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URBAN_WFTP

Introduction of Water Footprint (WFTP) Approach in Urban Area
to Monitor, Evaluate and Improve the Water Use

First version of the Urban Water Footprint approach

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Foreword

The present report was prepared within the context of the work package WP3 (‘Water use and management baseline assessment according to Water Footprint approach and sharing of results among partners’) of the URBAN_WFTP project (http://www.urban-wftp.eu).

Thanks are due to all partners of the URBAN_WFTP project for fruitful discussion and provision of city level data.

1. INTRODUCTION

The Water Footprint concept has become increasingly popular for analysing environmental issues associated with the use and management of water resources. The concept was introduced by Hoekstra in 2002 (Hoekstra, 2003), and subsequently elaborated by Chapagain and Hoekstra (2004) as an indicator of human appropriation of freshwater resources that incorporates both direct and indirect water use of a consumer or producer. This method has a wide applicability; it is possible to derive the Water Footprint of an individual, a community, a business or a nation (Jefferies et al., 2012).

1.1 Purpose of this document

The general goal of this work was to define a general Water Footprint Approach for any urban area in order to reach a complete and clear knowledge of actual water use and management aspects. The results obtained using this model will based on available historic data for the urban area will constitute a baseline.

1.2 Document scope

This document presents first application of Water Footprint common approach for urban areas. Such an approach is intended to answer the need to develop a common strategy on water management and use at central Europe basins level (see 2000/60/CE), based on clear indicators comparable at EU level. Moreover the results of the application of this approach will support the diffusion of water saving technologies and solutions.

1.3 Overview of URBAN_WFTP model

The Water Footprint concept is primarily intended to illustrate the hidden links between human consumption and water use and between global trade and water resources management (Galli et al., 2012). While this is a powerful tool for communication, the concept bears a number of shortcomings, most important the lack of data.

Blue, Green and Grey water indicators described in this report are based on existing knowledge on Water Footprint. They are assigned for an elementary module to better represent the water use and management aspects. After the definition and assessment of the Blue, Green and Grey water indicators suitable characterization factors are determined for each elementary module. The elementary module can be represented by the whole city, an area of the city or a single building as it will be explained below.

2. GENERAL INFORMATION

Analysis of urban system reveals the following activities which influence the water use within the city boundary (Figure 1):

- collection of water from a catchment,
- storage of the water ,
- cleansing and purification,
- distribution through water supply network,
- carrying wastewater into the sewers,
- processing at a sewage treatment plant,
- returning treated water to the catchment.

The model developed within the framework of URBAN_WFTP project does not take into account any water consumption related with industrial and agricultural activities.

Figure 1: Water cycle in urban area (source: http://www.jointheevolution.ca/blog/2009/06/22/the-water-that-flows-part-1/)

2.1 Primary function of URBAN_WFTP model

First of all the URBAN_WFTP model will be used to assess and measure the water use and management performances of a municipality. The application of characterization factors will determine the Blue, Green and Grey water indicators. Using the model Water Footprint Baseline of the city will be computed based on general data available for the whole city. Further study will enable to extend Water Footprint Approach to more detailed elements of the urban area.

2.2 Structure of URBAN_WFTP model

The term Water Footprint is used for both direct (real) and indirect (virtual) water use of a consumer and or producer (e.g. Vanham et al, 2013 and Galli et al., 2012) in a certain region. Therefore it is assumed that the model will calculate in parallel the fluxes of virtual and real water that occur within the city boundaries.

If we include the virtual water content that is inherent connected with the production process of goods, we find that we are utilizing an even greater area of (virtual) hinterland in order to derive a water balance. The water footprint indicator gives an idea how big such imbalance is.

In the schematic of the water flux model (Figure 2) one need to be concerned with both real water fluxes and virtual ones. The virtual water fluxes that are connected to trade are reported separately. Reason being that pure import-export of goods creates only a through flow of virtual water. As trading goods are neither created nor used the virtual water fluxes connected with those goods does not need to be considered specifically – but of course could be.

