Deliverable D33.1: WaterMet² Conceptual Model

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Abstract

Building on the WaterMet² functional requirements report, this report presents the comprehensive concepts behind the processes and components of the WaterMet² model that will be developed to quantify the generic Urban Water System (UWS) metabolism based performance model in the TRUST project (TRansitions to the Urban water Services of Tomorrow). This report is a project deliverable to describe different components and subsystems and their functionality in more details.

Two main aspects of the WaterMet² model are addressed here. The first part of the report illustrates the principal modelling concepts which will be used in the WaterMet² model. The UWS is characterised using four different spatial scales together with temporal resolution concept for time step modelling. Then, principal flows in the WaterMet² model along with two main aspects of water modelling (i.e. water quantity and quality modelling) are described.

The second part presents a more detailed description of modelling of components and processes in the WaterMet² model: (1) water supply and distribution; (2) water demand; (3) wastewater and (4) cyclic water recovery and resource recovery. For each component, all input and output flows along with the associated parameters and variables used for modelling of the intended components are described in detail.

This document is based on the authors' current best understanding of the UWS metabolism concept and the associated performance related issues. Therefore, as WaterMet² model development progresses, information presented in this report may evolve and change.

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1 Introduction

This report summarises the key concepts behind the modelling approach used in the WaterMet2 tool that is currently being developed (note: 'Met' stands for both metabolism and metropolitan hence '2'). The WaterMet2 model will be used to assess the performance of a general urban water system (UWS) under existing and a range of possible future conditions and scenarios. The report also provides the concepts used for the modelling of different UWS components and related processes and flows covering the full urban water cycle.

This report is a TRUST project deliverable D33.1 resulting from the work done in WP33. The report has been prepared based on the earlier recommendations made in the Scoping Report (Brattebø et al. 2011), the relevant risk modelling concepts provided by the SINTEF (WP32) and the existing Functional Requirements report (Behzadian et al. 2012).

This report provides basis for the later development of a more detailed WaterMet2 model and the related software tool. The detailed WaterMet2 model will be tested and verified on the Oslo case study in WP34. Once developed, the detailed WaterMet2 model will also be used for the development of risk assessment models in WP32 and it will become part of the decision support system for the long-term planning of UWS in WP54.

The rest of this report will address and describe the following key elements: (1) an overview of the WaterMet2 modelling concept; (2) methodology used for modelling different components and processes in the WaterMet2 model. The key messages are then summarised in the last section of this report.

2 WaterMet2 Modelling Concept

The WaterMet2 model is a simulation, mass balance based model which will quantify the metabolism\(^1\) related performance of the UWS with focus on sustainability related issues. The integrated modelling of the UWS implies the whole processes and components in an urban area related to water flows as a complex and interrelated system. The WaterMet2 model will quantify the principal water flows as well as all other system fluxes (e.g. energy, chemicals, etc.) sequentially in the UWS. All this, in turn, will enable quantifying a number of different indicators such as operational and maintenance costs, any risk and intervention assessment over some planning horizon. The WaterMet2 model will generally be developed as a generic UWS for the application to any city through the TRUST project partners although it is first applied to Oslo case study.

Figure 1 illustrates the main flows and storages modelled in the WaterMet2 which comprises four main subsystems. A mass balance approach of water is followed within the system. The water sources and sinks

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\(^1\) metabolism in UWS is referred to the flows and conversion processes of all kinds of water flows, materials and energy in UWS to fulfill the necessary functions
are the water boundaries which supply and receive water respectively. The water storages stand for any physical assets storing water in which some water related processes may take place. The water flows represent any physical assets conveying water flows between different water storages in the UWS. The model recognises various types of water streams, each of which demands special attention for storage and treatment and can only be allocated for particular water consumptions.

Both aspects of water quantity and quality modelling will be quantified by the WaterMet². While water quantity modelling calculates and track a daily mass balance of the water flows within the UWS elements, sequential daily water quality modelling allows tracking of any conservative and non-conservative contaminant loads. Other flows (e.g. energy, green gas emissions and chemicals) are also tracked within the system.

The storages are interrelated to each other through a variety of defined water flows. The user needs to specify daily capacity of all water flows and storages. Before describing the modelling concepts of subsystem and the associated elements, spatial and temporal representations of the UWS are specified in the following sections.

2.1 Spatial UWS Representation

The spatial limit of the UWS is defined as the administrative limits of an urban water utility. The WaterMet² Model recognises four spatial scales representing the whole urban water system:

- Indoor area;
- Local area;
- Subcatchment area;
- City area;
2.1.1 Indoor Area

The smallest spatial scale of the UWS in the WaterMet² model is an indoor area. It is used to represent a single household or property (e.g. residential, industrial, commercial, public, etc.) without any surroundings (e.g. garden or public open space representing any outdoor area). Particularly, the indoor area represents indoor water consumption in the WaterMet² model. This can be defined as either: (1) simple water consumption per capita per day (for residential water use) or consumption square meter (and per day) of commercial/industrial space (for industrial, commercial and public use) or (2) using detailed information on a broad range of water consuming appliances and fittings (mainly for residential use). For the latter definition, the specific appliances and fittings modelled by the WaterMet² are: (1) hand basin, (2) bath and shower, (3) kitchen sink, (4) dish washer, (5) washing machine and (6) toilet. Note that defining the appliances and fittings in WaterMet² model requires more data but also allows the user to model a range of intervention strategies related to the water demand management and decentralised water treatment options.
When defining appliances and fittings in WaterMet\textsuperscript{2} model, the principal flows and storages modelled on indoor area are represented in Figure 2 and in more detail in Table 5 of Appendix A. Each water outflow of this level is associated with the relevant flows/storages located on the next levels. Note that the user is able to define appliances and fittings not only for domestic consumption but also for other water consumptions. For example, the appliances and fittings for commercial water consumers can only account for toilet and hand basin. Thus, this will enable the user to effectively assess the impact of different appliances and fittings on the sustainability and performance criteria. Alternatively, in case of limited data available to define appliances and fittings, the user is able to define water consumption per capita/square meter.

Note that potable water in Figure 2 is the drinking water treated and supplied from WTWs. Grey water is the dilute wastewater flows originating from some clean water consumptions (e.g. shower, hand basin, dishwasher and washing machine). This type of water contains some organic and inorganic materials (e.g. detergents), sand and salt (Balkema, 2003). Also, black water is used to describe water from toilet and polluted water consumed by industrial/commercial users to be treated at a central scale. Recycling water is used to describe return water treated by water treatment options (centralised or decentralised) which will be illustrated in the following sections.

Finally, note that the above detailed information can be provided only for the representative, i.e. typical houses/properties (unless a very small spatial area is modelled using WaterMet\textsuperscript{2}, to e.g. investigate some specific, local issue) - see also next section.
2.1.2 Local Area

A group of similar typical households/properties with a surrounding area in the WaterMet² is represented as a local area. It can contain any number of indoor areas (i.e. properties) but they all must be of the same type, i.e. with identical demand and other data. The surrounding area is divided into pervious surfaces, impervious surfaces and water bodies (e.g. lake and river).

Figure 3 represents a schematic diagram of an example urban area with several groups of similar households/properties and the surrounding areas. For the purpose of WaterMet² modelling, this urban area can be represented using the following local areas:

1. Figures 4-6: Three residential local areas, each with a different type of house (i.e. indoor area) modelled. The surrounding area for these cases may be private gardens and a shared part of public pavement and road around the households.

2. Figure 7: The local area representing the institutional block and the surrounding area including private and public gardens.

3. Figure 8: The local area representing the commercial area with similar commercial properties (i.e. indoor areas) and the associated surrounding land.

Note that the above example presents a detailed (i.e. accurate) spatial representation of the relatively small urban area analysed. However, when covering larger urban/city areas in the WaterMet² model, the same approach outlined above can be used but it would typically involve larger individual local areas, each comprised of a larger number of ‘typical’ properties (i.e. indoor areas), e.g. a large residential block comprised of similar apartments (or houses) with the associated surrounding area. Therefore, a local area can be used to represent a relatively large (or small) spatial area depending on the size/type of the urban area analysed but also on the level of spatial resolution required (which is typically a function of the objectives of the study undertaken).

![Figure 3 Schematic diagram of a zone in a city with different types of properties](image)
Figure 4 Local area containing four similar detached houses

Figure 5 Local area including identical terraced houses

Figure 6 Local area with some similar flats in a series of households
The principal water flows and storages modelled in the local area are represented in Figure 9 and in more detail in Table 4 of Appendix A. The main processes and physical components modelled only on this level by the WaterMet² are:

1. Rainfall-runoff modelling on pervious and impervious surfaces;
2. Rainwater harvesting tank;
3. On-site water treatment options on local area scale;
4. Septic tank;
Figure 9 Water flows and storages on local area level in the WaterMet2 model

Note that groundwater withdrawal in Figure 9 is borehole extraction only for irrigation purposes in the WaterMet2 model. Also, green water is denoting here the treated rainwater modelled in local area scale. Furthermore, if a household is not connected to the domestic/combined sewer networks, the WaterMet2 model assumes that the wastewater drains into a septic tank in the respective local area. If on-site treatment options are not available at a local area, the grey water is then added to the black water stream while the volume of wastewater produced can be significantly reduced if recycling schemes are implemented.

Note that there is no modelling of the water distribution system nor stormwater/wastewater collection system at the local area level as they are both modelled on the next upper level described in the following sections.
2.1.3 Subcatchment Area

A subcatchment area is used in the WaterMet2 model to represent a group of neighbouring local areas. Each subcatchment area represents a stormwater/wastewater subsystem, i.e. ‘collection point’ in a separate/combined sewer system with associated water demand supplied by the potable water distribution system.

