TRANSITIONS TO THE URBAN WATER SERVICES OF TOMORROW

WaterMet^2 Model Functional Requirements

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Abstract

This report specifies the functional requirements of the WaterMet^2 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). The report is not a project deliverable but rather a work-in-progress to describe different aspects of the model and its functionality.

This report addresses two main parts of the WaterMet^2 Model functionality. The first part illustrates principal concepts of WaterMet^2 modelling as a mass balance base model. Two main aspects of water modelling (i.e. quantity and quality modelling approaches) are described and analysed first. Modelling of the intended risk analysis as one of the purpose of TRUST project is demonstrated. Then, the spatial and temporal scales of the model are better described as well as a brief description of intervention modelling.

Second part of the report presents the specific indicators of the WaterMet^2 model in three parts: (1) performance indicators linked to all water related flows in the UWS; (2) risk indicators based on the current data received from WA32; and (3) cost indicators including capital and operational ones. For all introduced indicators, the relevant input data requirements are presented. Finally, the model calibration approach is briefly described.

This document is based on the authors' current best understanding of the UWS metabolism concept and the associated performance related issues. Therefore, as WaterMet^2 model progresses in more details, information presented in this report is likely to evolve and improve.

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1 Introduction

The main task of WP33 is to develop a metabolism-based model for assessing the performance of an urban water system (UWS). This model is named the WaterMet^2 model (where 'Met' stands for both metabolism and metropolitan hence '^{2}'). The WaterMet^2 will be demonstrated , tested and verified on the city of Oslo in WP34. The input required for the development of the WaterMet^2 model is provided by WP31 (UWS performance framework) and WP32 (risk modelling).

The objective of this report is to specify the functional requirements for the development of the WaterMet^2 model in terms of envisaged output functionality. It should be noted that this report is not a project deliverable. Instead, it is work-in-progress report in which different modelling aspects and its functionality may change as the modelling progresses in more details during next steps. The report is based on the recommendations made in the Scoping Report (NTNU) and the relevant risk related input provided by SINTEF.

The rest of this report will address and describe the following key elements: (1) an overview of the WaterMet^2 modelling concept; (2) specification of key model outputs in terms of UWS performance, costs and risks; (3) an overview of input data requirements; (4) an outline of the model calibration approach. The key messages are then summarised in the last section of this report.

2 WaterMet^2 Modelling Approach

2.1 General

The WaterMet^2 model will be developed as a simulation type, mass balance based model which will quantify the metabolism related performance of the UWS covering environmental, economic and social aspects with focus on sustainability related issues.

The model will be based on the UWOT model/software developed previously by UNEXE/NTUA and will simulate the water cycle in a UWS by using a number of different type system components. These components will be integrated into a UWS configuration by principal water and wastewater flow links provided by the user.

The WaterMet^2 will quantify the principal water flows in the UWS. These flows will then be used to quantify all other system fluxes (e.g. energy, chemicals, etc.). All this, in turn, will enable quantifying a number of different operational and mainetance costs.

The UWS performance will be represented by a selected number of key water quantity and quality performance indicators, cost indicators and risk indicators. These indictors will be evaluated by running the WaterMet^2 simulation model for a user specified system configuration (key system elements and their characteristics/links), system load (demand, rainfall) and associated initial/boundary conditions.

The WaterMet^2 model will be developed as a dynamic model that will enable evaluating the present and future performance of the system at different spatial and temporal scales.

2.2 UWS Representation and Principal Flows

Based on the definition of the UWS in the scoping report provided by the NTNU, the WaterMet^2 model will simulate the UWS using five integrated subsystems shown in Figure 1 as: (1) water supply subsystem; (2) water demand subsystem; (3) wastewater subsystem; (4) cyclic water recovery subsystem; (5) resource recovery subsystem. The WaterMet^2 model will allow the user to define the main components of each subsystem and the principal mass balance water related flows, which are illustrated in more details in Figure 2.

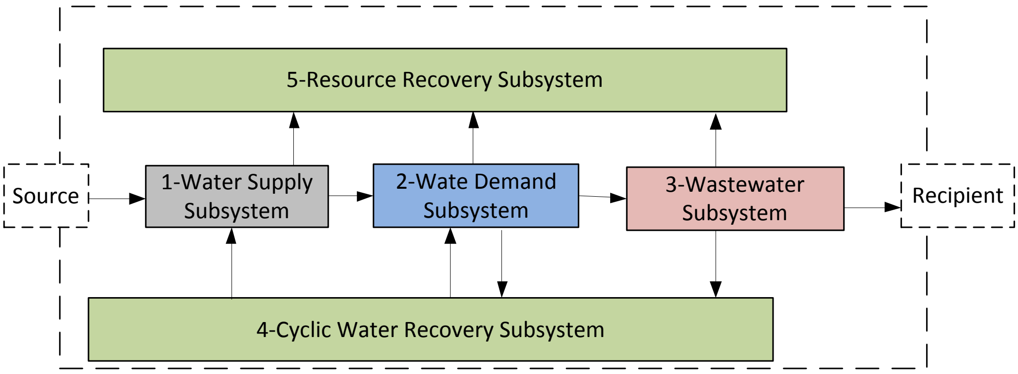

Figure 1: UWS subsystems modelled by the WaterMet^2 model

The main components of the water supply subsystem are pumping stations for raw water intake and clean water transmission, water treatment plants, clean water storages (e.g. tank/reservoir) and water distribution systems. The water demand subsystem will include all urban water consumers defined at various scales. Conventionally, water demand subsystem is connected to wastewater subsystem which contains wastewater/storm water collection and transport systems and wastewater treatment plants. Finally, the main components of cyclic water recovery subsystem are decentralised on-site storm water and wastewater treatment facilities as well as groundwater, This integrated subsystems, in turn, will enable modeling not only conventional systems but also more advanced ones involving water recycle/reuse schemes.

The water flows between UWS subsystems shown in Figure 2 include raw water, potable/clean water, wastewater and reused/recycled water. Particularly, the raw water is externally provided from water sources and will be delivered to WTPs through raw water pumping stations. The clean water flow provided from the WTPs will be distributed to the urban water demands. The reused/recycled water provided by decentralized on-site treatment facilities will be consumed in the water demand subsystem by various consumers. The reused/recycled water can also be provided by the centralized treatment system (i.e. WWTPs) at the system scale. The centralized recycled water can also be returned into the WTPs and/or consumed in the water demand subsystem. Finally, wastewater and storm water flows is collected through wastewater transport network to be delivered to the WWTPs for final treatment and reused /recharged/discharged by the sources/recipient(s).

The spatial limit of the UWS is defined as the administrative limits of an urban water utility. The actual spatial resolution, i.e. level of detail modelled, ranges from a single property to a whole city. The WaterMet^2 Model will represent the UWS at three spatial scales representing the whole urban water system shown in Figure 3: (1) land block; (2) region and (3) city/system. A brief description of the configuration for each spatial scale which needs to be defined by user as a system configuration is as follows:

- The smallest spatial scale is a land block which is composed of two different types of domestic and non-domestic properties. This classification is due to the different types of water related consumptions assigned for each type of land block. Each land block regardless of being domestic or non-domestic contains a building (indoor water consumption) and a private open space (outdoor water consumption). The building will be represented by various water usage technologies and fittings, which is defined as intervention options. The private open space is composed of pervious and impervious areas. The non-domestic properties can represent any commercial, industrial and institutional lands managed publicly or privately.
- The region is composed of a number of aggregated land blocks in addition to roads and public open spaces. Different number of the land blocks with identical intervention options can be defined in a region.
- The city scale enables aggregation of a number of different regions at the system level.

