{el}}{\eta_{Hf}}\right) \cdot A \cdot N_d \cdot N_{hm} \cdot 10^{-3}$$ *Equation 2.21*

  Where ES^{j}_{heat} is the energy saved in the hour j in the heating system (kWh), T^{j}_{out} is the average outside temperature for a winter day in the hour j (°C), T^{hset} is the building set point temperature for the cooling system (°C), %el is the percentage of the heating system that works with electricity, η_{He} is the efficiency of the electric heating system (a recommended value is 300%), η_{Hf} is the efficiency of the fuel heating system (a recommended value is 85%) and N_{hm} is the number of months that the heating system is used. When the energy saved is added for all the hours of building use, the total energy savings for the heating system are obtained.

Adding the energy saved of the cooling system and the heating system, the total energy saved produced by the green roof are obtained. These equations are based on the heat transfer equations and they are explained in detail in the Report on Energy in the urban water cycle of the E²STORMED project.

The difference in the heat transfer coefficient between a green roof and a conventional roof (ΔU) is estimated with the following equation:

$$\Delta U = U_{CONV} - \frac{1}{{}^{1}/_{U_{CONV}} + R_{GR}} \qquad \textit{Equation 2.22}$$

Where U_{CONV} is the thermal transmittance of conventional roofs (W/m²·K) and R_{GR} is the thermal resistance of the green roof (m²·K/W). Default values for thermal transmittance of conventional roofs (U_{CONV}) are obtained from Table 2.20. For countries that are not in this table, an average value of 0.474 W/m²·K can be used. The thermal resistance of the green roof is obtained by interpolation from the values of Table 2.21, as a function of the green roof thickness. These values are obtained from international experiments, as explained in the Report on Energy in the urban water cycle of the E²STORMED project.

Green roof thickness (mm)	Thermal resistance (W/m²·K)
50	0.13
100	0.17
150	0.2
350	0.34

Table 2.21. Thermal resistance value of a green roof as a function of its thickness.

Financial benefits of building insulation are estimated with the energy saved and with the electricity price in electric refrigeration systems or with the fuel price and energy production (Table 2.22.) in fuel heating systems.

Emissions avoided due to better building insulation are estimated using the electricity emissions factor for electric refrigeration systems or the fuel emissions factor for fuel heating systems. The electricity emissions factor is defined in Section 2.3. The emissions factor of the most important type of fuels used in heating systems are shown in Table 2.22.

	Units	Net calorific value kWh/unit	Emissions factor kg CO_2/kWh
Natural gas	m³	9.34	0.202
Liquefied Petroleum Gases	kg	13.15	0.227
Gasoline	l	9.11	0.249
Diesel	l	10.04	0.267
Other petroleum products	kg	11.18	0.264
Biofuels	l	6.61	0.255
Coal	kg	7.84	0.340
Wood/wood waste	kg	4.34	0.403

Table 2.22. Emissions factor and net calorific value of the most important type of fuels used in the buildings' heating system.

The data needed to solve these equations should be introduced in the building insulation estimation panel (Figure 2.41):

A. Collapse button: Used to hide the building insulation estimation panel.

B. Roof data: These data are used to estimate the heat transfer coefficient between a green roof and a conventional roof, according to Equation 2.20.

C. Heating system data: Heating system efficiency data to estimated energy saved on the basis of Equation 2.19. When heating system has electricity and fuel, the percentage of the heating system that works with electricity should be indicated.

D. Cooling system data: Cooling system efficiency data to estimate energy saved on the basis of Equation 2.18.

E. Building use data: Data about the schedule and periods of building use. Data used to estimate energy saved with Equations 2.18 and 2.19.

F. Energy saved profile: Represents graphically the daily heat balance and the energy saved in the cooling and the heating systems.

G. Graph toolbar: The options here allow the user to move the view, zoom it and return to the initial graph view. These options can also be used to show or hide a legend, to export the graph and to view the graph results in a table.

H. Estimate button: When all the data have been introduced, this button computes the building insulation benefits and the energy saved with the equations explained previously.

EXAMPLE

In the example, only scenario 2 has a green roof, so building insulation benefits are only estimated in this scenario. They are estimated with the following data:

- School heating system: Natural gas. Price: 0.475 €/m^3.
- Use schedule: From 9.00 to 17.00.
- Number of days of building use per month: 20.
- Winter months: From November to March.
- Summer months: From May to July.

To complete the required data, default values are used. The building insulation benefits are estimated in 11.98 €/year, 174.92 kWh saved/year and 35.99 kg CO_2 avoided /year. The energy saved profiles obtained are shown in Figure 2.42.

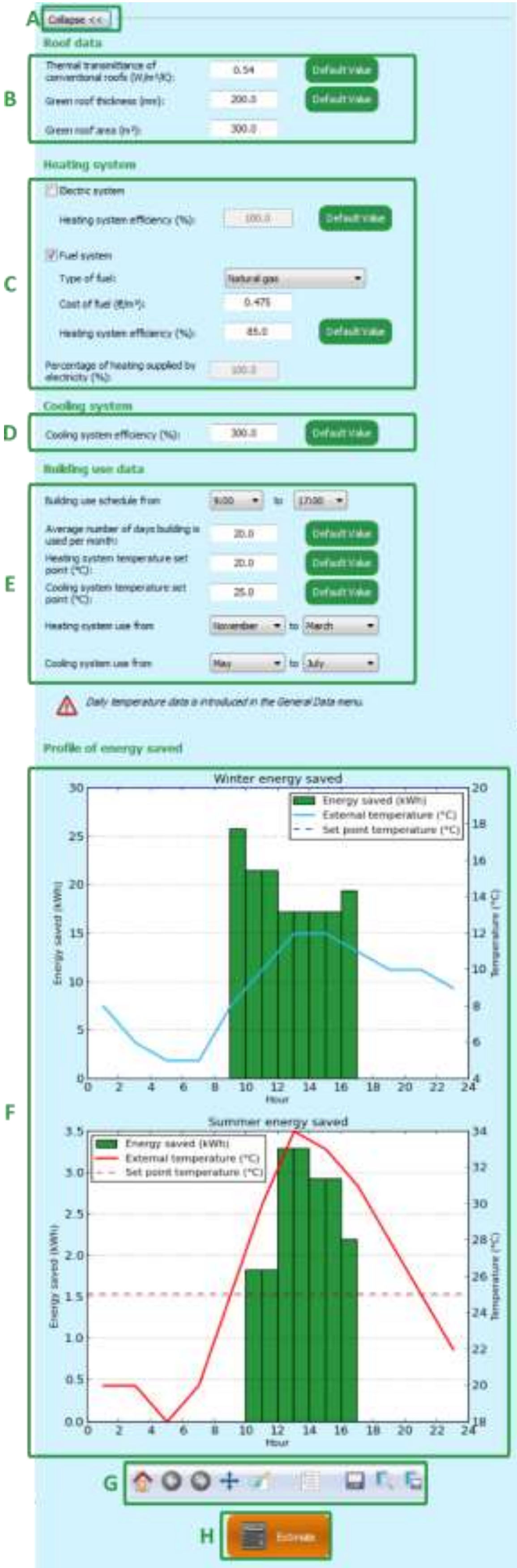


Figure 2.41. Building insulation estimation panel.

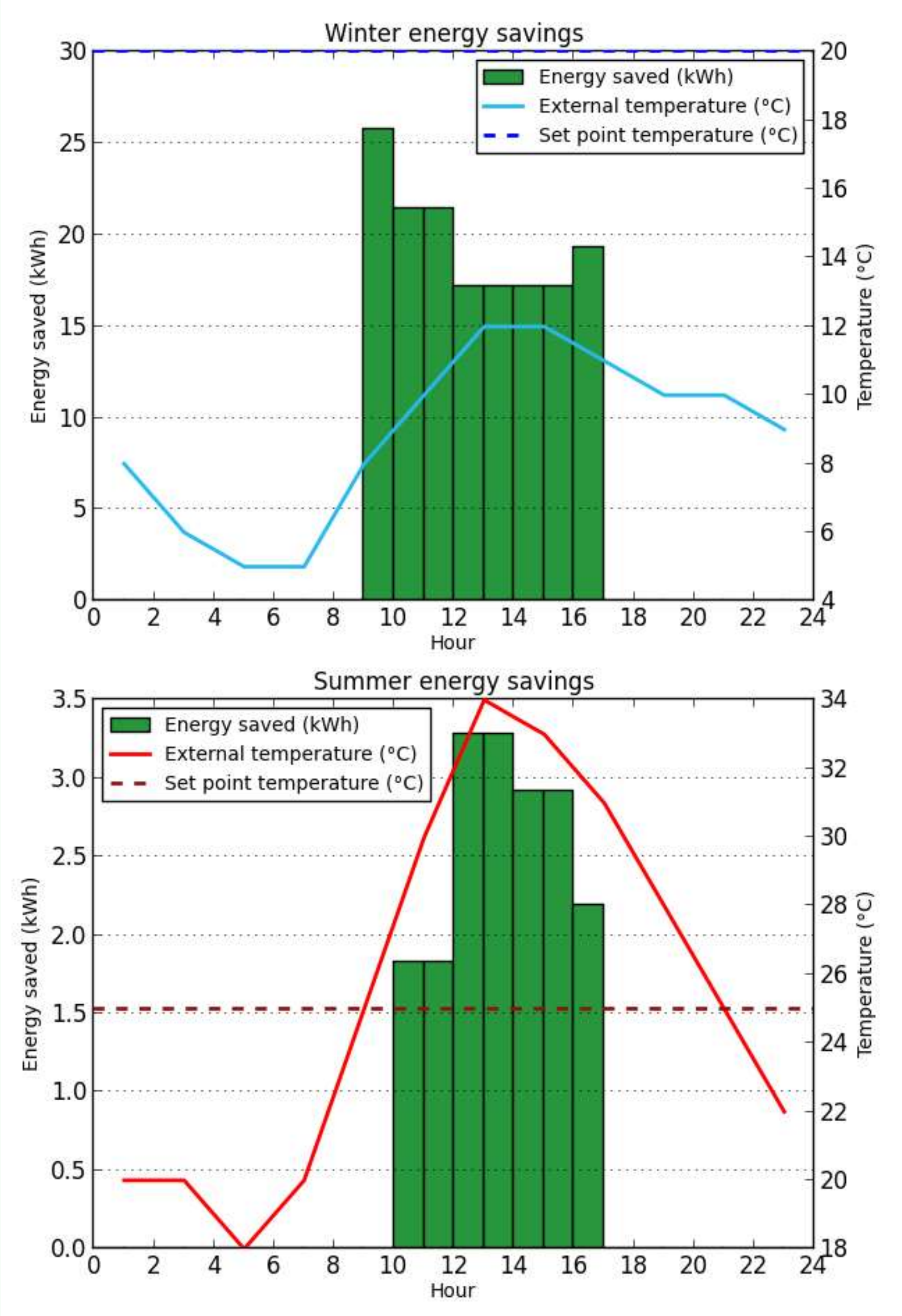


Figure 2.42. Building insulation heat transfer balance in the example.

2.13. ECOSYSTEM SERVICES

2.13.1. Introduction

Ecosystem services are the outputs of ecosystems from which people derive benefits. These benefits include:

- Resources for basic survival, clean air and water.
- A contribution to good physical and mental health, access to green spaces, both urban and rural, and genetic resources for medicines.
- Protection from hazards, regulation of our climate and water cycle.
- Support for a strong and healthy economy, raw materials for industry and agriculture, or through tourism and recreation.
- Social, cultural and educational benefits, and wellbeing and inspiration from interaction with nature.

Some drainage infrastructures (especially SuDS) can contribute to improve the urban ecosystem, providing ecosystem services that produce benefits in the urban area inhabitants. These ecosystem services may also be taken into account when different drainage options are compared.

Since the publication of the Millennium Assessment there has been increasing interest in valuing the benefits humans receive directly and indirectly from nature (ecosystem services). There are many current examples and attempts to value ecosystem services. The UKNEA (UKNEA, 2011) reviews current work on ecosystem services in the United Kingdom and makes an important contribution to their valuation. Many methods have been used to undertake the economic valuation of ecosystem services, some of them are reviewed in the Report on Ecosystem services of the E²STORMED project. This report can be very useful to analyze ecosystem services of stormwater management in a more detailed way.

In the E²STORMED DST, ecosystem services are mainly defined in a qualitative way, since ecosystem services valuation is a complex process and it is not the main focus of this tool. However, if ecosystems services benefits have been quantified, they can be added for each scenario in the Summary tab, as explained in Section 2.14. This tab can provide useful information about the benefits produced by each type of drainage infrastructure, so it can be used at the beginning to support the stormwater design.

The only process that is quantified in this tab is the equivalent CO_2 reduction provided by vegetation included in the drainage infrastructures, since it is an important input for the emissions balance.

2.13.2. Ecosystem services tab

The data required in this tab only need to be entered if a qualitative evaluation of ecosystem services is to be used as a criterion in the decision-making process. This tab provides information about the ecosystem services produced by each type of drainage infrastructure component introduced in each scenario. This information can be used as a guide to estimate a global qualitative value of ecosystem services produced in the scenario. Furthermore, the carbon dioxide reduction produced by vegetation can also be introduced. The different parts of this tab are:

A. Reduction of carbon dioxide: Annual reduction of carbon dioxide produced by the vegetation included in each scenario. The process to estimate this volume is explained in Section 2.13.3. This reduction can be estimated using the carbon dioxide reduction panel (shown when the estimate button is clicked).