To give an example, Figure 10 shows a schematic diagram of a city area that can be basically divided into two individual catchments in the north and the south (Figure 11) based on the different topography for storm drainage. These two catchments can be further divided into a number of subcatchments representing drinking water consumption points in water distribution system. In addition, they represent separate wastewater/stormwater collection points for centralised sewer system. Consequently, the city area in this example can be composed of 14 subcatchments including 8 subcatchments (A through H) in northern part and 6 subcatchments (I through N) in southern part.

![Figure 10 Schematic diagram of a city area modelled by the WaterMet2 model (photo taken from CPLA 2004)](image)

The subcatchment areas are defined by the user mainly based on the considerations of topology and the gravity of stormwater/wastewater collection systems. The subcatchment area can represent relatively large (or small) spatial areas depending on the city area size, the level of spatial resolution required and the available data for different subcatchments and associated local areas. For instance, if there is a lack of available data for defining a variety of subcatchments in a city area, one can consider the city area with a limited number of subcatchments bearing in mind that the reduced level of details modelled will have an impact on the accuracy of the calculated flows and associated variables such as frequency and duration of CSOs, pollutant graphs, energy and GHG fluxes, related operational and maintenance costs, etc. In addition, modelling city area using a small number of subcatchment areas will also reduce the spatial resolution required for modelling different interventions. Therefore, a trade-off exists between the spatial and other level of detail modelled and the accuracy and usefulness of the WaterMet2 model built.
Furthermore, a representation of spatial distribution of neighbouring local areas for each subcatchment of the above example as previously discussed can be shown in Figure 12. For instance, Subcatchment C can be divided into two different local areas and Subcatchment F can also be divided into three different local areas. As described earlier, the number of local areas modelled in each subcatchment can be small or large, depending on the level of accuracy required and the data available. Note that a subcatchment is populated by a number of pre-defined ‘typical’ local areas for each of which number of indoors/properties and total area is specified. Also when defining each ‘typical’ local area, unique water consumptions for indoor area and unique outdoor specifications (e.g. percentages of pervious, impervious area and so on) are determined for the respective ‘typical’ local area. In addition, the sum of wastewater/stormwater collected from different inside local areas in a subcatchment is delivered to sewer system and represented as wastewater/stormwater of the relevant subcatchment.
In addition, spatial distribution of neighbouring local areas for a subcatchment of the previously discussed example (Figure 3) can be represented in Figure 13. Here, five different local areas (A through E) are defined in the subcatchment based the methodology outlined above.

![Figure 13: An example of partitioning a subcatchment area into a number of local areas in the WaterMet2 model](image)

The principal flows and storages modelled on this level are represented in Figure 14 and in more detail in Table 3 of Appendix A. All the flows at this level are associated with the relevant flows/storages at the next levels (i.e. local area as the next lower level and city area as the next upper level). The only physical component particularly defined on this level is further water treatment system which will be described in more details in section 03. The other components are located inside local areas described in the previous section.
2.1.4 City Area

The WaterMet2 model recognises the main components of the UWS on a city area scale as the highest spatial level of UWS modelling. The city area in the WaterMet2 model can be divided into any number of different subcatchments.

The principal flows and storages modelled on this level are represented in Figure 15 and in more detail in Table 2 of Appendix A. The following main components are defined and modelled only at this level, which will be described in more details in sections 3.1, 3.3.3 and 3.4:

- Raw water sources;
- WTWs and WWTWs;
- Water distribution system;
- Separate/combined sewer system;
- Further water treatment at city level.
Figure 15 Water flows and storages on city area level in the WaterMet² model
All the processes and components modelled at different spatial levels of the WaterMet² are summarised in Table 1.

**Table 1 Various processes modelled at different spatial levels by the WaterMet²**

<table>
<thead>
<tr>
<th>Spatial level in the WaterMet² model</th>
<th>Indoor area</th>
<th>local area</th>
<th>subcatchment area</th>
<th>city area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>Description</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>water consumption points</td>
<td>including indoor and outdoor water usages</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>rainfall-runoff model</td>
<td>precipitation on either pervious, impervious areas and water bodies</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainwater harvesting tank</td>
<td>collection of rainwater from the roofs for water reuse</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>septic tank</td>
<td>wastewater storage of the properties which do not connect to any sewer system</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>on-site water treatment system</td>
<td>treatment of grey water and providing water reuse for indoor consumers</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>stormwater storage</td>
<td>storage of stormwater for water reuse</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>further water treatment option</td>
<td>treatment of stored stormwater and treated wastewater for water reuse in particular water usages</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Water distribution system</td>
<td>distribution of potable water from service reservoirs between water consumptions</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>combined/separate sewer system</td>
<td>collection of wastewater/ stormwater from urban area</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>WTWs, WWTWs</td>
<td>treatment of raw water and wastewater</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>service reservoirs</td>
<td>potable water storage before distributing between the customers</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>water sources</td>
<td>raw water intake for WTWs</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>
The WaterMet² model assumes a simplified approach for water distribution system that the potable water will be spatially distributed at the city area level between different subcatchments, i.e. each subcatchment is assumed to receive its share (i.e. percentage) of potable water from each of the service reservoirs. The elements that are modelled in the water supply and distribution system are as follows: 1-raw water sources; 2-WTWs, 3-service reservoirs; 4-principal flow ‘routes’ (denoting fractions of water received in the analysed subcatchment area from each source, i.e. WTW and/or service reservoir).

Figure 16 shows an example of the main components of potable water supply from raw water sources and drinking water distribution between different subcatchments. For instance, Water Source1 can supply raw water for WTWs1 which feeds service Reservoirs 3 and 4. Drinking water can be supplied from over one Service Reservoirs which will be defined by the user (e.g. drinking water of subcatchment M is supplied from Service Reservoirs 3 and 4 or subcatchment E is fed by Service Reservoirs 1 and 2). More details of the modelling assumptions are discussed in section 3.1. Note that there is no further modelling for the drinking water distribution system inside each subcatchment where drinking water is automatically allocated between different water consumers located at internal local areas.

Figure 16 An example of the water supply and distribution system representation in WaterMet² at the city scale

The waterMet² model also takes into consideration such a simplified approach for wastewater, stormwater and sewer system. The following system key elements are modelled in the sewer system: (1) principal wastewater/stormwater flow ‘routes’ (denoting mainly storm/waste/combined water draining routes between subcatchments modelled but also any recycling/reuse flow routes); (2) CSOs (and storm tank overflows), (3) WWTWs and (4) recipient, i.e. receiving water (only as a ‘sink’ point).

An example of the main components of a sewer system collecting wastewater/stormwater from different subcatchments of the schematic UWS is presented in Figure 17. In this figure, two individual combined/separate sewer systems are defined independently for two catchments of the UWS based on the topology of the system. The collected stormwater/ wastewater of local areas located inside a subcatchment
(represented by red solid circles) drains to the catch basin of the same subcatchment (represented by black solid rectangles). The sewer system is sequentially connected between different catch basins associated with different subcatchments based on the gravity of stormwater/wastewater collection systems. The WaterMet² model assumes that the stormwater/wastewater collected in the catch basin of a subcatchment can be drained to only one catch basin of the immediate downstream subcatchment although the wastewater/stormwater of over one upstream subcatchment can drain to a downstream subcatchment (e.g. subcatchments D and H draining to subcatchment F through W1-1 and W1-2 collection flow routes). The user can define a number of CSOs in the specific locations of sewer system (i.e. in potential catch basins) as well as some CSOs for WWTWs (e.g. CSO3 and CSO6 before WWTWs). More details of the modelling assumptions will be discussed in section 3.3.3.

![Figure 17 An example of the wastewater/stormwater collection system representation in WaterMet² at the city scale](image)

### 2.2 UWS Temporal Scales

As the metabolism WaterMet² model aims to support strategic planning level, a daily time step is selected as the default and smallest temporal scale. The WaterMet² model will use the daily time step to simulate the UWS performance for a period of \( N \) years which is specified by the user. The precipitation and temperature time series need to be provided by the user analysed time period. A minimum of one year is envisaged to
take into account any seasonal variations but longer simulation durations spreading across multiple years are more likely / desirable.

2.3 **Principal WaterMet 2 Fluxes**

The WaterMet 2 model analyses several principal flows in the UWS components as: (1) water flows, (2) energy flows; (3) greenhouse gas emission (GHG) flows; (4) material flows; (5) chemical fluxes; (6) pollutant flows. These flows are modelled whenever generated, rehabilitated, consumed, replaced and are aggregated temporally and spatially within components, subsystems and city area. A brief overview of these urban flows is described below:

2.3.1 **Water flows**

The WaterMet 2 model uses main water flows (Makropoulos et al. 2008) as: clean (potable) water, precipitation (stormwater), grey water, green water, recycling (reuse) water, groundwater, wastewater (black water). Water flows in WaterMet 2 are comprised of two parts, water quantity and water quality. Water quantity modelling encompasses within all subsystems while water quality modelling is included only within wastewater and cyclic water recovery subsystems. The principles of this modelling will be described in the following sections in more details.

2.3.2 **Energy flows**

WaterMet 2 calculates the energy consumed for each component of the UWS such as energy required for raw water transmission to WTWs, operation of WTWs, WWTWs and on-site water treatment options. Two sources of energy including fossil fuel and electricity drawn from the grid are taken into account by the WaterMet 2 model. In addition, The WaterMet 2 model calculates other heat and energy generated within the UWS as resource recovery. They include (1) electricity generated in water distribution network by micro-turbines, (2) heat and electricity generated in WWTWs by biogas, anaerobic digestion, turbine-generator and (3) heat generated from WWTWs effluents by heat pump.