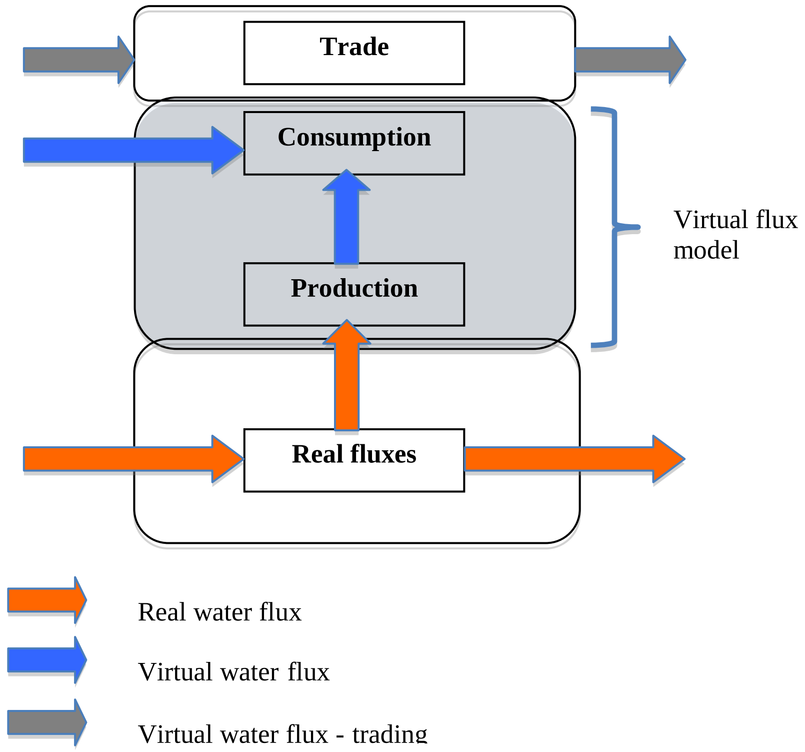


Figure 2: Water flux model on city level

2.2.1 Virtual water fluxes

The virtual water content can be determined for the production process of individual goods. If the used quantity of the goods (inside the model boundaries) is known then the virtual water flux for either persons or a region can be determined. The problem is the lack of data.

What has been achieved over the last years is a large database of virtual water demand that is connected with the production of specific goods – mostly agricultural products. Note that the demand varies based on the origin of the product as it is e.g. different if technical irrigation is needed for the growth process or not.

While there is data available for most agricultural production, less is known on the use of the products. Reliable data is only gathered on the national level and thus there is a database available on virtual water fluxes for most European nations. However, such data is rarely collected for smaller units as e.g. for urban catchments.

Virtual water fluxes are conveniently to be separated in fluxes connected to the consumption of goods = equals import of virtual water and to the production = equals export of virtual water. It is clear that the virtual water connected with production must be matched by real water fluxes. Last, some of the produced goods are consumed inside the city.

2.2.2 Real water fluxes

The consideration of real water fluxes inside model boundaries has been done for ages based on a mass balance approach. Likewise there is ample experience and data available on such input-output models. Most important these real flux models are used to express the balance of water resources and water usage in a certain catchment.

An equation by Mitchell et al. (2003) describes the water balance of urban catchments as:

$$\Delta S = (P + I) - (E_a + R_s + R_w)$$

where ΔS is change in catchment storage including water held in the soil profile, groundwater aquifers and natural and constructed surface water storages; P is precipitation; I is imported water; E_a is actual evapotranspiration; R_s is stormwater runoff; and R_w is wastewater discharge.

In the case of urban catchments it is clear that a water balance can no longer be established on the city catchment itself but requires a certain amount of hinterland.

3. MODEL DEVELOPMENT

The water, as a local resource, requires that its correct management is achieved even in urban areas. The water, in an urban area, can be used for domestic and industrial uses: while industrial uses are related to the dynamics of the process, civilian use are strongly influenced by the lack of awareness of citizens, which often involves severe wastage. In this context, it is evident that the proper management of the water through the rationalization of the civilian uses is a good way to counter future problems of this type, which permits excellent potential of reduction of the water wastage. To deal with the problem of urban water management the URBAN_WFTP project was set up which aims at improving the conservation of water resources through the deployment of new water-saving technologies and policies starting from citizens awareness. The element of strong innovation consists in the application of the Water Footprint (WFTP) approach to the urban areas as water management instrument and as planning tool. In addition, the project considers different urban contexts in order to obtain a common approach that will be used throughout the Central Europe in order to study and optimize water civilian consumptions. The application of the water footprint methodology to an urban area is not simple, represents an element of novelty and requires to overcome some obstacles due to the complexity and sizes of urban realities. Therefore, it was decided to use a multilevel modeling approach.