The WaterMet^2 Model will allow the user to specify the number of components when dealing with each spatial scale. For instance, at the largest scale (city/system), the number of regions will be defined by the user and at the next smaller scale, when defining each region scale, the user will specify the number of each identical item (e.g. identical domestic land blocks, identical non-domestic land blocks, roads and public open spaces).

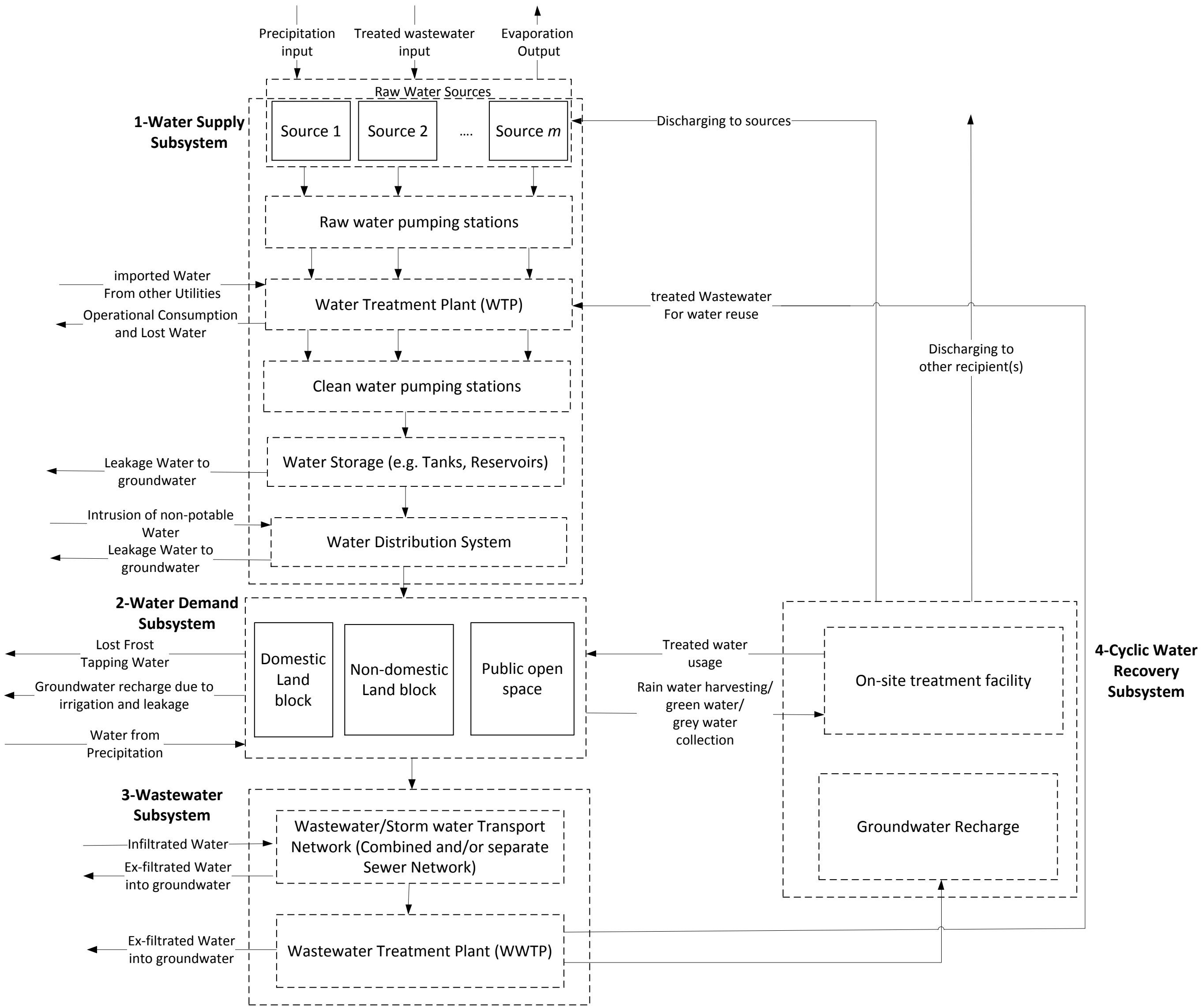

Figure 2: Principal water flows in the UWS

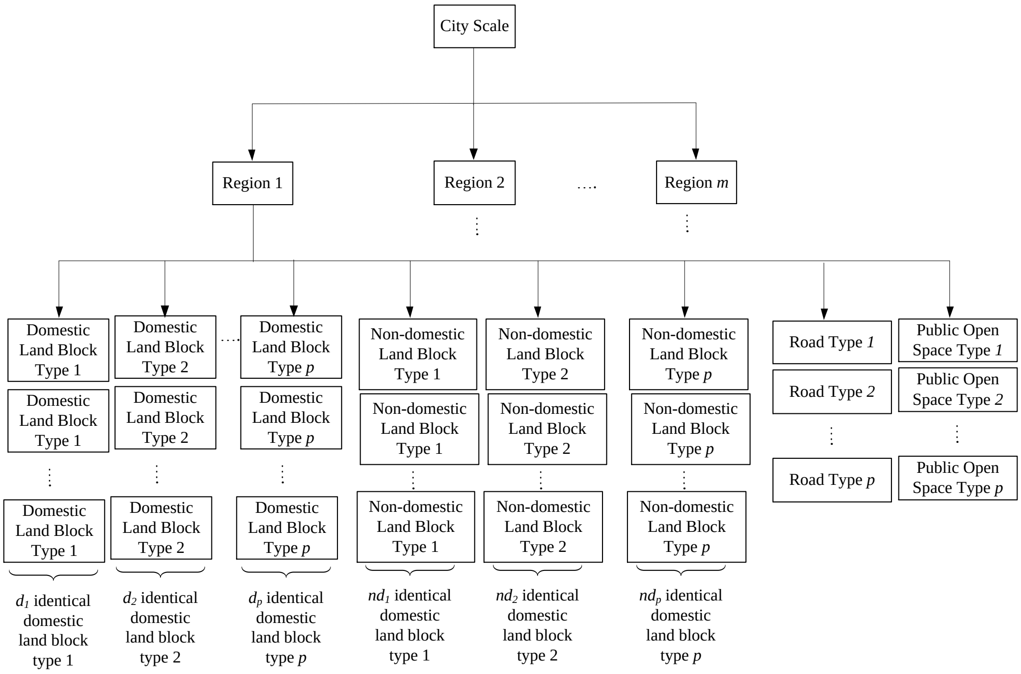

Figure3: Spatial scale of the WaterMet² model

As the metabolism WaterMet² model aims to support strategic planning level, a daily time step is selected as the default temporal scale. The WaterMet² model will use the daily time step to simulate the UWS performance for a period of N years. This is a user specified value and a minimum of one year is envisaged to take into account any seasonal variations. Although daily time step will be used for model computations, diurnal flow variation can be applied for comparison purposes among different water management options.

2.3 Water Supply Subsystem

The water supply subsystem will enable modelling supply from multiple (user-defined) external raw water sources including both surface (reservoirs, rivers, lakes, etc.) and groundwater sources. The raw water from these sources will be conveyed to and treated at respective WTPs. The daily water mass balancing is assumed between raw water sources and WTPs. The amount of water supplied will be calculated based on the aggregation amount for all urban water demands plus all water losses minus the supply from any centralised/decentralised wastewater and storm water treatment/storage strategies.