2.3.3 **Greenhouse gas emission (GHG) flows**

The WaterMet 2 model calculates GHG emission flows (e.g. CO₂) in three different ways: (1) those resulted directly from fossil fuel consumption in water pumping, WTWs and WWTWs to the atmosphere; (2) those resulted indirectly from electricity consumption in water pumping, WTWs, water treatment facilities and WWTWs to the atmosphere; (3) those resulted from material flows during the planning horizon (embodied) for the pipelines in water supply system, wastewater collection networks and chemicals consumed in any subsystem. Contribution of GHG emission is reported in kilograms of CO₂ emissions equivalent. This is because the main sources of energy flows in UWS (i.e. fossil fuel combustion used for electricity generation, motor transport and pipeline production) contribute mainly in CO₂ emissions as a main GHG emission.
2.3.4 Material fluxes

The WaterMet² model calculates the annual fluxes of materials used in the UWS over the analysed planning horizon. These material fluxes are linked to urban water system assets and their characteristics with focus on the water distribution and sewer pipes.

Any changes in the quantity of urban water system assets (e.g. pipe lengths) due to interventions (e.g. addition of new pipes, rehabilitation and/or removal of existing pipes, etc.) or simply aging (i.e. 'doing nothing') are tracked down over the planning horizon. The assets analysed are categorised using their several key characteristics (e.g. pipe material, diameter, age, etc.). This enables to first quantify the impact of aforementioned interventions on asset quantities and their key characteristics modelled and then, in turn, the further impact of this on the associated material fluxes and system performance. Note that the latter may require using some simple lookup curves/tables/equations linking one or more key asset characteristics to the analysed performance indicator (e.g. leakage).

Finally, the tracked down assets and associated material fluxes are used to calculate the embodied energy and related GHG emissions associated with the pipelines’ life cycle, including asset manufacturing, installation, operation/maintenance, rehabilitation and retirement (Venkatesh et al. 2009).

2.3.5 Chemical fluxes

The WaterMet² model calculates the fluxes of individual chemicals used in different UWS components (e.g. WTWs, WWTWs, water distribution system). The chemicals modelled are likely to include: Alum, Calcium hydroxide, Carbon dioxide, Microsand, Polyaluminium chloride and Polymer, all consumed in WTWs; chlorine consumed for disinfection in the water distribution system; and FeCl₃, Fe₂(SO₄)₃, PAX, Ca(OH)₂, Ethanol, Methanol, Polymer, Nitric acid all consumed in WWTWs.

2.3.6 Pollutant fluxes

In addition to tracking down water flows in the UWS, the WaterMet² model calculates and tracks down the fluxes of pollutants (e.g. BOD, TSS, Tot-P, Tot-N) in different parts of wastewater and cyclic water recovery subsystems once they are generated/removed. In addition, the sludge generated from pollutant removal is also calculated in the UWS. The pollutant fluxes are tracked down until they are discharged in the recipient water as sink points in the UWS.

2.4 Water Quantity Modelling Principles

To include the generic concept of metabolism modelling, five different subsystems may constitute in the WaterMet² model (see Figure 1), whose main characteristics are briefly described in the following and more details in section 3.
Water Supply Subsystem

This subsystem constitutes one water boundary type (i.e. water source) and three types of water flow 'routes' (i.e. raw water intake, transmission and water distribution system) and WTWs and service reservoirs in the WaterMet² model. This subsystem starts with water withdrawal from a number of raw water sources and transmission to WTWs. The treated potable water from WTWs stores in service reservoirs before it is distributed between water consumers. Note that the transmission of potable water within this subsystem can be done by either gravity or pumping.

Water Demand Subsystem

This subsystem constitutes all water consumption points including indoor and outdoor water usages in local areas. The water demand for consumers can be calculated based on the user specified method (e.g. appliances and fittings or water demand per capita). The potable water demand is directly supplied from drinking water distribution system. The non-potable water demand is first supplied from the available water source (e.g. recycling water, rainwater harvesting) in the respective local area except from drinking water distribution system. If not fully supplied, the remaining water demand is supplied by available non-potable water source at subcatchment level and treated wastewater of WWTWs, respectively. Finally, the remaining water demand will be supplied from potable water distribution system. Note that if different water sources (e.g. potable water, recycling water) are available for a specific water demand, water is allocated based on the priorities defined by user.

Wastewater Subsystem

This subsystem includes three main processes/components: (1) rainfall-runoff processes; (2) stormwater/wastewater collection systems; (3) WWTWs. It starts with the rainfall-runoff processes modelling at local level and sequentially the amount of runoff draining onto the stormwater collection systems at subcatchment level. The sanitary sewage collected from local areas is also discharged into wastewater collection systems at subcatchment level and transported to WWTWs for treatment, reuse and/or discharge.

Cyclic Water Recovery Subsystem

The WaterMet² model allows specifying both centralised and decentralised cyclic water recovery systems in the UWS. Centralised cyclic water recovery is characterised on city level by further treatment of two water sources (i.e. treated wastewater from WWTWs and collected stormwater in separate sewer systems). In contrast to centralised water treatment, the WaterMet² model allows defining two types of decentralised cyclic wastewater treatment known as partly decentralised and fully decentralised wastewater treatment options in smaller scales (Figure 18). The user can define optional partly decentralised wastewater treatment (storage SS2 in Figure 14) at subcatchment area to treat and recycle grey water. In addition, fully decentralised on-site systems located on local level (storage SL6 in Figure 9) can also collect and treat and recycle grey water/ rainwater harvested from the same local area.
2.5 Water Quality Modelling Principles

The WaterMet² uses a simplified, mass balance based approach to model water quality (i.e. tracking daily fluxes of different contaminants within the UWS). The load of contaminants (kg/day) is calculated sequentially for each daily time step after water mass balance calculation. This is always done wherever a contaminant is generated/added (e.g. wastewater generation in household consumption) or lost (e.g. on-site water treatment options) and tracked within the UWS once reaching a sink. The following principles are assumed in water quality modelling in the WaterMet²:

- The WaterMet² allows modelling of a limited number of user specified water quality parameters (e.g. BOD, TSS, Tot-P, and Tot-N) with the aim to characterize and quantify the fluxes of key pollutant loads.

- The water quality modelling will be based on the source-sink concept assuming a dominant advection transport process. The modelling assumes no dispersion, diffusion, decay or growth for different contaminant in the system.

- Contaminants load changes only once they are treated/generated assuming instantaneous and complete mixing. For example, once mixing multiple wastewater inflows at a junction the contaminant load is calculated as:

\[
L_{mix} = \sum_{i=1}^{n} C_i \times V_i \times 10^3 + \sum_{j=1}^{m} L_j
\]

where \(L_{mix}\) = mixed load of contaminant (kg/day); \(C_i\) = concentration of contaminant for inflow \(i\) (mg/l); \(V_i\) = daily volume of inflow \(i\) (m³/day); \(L_j\) = load of daily contaminant (substance) \(j\) (kg/day); \(n\) = number of inflows; \(m\) = number of contaminant load (substance).
2.6 Risk Modelling in WaterMet²

The deterministic, simulation type WaterMet² model will provide basis for the evaluation of a number of risk categories related to UWS performance. The specification of the risk indicators that will be supported by the WaterMet² model is provided in Functional Requirements report (Behzadian et al. 2012). To evaluate the risk indicators which require doing some sampling and multiple runs of the deterministic model, the WaterMet² model internally support risk assessment by estimating the required variables for risk indicators. The actual risk assessment of these indicators is performed outside the WaterMet² model. Some other risk indicators, which are estimated in a single simulation of the deterministic metabolism model over some planning horizon, can be calculated directly by a single run of the WaterMet² model. These risks are those associated with the principal WaterMet² flows (e.g. the risks related to availability of resources or related to exceedance of capacities of the UWS components). The methodology for the evaluation of all risks indicators will be provided by WP32.

- WaterMet² recognises and uses the following types of water flows with respect to different water quality aspects (Makropoulos et al. 2008): clean (potable) water, precipitation (stormwater), grey water, green water, recycling (reuse) water, groundwater and black water.
3 Modelling of UWS Components

3.1 Water Supply and Distribution Subsystem Modelling

The water supply subsystem starts with the abstractions from the sources. Three types of sources are included in the WaterMet², the surface (e.g. reservoirs, rivers), the groundwater and the saline (desalination plants) (see Figure 19). In this Figure, the triangle icon indicates energy consumption and the flask indicates consumption of chemicals. The abstracted raw water needs treatment before it can be considered as potable. For this reason the water is transferred from the sources with aqueducts to the WTWs. Afterwards, the treated water is transferred with pipes and stored in service reservoirs to ensure that the supply will meet the demand peaks. Finally, the water is supplied to the demand points (subcatchments in the WaterMet²) via a distribution network.

Water quality incidents in the clean water system (potable water supply) such as for example, contaminant intrusion or discoloration require hydraulic modelling at a fine time step to assess risk and its propagation. Since hydraulic modelling is outside the scope of a mass balance type modelling with a daily time step such as the WaterMet², true water quality modelling (such advection-dispersion equations) in the clean system is considered unnecessary for the WaterMet² model. Instead, normal operation of the water supply network is assumed, which means that water supplied by the WTWs meets the standards set by national/EU regulations.