B. List of infrastructures: Infrastructures components added in each scenario. When an infrastructure component (SuDS) is selected in this list, the ecosystem services list is automatically updated to show the services produced by the selected infrastructure.

C. Ecosystem services: List of ecosystem services provided by the infrastructure selected. In the Annex 2, the ecosystem services provided by each type of drainage infrastructure are shown. This list is explained in detail in the E²STORMED Report on Ecosystem services. The ecosystem services included in this list are:

- Aesthetics.
- Air quality improvement.
- Amenity Community education and engagement.
- Community space improvement.
- Enhancement of quality of life.
- Firm dry surfaces to park and walk on after heavy rain.
- Food growing.
- Habitat provision and enrich biodiversity.
- Improved community cohesion.
- Improvements to public health.
- Noise attenuation.
- Provision of educational opportunities.
- Recreational use.
- Reduction of greenhouse gas emissions.
- Regulation of urban microclimates.

- Visual and landscape benefits.

D. Evaluation of the ecosystem services in each infrastructure: Summary of ecosystem services provided by each type. These qualitative values are justified in the Report on E²STORMED Ecosystem services and are shown in Table 2.23.

E. Evaluation of global ecosystem services: In each scenario, a global value of ecosystem services should be selected by the user according to the ecosystem services provided by the SuDS used in the scenario. This estimate should be made by valuing services provided by each component and the proportion of drainage area managed by that type in relation to the total site area.

2.13.3. Estimation of Carbon Dioxide Reduction

→ Detailed analysis

Urban vegetation reduces carbon dioxide in the atmosphere by fixing carbon during photosynthesis and storing excess carbon as biomass. This effect is especially important when trees are planted, so increasing the number of trees might potentially slow the accumulation of atmospheric carbon dioxide. For this reason, vegetation included in the drainage infrastructures may reduce carbon dioxide and improve the urban ecosystem. This reduction has been included in this tool since its value can be really significant when the emissions balance of drainage infrastructures is analyzed.

Different studies have addressed to quantify the reduction of carbon dioxide produced by urban vegetation. Some aspects like urban temperature and oxygen concentration may be have an important influence on carbon dioxide reduction. Different procedures and references for this estimation are detailed in the E²STORMED Report on Ecosystem services.

→ Estimation

In the E²STORMED DST, a first estimation of the equivalent CO_2 reduced by vegetation can be made by adding the reduction provided by the trees and the green roofs. Therefore, the following fata is needed:

A. Total green roof area: Total area of green roofs in the scenario (m²).

B. Unit carbon dioxide reduction in green roofs: Average annual quantity of carbon dioxide reduced in green roofs per square meter (default value is 0.068 kg CO_2e/year/m²).

C. Number of trees: Number of trees included in the drainage infrastructures of the analyzed scenario.

D. Carbon dioxide reduction per tree: Average annual quantity of carbon dioxide reduced by each tree (default value is 10 kg CO_2e/year/tree).

These values have been obtained after investigating carbon cycle benefits accrued from vegetated SuDS involved a review of many peer reviewed publications, as explained in the E²STORMED Report on Ecosystem services. The conclusion of the review exercise was that carbon sequestration values assigned to trees and green roofs can be estimated and have been included. However the values for 'maintained lawns or turf-grass' is negligible (and occasionally negative) therefore not included.

This data is introduced in the carbon dioxide reduction panel (Figure 2.43) to obtain the annual volume reduction of carbon dioxide produced by vegetation.

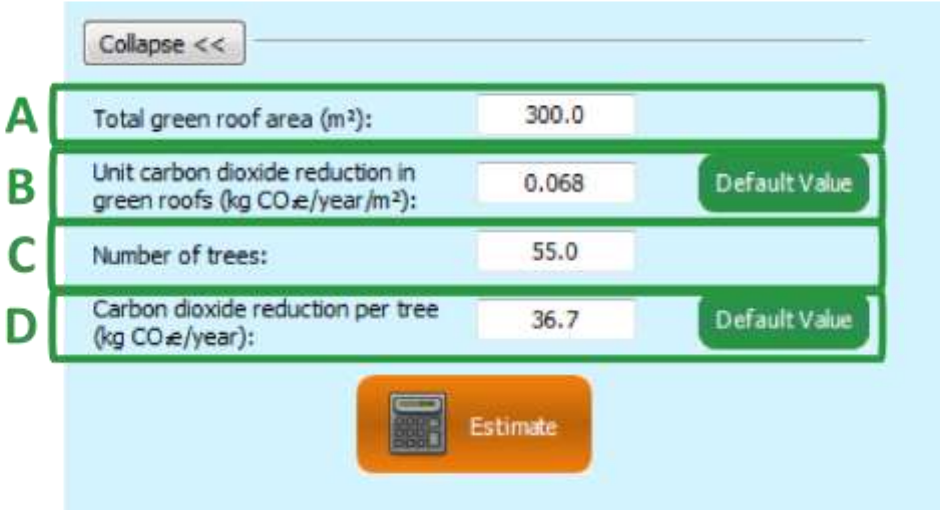


Figure 2.43. Carbon dioxide reduction panel.

EXAMPLE

In the example, only scenario 2 includes new urban vegetation in the drainage infrastructures. In this scenario, 55 new trees are planted as part of the drainage improvement and a green roof is built, so a reduction of 2038.9 kg CO_2e/year is obtained.

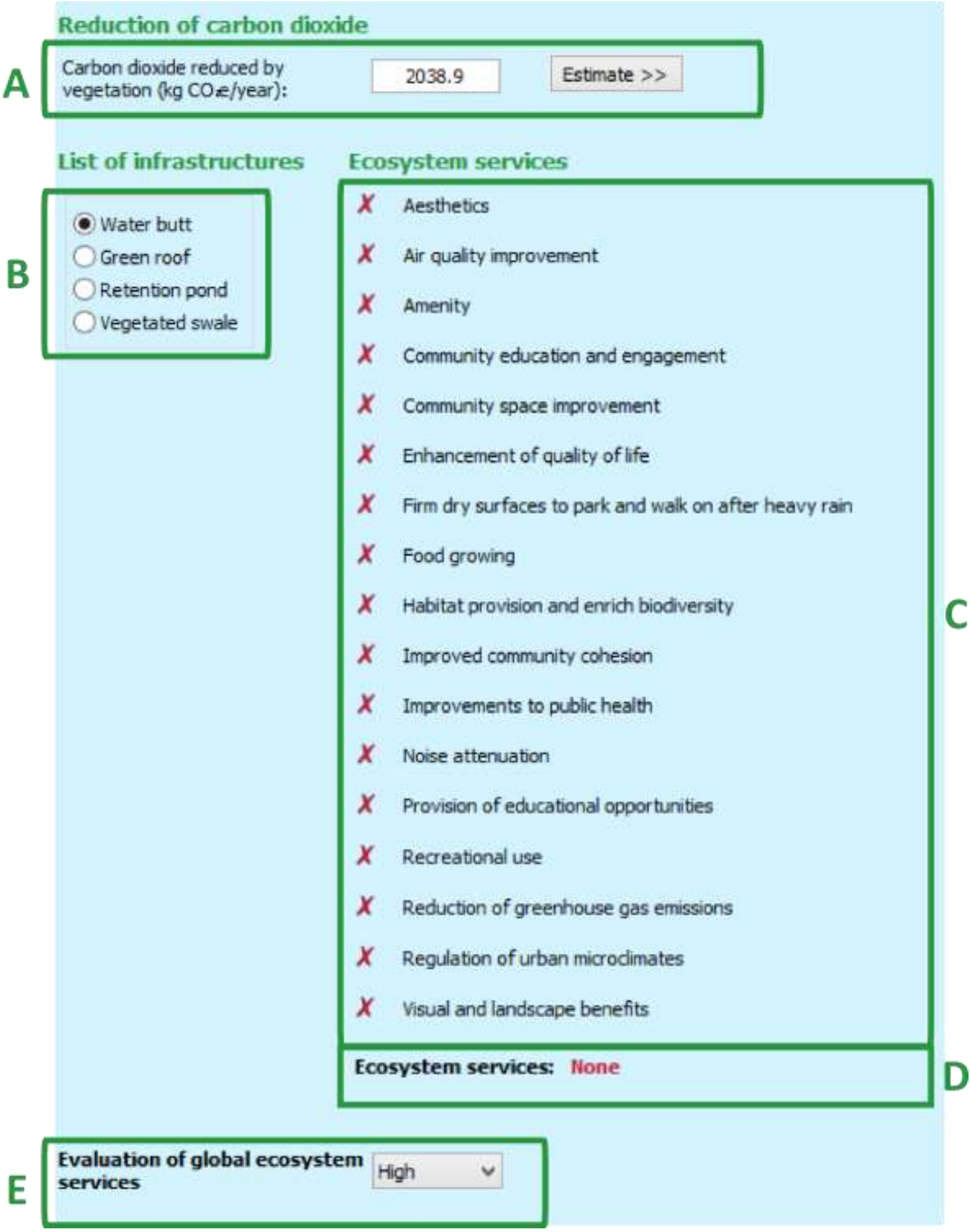


Figure 2.44. Ecosystem services tab.

Type of infrastructure	Ecosystem services evaluation
Conventional drainage networks	None
Conventional roofs	None
Standard pavements	None
Structural detention facilities	None
Bioretention areas	High
Constructed wetlands	High
Detention basins	Medium
Filter drains	Low
Filter strips	Low
Geocellular systems	None
Green roofs	High
Infiltration basins	Low
Infiltration trenches	Low
Permeable pavements	Medium
Rain gardens	High
Rain harvesting systems	None
Retention ponds	High
Soakaways	Low
Vegetated swales	High
Water butts	None

Table 2.23. Evaluation of ecosystem services in each type of drainage infrastructure.

EXAMPLE

In the example, it has been decided to evaluate the ecosystem services in scenario 1 as very low, since any infrastructure of this scenario has ecosystem benefits. In scenario 2, they have been evaluated as high, since the green roof, the vegetated swales and the retention pond produce significant ecosystem services.

2.14. SUMMARY

2.14.1. Introduction

This part of the tool is used to summarize the different costs, benefits, energy consumptions and emissions introduced in each tab of each scenario. With this summary, the most important parts of costs and energy consumption in the stormwater management can be easily identified.

2.14.2. Summary tab

The different parts of the summary tab are:

A. Results table: This table summarizes the financial, energy and emissions results of all the previous tabs for the selected scenario. In this table, negative values indicate financial benefits, energy savings or CO_2 emissions avoided. It can be easily exported to a spreadsheet or text file with the Export table… button. In the exported table, the results of the different scenarios are compared.

B. Other costs and benefits: This part of the tab can be used to add costs, benefits, energy consumptions or savings and emissions for each scenario that has not been included in any of the previous tabs. An example that could be included with this menu is the financial benefits of the equivalent CO_2 emissions reduction when some trees or plants are included in a drainage infrastructure. These quantitative values can be easily added indicating the type of cost or benefit, a name for it and its value, as shown in Figure 2.45.

C. Energy consumption table: This table summarizes the energy consumption and emissions per cubic metre of water in each pumping and treatment process of the urban water cycle for the selected scenario. These data are introduced in the Water supply tab and the Conveyance and treatment tab. This table can be easily exported to a spreadsheet or text file with the Export table… button. In the exported table, the results of the different scenarios are compared.

D. Infrastructures construction table: This table summarizes the costs, energy consumption and emissions of the construction of each infrastructure introduced in the scenario. These data is introduced as explained in Section 2.6.

E. Infrastructures maintenance table: This table summarizes the costs, energy consumption and emissions of the maintenance of each infrastructure introduced in the scenario. These data is introduced as explained in Section 2.6.

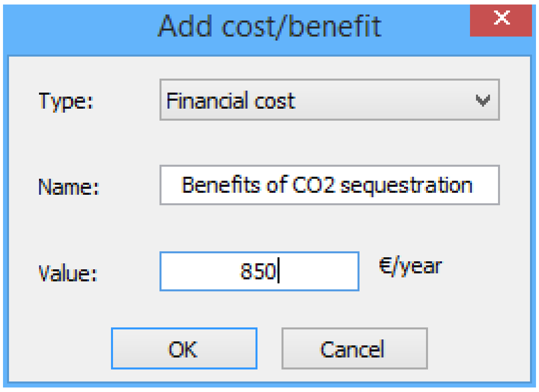


Figure 2.45. Add cost/benefit menu.