Once treated at WTPs, the potable/clean water is delivered into the water distribution system. This water is first distributed amongst different geographical regions modelled (as specified by the user/modeller). Water within each region is further subdivided into a number of smaller land blocks. It is assumed that a percentage of clean water is lost/

leaked through water distribution networks as well as a percentage of imported non-potable water to the water distribution networks.

2.4 Wastewater Subsystem

The WaterMet^2 model will take into account both separate and combined sewer systems in the UWS as shown in Figure 3 of the scoping report provided by NTNU. A user defined percentage of the clean/green/grey water consumed by costumers, if not treated by any on-site treatment facility, will be transformed and delivered to the wastewater transport network. The storm water runoff generated from rainfall events minus the water losses due to evaporation and groundwater infiltration will be collected by storm/sewer network systems. Water infiltrated/exfiltrated into/from wastewater/storm sewer systems will be modelled as user input. In order to estimate the overflow from combined/storm sewer systems, a daily conveyance capacity for the sewer system will be specified by the user. Any daily mass balance volume of collected wastewater/storm water above the daily capacity of the relevant sewer systems will be overflowed through CSO and STO structures and will not be delivered to the WWTPs.

For specifying wastewater and storm collection systems, the WaterMet^2 model will allow the user to define wastewater and storm interconnection pathways among different land blocks and roads and public open spaces in various regions. Similarly, these interconnection pathways will need to be defined by the user among different regions in the pilot city.

Precipitation as either rainfall or snow will be represented as daily time series of average precipitation in millimetres during the planning horizon (all user/model input). In addition, daily time series of average temperature for the same time horizon will be required to estimate snow melting and evaporation. In addition, soil characteristics need to be specified by the user to take into account the amount of water infiltrated into the groundwater. The rest of rainwater/melted snow neither evaporated nor infiltrated will contribute toward the urban surface runoff (see Figure 4).

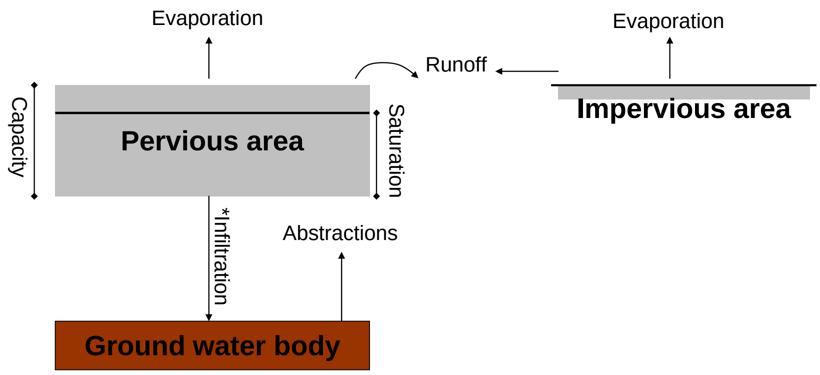

Figure 3: Modelling of pervious and impervious areas in the WaterMet^2 model

2.5 Water Demand Subsystem

The water demands will be classified in two main categories of consumption: (1) domestic consumption and (2) non-domestic consumption. The domestic consumptions includes both indoor and outdoor water usage (private garden irrigation). Indoor water usage is based on a number of different consumption points, i.e. fittings and appliances: hand basin, bath, shower, kitchen sink, toilet, washing machine, dish washer, etc. The non-domestic consumption will be further split into industrial, commercial (e.g. offices) and public (e.g. hospitals, schools, etc.).

The above demands can be supplied from one of the following sources: (1) potable water from water mains; (2) green water supplied from rainwater harvesting containers; and (3) centralised/decentralised (treated) grey water from water treatment facility and/or WWTPs. If more than one water source is available, the water demand will be satisfied by giving priority to localised resources (e.g. for a water demand required at land block scale, land block water source is preferred to the one at the regional scale). In addition, water demands of low quality requirements (e.g. toilet and garden irrigation) are assumed to use water treated to a lower standard. Other priorities in terms of using different water sources for different purposes will be based on user provided preferences.

2.6 Modelling of Other Flows

The WaterMet^2 model will calculate the energy consumed in the following components of the UWS: (1) pumping of raw water from water sources to WTPs and clean water from WTPs to demand points; (2) energy consumptions by water consumers at land block scale including domestic and non-domestic buildings and (3) the treatment processes in WTPs, WWTPs and decentralized treatment systems such as on-site wastewater recovery facilities. The energy consumption will be evaluated from corresponding water flows (m^3/s) and unit energy consumptions (KWh/m^3). The default type of energy consumed is the electricity supplied from the power grid. The model will also take into account any fossil fuel (or equivalent electrical) material consumed to generate power to compensate for power supply interruptions in the UWS. In addition, any energy obtained from methane recovery and heat generated within the treatment plants (by utilising the biogas) is calculated.

The WaterMet^2 model will calculate greenhouse gas (GHG) emissions wherever the energy is consumed in the UWS in two different ways: (1) direct emissions to the atmosphere resulted from full combustion of fossil fuels; (2) indirect emissions to the atmosphere resulted from electricity consumption. The WaterMet^2 model will not quantify the GHG emissions arising from carbon embodied in various materials and assets.

Furthermore, the consumption of chemicals required for water/wastewater treatment processes will be quantified from principal water flows (m^3/s) and relevant unit rates (e.g. t/m^3 of water/wastewater treated).

The UWS asset failure will be modelled using simplified asset deterioration models based on regression curves/equations which link failure rate to one or several key pipe attributes (e.g. materials, age, and diameter). The number of asset failures and related costs will be estimated at the system level only.

2.7 Water Quality Modelling Approach

A mass balance based approach is used to quantify water quality modelling in the WaterMet^2 model. Water quality related flows such as contaminant loads track water flows in each subsystem in the UWS. For example, the WaterMet^2 model allows tracking daily average concentrations of substances from raw water resources in water supply subsystem to different parts of water demand subsystem, and finally at receiving water. The WaterMet^2 model will also allow modelling of limited number of water quality parameters (e.g. BOD, TSS, Tot-P, Tot-N) with the aim to characterize and quantify the fluxes of pollutant loads.

The following assumption is taken into account for water quality modelling approach in WaterMet^2 model:

- The water quality modelling will be based on the source-sink concept assuming a dominant advection transport process. The model will not model any dispersion, diffusion or any other processes. No decay or growth is also assumed for different contaminant modelled in the system. It is assumed that the concentration of contaminant loads change at specific point of generation or treatment points.

- Instantaneous and complete mixing in UWS tanks and reservoirs is assumed to always occur. When combining multiple input water inflows at a junction (e.g. mixing wastewaters from home consumptions such as toilet and bathroom), the mixed concentration of a substance for the outflow is calculated based on the flow-weighted average of the concentrations of that pollutant for the water inflows. It is assumed that there is no generation of destruction of any mass or concentration in the mixed flow.

- The WaterMet^2 model will assume that contaminant load will only be generated/increased or removed/ decreased at specific points in each UWS subsystem. These fluxes are defined for contaminant production points (e.g. home appliances generating wastewater and surface runoff from rainfall generating contaminant load) and some others for pollutant removal (e.g. on-site wastewater treatment facility, WTP, WWTP).

- The WaterMet^2 model will allow tracking the water quality parameters of discrete parcels of water as they are conveyed between components and mix together at junctions as daily time steps.

- Flows of substances travelling with water (e.g. pollutants, treatment chemicals, etc.) will be estimated using the average concentrations/ unit consumption rates and aforementioned water flows.