3.1.1 Raw Water Sources

Arbitrary number of water sources can be defined by the user. For each source, either unlimited availability of water is assumed or an upper limit is provided by the user. The user can select between three different types of sources:

- The surface sources: This type corresponds to abstractions from rivers or lakes (including artificial lakes formed by dams). These abstractions require neither energy nor chemicals. In the rare cases where energy is required (e.g. directly pumping from rivers), it can be included in the transmission elements connecting surface source with the WTWs. Energy required for transmission and treatment is calculated in the dedicated components (see 3.1.2 and 3.1.3).

- The groundwater sources. This type corresponds to abstractions from aquifers through boreholes. Energy is consumed in boreholes to pump water. The required energy is estimated by multiplying the abstracted amount of water with a specific energy coefficient (i.e. energy consumed per pumped volume).

- The saline sources. This type corresponds to water supplied by desalination units. In this type, both energy and chemicals are consumed during the desalination process. The required energy is estimated, as in groundwater sources, by multiplying the volume of “produced” water with a specific energy coefficient. The amount of required chemicals (e.g. iron, chloride, sulphate, boron; Strategen, 2004) is estimated by multiplying the required amount per unit of treated water with the amount of “produced” water.
3.1.2 Raw Water Supply

The transmission of water from sources to WTWs is accomplished with aqueducts (trunk mains or channels). One aqueduct must be defined for each source. The energy required for the operation of an aqueduct is estimated by multiplying the amount of transmitted water (up to the aqueduct capacity) by a specific energy coefficient for either the electricity drawn from grid or fossil fuel. This coefficient, which is user defined, is assumed constant, which means that the required energy is assumed not to be affected by the water level fluctuations of the surface water sources. The aqueducts are characterised by their capacity and a leakage coefficient. The latter gives the leakages estimated as a percentage of the flowing water. The leakage coefficient is also user defined (and could be changed by the user to quantify impacts of rehabilitation interventions).

\[ S \rightarrow S(1-l) \]

Figure 20 Transmission of raw water. The triangle icon indicates energy consumption.

3.1.3 Water Treatment Works

WTWs treat raw water from sources and supply it to service reservoirs. WTWs can treat water from an arbitrary number of sources and supply it to an arbitrary number of service reservoirs. The total amount of inflows or outflows cannot exceed the capacity of WTWs. In WaterMet2 model, WTWs is represented within two processes: physical and chemical processes. For each process, the energy required for the operation of
WTWs is estimated by multiplying the amount of treated water by a specific energy coefficient. Subsequently, the GHG emission associated with energy consumption for each stage is also calculated by multiplying the amount of energy by a conversion coefficient for kg of CO₂ equivalent (this would be different for different energy fuel mixes). The required chemical flows (chlorine, iron, aluminium, sodium hydroxide, etc.; WHO 2004) are estimated by multiplying the amount of treated water volume (up to the water treatment capacity of WTWs) by the required chemicals per unit volume of treated water.

![Figure 21 Example of WTWs treating raw water from 2 sources and supplying water to 2 reservoirs. The triangle icon indicates energy consumption. The flask indicates consumption of chemicals.](image)

### 3.1.4 Water Distribution System

Water distribution systems carry potable water, from WTWs into service reservoirs and distribute it between subcatchments. It is comprised of two main components: 1- service reservoirs and 2-principal flow routes which supply water for service reservoirs and subcatchments from WTWs and service reservoirs, respectively. Each service reservoir is able to supply water to a number of subcatchments and to receive water from one WTW. The volume of each service reservoir is calculated at each time step of simulation based on the daily mass water balance between inflows and outflows of the service reservoir. Water overflows if the volume of water exceeds the service reservoir capacity.

![Figure 22 Example of a service reservoir serving two subcatchments.](image)

The flow routes are characterized by daily water transmission capacity, leakage coefficient, specific energy used for transmission/distribution of cubic meter of water in the form of both electricity and fossil fuel.
The energy used by a flow route is calculated by multiplying the specific energy coefficient by the transmitted flow (up to the conduit capacity). The leakage amount of a flow route is also calculated by multiplying daily volume of transmitted water by the leakage coefficient of the flow route.

The flow routes that carry water from service reservoirs to subcatchments are characterised by their capacity only. No energy is consumed at this part of the network and no leakages take place.

![Figure 23 Schematic of WTWs-reservoir conduit (upper) and distribution flow route (lower). The triangle icon indicates energy consumption.](image)

![Figure 24 Example of a water supply network topology.](image)

To calculate the split of flows, WaterMet2 needs from the user to specify the split coefficients ($b_1$, $b_2$, $i_1$, $i_2$ in Figure 24). The user can define these coefficients based on: (1) pre-specified percentage split of flows between different flow routes, (2) pre-specified priorities of water consumers supplied downstream, (3) proportional to demand required downstream (which can be easily worked out before simulation in the upstream direction, starting from most downstream nodes), (4) proportional to / limited by flow capacities of routes modelled (specified by the user either directly in l/s or indirectly, via diameters, etc.). To give an example of the first method, in the Figure 24 the WTWs treat raw water from two sources. In this case, the parameters $i_1$ and $i_2$ (with $i_1+i_2=1$) define the percentage of demand covered by the first and second source. In general, split-parameters are used wherever two or more nodes supply water to the same node downstream.

A water quality parameter of interest that can be modelled in the clean water system is water age, which can also be used as a quality proxy, enabling for example to investigate ill-designed UWS components such as oversized service reservoirs, or trade-offs between reduced consumptions (due to grey water use) and decreasing potable water quality (due to increase residence time in reservoirs). The WaterMet2 model will use the residence time index (Liu et al., 2010) to quantify the performance of reservoirs in terms of quality.
degradation due to prolonged storage. The residence time index can be estimated numerically using the following formula (Rozos and Makropoulos, 2011):

\[
RTI = \frac{\text{Number of days with } RT < 2}{\text{Number of days of simulation}}
\]

RTI can be calculated for different parts of the clean water system thus giving a mapping of potential quality issues across multiple scales. The RT in a reservoir is calculated according to the ‘first in first out’ (FIFO) assumption, which is the first volume of water to enter the reservoir as inflow is the first to leave as outflow. Therefore, the RT of a drop entering the reservoir with stored volume equal to \( V_0 \) at time \( t_0 \) equals the length of the period the volume \( V_0 \) suffices to cover the demand, i.e. \( V_0/Y_0 \), where \( Y_0 \) is the outflow from the reservoir.

In addition, the materials of the water distribution system are specified for each subcatchment in the asset representation of the pipeline. The materials for each subcatchment are quantified through the respective pipe lengths which are categorised by different sizes, ages and material types. The three main categories of concrete, plastics and ferrous materials are considered for material types. The age of each pipeline category should also be provided as input for the analysis.

The flow of materials is analysed based on the physical lifetime and economic lifetime approaches for a specific amount of rehabilitation/refurbishment of the pipelines (Venkatesh et al. 2009). The consequence of material inflows such as pipeline rehabilitation is reflected in flows of cost, energy and GHG emission and general system performance (such as leakage). In the WaterMet model, the impact of the state of a pipeline asset on the amount of leakage is analysed along with the costs associated with the failure rate (i.e. burst frequency). The impact of different interventions on leakage and burst frequency is quantified indirectly, via relevant pipe characteristics (see Material Fluxes section for further details on general approach used for quantifying impact of interventions on system performance).

### 3.2 Water Demand Subsystem Modelling

Water demand is the amount of drinking and non-drinking water required for different customers in the UWS. The WaterMet divides the urban water demand into two main categories of indoor and outdoor water usages. Drinking water demand can only be supplied through potable water distribution system while non-drinking water demand can be supplied by either potable water sources (i.e. potable water distribution system) or non-potable water sources (e.g. treated grey and green water).

Different types of water demand (e.g. indoor and outdoor water consumers) are supplied from different water sources (e.g. clean, green and treated grey water) based on the user specified priorities of water allocation for different water sources. For example, the priority of water allocation for toilet water consumption from water resources can be set based the following sequence: 1-treated grey water, 2-green water and 3-clean water respectively. A user defined percentage of consumed water (typically over 90% for
domestic and 85-95% for nondomestic (Metcalf & Eddy 2003)) is converted to wastewater (grey water and black water) and the rest is assumed to be lost.

3.2.1 Outdoor Water Demand

The WaterMet2 model assumes the outdoor water is used for plant irrigation and other user defined water usages (e.g. industrial and car wash and fire station) in the form of volume of daily water demand either per capita or per square metre of commercial area (e.g. office area). This demand can be supplied from the following water sources: (1) potable water; (2) groundwater extraction and (3) (treated) grey water; (4) green water.

3.2.2 Indoor Water Demand

Indoor water demand in the form of daily water demand per capita is water consumption points inside a property such as household, industrial and commercial water use. The WaterMet2 is also able to model indoor water demand based on the specific appliances and fittings previously described. The principal input data for the calculation of indoor water demand in WaterMet2 are:

- The number of occupancy
- Water demand per capita for each category (e.g. domestic, industrial and so on)
- If appliances and fittings are modelled, for each of them, the water consumption per use, total number of it, frequency of use per capita per day

3.3 Wastewater Subsystem Modelling

3.3.1 Rainfall-Runoff

The WaterMet2 model simulates a simplified rainfall-runoff process which is the principal component of the stormwater. The rainfall-runoff is simulated on local area level as the smallest hydrologic unit of the study area. Local areas can be divided into three surfaces: (1) pervious subareas; (2) impervious subareas and (3) water bodies. The impervious subareas are the areas with no infiltration and only depression storage which transforms the whole rainfall to runoff. The impervious subareas are divided into two parts: (1) roofs and (2) pavements and roads. Roofs are defined separately to be potentially used for rainwater harvesting. The pervious subareas at which surface runoff can infiltrate include open spaces and irrigation lands such as private/public gardens and parks. The main principal assumptions associated with rainfall-runoff process in the WaterMet2 model are:

- Evaporation is subtracted as a user defined evaporation percentage from the rainfall/snowmelt before any amount of generated runoff is calculated.
- The two-layer pervious soil storage approach employed by UVQ (Mitchell et al. 2010) and CWB (Last 2010) is used here for modelling pervious area storage. More specifically, it allows proportion
of water above the field capacity to drain to groundwater which is better to represent the areas with lower potential evaporation (Last 2010).