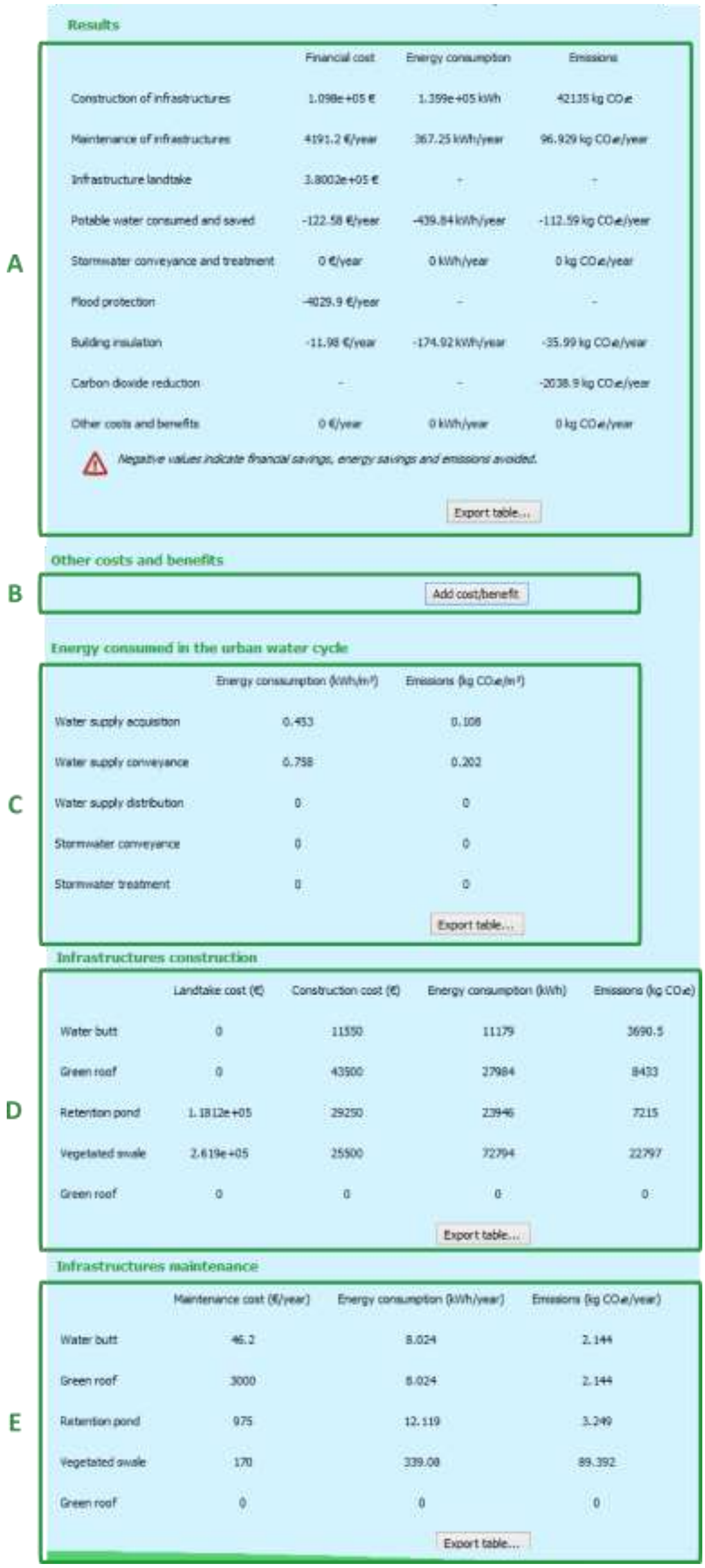


Figure 2.46. Summary tab.

3. Results

3.1. Time graph

It shows how stormwater management cost, energy consumption and emissions progress in the period of analysis. This graph is obtained with the corresponding toolbar button (Figure 3.1) or with the menu option *Results → Time graphs.*

Figure 3.1. Toolbar button to obtain time graphs.

These graphs represent the results of costs, energy consumption and emissions obtained for each scenario representing them cumulatively in the period of analysis. Annual increment of graphs is computed adding the results of water reuse benefits, runoff conveyance and treatment, flood protection benefits and building insulation benefits. Furthermore, construction and maintenance costs and energy consumption of each scenario's infrastructure are added as indicated in Figure 2.13.

The final point of these lines is equal to the total present value of costs, total energy consumption or total emissions of stormwater management in the analyzed period for each scenario. Negative values in these graphs indicate financial benefits, energy saved and CO_2 emissions avoided.

When financial values are represented in these graphs, costs and benefits are discounted to reflect its present value, as if it existed today. The present value is always less than or equal to the future value because money has interest-earning potential. The present value is computed with the following equation:

$$PV = {}^{FV}\!\Big/\!\left(1 + {}^{r}\!/_{100}\right)^{t} \qquad \text{Equation 3.1}$$

Where *PV* is the present value (economic units), *FV* is the cash flow whose present value is computed (economic units), *r* is the discount rate (%), which is introduced in the General data menu, and *t* is the year when the cash flow FV is produced.

The different parts of the time graphs window (Figure 3.2) are:

- **A.** Type of time graph: This menu allows the user to choose what is represented in the Y-axis of the time-graph. There are three options: present value of financial costs, energy consumption and CO_2 emissions. When the option chosen is changed, the graph is automatically updated.
- **B.** Time graph: Time graph for the scenarios compared in the analysis. Each line represents the data of one scenario. Higher values of the time graph indicate that a scenario is worse compared to the others from a financial, energy or environmental point of view.
- **C.** Costs and benefits considered: This menu allows the user to choose what costs and benefits are represented in the time graph. These values correspond to the different data introduced in

the DST as indicated in Section 2. When the selected cost and benefits change, the graph is automatically updated.

D. Select/Deselect all button: Used to select or unselect all the cost and benefits of the upper list.

E. Graph toolbar: Options allow the user to move the view, zoom it and return to the initial graph view. These options can also be used to show or hide a legend, to export the graph and to view the graph results in a table.

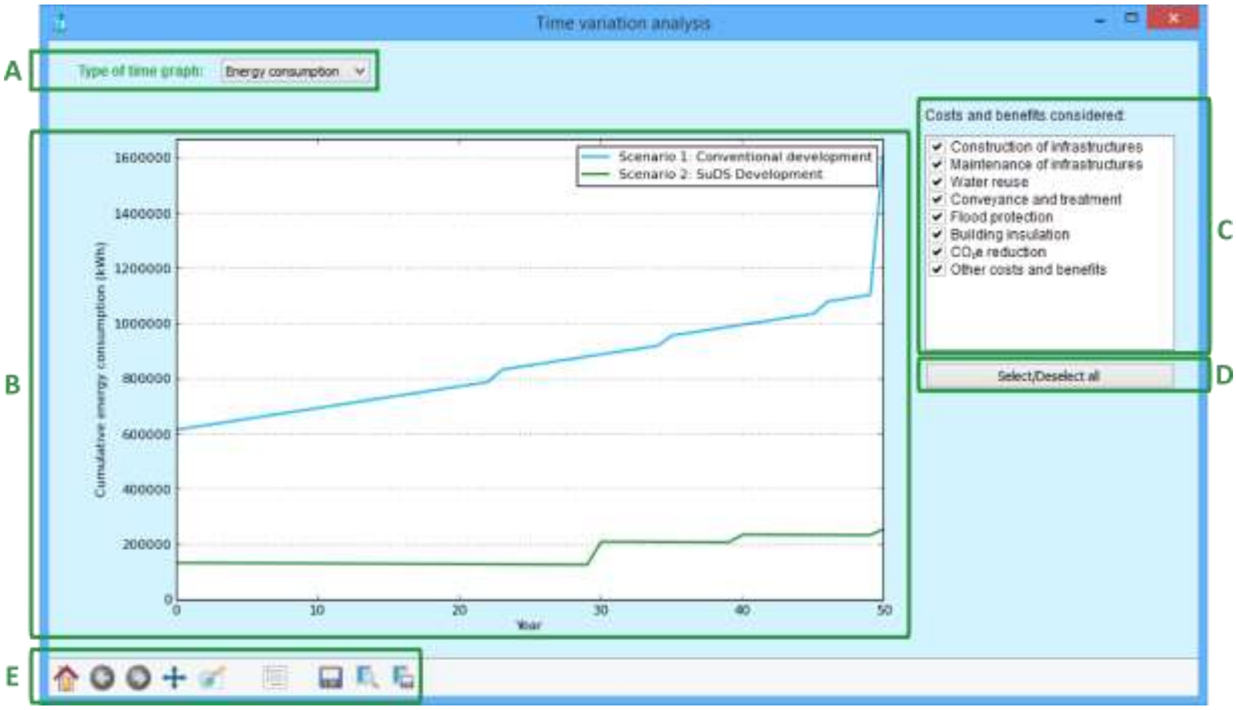


Figure 3.2. Time graphs window.

EXAMPLE

Figure 3.3, Figure 3.4 and Figure 3.5 show the time graphs obtained with the example data. As can be seen, the two scenarios have very similar final costs, although energy consumption and emissions in scenario 2 are lower.

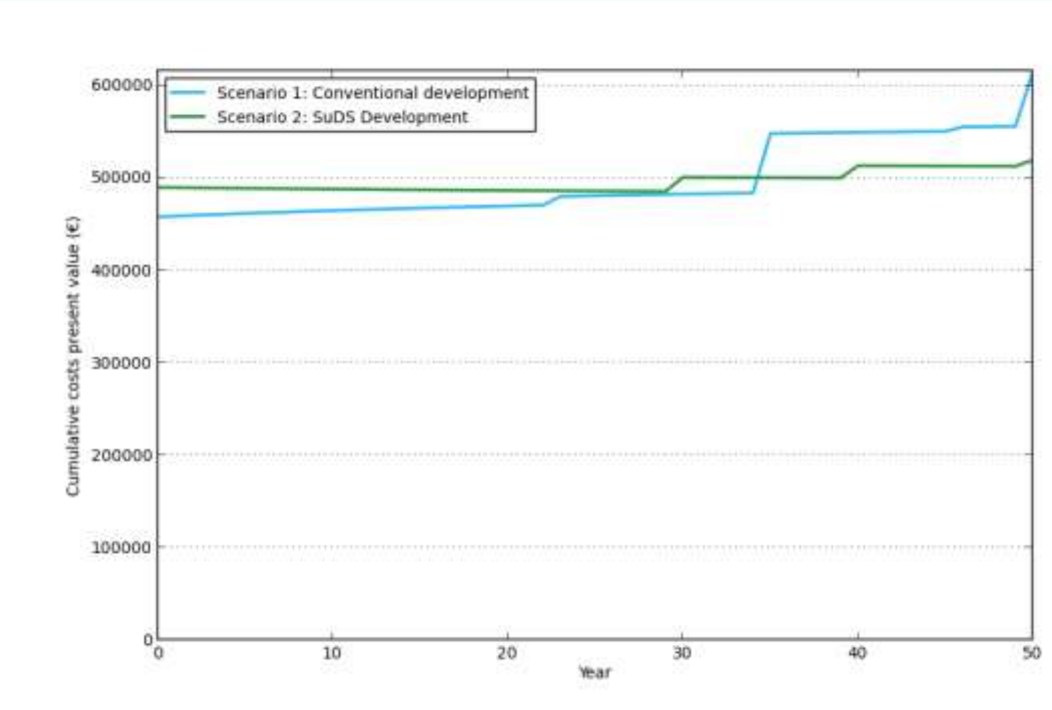


Figure 3.3. Financial time graph obtained in the example.

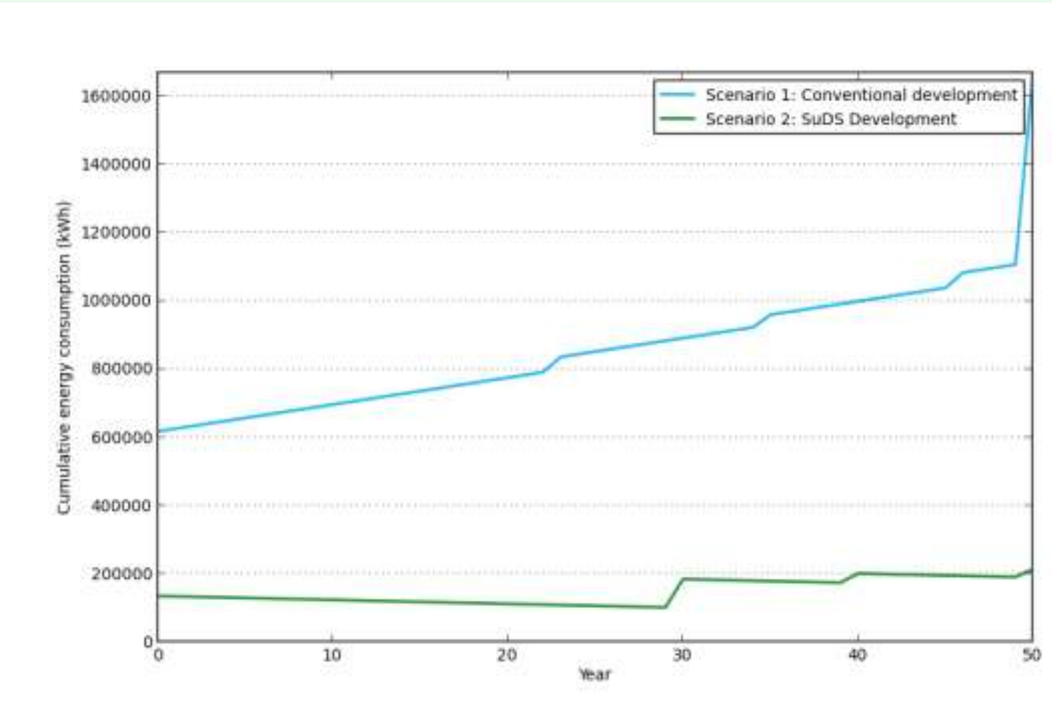


Figure 3.4. Energy time graph obtained in the example.