3.1 Overview of development process

The water balances defined by the WFTP methodology have been structured in three different levels of application. For each level a specific model has been drawn up. The three different levels are distinguished by the degree of details, the information they provide and the load of data that are require (Figure 3).

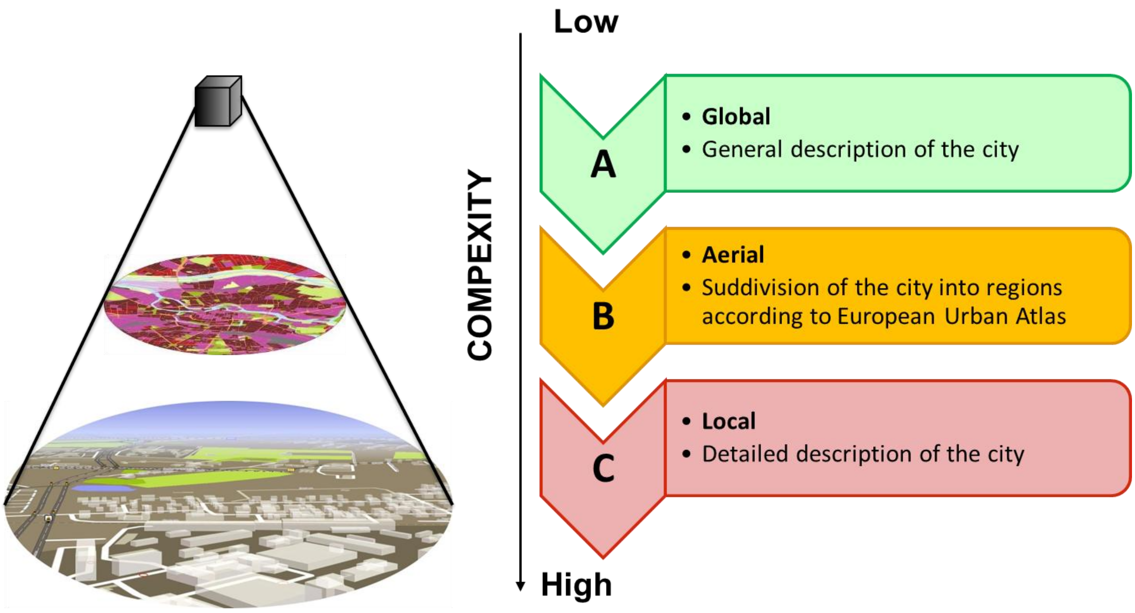


Figure 3: Three level model of Urban WFTP

The first level is the global level. The city is defined as a black box, and all water fluxes are studied with an input-output approach. The second level is represented by the areal model and the focus is posed on the different land uses that can be possible to distinguish in the city and how they interfere with water uses. Through the use of geographical information system (GIS), it will be possible to create a map of the city that shows the hot spots where the WFTP is the highest. The last level is the local model which analyses all the structures that generate the water consumptions. Starting from the data of a representative district and using a multi-linear regression the model will allow the calculation of the WFTP of the city using bottom-up approach.

The innovative approach used in the project allows to study the water uses in the city in order to identify points of intervention and choose the specific technologies to be introduced to reduce consumptions. The URBAN_WFTP project is in full implementation phase, but already represents a good example of application of the water footprint as an instrument for the urban water management.

3.2 Water footprint methodology

The Water Footprint is an indicator of freshwater use that looks not only at direct water use of a consumer or producer, but also at the indirect water use. (Hoekstra et al., 2011)

3.3 Definitions

Water Footprint indicator assess and represent three aspects of water use called blue water, green water, grey water.

The blue water refers to consumption of blue water resources (surface and groundwater). "Consumption" refers to loss of water from the available ground-surface water body in a catchment area. Losses occur when water evaporates, returns to another catchment area or the sea or is incorporated into a product.

The green water refers to consumption of rainwater insofar as it does not become run-off. It is therefore this part of rainwater which evaporates from the surface and/or is transpired by the crops.