- The generated runoff in all local areas in a subcatchment contributes to the basin of the respective subcatchment separate/combined sewer systems. This runoff is collected at subcatchment outlets.

- The user defined infiltration rate for each local area is only applied to pervious surfaces and is subtracted before generated runoff is calculated for pervious surfaces.

The principal storages used in the modelling of rainfall-runoff process in the WaterMet² are: (1) snow storage; (2) impervious area storage; and (3) pervious area storage.

**Snow Storage**

Precipitation in both forms of rain and snow is modelled in waterMet² by precipitation amount and air temperature time series as input data. The precipitation falls as snow on all surface types when the average air temperature becomes below snowfall threshold temperature (default value as 0 °C). Then, the snowfall is accumulated on all the surfaces and fills snow storage. The snow storage melts when the daily average air temperature is above the user defined snowmelt temperature threshold (default value as 0 °C). The snowmelt coming off the storage is treated as an additional rainfall input onto the surface of local area. The following principal assumptions are associated with the process of snow storage and snowmelt in the WaterMet² model:

- The precipitation amount is distributed spatially uniform and the air temperature, snowfall and snowmelt temperature threshold are temporally uniform within the study area during each day.

- The amount of snowmelt is determined by a constant melt rate coefficient ranging from approximately 2 to 8.4 mm/°C/day (SemáDeni-Davies et al., 2000) multiplied by the amount of daily average air temperature above the snowmelt temperature threshold. All the factors influencing the snowmelt are included in melt rate coefficient which is constant within the study area.

- Snow storage accumulated in each surface, when melted, will contribute to the stormwater of that surface.

**Impervious Area Storage**

Imperviousness tends to be the most sensitive parameter in the hydrologic characteristics ranging from 5% for undeveloped areas up to 95% for high-density commercial areas (Gironás et al. 2009). The only inflow of the impervious area storage is the precipitation (FL4) in the form of either rainfall or snowmelt (see Figure 9). The outflows from this storage are: (1) rainwater harvesting from roofs (FL12); (2) surface runoff flow towards stormwater storage (FL14); (3) evaporation (FL7).

**Pervious Area Storage**

The inflows to the pervious storage are: (1) rainfall and snowmelt (FL5); (2) potable water for irrigation (FL2); (3) borehole extraction for irrigation (FL32); (4) (treated) grey water for irrigation (FL22). The outflows from
the storage are: (1) surface runoff generated from excess rainfall draining to stormwater collection system on subcatchment area (FL16); (2) groundwater recharge (FL21); and (3) evaporation.

Figure 25 Inflow and outflows in pervious storage

A percentage of pervious surfaces in each local area is assigned for irrigation. In the WaterMet2 model, the total volume of water required for irrigation is fed by three water sources: (1) potable water (FL2); (2) treated grey water (FL22) and (3) borehole extraction (FL32). The amount of required irrigation water of pervious surfaces is determined based on the concept presented by UVQ (Mitchell et al. 2010) in which irrigation is applied to the soil storage when the water storage level drops below the user defined “trigger to irrigate” threshold level. The following principal assumptions are associated with all the processes in pervious storage:

- The irrigation demand is uniformly distributed within the pervious areas and therefore, if the water level in the upper layer of pervious soil in a local area drops in a day below threshold level known as “trigger to irrigate”, irrigation is performed during that day.

- The order of inflows and outflows for a pervious storage are as follows: at the first, precipitation and evaporation occur simultaneously at the beginning of the day. Groundwater recharge and surface runoff occur with respect to the parameters of the soil layers. Then, irrigation demand from all sources is supplied if necessary at the end of the day.

3.3.2 Sewer System

The WaterMet2 model simulates a simplified stormwater and wastewater collection system between different subcatchments on city level as shown in Figure 17. In other words, separate/combined sewer systems collect stormwater and wastewater from all local areas inside each subcatchment at the most downstream point of
the subcatchment characterised by an outlet (black rectangles in Figure 17). Then, they are transported by flow routes to WWTWs. The following principal assumptions are associated with sewer collection network in the WaterMet2 model:

- Sewer systems are mainly characterised by sewer routes specified between different subcatchment outlets (e.g. w1-1, w1-2). The routes are sequentially connected to each other based on the tree shape of the gravity of stormwater/wastewater collection systems. The sewer route of a subcatchment is connected to the outlet of the immediately next downstream subcatchment. A downstream subcatchment node can receive the wastewater/stormwater of more than one upstream subcatchment through the routes (e.g. subcatchments D and H draining to subcatchment F through W1-1 and W1-2 routes in Figure 17).

- The user can define a number of CSOs (combined sewer overflow) and STOs (storm tank overflow) for different sewer routes of the network as well as some CSOs for WWTWs (e.g. CSO3 and CSO6) before WWTWs. The CSO and STO structures divert the excess volume of the wastewater/stormwater exceeding daily transmission capacity from a route in a combined sewer systems and stormwater systems respectively.

- The user can specify separate or combined flow route for sewer systems of each subcatchment independently. This is done through defining a percentage of stormwater draining onto sewer system. For example, in combined sewer systems, 100 percentage of stormwater drain the system.

- The energy and the associated GHG emission if applicable for each flow route are calculated by multiplying the transported wastewater/stormwater by a specific coefficient. These coefficients can vary for different source of the energy (e.g. electricity and fossil fuel).

- The main required parameters of sewer systems for each subcatchment in the WaterMet2 are:
  - Daily transmission capacity.
  - Various daily energies consumed.
  - Total annual cost.
  - Immediate downstream subcatchment/WWTWs.

Similar to the flows of pipelines in water distribution system, flows of pipelines of sewer systems for each subsystem will be analysed. Again, material flows are quantified using the pipe lengths (i.e. masses) which are categorised by different sizes, ages and material types (see section 2.3.4 for further details).

3.3.3 Wastewater Treatment Works

The WaterMet2 allows modelling wastewater treatment works (WWTWs) on city level as the final destination of combined/sanitary sewer systems, which treat combined/sanitary wastewater and produce treated effluent and solid waste as resource recovery. In the WaterMet2, WWTWs are divided into three parts (Figure 26): (1) WWTWs CSO; (2) wastewater treatment; and (3) energy and material recovery.
Total amount of daily wastewater inflows (FC24, FC25) to WWTWs is limited to the capacity of the respective WWTWs. A CSO structure diverts such a surplus stormwater/wastewater volume exceeding the daily capacity of WWTWs into receiving waters (FC30).

The WaterMet2 allows modelling a number of user-defined treatment stages in a sequence. For each treatment stage, energy used in the form of either electricity or fossil fuel, chemicals used for treatment and total annual cost are specified by the user per unit volume of treated wastewater.

Treated wastewater is split between the available options (e.g. discharge to receiving water such as river, sea and lake (FC35), further water treatment (FC32), and groundwater recharge (FC31)). In addition, the contaminant load and sludge generated are also calculated based on the complete mixing assumptions (Mitchell and Diaper 2010):

\[
\begin{align*}
LTSC10_{t} &= LSC10_{t} + FC29_{t} \times CFC10_{t} \\
SSC10_{t} &= LTSC10_{t} \times (\%Rww_{t}) \\
LSC10_{t+1,i} &= LTSC10_{t} \times (1 - \%Rww_{t})
\end{align*}
\]

where \(LTSC10_{t}\) and \(LSC10_{t}\) = contaminant load of WWTWs storage \(i\) at day \(t\) after and before mixing with inflow, respectively (kg/day); \(CFC10_{t}\) = contaminant concentration of inflow to WWTWs storage \(i\) at day \(t\) (mg/l), \(Rww_{t}\) = removal percentage of a contaminant for wastewater in WWTWs storage \(i\) (%/100); \(SSC10_{t}\) = sludge generated from WWTWs storage \(i\) at day \(t\) (kg), \(LSC10_{t+1,i}\) = contaminant load of WWTWs storage \(i\) at day \(t+1\) (kg/day).