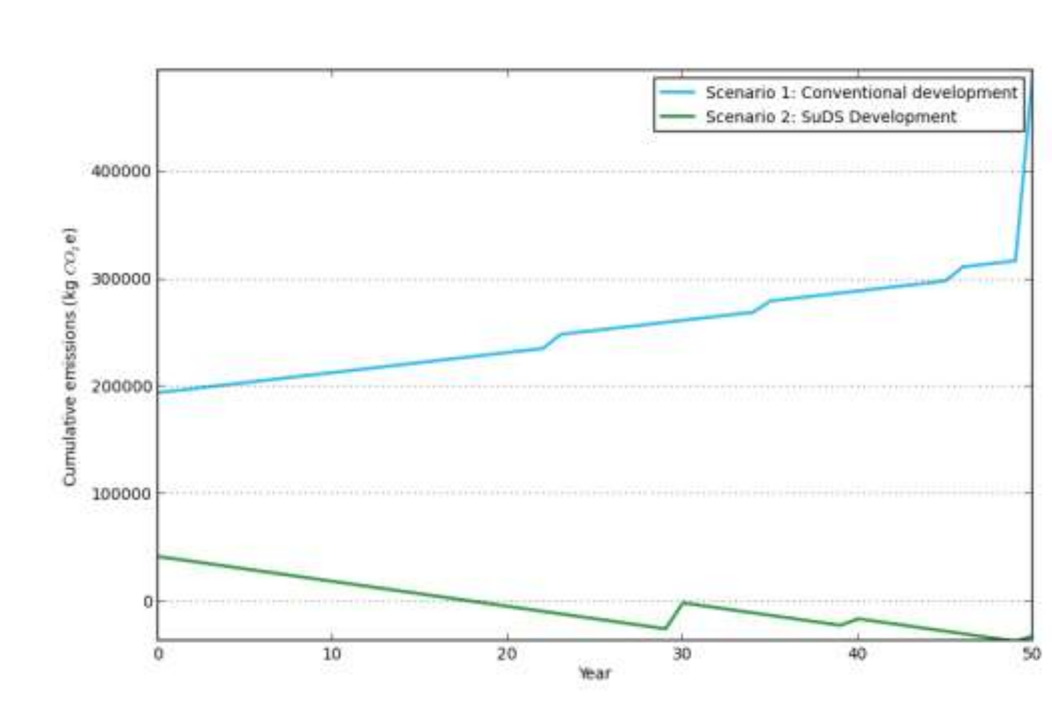


Figure 3.5. Time graph of emissions obtained in the example.

3.2. Define decision criteria

This menu allows the user to choose the qualitative and quantitative decision criteria that will be used in the multi-criteria analysis. The criteria defined in this menu are used to obtain the results diagrams explained in the two following sections. This menu is shown with the corresponding toolbar buttons (Figure 3.1) or with the menu option *Results → Decision criteria…*

Figure 3.6. Toolbar buttons to define decision criteria.

As explained in the E²STORMED Report on Management and decision assessment tools, multi-criteria analysis (MCA) is an established process which can be used to assist decision makers when comparing different complex options. It should be noted that MCA is not intended to make decisions, rather to guide decision makers to make the most appropriate choice.

MCA techniques generally include the use of weighted and scored matrices, and hence require the establishment of measurable criteria, whether qualitative or quantitative, to assess the extent to which objectives may be fulfilled (UKEA, 2013). The MCA process involves a number of steps which are summarized in Figure 3.1.

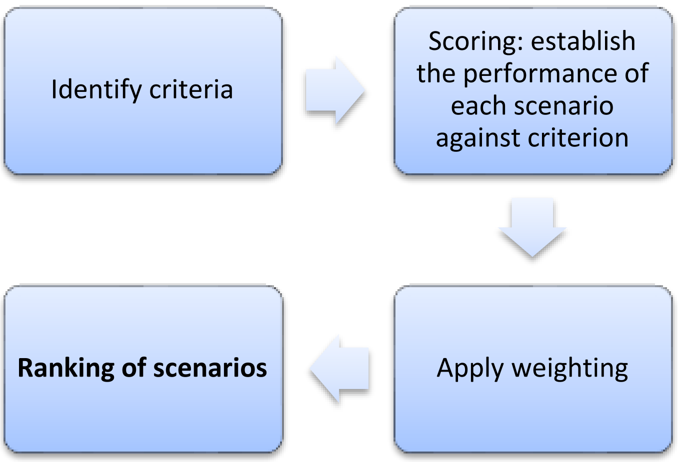


Figure 3.7. Multi-criteria analysis process overview.

In the E²STORMED DST, multi-criteria analysis to compare quantitative and qualitative criteria is made with the data introduced of each scenario. The decision criteria available in this tool are:

- Financial criteria:
  - Cost of stormwater management: Total present value of stormwater management cost obtained adding costs of infrastructures construction and maintenance and runoff treatment and conveyance.
  - Net cost of stormwater management: Cost of stormwater management minus benefits produced by water reuse, flood protection and building insulation.

- Construction and land take cost: Sum of construction and land take costs of all the drainage infrastructure required for each scenario.
- Maintenance cost: Sum of annual maintenance costs of all the drainage infrastructures in each scenario.
- Total construction and maintenance cost: Total present value of construction and maintenance costs.
- Water reuse net benefits: Annual benefits of water reutilization. These benefits are obtained in the Water supply tab, as explained in Section 2.7.
- Stormwater treatment and conveyance cost: Annual costs of runoff pumping and treatment. These costs are obtained in the Conveyance and treatment tab, as explained in Section 2.9.
- Building insulation benefits: Annual financial benefits of buildings insulation improvement produced by green roofs. These benefits are obtained using the Building insulation tab, as explained in Section 0
- Flood protection benefits: Annual economic benefits of flood protection produced by drainage infrastructures. These benefits are obtained using the Flood protection tab, as explained in Section 2.11.

- Energy criteria:
  - Energy consumed by stormwater management: Total stormwater management energy consumed obtained adding energy consumed by infrastructures' construction and maintenance and runoff treatment and conveyance.
  - Net energy consumed by stormwater management: Energy consumed by stormwater management minus energy saved by water reuse and building insulation.
  - Energy consumed during construction: Sum of energy consumed during construction of all the drainage infrastructures of each scenario.
  - Energy consumed in maintenance: Sum of annual maintenance energy consumed of all the drainage infrastructures of each scenario.
  - Energy consumed in construction and maintenance: Total infrastructures' construction and maintenance energy consumed during the analyzed period.
  - Water reuse net energy saved: Annual energy saved through water reutilization. This energy saved is obtained in the Water supply tab, as explained in Section 2.7.
  - Treatment and conveyance energy consumption: Annual energy consumption of runoff pumping and treatment. This consumption is obtained in the Conveyance and treatment tab, as explained in Section 2.9.

- Building insulation energy saved: Annual energy saved through buildings insulation improvement produced by green roofs. This energy saved is obtained in the Building insulation tab, as explained in Section 0

- Emissions criteria:

  - Emissions due to stormwater management: Total stormwater management CO_2 emissions obtained by adding the emissions from infrastructure construction and maintenance and runoff treatment and conveyance.

  - Net emissions due to stormwater management: Emissions of stormwater management minus emissions avoided due to water reuse and building insulation.

  - Emissions during construction: Sum of CO_2 emissions during construction of all the drainage infrastructures of each scenario.

  - Emissions in maintenance: Sum of annual maintenance emissions of all the drainage infrastructure in each scenario.

  - Total emissions during construction and maintenance: Total construction and maintenance emissions during the period analyzed.

  - Water reuse net emissions avoided: Annual emissions avoided by water reutilization. These emissions are obtained in the Water supply tab, as explained in Section 2.7.

  - Treatment and conveyance emissions: Annual CO_2 emissions of runoff pumping and treatment. These emissions are obtained in the Conveyance and treatment tab, as explained in Section 2.9.

  - Building insulation emissions avoided: Annual emissions avoided by buildings insulation improvement produced by green roofs. These emissions are obtained in the Building insulation tab, as explained in Section 0

  - Carbon dioxide reduced by vegetation: Annual quantity of carbon sequestration by the vegetation included in the drainage infrastructures. This reduction is computed in the Ecosystem services tab, as explained in Section 2.13.

- Other quantitative criteria:

  - Volume of water reused: Annual volume reused thanks to rainwater harvesting systems and water butts. This volume is obtained in the Water supply tab, as explained in Section 2.7.

  - Volume of runoff produced: Annual runoff volume produced in each drainage scenario. This volume is obtained in the Stormwater runoff tab, as explained in Section 2.8.

- Volume of discharge from Combined Sewer Overflows: Annual volume of Combined Sewer Overflow (CSO) spills produced in each drainage scenario. These data are introduced in the Stormwater runoff tab, as explained in Section 2.8.
- Number of CSO spills per year: Average number of Combined Sewer Overflow spills per year. These data are introduced in the Stormwater runoff tab, as explained in Section 2.8.
- Peak outflow rate: Maximum outflow rate produced in each scenario for the storm of design. These data are introduced in the Stormwater runoff tab, as explained in Section 2.8.
- Aquifer recharge and evapotranspiration: Annual runoff volume of stormwater used for aquifer recharge and evapotranspiration. This volume is obtained in the Stormwater runoff tab, as explained in Section 2.8.
- Water losses in the network: Percentage of water losses in the sewage network. These data are introduced in the Conveyance and treatment tab, as explained in Section 2.9.

- Environmental and water quality criteria:
  - Global outflow water quality: Qualitative evaluation of stormwater quality when is released into the environment. This evaluation is introduced in the Water quality tab, as explained in Section 2.10.
  - Suspended solids removal efficiency: Qualitative evaluation of the capacity of the drainage system to remove suspended soils. This evaluation is introduced in the Water quality tab, as explained in Section 2.10.
  - Nutrients removal efficiency: Qualitative evaluation of the capacity of the drainage system to remove nutrients. This evaluation is introduced in the Water quality tab, as explained in Section 2.10.
  - Heavy metals removal efficiency: Qualitative evaluation of the capacity of the drainage system to remove heavy metals. This evaluation is introduced in the Water quality tab, as explained in Section 2.10.
  - Evaluation of ecosystem services: Qualitative evaluation of ecosystem services produced by drainage infrastructures of each scenario. This evaluation is introduced in the Ecosystem services tab, as explained in Section 2.13.

In addition to these criteria which are automatically computed by the E²STORMED DST, other quantitative and qualitative criteria can be added to complement the multi-criteria analysis. When using new criteria, their values for each scenario must be introduced.

When different quantitative criteria are compared, it is necessary to put them in the same range and to define the performance of each scenario in each criterion. In the E²STORMED DST, this transformation is made with the **utility value**, which is a score that defines what values of the criteria are desirable (utility around 100%) or not (utility around 0%). In each criterion its best value (utility =

100%) and worst value (utility=0%) are defined. The utility of the criterion value of each scenario is obtained interpolating between these two values, as shown in Figure 3.8.

In the E²STORMED DST, default values are proposed for the best and worst values, obtained from the maximum and minimum of each criterion for all the compared scenarios. It is important to adjust best and worst values in order to obtain suitable utility results. An example where this worst value can be useful is with the maximum allowable outflow rate for the peak outflow rate criterion. Hence, all the scenarios should fulfil this requirement and the lower the flow rate, the higher the utility value will be. Other example is to use as worst value, the maximum forecasted budget or energy consumption during the period of analysis for stormwater management. Other option could be choosing as best value for costs 0 € and as worse value the double of the higher value for all the scenarios. Best and worst values do not change the order of the scenarios but the utility values of each scenario in each criterion.

Finally, to obtain the global score of each scenario according to the multi-criteria analysis, a weight must be defined for each criterion. A higher weight indicates that the criterion will be more important in the decision making. The sum of the weight of all the criteria should be equal to 100%. Therefore, the global score for each scenario is obtained with the following formula:

$$GS_i = \sum_{j=1}^{N} W_j \cdot UV_{ij} \qquad \text{Equation 3.2}$$

Where GS_i is the global score of scenario i (%), N is the number of criteria, W_j is the weight of the criterion j (%) and UV_{ij} is the utility value of the scenario i in the criterion j (%).

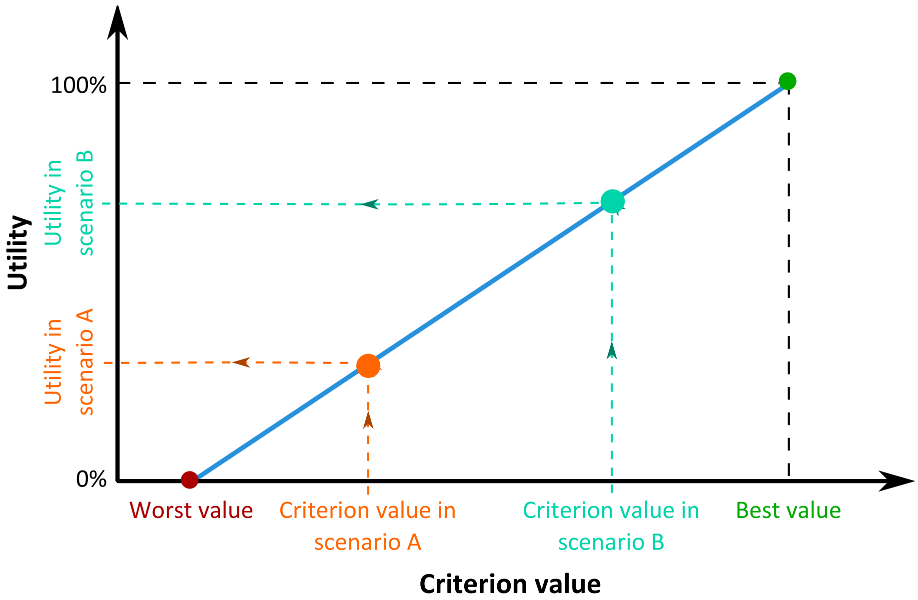


Figure 3.8. Method to obtain the criterion utility value for each scenario.