The grey water refers to pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants given natural background concetrations and existing ambient water quality standards.

3.4 Parameters

The urban parameters that can affect the water footprint are numerous and could include (Novotny et al. 2010):

- Population density
- Percent imperviousness
- Percent irrigated area per household
- Living standard
- Irrigated area per dwelling unit
- Water needs for street flushing, irrigation of public parks, and fire fighting

- Geographical location and meteorological conditions (arid vs. humid; warm vs. temperate)
- Food consumption and type (virtual water)
- Virtual water in other products (e.g., bottled water, textiles, paper, automobiles, etc.)

For the purpose of this model the parameters of virtual and real (direct) water are separated.

3.4.1 Virtual water

The parameters describing virtual water flow in the city are summarised in Table 1.

Table 1: Parameters of virtual water flow model

Notation	Unit	Name	Description
VWi	m3/year	Virtual Water imported	Total virtual Water imported to city
VWe,r	m3/year	Virtual Water imported and re-Exported	Virtual water that is just passed through in trading goods
VWe,d	m3/year	Virtual Water exported goods produced with domestic water	Virtual water that is generated with domestic water for exported goods
VWe	m3/year	Virtual Water exported	Total Virtual water that is exported
IWFcons	m3/year	Internal Water footprint consumed goods	Water footprint of consumed goods produced with domestic real water
EWFcons	m3/year	External Water footprint consumed goods	Water footprint of consumed goods produced with external real water
WFcons	m3/year	Water footprint consumed goods	Total Water footprint of consumed goods

3.4.2 Real water

The parameters describing real water flow in the city are summarised in Table 2.

Table 2: Parameters of real water flow model

Notation	Unit	Name	Description
PREC	mm/year	Annual Precipitation	Rainwater volumes per year per unit of surface

A	m2	Total Area	Total surface managed by the municipality
Qprec	m3/year	Total annual precipitation	Total reainwater volumes in the city
Qgw	m3/year	Groundwater uptake	Volume of freshwater uptaken from fresh ground-water resources
Qsw	m3/year	Surface water uptake	Volumes of freshwater uptaken from fresh surface-water resources
Qimp	m3/year	Imported water	Volume of fresh water imported from other basin (outside city boundary)
Qsuppl	m3/year	Annual water supply inflow	Total Volume of freshwater uptaken
QId	m3/s	Industry/farming demand	Volume of water withdrawn for Industry and farming use
QE	m3/year	Water use for Energy (heating)	Volume of water withdrawn for heating and cooloing
QIe	m3/year	Industry/farming effluent	Volume of water discharged from industries and farms
Qinflow	m3/year	total water inflow	Total Volume of freshwater inflow
Aperm	m2	permeable area (Green)	Total permeable surface manager by the Municipality
Aimperm	m2	impermeable area (Build-up)	Total impermeable surface manager by the Municipality
Yperm	-	Runoff coefficient	% of rainwater that becomes runoff from permeable surface
Yimperm	-	Runoff coefficient	% of rainwater that becomes runoff from impermeable surface
Qrunoff	m3/year	Total runoff	Total Volume of freshwater runoff
Rtreat	-	Treated Runoff coefficient	% of total runoff that goes to treatment systems
Qrt	m3/year	Treated runoff	Total Volume of treated runoff
Qexp	m3/ year	Exported water	Volume of freshwater exported to another water basin or outside of the basin that the city uptake water from

Qoutflow	m3/year		Total volume of freshwater that leave the city
ETP	mm/year	Potential evapotranspiration	
Awater	m2	Area under surface waters	Total surface water area
Kperm	-	Evapotranspiration coefficients	% of rainwater that evapotranspirates from permeable surface
Kimperm	-	Evaporation coefficients	% of rainwater that evaporates from impermeable surface
Kwater	-	Evaporation coefficients	% of rainwater that evaporates from surfacewater
Qetr	m3/year	Evaporated volume	Total volume of water evaporated from the city
Rloss	-	Runoff loss coefficient	% of runoff water going to surface water
Qrl	m3/year	Loss	Total volume of runoff going to surface water
I	-	Infiltration coefficient	% of rainwater infiltrating in the ground
Qinfil	-	Infiltration volume	Total volume of rainwater infiltrating in the ground
Tloss	-	Transport loss coefficient	% of freshwater uptaken infiltrating in the ground
Qtl	m3/year	Transport loss	Total volume of freshwater losses during transportation
Qdel	m3/year	Long term freshwater storage	Water does not return in the same period (e.g. it is withdrawn in a scarce period and returned in a wet period)
Qtreated	m3/year	Wastewater treated	Volume of water out of the wastewater treatment
QU	m3/year	Additional water use	
QUeff	m3/year	Additional water discharge	Discharge from other uses such as Industries, Farms and energy
c(i)	mg/m3	Main Pollutant	reference i-Pollutant (after treatment)