- The user needs to specify the concentration of contaminant loads once they are entered from external water sources as input data and the WaterMet^2 model will calculate the contaminant loads of output flows based on the above assumptions for specific components as key performance indicators.

2.8 Risk Modelling Approach

As mentioned earlier, the WaterMet^2 model is a deterministic, simulation type model of the UWS. To evaluate most of the suggested risks (Appendix B) which require doing some sampling and multiple runs of the deterministic model, the WaterMet^2 model needs to be developed internally to support risk assessment and the actual risk assessment is performed outside the WaterMet^2 model in a separate module in the DSS.

The WaterMet^2 model employs direct, approximate and indirect methods to estimate risks. The risks that can be estimated directly are those linked with the principal flows simulated by WaterMet^2 model. These are the following:

- The risks related to availability of resources, which is influenced either by climatic factors, like the rainfall, or by social factors like average per capita consumption.

- The risks related to exceedance of capacities of the UWS components. This includes both transmission (aqueducts, sewerage) and treatment (WTP and WWTP).

- The risks related to reduction of aquifer recharges or increase of storm water volume due to increased imperviousness of urban catchments.

The approximate methods are based on post-processing of the WaterMet^2 model results to estimate a risk. This category includes the following risks:

- The risk of flooding. Flooding of urban areas is simulated using simple models, like "flooding cones", based on the overflowing volume calculated by WaterMet^2.

- The risk of high velocity runoff. The velocity of runoff in public streets is estimated using simple models based on the overflowing volume calculated by WaterMet^2.

The indirect methods estimate a risk from a quantity that is simulated by WaterMet^2 and is related to the risk. The following risks are evaluated indirectly:

- The risk of low quality water at the tap. Quality of the supplied water is estimated based on two assumptions. The first is that the quality of the supplied water decreases with the age of the distribution network. The second assumption is that the reduction of the water resources availability decreases the water quality.

- The risk of profit reduction due to the need to replace and upgrade the aged parts of the water system. The increased maintenance frequency is estimated based on the assumption that the older the network components the less reliable are and thus the more maintenance is needed.

- The risk of prolonged periods without supply is estimated based on the assumption that the less reliable the components of a network are the more the probability of a critical component to fail.

- The risk of low pressure for extended periods is estimated in a similar manner with the previous.

- The risk of injuries due to infrastructure collapse or burst is estimated in a similar manner with the previous.

2.9 Intervention Modelling

WaterMet^2 model will be used by the Decision Support System (DSS) developed in WP54 to quantify the impact of different interventions/technologies (developed in WA4) on the UWS performance, including associated risks and costs). Given a set of interventions defined over some planning horizon (iin terms of type, size/quantity, timing, etc.), the relevant WaterMet^2 input variables will be modified and the asscoaietd model outputs will then be used to quantify the impact of this set of interventions on the UWS performance.

3 WaterMet^2 Functional Requirements Specifications

3.1 Performance Indicators

The UWS performance will be evaluated by calculating a range of performance indicators. The emphasis here is on a relatively *small* number of *key* performance indicators (KPI). These KPIs are classified with respect to different subsystems in the UWS shown in Figure 1. The WaterMet^2 model will calculate a range of primary indicators which can then be aggregated both spatially (e.g. element/subsystem/system level) and/or temporally (e.g. monthly or annual values obtained from aggregation of daily values simulated by the model).

The following KPI categories are introduced that will be used by the WaterMet^2 model *to quantify* urban water cycle flows/operational characteristics:

1. Water balance components
2. Energy consumption
3. Water quality
4. Asset failure rates
5. Chemical consumption
6. Sludge
7. GHG emissions
8. Flooding

For each of the above categories, the currently envisaged specific KPIs that will be quantified by the WaterMet^2 model are listed in Appendix A. Note that the KPIs demonstrates all types of water related flows (i.e. water, energy and water quality flow) linked to clean/harvested/treated water in each subsystem.

3.2 Cost Indictors

The WaterMet^2 model will take into account both capital and operational costs for all the UWS components and intervention options modelled. Annual capital and operational costs will be provided for all current and future components of the UWS. The annual costs of components are also estimated with respect to their lifetime and the interest rate. Finally, the cost is represented in terms of total, capital, operational for each subsystem and the whole system as any required format (e.g. at present value, specific time or annually or at the time they are applied). A description of envisaged cost indicators can be found in Appendix C.

3.2.1 Capital costs

The capital cost related to different capital works which will be calculated in the WaterMet^2 model is listed in Table 10 of Appendix C. In this Table, all the capital costs related to all components of the UWS during the time horizon of strategic horizon are taken into account as an annual capital cost. In this Table, the capital works and associated works related to water supply subsystem are: 1-borehole/well; 2-pump stations; 3-tank/reservoir; 4-pipe/ fittings/ valves; 5-WTP components. The capital works related to water demand subsystem are only various types of appliances and fittings used for different land blocks. In the wastewater subsystem any capital cost related to pipes/fittings and WWTP components will take into account. Finally, capital works related to decentralized water recovery facilities in the cyclic water recovery subsystem will also take into account in the WaterMet^2 model.

3.2.2 Operational and maintenance costs

The operational and maintenance costs associated with each component of the UWS are listed in Table 11 of Appendix C. Similarly, the associated costs are presented for all subsystems. In this Table, the operational costs of water supply subsystem are divided into 1-the operational costs related to the maintenance of pumps, tank/reservoirs, Pipe/fittings/valves, WTP components; 2-energy consumption costs associated to the operation of pumps and WTP components; 3- chemical costs used in WTPs. In addition, the operational costs of water demand subsystem are related only to the costs of maintenance and energy consumption for all the appliances and fittings applied. Furthermore, the operational costs of wastewater subsystem are: (1) the maintenance cost of wastewater pipe/fittings; (2) the maintenance costs of WWTP components; (3) the energy costs consumed in WWTPs; (3) the chemicals cost used in WWTPs. The operational costs of cyclic water recovery subsystem are: (1) the maintenance costs of decentralized water recovery facilities; (2) the energy costs consumed in decentralized water recovery facilities; (4) the chemicals cost used in decentralized water recovery facilities.

3.3 Risk Indicators

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 WaterMet^2 model is provided in Appendix B. The methodology for the evaluation of all risks mentioned there will be provided by WP32. Also, Note that quantifying some risks will require repetitive WaterMet2 model runs in a batch type procedure. The necessary care will be taken to make sure that the estimations of different risks are computationally feasible.

3.4 Input Data Requirements

Input data required for various WaterMet^2 components are described in the following with respect to the three aspects of overall system quality (performance, cost, risk). In addition, the values of some input data are directly determined by the user before simulating the WaterMet^2 model. However, some other input data are available in the pre-specified library of the model which needs to be specified by the user.

Input data required for key performance indicators are given in an individual column of the relevant tables given in Appendix A. Note that the input data provided in each row is directly required for the calculation of the KPI in the same row however some other indirect input data may be required which are provided from other parts of the model.

Input date requirements for risk analysis will be provided by WP32. The current input data required for all aspects of risk analysis agreed with WP32 is provided in an individual column of Table 10 in Appendix B. Note that some missing input data requirements in the relevant Table will be provided by WP32 in the near future.

The input data required to calculate cost in the WaterMet^2 model are given in Appendix C in an individual column for each item relating to capital and operational costs. For the capital cost items, the time of investment, lifetime and the current value of each component of the UWS are required to calculate the annual costs. In addition, the interest/inflation rate needs to be defined at different strategic time horizon.