The decision criteria menu (Figure 3.9) has the following parts:

A. Type of decision criteria: Used to select the type of decision criteria that are shown in the decision criteria list.

B. Obtained decision criteria: Decision criteria that can be obtained with the E²STORMED DST when all the necessary data is introduced in each scenario. These criteria are explained in the previous pages.

C. Add decision criterion: This button allows the user to choose the selected decision criterion for the multi-criteria analysis. The value of this criterion for each scenario is computed by the E²STORMED DST. When this button is selected, the menu shown in Figure 3.10 should be completed:

- Name: Criterion name that will be used to represent multi-criteria results.

- Criterion weight: Importance of the criterion for the multi-criteria analysis, according to Equation 3.2. The sum of the weight of all the criteria should be equal to 100%.

- Worst value: Criterion value whose utility is 0%, according to Figure 3.8. Proposed value is obtained from minimum (or maximum if the criterion is worse for higher values) values of the criterion for all the compared scenarios. This value does not need to be defined for qualitative criteria.

- Best value: Criterion value whose utility is 100%, according to Figure 3.8. Proposed value is obtained from the maximum (or minimum if the criterion is worse for higher values) values of the criterion for all the compared scenarios. This value does not need to be defined for qualitative criteria.

D. Add another quantitative decision criterion: This button allows the user to add a quantitative decision criterion that has not been computed by the E²STORMED DST. An example of these criteria could be outflow pollutants concentration. When this button is selected, the menu shown in Figure 3.11 should be completed. This menu is equal to the menu explained in the previous point, but the quantitative value of the criterion for each scenario should be introduced.

E. Add another qualitative decision criterion: This button allows the user to add a qualitative decision criterion that has not been introduced by default in the E²STORMED DST. An example of these criteria could be the social acceptance or public opinion of each drainage scenario. When this button is selected, the menu shown in Figure 3.12 should be completed. This menu is equal to the menu explained in the previous points, but the qualitative value of the criterion for each scenario should be introduced.

F. List of decision criteria selected: Decision criteria added to be used in the multi-criteria analysis. The sum of the weight of all the criteria should be equal to 100%. These criteria can be modified and removed by right-clicking on them.

G. Default decision criteria: In order to provide a first suggestion of potential decision criteria to be chosen, this button allow to directly define five decision criteria, which are:

- Net cost by stormwater management in the urban area: 20%.

- Net energy consumption by stormwater management in the urban area: 20%.
- Net emissions from stormwater management in the urban area: 20%.
- Ecosystem services provided by drainage infrastructures: 20%.
- Outflow water quality: 20%.

EXAMPLE

In the example, the following decision-criteria have been chosen for the multi-criteria analysis:

- Net cost by stormwater management in the urban area: 40%.
- Net energy consumption by stormwater management in the urban area: 15%.
- Net emissions from stormwater management in the urban area: 15%.
- Ecosystem services provided by drainage infrastructures: 20%.
- Outflow water quality: 10%.

All these criteria are computed directly by the E^{2}STORMED DST using the data previously introduced. The best and worst default values has been used in all the criteria, but in the net cost criteria, in which a worst value of 1 M€ has been introduced (maximum budget for stormwater management in this urban area for the period analyzed).

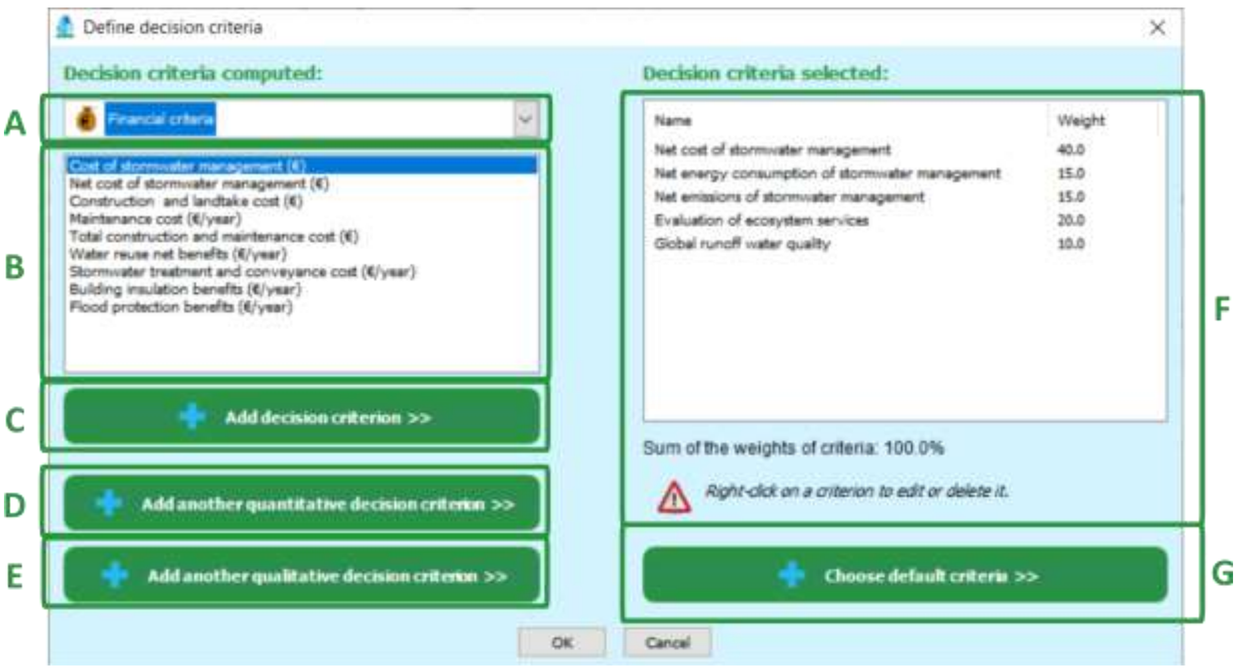


Figure 3.9. Decision criteria menu.

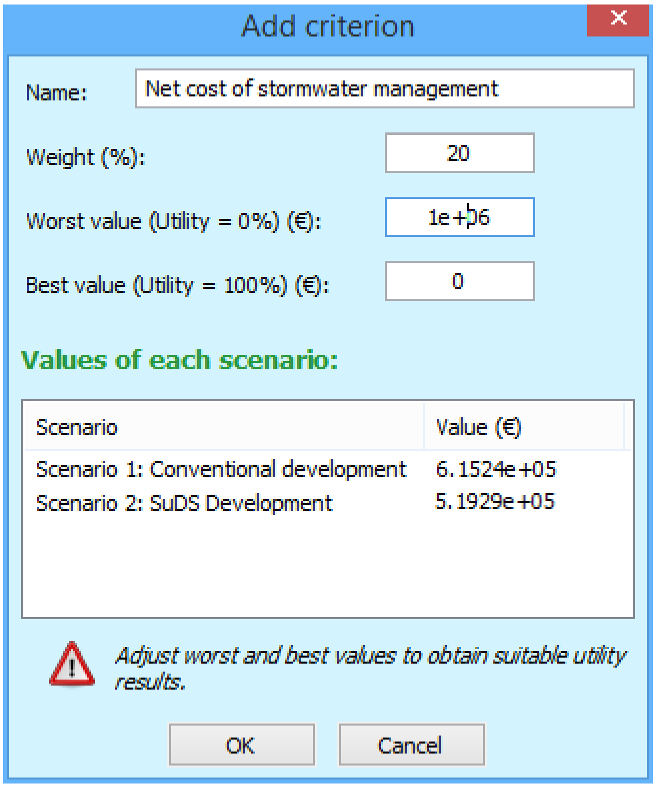


Figure 3.10. Add criterion menu.

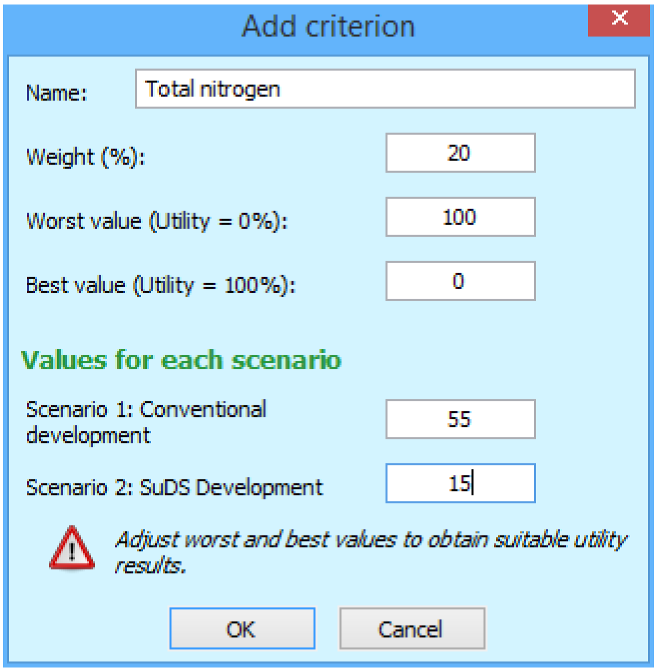


Figure 3.11. Menu to add other quantitative criterion.

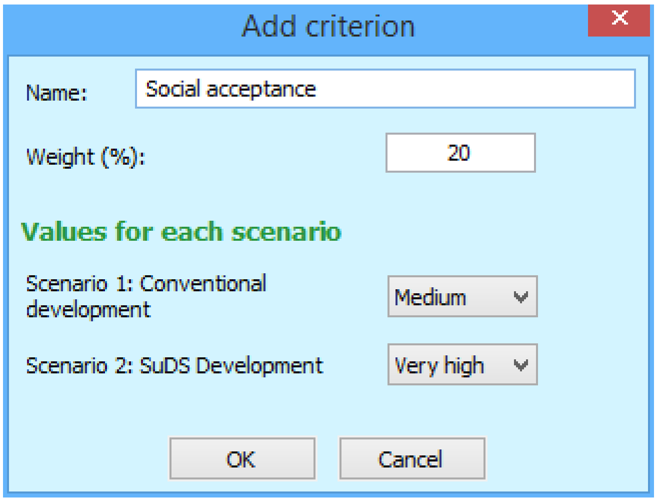


Figure 3.12. Menu to add other qualitative criterion.

3.3. Results of multi-criteria analysis per scenario

Results of the multi-criteria analysis for each scenario are shown in a diagram that depicts the weight and utility of each criterion for the selected scenario. The corresponding toolbar button is shown in (Figure 3.13) or the menu option *Results* → *Results per scenario* may be used.

Figure 3.13. Toolbar button to show results of multi-criteria analysis per scenario.

Figure 3.14 is an example of these circular diagrams which show the weight and utility of each criterion for the scenario. The width of each circular sector represents the criterion weight; the wider a circular sector is the more important is the criterion. The radius of each circular sector is the utility value of the selected scenario for the criterion. The larger is the radius; the better is the performance of the scenario being studies for the criterion under consideration. In summary, the larger the circular diagram, the better is the scenario being analyzed according to the multi-criteria analysis. The diagrams for two different scenarios can be compared by double clicking on the toolbar button of this diagram and placing them side by side on the screen.

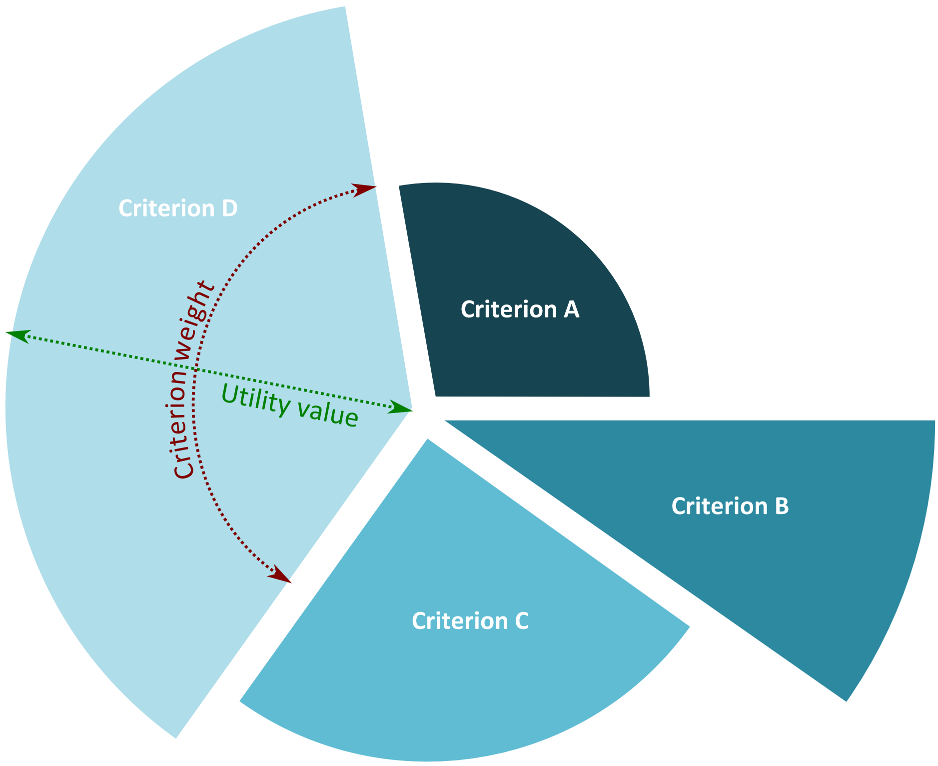


Figure 3.14. Diagram of results of multi-criteria analysis per scenario.