Energy and material recovery in WWTWs can be any envisaged resource recovery. Some examples of the material recovery are anaerobic digestion, ammonium nitrate, sludge handling in WWTWs which are calculated per unit volume of treated wastewater. Some examples of energy recovery are heat and electricity generated in WWTWs by utilising the biogas, anaerobic digestion, turbine-generator and heat pump. The main parameters required to define an energy and material recovery in the WaterMet2 are:

- Daily capacity of wastewater flow from WWTWs
- Coefficients required for energy and material recovery per unit volume of wastewater

The WaterMet2 calculates the energy consumed for daily treated wastewater and GHG emissions by multiplying the volume of treated wastewater by specific coefficients. The WaterMet2 also calculates the individual chemicals required for wastewater treatment in WWTWs (such as FeCl₃, Fe₂(SO₄)₃, Ca(OH)₂) by multiplying the amount of treated wastewater by the required individual chemicals per unit volume of treated wastewater.
3.4  Cyclic Water Recovery Modelling

Cyclic water recovery facilities can be divided into two groups of centralised and decentralised facilities. In WaterMet model, the centralised water treatment recovery is modelled at city scale as further water treatment for recycling water in different subcatchments (Figure 15). Decentralised water treatment facilities are modelled in the WaterMet model in both subcatchment and local area scales. Decentralised cyclic water recovery facilities at local area scale are rainwater harvesting storage (SL9), on-site treatment system (SL6) and septic tanks (SL7) (see Figure 9). The WaterMet model takes into account further water treatment options on subcatchments area scale as a decentralised cyclic water recovery facility (see Figure 14). A more details of the above water recovery facilities are described in the following sections.

3.4.1  Rainwater Harvesting Tank

In the WaterMet model, the runoff generated from building roofs of a local area can be collected and stored in a rainwater harvesting tank which can be used for indoor/outdoor water demands in the same local area as green water. The water volume exceeding the capacity of the tank overflows directly to the stormwater storage on subcatchment level. The WaterMet model also assumes drainage of a fixed percentage of inflows as first flush flow containing more contamination. The inflows and outflows in a rainwater harvesting tank are shown in Figure 27. The only inflow is the runoff generated from building roofs of local area (FL12). The outflows are indoor/outdoor water usages (FL18) and overflow/first flush flows (FL17). The WaterMet model.
assumes that the storage volume is first controlled by daily inflow. Then, the daily outflow is sequentially withdrawn in the same day and eventually the final volume of that day is calculated. Therefore, the overflow of the tank (FL17) is only affected by inflow and the volume of the tank left from the previous day.

Figure 27 inflows and outflows in rainwater harvesting tank

Rainwater usually carries small pollutant loads. Therefore, rainfall and snowmelt will convey a user defined mass of different contaminants. Light treatment and disinfection is generally adequate for rainwater treatment to non-potable standards.

3.4.2 On-site Water Treatment Systems

The WaterMet\textsuperscript{2} model allows the user to define on-site water treatment (SL6) in local area (see storage SL6 in Figure 9). The system can provide recycling water for indoor and outdoor water demands in the same local area (Figure 28). The inflows of this storage are green and grey water collected in the same local area (FL18, FL8 respectively) and treated water/wastewater from subcatchment area (FL28). The specific outflows are recycling water for indoor water use (FL9) and outdoor water use (FL22) as well as grey water overflow from storage tank.
The processes required for water treatment in this system with three different types of water inflows may vary. The WaterMet\textsuperscript{2} assumes a further decomposed configuration for this system shown in Figure 29 to model individual treatment processes at local level. Two treatment facilities are assumed for two types of water flows due to the difference in the treatment requirements which will be separately specified by the user (e.g. Treatment1 and Treatment2 in Figure 29). However, the output of these two potential water treatments is combined together as recycling water to be dispatched between the associated water demands. Collected grey water from local area also needs a storage tank with the associated overflow which is directed to stormwater storage in subcatchment area (SS2). The calculation of the storage volume and the overflow follows the same as that described previously in rainwater harvesting tank.
The WaterMet² model will also calculate the flows of energy, cost and chemicals used in these processes. The principal data requirements for this system in each local area are:

- Capacity of storage tank;
- Chemicals, energy and cost used for unit volume of treated water in each treatment type;
- Removal level of treatment for each contaminant concentration;

### 3.4.3 Septic Disposal

The WaterMet² assumes septic tank on local area level if there is no connection to the domestic/combined sewer systems (i.e. FL11=FL10, FL29=0). It should be noted that a septic tank can be modelled for each local area and not for each single household/property (i.e. indoor area) unless that single household/property represents a single local area. The only inflow of a septic tank is the black water from indoor water consumptions (FL11). The WaterMet² model assumes that the outflow of a septic tank (FL20) infiltrates into groundwater which is equal to the inflow (FL11=FL20). Note that if there is no on-site water treatment facility implemented at a local area, all the grey water is converted to black water.

### 3.4.4 Further Water Treatment for Water Reuse

Both centralised and partly decentralised types of further water treatment are modelled in the WaterMet². The centralised one (SC11 in Figure 15) located on city level has two inflows: (1) treated wastewater from WWTWs (FC32) and (2) stormwater from storm sewer networks (FC23) if available. The only outflow is treated water/wastewater delivered to partly decentralised further water treatment (SS2 in Figure 14 and Figure 30) on subcatchment level. To use recycling water by consumers, the user needs to specify the subcatchments required recycling water.

![SS2-Storm Water Store and Further Water Treatment Options on Subcatchment Scale](image)

Figure 30 inflows and outflows of stormwater storage and water treatment options (SS2) on subcatchment scale in WaterMet² model
Partly decentralised water treatment in subcatchment area is further decomposed into different parts as shown in Figure 31 in which the inflows are: (1) grey water overflows from the storages of all inside local areas (FS3), (2) surface runoff from all inside local areas (FS1) and (3) treated stormwater/wastewater imported from centralised water treatment (FS14). The outflows are (1) treated stormwater/wastewater to be dispatched to different water demand in inside local areas and (2) surface runoff and grey water overflows from the relevant storage tanks. The water balance and contaminant load for the tanks (Storage Tank1 and Storage Tank2) and the treatments (Treatment1 and Treatment2) are defined similarly to the ones in the on-site water treatment in local area.

![Figure 31 Further decomposition of stormwater storage and water treatment options (SS2) on subcatchment scale in WaterMet2 model](image)

### 4 Summary and Conclusions

The WaterMet2 model is an urban metabolism model that simulates the flows of water (water quantity and quality), material, energy, cost and chemicals. The WaterMet2 model supports also various risk analysis calculations related with the urban water flows.

The urban water flows are simulated, using a simplified, mass balance approach, starting from the water resources (reservoirs for surface sources, boreholes for groundwater sources and desalination treatment plants for saline sources) and ending to the receiving water bodies. Concerning the representation of the UWC components, the WaterMet2 model uses a multi-level approach that includes the following four levels:

- **The indoor level.** This level includes the in-house water appliances and fittings. Inputs at this level are the potable water and any treated grey water. Outputs are the grey water and the black water from toilet.
- **The local level.** This includes the neighbouring households/properties including the pervious (e.g. garden) and impervious areas (e.g. roads), any local grey water treatment unit, any local rainwater harvesting tank. The inputs at this level are the precipitation, the potable water from mains, any
groundwater from local boreholes and any treated grey water at subcatchment level. The outputs are the evaporation, the infiltrations from the pervious areas to the aquifer, the stormwater, the grey water in case of an installed treatment unit at subcatchment level, and the black water.

- The subcatchment level. This includes a number of neighbouring local areas represented as water demand points for consuming potable water from water distribution systems and draining wastewater/stormwater to sewer systems, and any treatment unit at subcatchment level. The flow of materials is also modelled at this level.
- The city level. This is the whole city including the water resources (surface, groundwater or saline), the transmission, WTWs, service reservoirs, water distribution system, the subcatchments, the sewer system, WWTWs, and the receiving water bodies. The inputs at this level are the abstractions from the water sources and the outputs are the disposals to the water bodies.

The spatial resolution of the WaterMet2 model, i.e. the spatial level at which a WaterMet2 entity can be defined geographically, is the subcatchment. Subcatchments are represented geographically with nodes placed at the centre of gravity of the subcatchment area. To simulate the inflows and outflows to/from each node, the WaterMet2 model simulates the operation of two networks: (1) the water supply network and (2) the wastewater/stormwater collection system. The water supply network includes the abstractions, the treatment, the temporal storage and the distribution of potable water to demand nodes. The wastewater/stormwater collection system collects the wastewater/stormwater from the subcatchment nodes, treats the wastewater and disposes it to the water bodies.

Starting from the lower level (indoor level), the WaterMet2 model simulates the flows between the components of the same level and after the completion proceeds with the flows between the components of the next level. The simulation of a time step ends with the simulation of the flows between every component of the highest level i.e. the city level.

In addition to the water flow, the WaterMet2 model simulates the flows of pipeline materials for both water supply and wastewater collection systems. The flow of lengths (masses) of pipelines are categorised on the basis of different sizes, material types, ages for each subcatchment. The impact of materials inflow (e.g. rehabilitation rate) on general system performance (e.g. leakage reduction and failure rate and its associated cost) is also quantified on the basis of user defined mappings.

The WaterMet2 model employs a method for tracking the release of substances to the environment. The method is based on a source-sink concept assuming a dominant advection transport process, and instantaneous and complete mixing in UWS tanks and reservoirs.