4 WaterMet^2 Model Calibration

The WaterMet^2 model has to be calibrated before it can be used to model the UWS of a specific city/system. This is true for any simulation model, especially the model which is based on simplified, mass balance approach. Therefore, an integral part of the WaterMet^2 model development will be to identify (1) the variables in the model that should act as likely calibration parameters; and (2) model outputs that are likely to be observed, i.e. used to drive the calibration process.

The WaterMet^2 model calibration procedure will be based on a manual, trial-and-error approach where the user will select the calibration parameters to calibrate, assume their values and then run the WaterMet^2 model to see how well the model predicitons match the observations available. The above process will be repeated until a satisfactory agreement between model predictions and related observations has been reached.

Model calibration can be performed at different temporal scales including monthly and yearly as well as different special scales including regional and city scale.

5 Summary

The WaterMet^2 model will be developed as a deterministic, quantitative, simulation type, model based on mass conservation of water in the UWS of a generic city. The model will provide quantitative analysis for the following principal flows:

- Water flows: The WaterMet^2 model simulates the “standard” urban water flows (potable water, wastewater and runoff) as well as their integration through recycling schemes at various application scales.
- Energy flows: The WaterMet^2 model will calculate the energy consumed during the operation of the urban water cycle and the cost required for the normal operation of the urban water cycle components.
- Water quality related flows: Flows of substances travelling with water (e.g. pollutants, treatment chemicals, etc.) will be estimated using the average concentrations/ unit consumption rates and aforementioned water flows.

Most of risk indicators will be calculated outside of the WaterMet^2 model by running this model in a batch type procedure. Other risks related to the operation of the urban water cycle will be estimated by using approximate methods (e.g. flooding of urban areas estimated using 'flooding cones').

The WaterMet^2 model will also allow modelling of limited number of water quality parameters with the aim to characterize and quantify the fluxes of pollutant loads. The water quality modelling will be based on the source-sink concept assuming dominant advection transport process and instantaneous and complete mixing in UWS tanks, reservoirs and junctions.

The WaterMet^2 model uses time series to describe social and environmental boundary conditions (e.g. rainfall time series, population time series). This allows to access the performance of a UWS for the past, present and future (using both historic and synthetic time series), which, in turn, will lead toward better understanding of critical sustainability issues (and related variables) in the UWS and, eventually, better future (re)development strategies.

Finally, note that all the information provided in this report is based on the authors' current best understanding of the UWS metabolism concept and the associated performance related issues. As such, the information presented in this report is likely to evolve as the authors' develop the WaterMet^2 model and improve their understanding of the UWS metabolism concept.

6 Appendix A: Performance Indicators

*Table 1: Specific KPIs of **Water Balance Components** quantified by the WaterMet^2 model*

Subsystem no	Subsystem	KPI	Unit	Input Data	Description
1	Water Supply	Water abstraction/ intake	Cubic meters per capita, source, subsystem, per day, month, year	daily water withdrawal capacity from each source, groundwater specification	Water taken up by WTPs from raw water sources
1	Water Supply	Raw water consumption and losses	Cubic meters per capita, subsystem, per day, month, year	daily average water loss	Water consumed internally plus volume of water lost within WTPs or not supplied to the pipeline network
1	Water Supply	Treated/potable water supplied	Cubic meters per capita, subsystem, per day, month, year	daily water capacity for each WTP and water main	Water delivered to the pipeline network by WTPs
1	Water Supply	Treated/potable water imported/ exported	Cubic meters per capita, subsystem, per day, month, year	daily water imported/exported for each water main	Treated water imported or exported downstream WTPs before costumer delivery
1	Water Supply	Treated/potable water lost/leaked	Cubic meters per capita, per day, month, year	daily average water loss	Treated water lost/leaked through water distribution system and no delivered to consumers as a percentage of clean water
1	Water Supply	Treated/potable water supplied/ distributed	Litres per capita, per day, month, year	daily water capacity for each water main	Treated water delivered to consumers by WDS

Subsystem no	Subsystem	KPI	Unit	Input Data	Description
2	Water Demand	Treated/potable water used by domestic appliances	Litres per capita, household, per day, month, year	occupancy of each land type, water demand of each component, frequency of usage	Treated/potable water used by each household appliances including washing machine, dish washer, hand basin, bath, shower, kettle, kitchen sink, toilet, garden watering
2 & 4	Water Demand & Cyclic Water Recovery	Harvesting/green water used by domestic appliances	Litres per capita, household, per day, month, year	rain water harvesting area for each land type, preference of usage	Harvesting/green water used by each household appliances including hand basin, bath, shower, toilet, garden watering
2 & 4	Water Demand & Cyclic Water Recovery	Grey water used by domestic appliances	Litres per capita, household, per day, month, year	grey water generated from each appliance type, preference of usage	Grey water used by each household appliances including toilet and garden watering
2	Water Demand	Treated/potable water used by nondomestic building	Litres per capita, non-domestic, per day, month, year	occupancy of each land type, water demand of each appliance, frequency of usage	Treated/potable water used by non-domestic building (Industrial & commercial) including industrial, public, private building
2 & 4	Water Demand & Cyclic Water Recovery	Harvesting/green water used by nondomestic building	Litres per capita, building, per day, month, year	rain water harvesting area for each land type, preference of usage	Harvesting/green water used by each nondomestic building (Industrial & commercial) appliances including hand basin, bath, shower, toilet, garden watering

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Subsystem no	Subsystem	KPI	Unit	Input Data	Description
2 & 4	Water Demand & Cyclic Water Recovery	Grey water used by nondomestic building	Litres per capita, building, per day, month, year	grey water generated from each appliance type, preference of usage	Grey water used by each nondomestic building (Industrial & commercial) including toilet and garden watering
2	Water Demand	Treated/potable water used by other usages	Litres per capita, land use, per day, month, year	water demand of each component, frequency of usage	Treated/potable water used by public services including fire fighting, green area watering, agriculture
2 & 4	Water Demand & Cyclic Water Recovery	Harvesting/green water used by other usages	Litres per capita, land use, per day, month, year	rain water harvesting area for each land type, water demand, preference of usage	Treated/potable water used by public services including fire fighting, green area watering, agriculture
2 & 4	Water Demand & Cyclic Water Recovery	Rain harvesting obtained from public area	Litres per land use, per day, month, year	rain water harvesting area for each land type, connection of public areas	Rain harvesting obtained from public area used for public area watering
3	Wastewater	Storm water runoff	Cubic meters per area, per day, month, year	pervious and impervious partitioning of areas	Storm water runoff obtained from rainfall, evaporation and infiltration
3	Wastewater	infiltration/exfiltration	Cubic meters per pipe meter, per day, month, year	a percentage of wastewater/storm water as infiltration/exfiltration	Water infiltration/exfiltration into/from wastewater transportation system
3	Wastewater	wastewater discharge	Cubic meters per capita, per day, month, year	wastewater generated from each appliance type, frequency of usage	Wastewater collection from consumer base into the wastewater transport network

Subsystem no	Subsystem	KPI	Unit	Input Data	Description
3	Wastewater	Combined Sewer Overflow (CSO)/Storm Overflow (STO)	Cubic meters per capita, per day, month, year	sewer system capacity, CSO/STO capacity	Untreated sewer/storm overflow from combined/separate sewer transport system into receiving water
3	Wastewater	Wastewater delivered	Cubic meters per capita, per day, month, year	daily capacity for each WWTP	Wastewater delivered to WWTP from wastewater transport system
3	Wastewater	Treated wastewater re-circulated	Cubic meters per capita, per day, month, year	treated wastewater assignment for each WWTP	Treated wastewater re-circulated from WWTP to WTP for possible further treatment and reuse
3	Wastewater	Wastewater treated	Cubic meters per capita, per day, month, year	treated wastewater assignment for each WWTP	Wastewater treated and discharged by WWTP to groundwater
3	Wastewater	Overflow wastewater of WWTP	Cubic meters per capita, per day, month, year	daily capacity for each WWTP	Overflow untreated wastewater from WWTP into groundwater