The different parts of this diagram (Figure 3.15) are:

A. Scenario: This choice is used to select the scenario whose results are to be shown. When the selected scenario changes, the diagram is automatically updated.

B. Results diagram: Circular diagram showing the multi-criteria analysis results per scenario.

C. Diagram toolbar: The options of this toolbar allow the user to move the view, zoom it and return to the initial view. These options can also be used to show or hide a legend, to export the diagram and to view the results in a table, as shown in Figure 3.16.

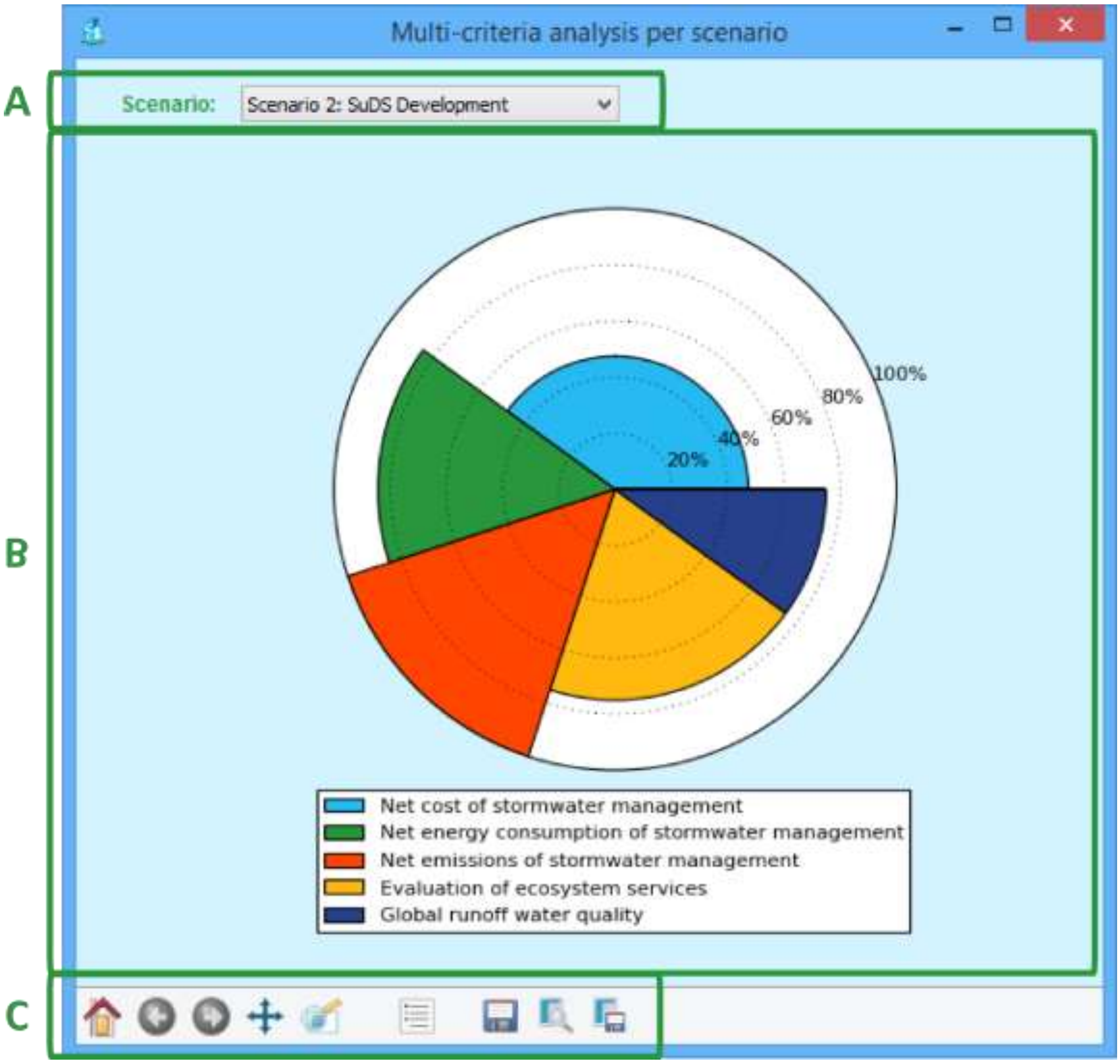


Figure 3.15. Window of results of multi-criteria analysis for one scenario.

Results

	Criterion	Weight (%)	Utility (%)
1	Net cost of stormwater management	40.0	48.0711000936
2	Net energy consumption of stormwater management	15.0	87.1504114011
3	Net emissions of stormwater management	15.0	99.9999501807
4	Evaluation of ecosystem services	20.0	75.0
5	Global runoff water quality	10.0	75.0

Figure 3.16. Table of results of multi-criteria analysis per scenario.

EXAMPLE

Diagrams for the two scenarios analyzed in the example have been drawn and the results are shown in Figure 3.17. It can be seen that the first criterion (net cost) is very similar for the two scenarios. For the other criteria, scenario 2 is clearly better than scenario 1. In summary, scenario 2 would be recommended according to the multi-criteria analysis results.

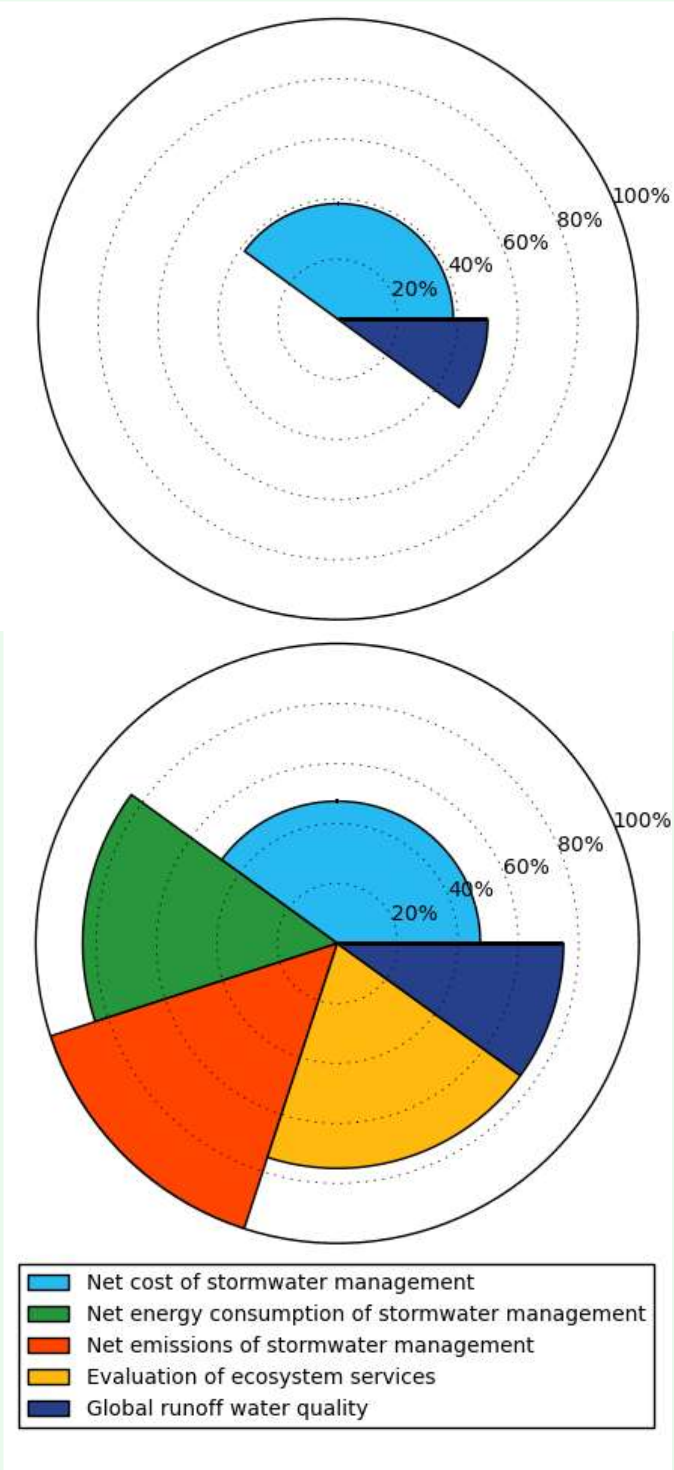


Figure 3.17. Multi-criteria results in the example for scenario 1 (upper) and scenario 2 (lower).

3.4. Global results of multi-criteria analysis

A comparison of the results from the multi-criteria analysis for all the scenarios is shown in the Global Results histogram, which depicts the global score of each scenario according to Equation 3.2. This histogram is brought up using the corresponding toolbar button (Figure 3.18) or with the menu option *Results → Global results.*

Figure 3.18. Toolbar button to show global results of the multi-criteria analysis.

Figure 3.19 shows the global score bars for each scenario in the multi-criteria analysis. These bars are obtained multiplying the weight and the utility value for each criterion. The larger the bar, the better is the scenario.

The different parts of this histogram (Figure 3.20) are:

- **A.** Results histogram: Shows the multi-criteria analysis results for all the scenarios analyzed.
- **B.** Histogram toolbar: Allows the user to move the view, zoom it and return to the initial histogram view. These options can also be used to show or hide a legend, to export the histogram and to view the histogram results in a table, as shown in Figure 3.21.

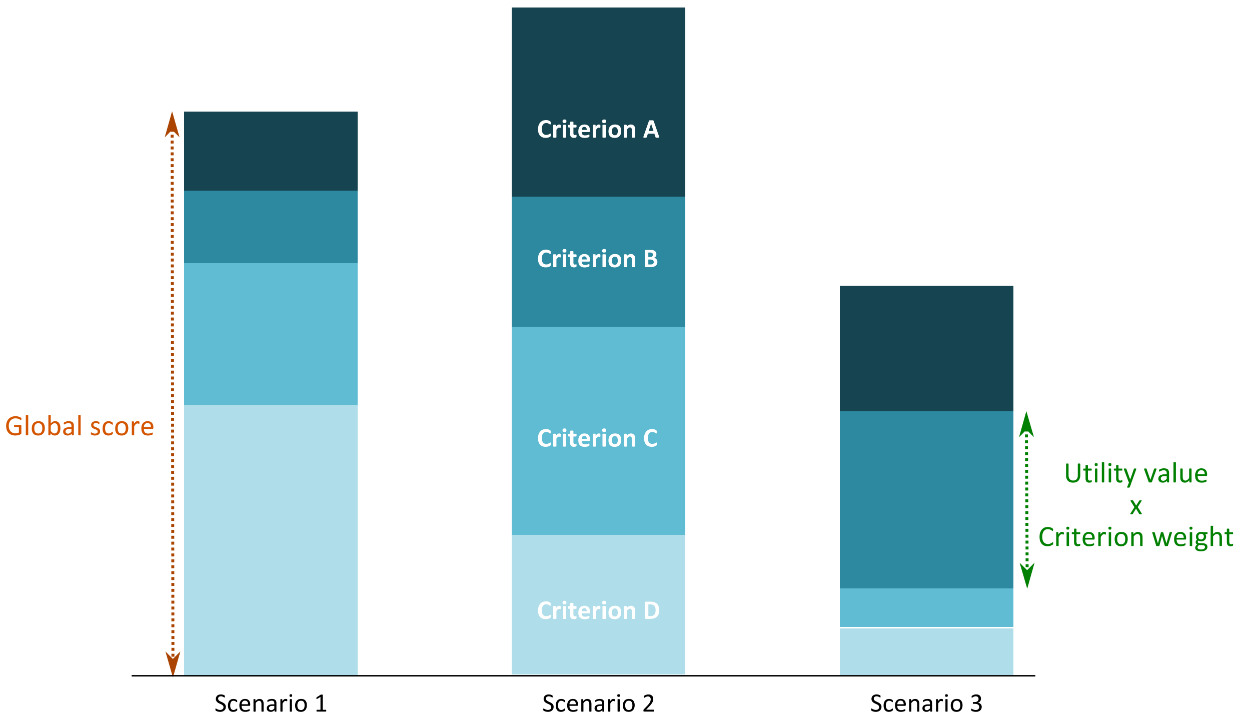


Figure 3.19. Histogram of global results of multi-criteria analysis.