The WaterMet2 model also calculates the energy consumed and the GHG emission flows (e.g. CO2 equivalent) in different forms of either directly from fossil fuel consumption or indirectly from electricity consumption or from material flows (embodied) for the pipelines in water supply system, wastewater collection networks and chemicals consumed in any subsystem. Finally, the outcome of the WaterMet2 model in which how the general criteria for sustainability are met will be reflected in more detail in another report once the model applies to the Oslo case study in WP34.
5 References


IWA (2012). “Global Trends & Challenges in Water Science, Research and Management, (Decentralised wastewater management: an overview)”, Specialist Group on Sanitation and Water Management in Developing Countries of International Water Association, pp. 73-75


6 Appendix A: Functionality of Storages and Flows

Table 2 Functionality of city area storages and flows

<table>
<thead>
<tr>
<th>Storage no</th>
<th>Storage name</th>
<th>Storage description/functionality</th>
<th>Flow no</th>
<th>Flow name/description</th>
<th>Flow type</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC1</td>
<td>Water Treatment Works</td>
<td>A number of water treatment works located in city area, each receives raw water from one or a number of water sources, and produces treated water</td>
<td>Inflows</td>
<td>FC1 Raw water input to WTWs</td>
<td>Potable water</td>
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<tr>
<td></td>
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<td></td>
<td>FC4 Treated water as drinking water</td>
<td>Potable water</td>
</tr>
<tr>
<td>SC2</td>
<td>service reservoirs</td>
<td>A number of drinking water storages located at city area, each receives treated water from one or more WTWs and supply drinking water for a number of subcatchments.</td>
<td>Inflows</td>
<td>FCS Treated water input to service reservoirs</td>
<td>Potable water</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>FC8 Drinking water supply for subcatchments</td>
<td>Potable water</td>
</tr>
<tr>
<td>SC3</td>
<td>Subcatchment Area</td>
<td>A number of subcatchments which receive drinking water from water distribution systems and drain stormwater and wastewater to sewer systems</td>
<td>Inflows</td>
<td>FC8 Drinking water supply for subcatchments</td>
<td>Potable water</td>
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<td>FC11 Rainfall/snow for subcatchment areas</td>
<td>Precipitation</td>
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<td>FC33 Centralised treated water/wastewater reuse for subcatchments</td>
<td>Recycling water</td>
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<td></td>
<td>FC37 borehole extraction for subcatchments</td>
<td>Ground water</td>
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<td>Outflows</td>
<td>FC12</td>
<td>Water evaporated from subcatchments</td>
<td>Evaporation</td>
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<td>FC13</td>
<td>Water infiltrated into groundwater from subcatchments</td>
<td>Ground water</td>
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<td></td>
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<td></td>
<td>FC14</td>
<td>Black water from subcatchments</td>
<td>Black water</td>
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<td></td>
<td></td>
<td></td>
<td>FC15</td>
<td>Runoff generated from subcatchments</td>
<td>Stormwater</td>
</tr>
<tr>
<td>SC4</td>
<td>Storm Sewer Systems</td>
<td>Storm sewer is a part of separate sewer system which simulates stormwater collection system. It collects stormwater from a number of subcatchment areas and transports it to receiving waters. This is also able to return stormwater for further water treatment for water reuse on city area scale</td>
<td>Inflows</td>
<td>FC15</td>
<td>Runoff generated from subcatchments</td>
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<td>FC16</td>
<td>Infiltrated water from groundwater into stormwater sewer system</td>
<td>Ground water</td>
</tr>
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<td>Outflows</td>
<td>FC17</td>
<td>Exfiltrated water from stormwater sewer systems into groundwater</td>
<td>Ground water</td>
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<td></td>
<td>FC28</td>
<td>Total volume of stormwater exceeding the daily capacity of storm sewer system draining into receiving water</td>
<td>Stormwater</td>
</tr>
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<td></td>
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<td></td>
<td>FC23</td>
<td>Return flow for further water treatment for water reuse</td>
<td>Stormwater</td>
</tr>
<tr>
<td>SC5</td>
<td>Domestic Sewer Systems</td>
<td>Domestic sewer is a part of separate sewer system which simulates wastewater collection systems. It</td>
<td>Inflows</td>
<td>FC14</td>
<td>wastewater from subcatchments</td>
</tr>
<tr>
<td>Storage no</td>
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<td>Storage description/functionality</td>
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<td>Flow name/description</td>
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<td>collects sanitary wastewater from a number of subcatchment areas and transports it to WWTWs</td>
<td>FC18</td>
<td>Infiltrated water from groundwater into domestic sewer system</td>
<td>Ground water</td>
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<td>FC19</td>
<td>Exfiltrated water from domestic sewer systems into groundwater</td>
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<td>FC24</td>
<td>Total volume of wastewater transported to WWTWs</td>
<td>Black water</td>
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<td></td>
<td></td>
<td>FC27</td>
<td>Overflow from domestic sewer systems draining into receiving waters</td>
<td>Black water</td>
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<tr>
<td></td>
<td></td>
<td>Combined sewer simulates waste water and stormwater collection systems which collects wastewater/stormwater from a number of subcatchment areas and transports them to WWTWs</td>
<td>Inflows</td>
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<td></td>
<td></td>
<td></td>
<td>FC14</td>
<td>wastewater from subcatchments</td>
<td>Black water</td>
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<td></td>
<td></td>
<td></td>
<td>FC15</td>
<td>Runoff generated from subcatchments</td>
<td>Stormwater</td>
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<tr>
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<td></td>
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<td>FC20</td>
<td>Infiltrated water from groundwater into combined sewer systems</td>
<td>Ground water</td>
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<td>FC21</td>
<td>Exfiltrated water from combined sewer systems into groundwater</td>
<td>Ground water</td>
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<td>FC25</td>
<td>Total volume of wastewater transported to WWTWs</td>
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<td>FC34</td>
<td>Total volume of wastewater exceeding the daily capacity of a combined sewer draining into receiving water</td>
<td>Black water</td>
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**Storage:**
- Storage no
- Storage name
- Storage description/functionality

**Flow:**
- Flow no
- Flow name/description
- Flow type
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<tr>
<th>Storage no</th>
<th>Storage name</th>
<th>Storage description/functionality</th>
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<th>Flow name/description</th>
<th>Flow type</th>
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<tbody>
<tr>
<td>SC7</td>
<td>Wastewater Treatment Works</td>
<td>Wastewater treatment works located on city area which treat wastewater and produce environmentally safe treated water for different application or discharging into receiving water</td>
<td>Inflows</td>
<td>FC29 Wastewater inflow to WWTWs</td>
<td>Black water</td>
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<td>FC30 Wastewater overflow exceeding the daily capacity of WWTWs draining into receiving waters</td>
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<td>FC31 Treated wastewater recharging into groundwater</td>
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<td>FC32 Treated wastewater for centralised further treatment and reuse in subcatchments</td>
<td>Recycling water</td>
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<td></td>
<td>FC35 Treated wastewater discharging into receiving waters</td>
<td>Recycling water</td>
</tr>
<tr>
<td>SC8</td>
<td>Further Water Treatment On City Scale</td>
<td>Centralised water treatment unit receiving treated wastewater from WWTWs and stormwater system for water reuse at different subcatchments</td>
<td>Inflows</td>
<td>FC23 Return flow for further water treatment for water reuse</td>
<td>Stormwater</td>
</tr>
<tr>
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<td></td>
<td>FC32 Treated wastewater for centralised further treatment and reuse in subcatchments</td>
<td>Recycling water</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>FC33 Treated water/wastewater for reuse at different subcatchments</td>
<td>Recycling water</td>
</tr>
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</table>
### Table 3: Functionality of subcatchment area storages and flows

<table>
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<tr>
<th>Storage no</th>
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<th>Storage description/functionality</th>
<th>Flow no</th>
<th>Flow name</th>
<th>Flow type</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS1</td>
<td>Local Area</td>
<td>A subcatchment contains a number of local areas. Each local area receives drinking water, recycling water and withdraws groundwater from the relevant subcatchments and delivers stormwater, grey water and black water to the relevant subcatchment area level.</td>
<td>Inflows</td>
<td></td>
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<td></td>
<td>FS9</td>
<td>Drinking water for each local area</td>
<td>Potable water</td>
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<td>FS10</td>
<td>Rainfall/snow for each local area</td>
<td>Precipitation</td>
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<tr>
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<td></td>
<td>FS13</td>
<td>Borehole extraction for consumption on local area scale (e.g., toilet, garden and open space irrigation, carwash, etc.)</td>
<td>Ground water</td>
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<td></td>
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<td></td>
<td>FS4</td>
<td>Treated water reuse/recycling for each local area (e.g., toilet, garden and open space irrigation, carwash, etc.)</td>
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<td>FS11</td>
<td>Water evaporated from the precipitation from each local area</td>
<td>Evaporation</td>
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<td>FS12</td>
<td>Water infiltrated into groundwater from stormwater on pervious areas and septic tanks</td>
<td>Ground water</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FS1</td>
<td>Stormwater collected from impervious, pervious areas and excess rainwater harvesting capacity for each local area</td>
<td>Stormwater</td>
</tr>
<tr>
<td>Storage no</td>
<td>Storage name</td>
<td>Storage description/functionality</td>
<td>Flow no</td>
<td>Flow name</td>
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<td></td>
<td>FS2</td>
<td>Black water collected for each local area</td>
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<td>FS3</td>
<td>Grey water collected from inside local areas</td>
<td>Grey water</td>
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<tr>
<td>SS2</td>
<td>Further Water Treatment Options on Subcatchment Scale</td>
<td>Water treatment options located in each subcatchment is to collect the excess stormwater and grey water from the daily capacity of the relevant storage on local area level for treatment and reuse on local area level</td>
<td>Inflows</td>
<td>FS3</td>
<td>Grey water collected from inside local areas</td>
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<td></td>
<td></td>
<td></td>
<td>FS1</td>
<td>Stormwater collected from impervious, pervious areas and excess rainwater harvesting capacity for inside local areas</td>
<td>Stormwater</td>
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<td></td>
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<td>FS14</td>
<td>Treated water/wastewater from WWTWs on city level</td>
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<td></td>
<td>FS4</td>
<td>Treated water reuse/recycling for each local area (e.g. toilet, garden and open space irrigation, carwash, etc.)</td>
<td>Recycling water</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>FS7</td>
<td>Stormwater overflow in the unit exceeding the daily capacity of the relevant storage</td>
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<td>FS8</td>
<td>Grey water overflow in the unit exceeding the daily capacity of the relevant storage</td>
<td>Black water</td>
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### Table 4 Functionality of local area storages and flows