*Table 2: Specific KPIs of **energy consumed** quantified by the WaterMet[2] model*

Subsystem no	Subsystem	KPI	Unit	Input Data	Description
1	Water Supply	Pump energy consumption	MWh per resource, per cubic meters supplied, per day, month, year	pump energy required for each cubic meter	Total energy consumed for pumping water during water supply subsystem
1	Water Supply	Energy consumption in WTP	MWh per WTP, per cubic meters supplied, per day, month, year	water treatment energy required for each cubic meter	
1	Water Supply	Fossil fuel energy consumption	Litre (MWh) per resource, subsystem, per cubic meter supplied, per day, month, year	energy required for each power generator, frequency of power outage	Fossil fuel (or equivalent electrical) material e.g. natural gas, heating oil consumed to generate power to compensate for power supply interruptions in water supply (e.g. water pumping, WTP)
2	Water Demand	Energy consumption by appliances	MWh per household, subsystem, per cubic meter supplied, per day, month, year	energy required for each appliance	Electrical energy consumed by each of domestic and non-domestic consumptions
3 & 5	Wastewater and resource recovery	Energy consumption in WWTP	MWh per resource, subsystem, per cubic meter supplied, per day, month, year	wastewater treatment energy required for each cubic meter	Electricity drawn in from the grid and methane recovery

Subsystem no	Subsystem	KPI	Unit	Input Data	Description
4	Cyclic Water Recovery	Energy consumption in appliances and fittings	MWh per resource, subsystem, per cubic meter supplied, per day, month, year	energy required for each facility	Electricity drawn in from the grid for cyclic water recovery facilities such as land/regional grey water treatment
4	Cyclic Water Recovery	Fossil fuel energy consumption	Litre (MWh) per resource, subsystem, per cubic meter supplied, per day, month, year	energy required for each power generator, frequency of power outage	Fossil fuel (or equivalent electrical) materials e.g. natural gas, heating oil consumed within the WWTPs
5	Resource Recovery	Heat and electricity generated in WWTP	MWh per resource, subsystem, per day, month, year	biogas generated for each cubic meter of treated wastewater, heated generated from each cubic meter of biogas	Heat and electricity generated within the wastewater treatment plant by utilising the biogas, anaerobic digestion, turbine-generator

*Table 3: Specific KPIs of **water quality** quantified by the WaterMet^2 model*

Subsystem no	Subsystem	KPI	Unit	Input Data	Description
1	Water Supply	water quality	abstract characterisation (excellent, good, acceptable)	Parameters for supplied water quality estimation, water quality of raw water, clean water after WTP	The quality of the supplied water is indirectly estimated based on two factors: (a) the age of the distribution system and (b) the water storage inside reservoirs (the lower the worse the quality).
2	Water Demand	pollutant load generated by wastewater (e.g. TSS, BOD, Tot-P, Tot-N)	Mg/ litre, kg/day, month, year	Water quality of clean/ green/ (treated) grey water	The wastewater produced by each household appliance is characterized by a quality index. The overall quality is obtained by mixing the qualities of the individual flows.
3	Wastewater	pollutant load by CSO/STO	Mg/ litre, kg/day, month, year	Water quality of wastewater, storm water	Wastewater and runoff are mixed in case of combined sewer. Overflows (in case of capacity exceedance) are characterised by the quality index.
3	Wastewater	pollutant load for the output of WWTP and on-site treatment facilities	Mg/ litre, kg/day, month, year	Water quality of treated wastewater, pollutant removal in WWTP and treatment facilities	The quality of wastewater is improved after the treatment according to the characteristics of each treatment plant (registered in the technology library).

Table 4: Specific KPIs of ***asset failure rates*** *quantified by the WaterMet² model*

Subsystem no	Subsystem	KPI	Unit	Input Data	Description
1	Water Supply	pipe bursts	frequency, duration per km, per month, year	Pipe characteristics (e.g. material, diameter, age), parameters for asset failure modelling	Pipe burst estimated from basic asset properties (e.g. pipe material, diameter, age, etc.) by using regression type asset deterioration models
3	Wastewater	sewer collapses/blockages	frequency, duration per km, per month, year	sewer pipe characteristics (e.g. material, diameter, age), parameters for asset failure modelling	sewer collapses/blockages estimated from basic asset properties (e.g. pipe material, diameter, age, etc.) by using regression type asset deterioration models

*Table 5: Specific KPIs of **chemical consumption** quantified by the WaterMet² model*

Subsystem no	Subsystem	KPI	Unit	Input Data	Description
1	Water Supply	Chemicals in WTP	Tons per cubic meter of water treated, per day, month, year	Chemicals required per unit of treated water	The required chemicals (masses of chemicals consumed for coagulation-flocculation in WTP e.g. Alum, Calcium hydroxide, Carbon dioxide, Microsand, Polyaluminium chloride, Polymer) are estimated based on the water demand at the WTP output.
1	Water Supply	disinfectants in WTP	Tons per cubic meter of water treated, per day, month, year	disinfectants required per unit of treated water	The required disinfectants (masses of disinfectants consumed in WTP e.g. different types of chlorine) are estimated based on the water demand at the WTP output.
1	Water Supply	disinfectants in WDS	Tons per cubic meter of water treated, per day, month, year	disinfectants required per unit of treated water	The required disinfectants (masses of disinfectants consumed within WDS e.g. different types of chlorine) are estimated based on the demand at the WTP output
3	Wastewater	Chemicals in WWTP, on-site treatment facilities	Tons per cubic meter of water treated, per day, month, year	Chemicals required per unit of treated water	The required chemicals are estimated based on the volume of treated wastewater.

Table 6: Specific KPIs of ***sludge*** *quantified by the WaterMet² model*

Subsystem no	Subsystem	KPI	Unit	Input Data	Description
1	Water Supply	Sludge in WTP	Tons per resource, per day, month, year	Mass of sludge per unit of treated water	Mass of sludge generated during the procedure (sedimentation screening and filtration units) is estimated based on the water demand at the WTP output.
5	Resource Recovery	Sludge handling in WWTP	Tons per resource, per day, month, year	Mass of sludge per unit of treated wastewater	Mass of digested, dewatered and dried sludge to end-uses (e.g. fertiliser substitute) is estimated based on the volume of treated wastewater.
5	Resource Recovery	Ammonium nitrate recovery	Tons per resource, per day, month, year	Mass of ammonium nitrate recovered per unit of treated wastewater	ammonium nitrate recovery in WWTPs for use as fertiliser substitute

Table 7: Specific KPIs of ***GHG emission*** *quantified by the WaterMet^2 model*

Subsystem no	Subsystem	KPI	Unit	Input Data	Description
1	Water Supply	Direct GHG emission	tones of CO2-equivalent (or) tones of individual emissions per element, subsystem, per day, month, year	GHG emissions resulted from full combustion of each fuel type	GHG emissions resulted directly from fuel consumption in water pumping and WTP to the atmosphere
1	Water Supply	Indirect GHG emissions	tones of CO2/SO2-equivalent (or) tones of individual emissions per element, subsystem, per day, month, year	GHG emissions resulted indirectly from each KWh of generated electricity consumption	GHG emissions resulted indirectly from electricity consumption in water pumping and WTP to the atmosphere