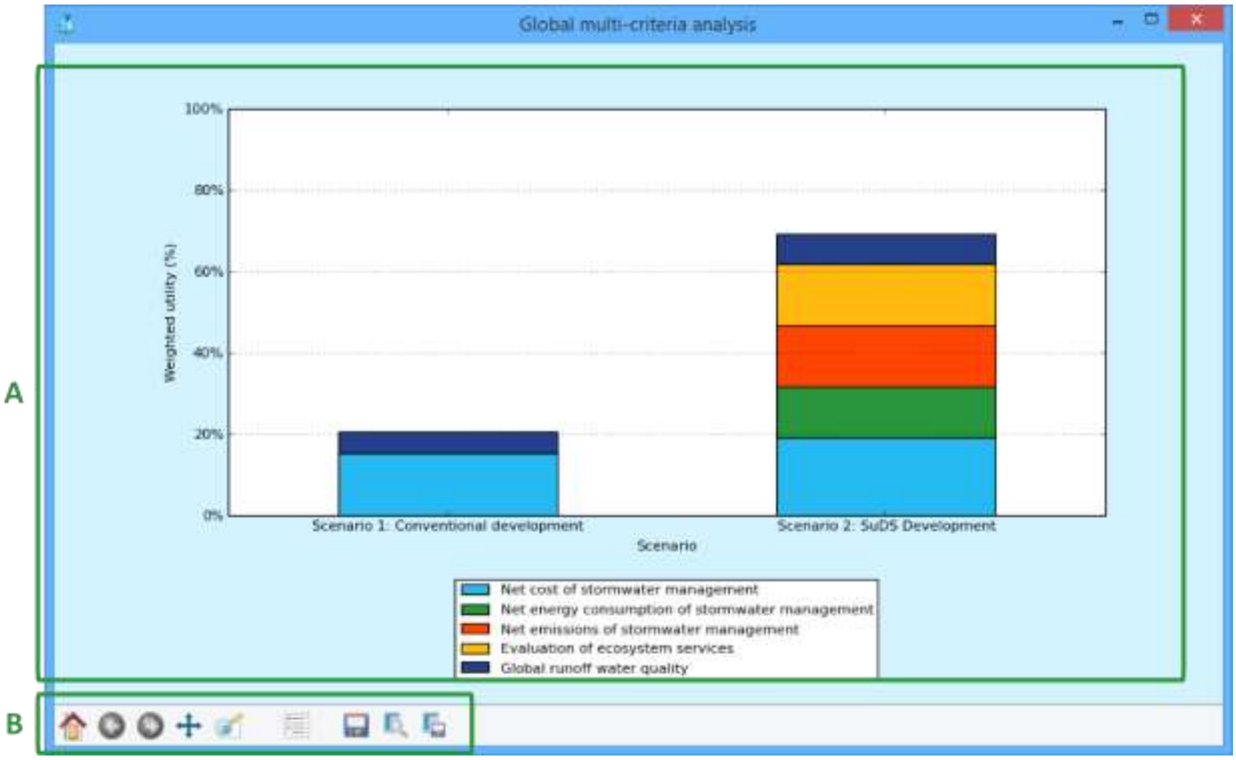


Figure 3.20. Window of global results of multi-criteria analysis.

Results

	Criterion	Weighted utility (%): Scenario 1: Conventional development	Weighted utility (%): Scenario 2: SuDS Development
1	Net cost of stormwater management	15.3904592942	19.2284400375
2	Net energy consumption of stormwater management	0.0	13.0725617102
3	Net emissions of stormwater management	0.0	14.9999925271
4	Evaluation of ecosystem services	0.0	15.0
5	Global runoff water quality	5.0	7.5
6	Total	20.3904592942	69.133511583

Figure 3.21. Table of global results of multi-criteria analysis.

EXAMPLE

The histogram of the results for the example are shown in Figure 3.22. T the global score for scenario 2 (72.36%) is much higher than for scenario 1 (29.8%). In summary, scenario 2 would be recommended from the multi-criteria analysis point of view.

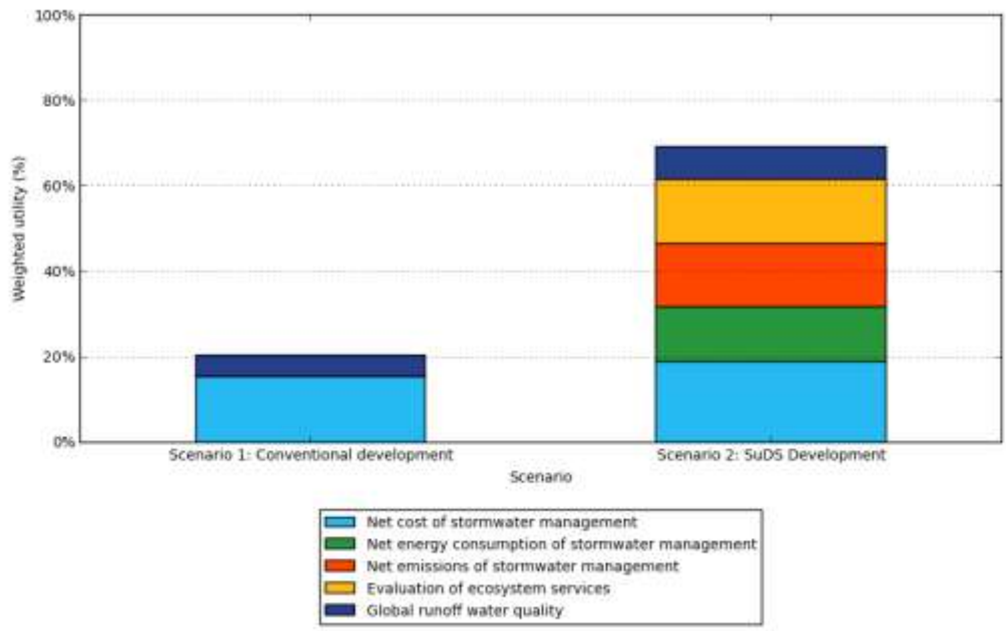


Figure 3.22. Multi-criteria global results in the example.

3.5. UNCERTAINTY ANALYSIS

This last menu allows evaluating the effect of input data variations on the multi criteria analysis results. This evaluation can be made using the corresponding toolbar button (Figure 3.23) or with the menu option *Results → Uncertainty analysis.*

Figure 3.23. Toolbar button to make uncertainty analysis.

The different parts of the menu shown to make this uncertainty analysis (Figure 3.20) are:

A. Variable selection: These three menus are used to select the input variable that will be used for the uncertainty analysis. This variable should be one of the input data introduced in one of the scenarios.

B. Value in base case: This text shows the current value of this variable in the selected scenario. This is the value used in the multi-criteria analysis.

C. Maximum value: Upper limit of the variable selected to be evaluated in this uncertainty analysis.

D. Minimum value: Lower limit of the variable selected to be evaluated in this uncertainty analysis.

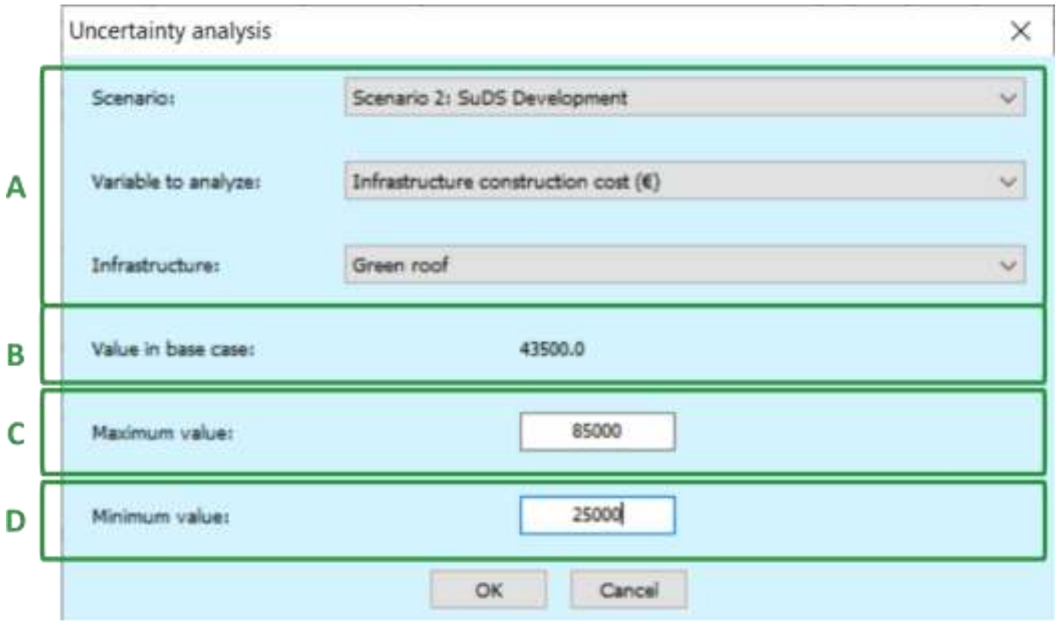


Figure 3.24. Window to define input data for uncertainty analysis.

Hence, when these data are defined, results on how global multi-criteria analysis outputs change are shown (Figure 3.25). In this figure, the bar labeled as *Min* shows the results of the multi-criteria analysis using the minimum value defined for the variable evaluated. In the same way, the *Max* bar shows the multi-criteria analysis results using the Maximum value of the variable.

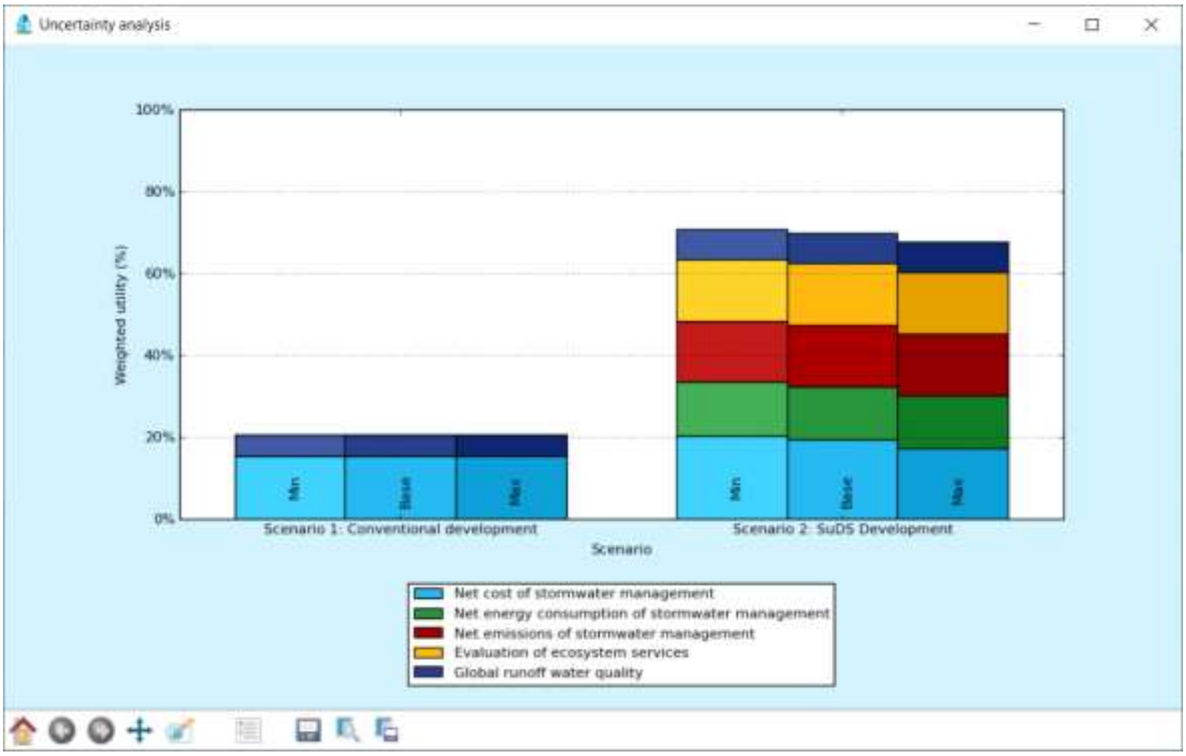


Figure 3.25. Example of results for uncertainty analysis.