<table>
<thead>
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<th>Storage no</th>
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<th>Storage description/functionality</th>
<th>Flow no</th>
<th>Flow name</th>
<th>Flow type</th>
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</thead>
<tbody>
<tr>
<td>SL1</td>
<td>Indoor Water Use</td>
<td>Each indoor water use represents a specific type of water consumption point (e.g. residential, industrial, commercial, etc.). It receives drinking water and recycling water and converts to grey water and black water</td>
<td>Inflows</td>
<td>FL1 Drinking water</td>
<td>Potable water</td>
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<td></td>
<td></td>
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<td>FL9 recycling water for specified water use (e.g. toilet flushing)</td>
<td>Recycling water</td>
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<td></td>
<td></td>
<td>Outflows</td>
<td>FL8 Grey water collected from different types of indoor water consumption except toilet flushing</td>
<td>Grey water</td>
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<td></td>
<td>FL10 Black water collected from toilet flushing</td>
<td>Black water</td>
</tr>
<tr>
<td>SL2</td>
<td>Impervious Areas</td>
<td>The areas in each local area with no infiltration such as building roofs which can be used for rainwater harvesting, roads and pavements</td>
<td>Inflows</td>
<td>FL4 Rainfall/snow on impervious areas for each local area</td>
<td>Precipitation</td>
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<td>FL7 Water evaporated from the precipitation on impervious areas</td>
<td>Evaporation</td>
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<td>FL12 Runoff generated from rainfall and snow-melt on roofs used for rainwater harvesting purposes</td>
<td>Stormwater</td>
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<tr>
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<td></td>
<td></td>
<td>FL14 Run-off generated from rainfall and snow-melt on impervious areas draining to sewer systems</td>
<td>Stormwater</td>
</tr>
<tr>
<td>SL3</td>
<td>Pervious Areas</td>
<td>The porous areas in each local area with infiltration into the ground (e.g. public open space, private gardens, etc.)</td>
<td>Inflows</td>
<td>FL2 Drinking water for irrigation and outdoor application (e.g. private garden, public open spaces, carwash, etc.)</td>
<td>Potable water</td>
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<td>FL5 Rainfall/snow on pervious areas for each local area</td>
<td>Precipitation</td>
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<td>FL22 Recycling water for irrigation and outdoor applications (e.g. private garden, public open spaces)</td>
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<td>Storage description/functionality</td>
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<td>FL32</td>
<td>Borehole extraction for irrigation and outdoor applications (e.g. garden and open space irrigation, carwash, etc.)</td>
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<td>FL3</td>
<td>Daily water evaporated from the precipitation on pervious areas</td>
<td>Evaporation</td>
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<td>Water infiltrated into groundwater</td>
<td>Stormwater</td>
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<td>FL16</td>
<td>Portion of runoff on pervious areas which drains to stormwater system on subcatchment level</td>
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<td>SL5</td>
<td>Rainwater Harvesting Tank</td>
<td>Inflows</td>
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<tr>
<td>FL12</td>
<td>runoff generated from rainfall and snow-melt on roofs for rainwater harvesting purposes</td>
<td>Stormwater</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FL18</td>
<td>Rainwater harvested flow for water reuse</td>
<td>Green water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FL17</td>
<td>Overflow/first flush of rainwater from the rainwater harvesting tank draining into stormwater system on subcatchment level</td>
<td>Stormwater</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SL6</td>
<td>On-site Water Treatment System</td>
<td>Inflows</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FL28</td>
<td>treated water/wastewater imported from subcatchment area</td>
<td>Recycling water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FL8</td>
<td>Grey water collected from different types of indoor water consumption except toilet flushing</td>
<td>Grey water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FL18</td>
<td>Rainwater harvested flow for water reuse</td>
<td>Green water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FL22</td>
<td>recycling water for outdoor water usages (e.g. green area irrigation)</td>
<td>Recycling water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FL9</td>
<td>recycling water for indoor water usages (e.g. toilet flushing)</td>
<td>Recycling water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage no</td>
<td>Storage name</td>
<td>Storage description/functionality</td>
<td>Flow no</td>
<td>Flow name</td>
<td>Flow type</td>
</tr>
<tr>
<td>-----------</td>
<td>--------------</td>
<td>-----------------------------------------------------------------------------------------------------------------</td>
<td>---------</td>
<td>---------------------------------------------------------------------------------------------------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td></td>
<td>SL7</td>
<td>Septic Tank: The tank located in each local area which are not connected to combined/domestic sewer systems and receives black water from indoor areas</td>
<td>FL11</td>
<td>Black water collected from toilet flushing for the local areas that are not connected to combined/domestic sewer systems</td>
<td>Black water</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FL20</td>
<td>wastewater infiltrated into groundwater</td>
<td>Ground water</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FL27</td>
<td>Overflow of grey water from the treatment tank of the local area and draining into water treatment systems located on subcatchment area level</td>
<td>Grey water</td>
</tr>
</tbody>
</table>
Table 5: Functionality of Indoor storages and flows

<table>
<thead>
<tr>
<th>Storage no</th>
<th>Storage name</th>
<th>Storage description/functionality</th>
<th>Flow no</th>
<th>Flow name</th>
<th>Flow type</th>
</tr>
</thead>
<tbody>
<tr>
<td>SI1</td>
<td>Hand Basin</td>
<td>Receives drinking water and converts to grey water</td>
<td>Inflows</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>F1</td>
<td>Drinking flow for handbasin on indoor scale</td>
<td>Potable water</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Outflows</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>F7</td>
<td>Grey water collected from hand basins on indoor scale</td>
<td>Grey water</td>
</tr>
<tr>
<td>SI2</td>
<td>Bath &amp; Shower</td>
<td>Receives drinking water and converts to grey water</td>
<td>Inflows</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>F2</td>
<td>Drinking flow for Baths &amp; showers on indoor scale</td>
<td>Potable water</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Outflows</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>F8</td>
<td>Grey water collected from Baths &amp; showers on indoor scale</td>
<td>Grey water</td>
</tr>
<tr>
<td>SI3</td>
<td>Dish Washer</td>
<td>Receives only drinking water and converts to grey water</td>
<td>Inflows</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>F3</td>
<td>Drinking flow for dish washer for indoor scale</td>
<td>Potable water</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Outflows</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>F9</td>
<td>Grey water collected from dish washer on indoor scale</td>
<td>Grey water</td>
</tr>
<tr>
<td>SI4</td>
<td>Washing Machine</td>
<td>Receives drinking water and converts to grey water</td>
<td>Inflows</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>F4</td>
<td>Drinking flow for washing machine on indoor scale</td>
<td>Potable water</td>
</tr>
<tr>
<td>Storage no</td>
<td>Storage name</td>
<td>Storage description/functionality</td>
<td>Flow no</td>
<td>Flow name</td>
<td>Flow type</td>
</tr>
<tr>
<td>------------</td>
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<td>---------------------------------------------------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Outflows</td>
<td>FL10</td>
<td>Grey water collected from washing machine on indoor scale</td>
<td>Grey water</td>
</tr>
<tr>
<td>SI5</td>
<td>kitchen Sink</td>
<td>Inflows</td>
<td>FI5</td>
<td>Drinking flow for kitchen sink on indoor scale</td>
<td>Potable water</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FL12</td>
<td>black water collected from kitchen sink on indoor scale</td>
<td>Grey water</td>
</tr>
<tr>
<td>SI6</td>
<td>Toilet</td>
<td>Inflows</td>
<td>FI6</td>
<td>Drinking flow for toilet flushing on indoor scale</td>
<td>Potable water</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FL9</td>
<td>Recycling water from on-site water treatment system</td>
<td>Recycling water</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FL10/FS2/FC14</td>
<td>black water collected from toilet flushing for septic tank</td>
<td>Black water</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FL10/FL11</td>
<td>black water collected from toilet flushing for combined/domestic sewer systems</td>
<td>Black water</td>
</tr>
</tbody>
</table>
### Table 6 Functionality of sources and sinks

<table>
<thead>
<tr>
<th>Source/Sink no</th>
<th>Source/Sink Type</th>
<th>Storage name</th>
<th>Storage description/functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Source</td>
<td>Water Source</td>
<td>Limited source of water in which raw water can be taken for treatment and used as drinking water (e.g. reservoir, lake, well, river, etc.)</td>
</tr>
<tr>
<td>2</td>
<td>Source</td>
<td>Precipitation</td>
<td>time series of precipitation on urban areas during planning horizon as input data</td>
</tr>
<tr>
<td>3</td>
<td>Sink</td>
<td>Evaporation</td>
<td>the volume of water evaporated from urban areas including evapotranspiration</td>
</tr>
<tr>
<td>4</td>
<td>Sink</td>
<td>Receiving Waters</td>
<td>The water bodies receiving stormwater and treated wastewater including rivers, lakes, groundwater</td>
</tr>
<tr>
<td>5</td>
<td>Sink/source</td>
<td>Groundwater</td>
<td>An unlimited water source/sink in which water can be infiltrated/exfiltrated/withdrawn/discharged/recharged</td>
</tr>
<tr>
<td>6</td>
<td>Sink</td>
<td>Water Bodies</td>
<td>The water bodies (e.g. lake, river, etc.) receiving precipitation</td>
</tr>
</tbody>
</table>