Subsystem no	Subsystem	KPI	Unit	Input Data	Description
2 & 4	Water Demand & Cyclic Water Recovery	Indirect GHG emissions in WDS	tones of CO2-equivalent (or) tones of individual emissions per element, subsystem, per day, month, year	GHG emissions resulted indirectly from each KWh of generated electricity consumption	GHG emissions resulted indirectly from electricity consumption for appliances and cyclic water recovered at land/regional scale
3	Wastewater	Direct GHG emission	tones of CO_2/SO_2/hydrogen sulphide-equivalent (or) tones of individual emissions per element, subsystem, per day, month, year	GHG emissions resulted from full combustion of each fuel type	GHG emissions resulted directly from fuel consumption in WWTP to the atmosphere
3	Wastewater	Indirect GHG emissions	tones of CO_2/SO_2-equivalent (or) tones of individual emissions per element, subsystem, per day, month, year	GHG emissions resulted indirectly from each KWh of generated electricity consumption	GHG emissions resulted indirectly from electricity consumption in WWTP to the atmosphere

*Table 8: Specific KPIs of **flooding** quantified by the WaterMet^2 model*

Subsystem no	Subsystem	KPI	Unit	Input Data	Description
3	Wastewater	Flooding in wastewater transportation system	m^3, m^2	Capacity of sewer systems, parameters for simplified flood estimation	Overflowing volume from the wastewater transport network (flow exceeding the capacity of sewer systems) is translated to flooded area using rough assumptions and a simplistic model.

7 Appendix B: Risk Indicators

*Table 9: List of specific **risks** quantified by the WaterMet^2 model*

Risk CODE	Risk Event	General description	Hazard CODE	Hazard	WP33 Comments	Requirement for Multiple MM runs	Input Data
R1	Inability to recover investments done to meet water demand or improve the efficiency of the system.	In order to achieve better sustainability performances, investments should be done (i.e. The change of the management approach, from a public to private or mixed management). Of course, the main objective of the investors is to gain from the investments. The risk event consists in the failure of this goal.	R01HZ01	Increased costs for water supply due to reduced availability of resource.	Water balance and storage of reservoirs are fully simulated.	YES	-
			R01HZ02	Cost increase and revenue reduction due to the need to comply with NEW or additional regulatory provision.	The required cost of the interventions can be estimated provided availability of required information (capital and operational cost of intervention).	NO	-
			R01HZ03	Profit reduction due to the need to replace and upgrade the aged part of the water system.	Both the increase of operational cost due to increased maintenance frequency and the cost of replacing aged parts can be indirectly estimated from the reliability, which is simulated separately for each group of components. The relationship between age and component reliability needs to be defined.	DESIRABLE	-

Risk CODE	Risk Event	General description	Hazard CODE	Hazard	WP33 Comments	Requirement for Multiple MM runs	Input Data
			R01HZ04	Increased cost of water to meet growing water demand associated with population growth and economic development.	Time series of population are used for the estimation of the demand. If demand reaches capacity interventions are required, of which the cost can be estimated by the WaterMet^2 model	DESIRABLE	-
			R01HZ05	Rise of energy costs (i.e. cost per kWh)	The energy required for the operation of every component of the urban water cycle is recorded at every time step of the simulation. User can easily convert it to cost, if cost per kWh is available.	DESIRABLE	-
R2	Inability to reach the "green score" target given by governance at regional, national or EU level (i.e. targets given in order to comply with the Kyoto agreement).	Water systems require a lot of energy for their operation. In order to achieve greater sustainability, operators of water systems can reduce the use of energy from fossil fuel and self-produce renewable energy through more sustainable	R02HZ01	Lower renewable energy production in comparison with the expected one.	All flows of the urban water cycle are fully simulated. This allows the simulation of the amount of renewable energy produced by urban flows (e.g. microturbines).	DESIRABLE	CDF of Climate Changes effects, reference time span, Energy sources type.

Risk CODE	Risk Event	General description	Hazard CODE	Hazard	WP33 Comments	Requirement for Multiple MM runs	Input Data
		technologies. The failure of this objective constitutes a risk event.					
R3	Water bodies become incompatible with the life of plants and animals.	Failure in the adjustment of environmental protection of water bodies leading to plant and fish dead.	R03HZ01	Increase of CSO's frequency or volume increasing pollutant discharge into natural water bodies.	The operation of sewerages is simulated and the capacity exceedance gives CSO.	YES	CDF of Climate Changes effects/ increase of Population, reference time span

Risk CODE	Risk Event	General description	Hazard CODE	Hazard	WP33 Comments	Requirement for Multiple MM runs	Input Data
			R03HZ02	Increase pollutant discharge into natural water bodies due to under designed WWTP.	The water flows are characterized by a quality value related to BOD. Underdesigned WWTP will result in a part of the WW flow to bypass the TP. This will increase the BOD at the output of the WWTP (where treated WW and bypassed are mixed).	YES	WWTP failure probabilities, CDF of Climate Changes effects/ increase of Population, reference time span
R5	Ingestion of Poor water quality at the tap leading to sickness…	Low quality water at the tap produces public health problems due to ingestion.	R05HZ01	Presence of microbial pathogens in tap water; Presence of cyan toxins/chemical/SOLIDS in tap water;	Detailed contamination modelling requires specialized models. However, indirect estimation of the contamination risk can be inferred from the reliability of critical, for the water quality, components. A relationship between reliability and age of critical components should be provided.	YES	WTP performance, component failure CDF

Risk CODE	Risk Event	General description	Hazard CODE	Hazard	WP33 Comments	Requirement for Multiple MM runs	Input Data
R7	Damage due to flooding to persons and/or properties	Increase of flood frequency and intensity due to CHANGE IN IMPERVIOUNESS.	R07HZ01	Changes in the urban catchment imperviousness leading to manholes surcharge.	The simulation of the exact hydrograph would require detailed non-steady flow modelling. However, the incorporated runoff model is capable of estimating the runoff volume. To estimate surcharges, this volume can be compared with the capacity of components that transmit water to estimate overflows. Simplified methods can be used to give a rough estimation of the flooded area.	YES	CDF of the increase population at given time horizon.
		Increase of flood frequency and intensity due to changed rain paths.	R07HZ02	Changes in the rain intensity and duration lead to pipe surcharges in urban area.	See previous comment.	YES	CDF of climate change effects.
			R08HZ03	Expansion/Development of industries highly water demanding, such as frozen foods production etc.	Water demand for industrial uses is not simulated in the same detail as the demand for domestic uses. However, the model can take care of any demand type	DESIRABLE	-

Risk CODE	Risk Event	General description	Hazard CODE	Hazard	WP33 Comments	Requirement for Multiple MM runs	Input Data
					using externally provided time series.		
			R08HZ04	Higher population to serve compared to system design one producing extended periods without supply (due to a generalized insufficiency of WS infrastructures).	The population is provided as time series. See also previous answer about population growth.	DESIRABLE	CDF of the increase population at a given time horizon, current level of service (water quantity and quality and pressure).
			R08HZ05	Increase of water demand due to changes of population habits.	Every household water appliance is characterized by a value of frequency-of-use. This value can be changed to reflect changes of habits.	NO	-
			R08HZ06	Infrastructure collapses/bursts potentially causing extended periods without supply (high level of Leakage)	This can be estimated indirectly from the reliability of components. The relationships between age and reliability should be provided for each component.	YES	Construction materials and burst rates prediction models, current level of service (water quantity and quality and pressure).
			R08HZ07	Insufficient CAPACITY AT RESERVOIRS due to climate changes (rain/gw recharge path alteration).	Reservoirs' storage is simulated at each time step. Changes in the rainfall time series will have impact on the	YES	CDF of climate change effects, current level of service (water quantity and quality and pressure).