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LIST OF FIGURES AND TABLES

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ANNEX 1. CATALOGUE OF INFRASTRUCTURES

ANNEX 2. BENEFITS FROM DRAINAGE INFRASTRUCTURES

Benefits from SUDS: Summary table

	Conventional drainage networks	Structural detention facilities	Bioretention areas	Constructed wetlands	Detention basins	Filter drains	Filter strips	Geocellular systems	Green roofs
Aesthetics			✓	✓	✓				✓
Air quality improvement									✓
Amenity			✓	✓	✓				✓
Base flow augmentation			✓		✓				
Community education and engagement									✓
Community space improvement			✓	✓					✓
Cost savings for surface water management									✓
Cost-effective to construct					✓				
Decreased burden on the sewage system									✓
Enhancement of quality of life				✓					
Extension of operational life of roof									✓
Firm dry surfaces to park and walk on after heavy rain	✓	✓							
Food growing			✓						
Groundwater recharge					✓			✓	
Gross value added growth					✓				
Habitat provision and enrich biodiversity			✓	✓	✓				✓
Improved community cohesion			✓						✓
Improved insulation									✓
Improvements to public health			✓			✓	✓		
Increase in property values			✓	✓					✓
Maximisation of the longevity of the road surface						✓	✓		
Noise attenuation									✓
Prevention of further increase in non-point urban loads									
Protection of receiving waters						✓	✓		
Provision of educational opportunities									✓
Recreational use			✓						
Reduced land take/small footprint	✓	✓				✓	✓		
Reduction in energy bills/ costs			✓	✓					✓
Reduction in the demand on water supply									
Reduction of flood risk	✓	✓	✓	✓	✓				✓
Reduction of greenhouse gas emissions			✓	✓					✓
Reduction of gullies need									
Reduction of surface ponding cost-effective and durable source control technique									
Regulation of urban microclimates			✓	✓					✓
Removal of urban pollutants			✓	✓	✓	✓	✓		✓
Restore natural hydrology									✓
Retrofitable			✓						
Runoff reduction and attenuation			✓	✓	✓			✓	✓
Speedy removal of surface water to enhance safety	✓	✓				✓	✓		
Suitable for a wide range of locations						✓	✓		
Visual and landscape benefits				✓					✓
Water quality control			✓	✓	✓	✓	✓		✓
Water quantity control	✓	✓	✓	✓				✓	✓
Water storage and re-use				✓				✓	

	Infiltration basins	Infiltration trenches	Other pre-treatment devices	Permeable pavements	Rain gardens	Rain harvesting systems	Retention ponds	Soakaways	Vegetated swales	Water butts
Aesthetics	✓			✓	✓		✓			
Air quality improvement										
Amenity	✓			✓	✓		✓			
Base flow augmentation	✓									
Community education and engagement									✓	
Community space improvement					✓		✓		✓	
Cost savings for surface water management										
Cost-effective to construct	✓									
Decreased burden on the sewage system										
Enhancement of quality of life										
Extension of operational life of roof										
Firm dry surfaces to park and walk on after heavy rain				✓						
Food growing					✓					
Groundwater recharge	✓	✓		✓				✓	✓	
Gross value added growth	✓						✓			
Habitat provision and enrich biodiversity	✓	✓		✓	✓		✓	✓	✓	
Improved community cohesion		✓			✓			✓		
Improved insulation										
Improvements to public health					✓					
Increase in property values					✓		✓		✓	
Maximisation of the longevity of the road surface										
Noise attenuation										
Prevention of further increase in non-point urban loads		✓						✓		
Protection of receiving waters			✓	✓						
Provision of educational opportunities									✓	
Recreational use		✓			✓		✓	✓	✓	
Reduced land take/small footprint				✓						
Reduction in energy bills/ costs				✓	✓				✓	✓
Reduction in the demand on water supply										✓
Reduction of flood risk	✓				✓		✓		✓	
Reduction of greenhouse gas emissions				✓	✓		✓		✓	
Reduction of gullies need				✓						
Reduction of surface ponding cost-effective and durable source control technique				✓						
Regulation of urban microclimates					✓		✓		✓	
Removal of urban pollutants	✓	✓	✓	✓	✓		✓	✓	✓	
Restore natural hydrology				✓						
Retrofitable				✓	✓					
Runoff reduction and attenuation	✓	✓		✓	✓		✓	✓	✓	✓
Speedy removal of surface water to enhance safety										
Suitable for a wide range of locations										
Visual and landscape benefits				✓			✓		✓	
Water quality control	✓	✓	✓	✓	✓		✓	✓	✓	
Water quantity control				✓	✓				✓	✓
Water storage and re-use		✓		✓			✓	✓		✓

Benefits from SUDS: Detailed table

This annex to the E[2]SSTORMED DST guide presents some results from an extensive review of urban stormwater management measures and the multiple benefits which they provide. This list is intended to be a quick reference resource which indicates the multiple benefits which can be gained from the implementation of SUDS as stormwater management measures. The benefits listed in this section are based on an in-depth review but are presented in a simple table so they can be accessed quickly by decision-makers. References which support the list of benefits are at the end of this Annex.

Benefits table: Multiple benefits associated with SUDS (adapted from Wade et al. 2013)				
Stormwater management Measure	Supporting information	Actors/ Decision-makers	Reported Benefits	Reference ID
Street trees and planters	Construction of tree pits with additional subsurface storage for surface water management.	Local authorities, environmental protection agencies, consultants	Improved water quality and quantity / reduced energy bills / reduction of urban heat island effect / reduced greenhouse gas emissions / increased property values, improved community space	31
			Aesthetics / shade / lower energy costs / improves air quality / increase in property prices / surface water reduction / regulate urban microclimates / attenuate noise / sequester carbon / provides habitat and enrich biodiversity / promotes access to nature	44
			Improved community cohesion / enhanced quality of life / gross value added growth / job creation / business creation / reduces the number of working age people with no qualifications / increase in the number of people in the workforce with graduate qualifications / reduces the number of deprived areas / reduces CO2 emissions per unit (£) of gross value added	27
			Small footprint solution for busy urban street / amenity / urban surface water treatment / protection of receiving waters / community education and engagement	9
Green streets	To convert paved, vacant traffic islands and medians into green spaces filled with shade trees, shrubs, and groundcover.	Local authorities, environmental protection agencies, consultants	Improved water quality and quantity / reduced energy bills / reduction of urban heat island effect / reduced greenhouse gas emissions / increased property values, improved community space, urban air quality improvement, reduction of aerosol production	31 35

Stormwater management Measure	Supporting information	Actors/ Decision-makers	Reported Benefits	Reference ID
Water butts	Water butts can help reduce surface water runoff flow to the sewer system. Stored water can be used for other uses.	Local authorities, environmental protection agencies, consultants	Reduces surface water runoff / reduces the demand on water supply during summer's hottest days	31
			Source control / water re-use / reduction in demand for potable water supply / energy savings	7
Permeable pavements	Permeable pavement includes pavers, asphalt, or concrete that allows water to pass through into a specially-designed sub grade gravel bed or other porous medium.	Local authorities, environmental protection agencies, consultants	Improved water quality and quantity / reduces energy bills / reduces greenhouse gas emissions	31
			Maintain the natural hydrological cycle / aesthetic appeal	21
			Reduction in energy requirements / attenuation of runoff / removing of urban pollutants	4
			Allows run-off to percolate naturally into ground or into collection chamber / reduces run-off from hard surfaces / first line of defence against pollution / allows dual use of space and therefore reduced land take / firm dry surfaces to park and walk on after heavy rain / appropriate design can bring visual and landscape benefits / protection and enhancement of water quality in the receiving water body / gravel can be planted with nectar-rich plants, tolerant of drought, foot and vehicle damage / gravel turf can be used where compacted gravel is turfed or sown with a flower-rich grassland mix / cellular blocks can be seeded with native flower-rich grass mixes of known provenance	33
			Removal of pollutants / retrofitable / reduces need for gullies / reduces surface ponding cost-effective and durable source control technique	5
			Run-off infiltration / Medium - High pollutant removal	42

Stormwater management Measure	Supporting information	Actors/ Decision-makers	Reported Benefits	Reference ID
Swales	Linear vegetated drainage features that store or convey surface water. Can be designed to allow infiltration, where appropriate.	Local authorities, environmental protection agencies, consultants	Improved water quality and quantity / reduced energy bills / reduction of urban heat island effect / reduced greenhouse gas emissions / increased property values, improved community space	31
			Water quality and quantity control / to maintain or enhance the landscape or nature conservation value of the area	16
			Recreational use when dry	21
			Allows infiltration into soil and removal of pollutants / reduces flood risk downstream / high biodiversity where water quality is good / multi-functional uses (e.g. children's play areas, football pitches, picnic areas) / using site interpretation and events to raise awareness / enhances visual appeal / nectar source for insects / some plants and animals require ephemeral water bodies as part of their lifecycle / habitat for wetland plants	33
			Good removal of urban pollutants	7
			Run-off conveyance / Medium pollutant removal	42
Green roofs	Methods for rooftop retention, generally consist of a multi-layered structure, designed according to the function and size of the roof system.	Local authorities, environmental protection agencies, consultants	Roof type comparison to assess benefits: Improved water quality and quantity / reduced energy bills / reduction of urban heat island effect / reduced greenhouse gas emissions / increased property values, improved community space	31
			Reduces the risk of flooding, surface water flows and stress on surface water sewers / restore natural hydrology / cost savings for surface water management / aesthetics	21
			Enhanced overall visual quality / improved insulation / rainfall retention / reduction of urban heat island effect / reduced rainwater runoff / decreased burden on the sewage system / urban biodiversity benefits / increased value of properties	2
			Slows and reduces run-off / generates supply of filtered water suitable for wildlife / reduction in the urban heat island effect / traps airborne pollutants / noise reduction / increased visual and physical access to green spaces / can provide a community resource / educational opportunities / feeding and foraging areas for birds and invertebrates /	33

			habitat for breeding invertebrates / stepping stone habitat in urban areas / potential for water features to be included	
			Good removal of urban pollutants / biodiversity and amenity benefits / extended operational life of roof / energy efficiencies	7
			Removal of urban pollutants / biodiversity benefits	6
Stormwater management Measure	**Supporting information**	**Actors/ Decision-makers**	**Reported Benefits**	**Reference ID**
Wetlands	Wetlands are constructed shallow marsh systems with a range of deep and shallow water areas, designed to treat urban surface water runoff.	Local authorities, environmental protection agencies, consultants	Improved water quality and quantity / reduced energy bills / reduction of urban heat island effect / reduced greenhouse gas emissions / increased property values, improved community space	31
			Low-carbon water-sourced heating, cooling and surface water re-use	45
			Water quality and quantity control / To maintain or enhance the landscape or nature conservation value of the area	16
			Successful management of flood events	8
			Good removal capability of urban pollutants, community acceptance, ecological and aesthetic value	7
			High pollutant removal / Provides single level of treatment	42
Basins	Dry basins designed to store runoff and provide water quality improvements.	Local authorities, environmental protection agencies, consultants	Runoff reduction / pollutant removal / groundwater recharge / base flow augmentation / cost-effective to construct / can add amenity and biodiversity value	7
			Pollutant removal for highway runoff	16
			Water treatment pollutant removal / flood attenuation / amenity	42
			Added value from alternative management of surface water	8
Ponds	Ponds are basins which have a permanent pool of water. They provide a wide range of pollutant removal mechanisms.	Local authorities, environmental protection agencies, consultants	Low-carbon water-sourced heating, cooling and surface water reuse	45
			Hold rainwater / landscape / improves water quality / aesthetic amenity / increases humidity / lowers summer temperatures	21
			Water treatment pollutant removal / Flood attenuation / Amenity	42
			Reduction of flood risk / Maximising of the value of diverting excess surface water flows into an existing natural urban park area for public enjoyment	8

Stormwater management Measure	Supporting information	Actors/ Decision-makers	Reported Benefits	Reference ID
			Good removal capability of urban pollutants / Adds ecological and community benefits, can add value to local properties	7
Bioretention	Shallow landscaped depressions, which typically underdrained and rely on engineered soils and enhanced vegetation and filtration.	Local authorities, environmental protection agencies, consultants	Improved water quality and quantity / reduced energy bills / reduction of urban heat island effect / reduced greenhouse gas emissions / increased property values, improved community space	31
			Retention and heavy metal build-up	46
			Pollution removal / reduces downstream runoff / recreation	21
			Reduces flooding / filters and cleans surface water run-off / mitigates urban heat island effect / space for relaxation and quiet enjoyment / aesthetically pleasing / may be used to grow food / flowers can attract nectar-feeding insects / invertebrate 'hotels' can be added along with other habitat features / acts as a 'stepping stone' habitat in urban areas	33
			Very effective at removing urban pollutants / can be planned as landscaping features, flexible and suitable for retrofits	7
			Reduction of run-off volumes / High pollutant removal / Single level of treatment provided	42
Infiltration devices	Temporarily store runoff from a development and allow it to percolate into the ground.	Local authorities, environmental protection agencies, consultants	To prevent further increase in non-point urban loads / to address water quality failures attributed to diffuse sources	22
			To beautify a neighbourhood	21
			Water storage / recreation / ecological habitat	49
			Can be very effective at pollutant removal / contributes to groundwater recharge	7
			Treatment and temporary storage of run-off / Medium to high pollutant removal / Single level of treatment provided	42
Filtration systems	Filter drains, strips and trenches filled with permeable material. Surface water from the edge of paved areas flows into the structures, is filtered and	Local authorities, environmental protection agencies, consultants	Water surface runoff treatment	21
			River pollution prevention / improvements to water quality and public health	39
			Urban runoff pollutants removal / small footprint / suitable for a wide range of locations	7
			Minimise the environmental impact of road runoff on the receiving water environment / speedy removal of surface water to enhance safety and minimise disruption to road users / maximise the longevity of the road surface and	20

	conveyed to other parts of the site.		associated infrastructures	
			Medium pollutant removal (sediments, oil & grease, metals, organics and nutrients) / Single level of treatment provided	42
Stormwater management Measure	**Supporting information**	**Actors/ Decision-makers**	**Reported Benefits**	**Reference ID**
Geocellular tanks	Modular plastic geocellular systems with a high void ratio that can be used to create a below ground infiltration or storage structure.	Local authorities, environmental protection agencies, consultants, Developers	Limited pollutant removal potential but can be used as a volume solution along with conventional SUDS / can be used for infiltration	7

References to support benefits table	
ID	**Reference**
2	Berlin Senate for Urban Development Communications (2010). Available here: http://www.worldgreenroof.org/files/pdf/SenStadt_Regenwasser_engl_bfrei_final.pdf
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