	or mg/l	concentration	
cmax(i)	mg/m3 or mg/l	legal concentration of i-pollutant	legal limit concentration of reference i-pollutant in the receiving water body
cnat(i)	mg/m3 or mg/l	natural concentration of i-pollutant	natural concentration of i-pollutant in the receiving water body

When assigning values of runoff, evaporation and infiltration coefficients for surfaces the following condition must be met:

$K + Y + I \leq 1$

3.5 Accounting

3.5.1 Virtual water

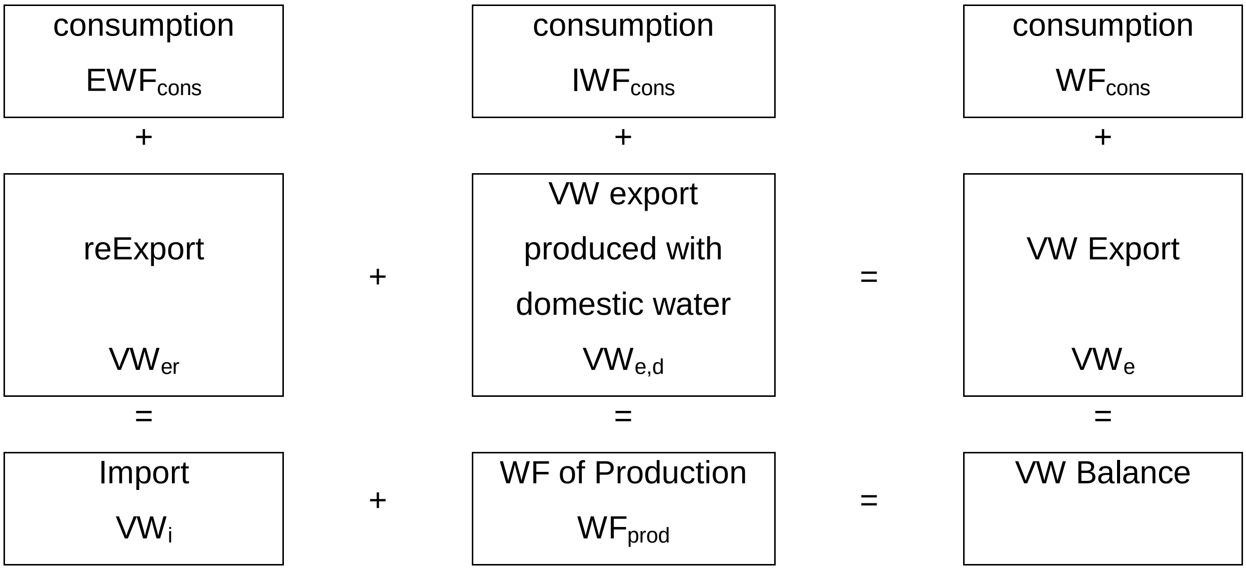
For the creation of the virtual flux model it is important to consider the dimensions of the different quantities of the virtual fluxes. Data by Vanham et al., 2013 suggest the following relation in a European Dimension (Table 3).

Table 3: Specific water fluxes in l/cap/d for Europe after Vanham et al., 2013

	Agricultural Products	Industrial Products
Production	3100	207
Consumption	4265	436

Most important from the data above is the following fact for the European situation: Agricultural products are by the far the most important virtual water flux. Industrial products amount to only app. 1/10 of that quantity

External WF of + Internal WF of = WF of



VW_i Virtual Water imported

$VW_{e,r}$ Virtual Water imported and re-Exported

$VW_{e,d}$ Virtual Water exported goods produced with domestic real water

VW_e Vitual Water exported

IWF_{cons} Water Footprint consumed goods produced with domestic real water

EWF_{cons} Water Footprint consumed goods produced external with external water

WF_{cons} Water Footprint consumed goods

WF_{prod} Water footprint produced goods

Figure 4: Geographical WFTP accounting scheme after Vanham et al., 2013

Vanham et al., 2013 present a geographical WFTP accounting scheme (Figure 4) based on earlier work from Hoekstra et al., 2011. This accounting scheme is a more refined version of the water flux schematic presented earlier. As this scheme is already established in the literature it is most suitable for establishment of a Virtual water balance for an urban environment (Figure 5).