Risk CODE	Risk Event	General description	Hazard CODE	Hazard	WP33 Comments	Requirement for Multiple MM runs	Input Data
					storage, i.e. water available for supply.		
			R08HZ08	Insufficient CAPACITY AT RESERVOIRS due to INCREASE OF WATER DEMAND.	See previous.	DESIRABLE	CDF of population increases, current level of service (water quantity and quality and pressure).
			R08HZ09	Less availability of Water from raw water due imperviousness of the recharge catchment, etc.	The WaterMet[2] runoff model distinguishes between pervious and impervious to estimate runoff. In case of imperviousness increase the model will result in more runoff but less recharger.	NO	CDF of the increase population at a given time horizon, pervious and impervious maps, current water sources maps.
			R08HZ11	Low pressure for extended period due to system aging, bottle necks, pump efficiency etc.	This risk can be estimated indirectly if it can be linked with the age of the system components. Direct estimation would require detailed hydraulic modelling (as pressure cannot be modelled in a mass balance type model).	DESIRABLE	Aging of pipes, pump efficiency aging, current level of service (water quantity and quality and pressure).

Risk CODE	Risk Event	General description	Hazard CODE	Hazard	WP33 Comments	Requirement for Multiple MM runs	Input Data
			R08HZ12	Rise of average temperature as effect of the climate change causes an increase of water consumption.	See comments about population habits.	YES	CDF of climate change effects, current level of service (water quantity and quality and pressure).
			R08HZ13	Water availability concentrated just in some periods of the year due to climate changes (i.e. water scarcity/water droughts).	The runoff and the reservoir storage are fully simulated using rainfall time series.	YES	CDF of climate change effects, current level of service (water quantity and quality and pressure).
R9	Inability to meet the acceptable standards of urban security	The urban water system causes frequent injuries to people and damages to structure and/or transport service disruptions.	R09HZ01	Infrastructure collapses or bursts potentially causing injuries to public.	This can be estimated indirectly from the components' reliability.	YES	overland infrastructure, materials and operational values connected to the current level of service
			R09HZ02	High velocity runoff in public streets during storm events.	Indirect estimation of this risk can be obtained from the amount of the overflowing volume. The velocity would require non-steady flow modelling. See also comments about CSO and pipe surcharges in urban area.	YES	CDF of climate change effects, urban infrastructures (i.e. building, streets, surface elevation etc.).

8 Appendix C: Cost Indicators

*Table 10: Specific **capital cost** indicators quantified by the WaterMet^2 model*

Subsystem no	Subsystem	Cost items	Unit	Input Data	Description
1	Water Supply	New/ extended borehole/well	1000xEuro	overall cost of capital works for each well size	Any borehole/well in the water supply subsystem for water withdrawal
1	Water Supply	New/ replaced/ upgrading pump	1000xEuro	overall cost of capital works for each pump power	Any pump in the subsystem for water transmission and distribution. Lifetime is required to calculate annual cost
1	Water Supply	New/ replaced/ rehabilitated tank/reservoir	1000xEuro	overall cost of capital works for each reservoir volume and material	Any tank/reservoir in the subsystem for water storage. Lifetime is required to calculate annual cost
1	Water Supply	New/ replaced/ rehabilitated Pipe/fittings/valves	Euro per meter	overall cost of capital works for each pipe meter, diameter and material	Any pipe/fittings/valves in the subsystem for water transmission and distribution. Lifetime is required to calculate annual cost
1	Water Supply	New/ replaced/ rehabilitated components in WTP	1000xEuro	overall cost of capital works for each component	Any component in WTP. Lifetime is required to calculate annual cost

Subsystem no	Subsystem	Cost items	Unit	Input Data	Description
2	Water Demand	New/replaced/ rehabilitated appliances	1000xEuro per appliance	overall cost of capital works for each appliance	Any appliances installed/replaced/ rehabilitated for domestic/non-domestic usage
3	Wastewater	New/ replaced/ rehabilitated Pipe/fittings	Euro per meter	overall cost of capital works for each pipe meter, diameter and material	Any pipe/fittings/valves in the subsystem for wastewater transmission. Lifetime is required to calculate annual cost
3	Wastewater	New/ replaced/ rehabilitated components in WWTP	1000xEuro	overall cost of capital works for each component	Any component in WWTP. Lifetime is required to calculate annual cost
4	Cyclic Water Recovery	New/ replaced/ rehabilitated of decentralized water recovery facilities	Euro per appliance	overall cost of capital works for each facility	Any facility such as rainwater harvesting/grey water treatment installed/replaced/ rehabilitated for domestic/non-domestic building and regions

*Table 11: Specific **operational cost** indicators quantified by the WaterMet^2 model*

Subsystem no	Subsystem	Cost items	Unit	Input Data	Description
1	Water Supply	pump operation and maintenance	1000xEuro per lifetime	annual failure frequencies and repairing price (maintenance cost)	Cost can be calculated based on the repairing price multiplied by failure frequencies during life time or a percentage of capital cost
1	Water Supply	energy consumption of pump	Euro per m^3, kWh	time series of average energy cost	energy consumption for pumping water in the subsystem
1	Water Supply	tank/reservoir operation and maintenance	1000xEuro per lifetime	annual maintenance cost for each reservoir volume, material	assumed as a percentage of capital cost
1	Water Supply	Pipe/fittings/valves maintenance	Euro per meter	annual maintenance cost for each pipe meter, diameter and material	Cost linked to pipe/fittings burst/valve failure per unit pipe meter during the pipe lifetime as a percentage of capital cost
1	Water Supply	WTP operation and maintenance	1000xEuro per year	annual maintenance cost for a WTP	Cost associated with all components as a whole in WTPs as a percentage of capital cost
1	Water Supply	energy consumption in WTP	Euro per m^3, kWh	time series of average energy cost	energy consumed in WTPs

Subsystem no	Subsystem	Cost items	Unit	Input Data	Description
1	Water Supply	chemical consumption in WTP	Euro per cubic meters	overall cost for each chemical used	chemical consumed in WTPs
2	Water Demand	Appliances operation and maintenance	Euro per appliance per year	annual maintenance cost for each appliance	assumed as a percentage of capital cost
2	Water Demand	energy consumption for appliances	Euro per m^3, kWh	time series of average energy cost	required by appliances such as water warming and cleaning by water
3	Wastewater	Pipe/fittings maintenance	Euro per meter	annual maintenance cost for each pipe meter, diameter and material	Cost linked to pipe/blockage repairs per unit pipe meter during the pipe lifetime
3	Wastewater	WWTP operation and maintenance	1000xEuro per year	annual maintenance cost for a WTP	Cost associated with all components as a whole in WWTPs
3	Wastewater	energy consumption in WWTP	Euro per m^3, kWh	time series of average energy cost	energy consumed in WWTPs
3	Wastewater	chemical consumption in WWTP	Euro per cubic meters	overall cost for each chemical used	chemical consumed in WWTPs
4	Cyclic Water Recovery	operation and Maintenance of decentralized facilities	Euro per appliance per year	annual maintenance cost for each facility	assumed as a percentage of capital cost