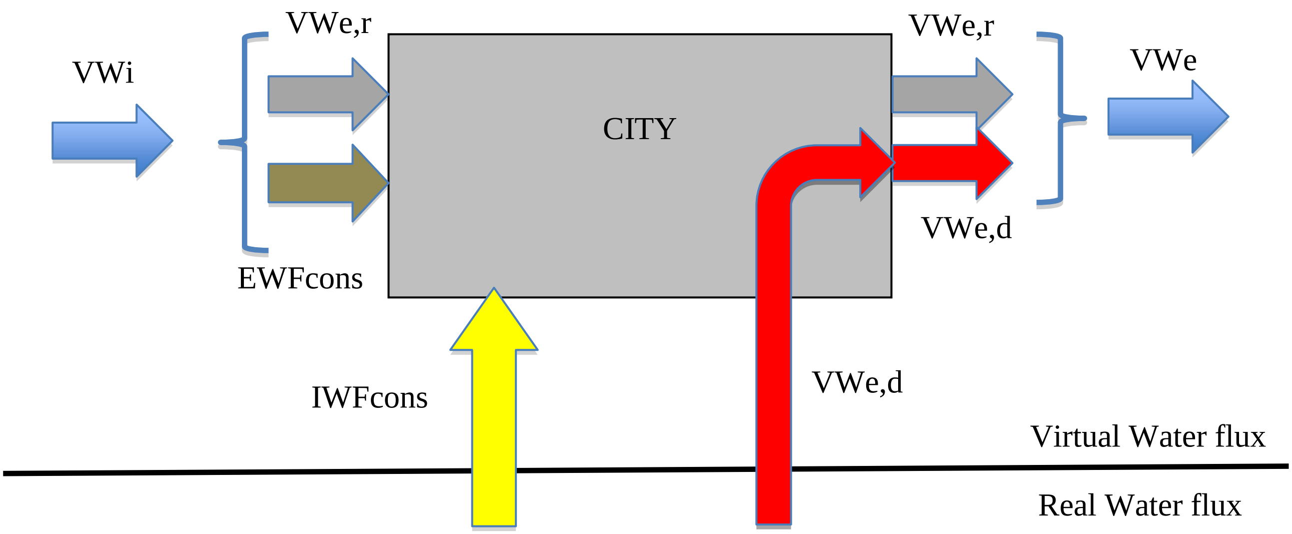


Figure 5: Virtual water flux model

The general equations applying to virtual water flux model are following:

VWi = VWe,r + EWFcons

VWe = VWe,r + VWe,d

WFcons = EWFcons + IWFcons

VWe,d + IWFcons < Summ of real water fluxes (green, blue, grey)

Example:

The determination of the parameters must be based on an assessment of the available data from production and consumption within the urban environment. As a very first attempt it is possible to use mean data per capita that have been derived based on national databases

VWi = 200 + 1950 = 2150 (l/cap/a)

VWe = 200 + 550 = 750 (l/cap/a)

WFcons = 1950 + 2850 = 4800 (l/cap/a)

Summ of real water fluxes (green, blue, grey) > 550 + 2850 = 3400 (l/cap/a)*

* Note that this last relation must not hold for a specific city. Reason is that national data is derived from considering all agricultural production in the country. Hence it is likely that the internal water footprint IWFcons is grossly overestimated – and likewise EWFcons underestimated as the agricultural goods are not produced in the city boundaries but outside.

3.5.2 *Real water*

In order to calculate the water footprint indicators (green water, blue water and grey water) it is recommended to make annual balance of real water fluxes for the total area of the city or just for urbanized area (excluding agricultural area). All elements of the real water flow which need to be considered are presented on Figure 6.

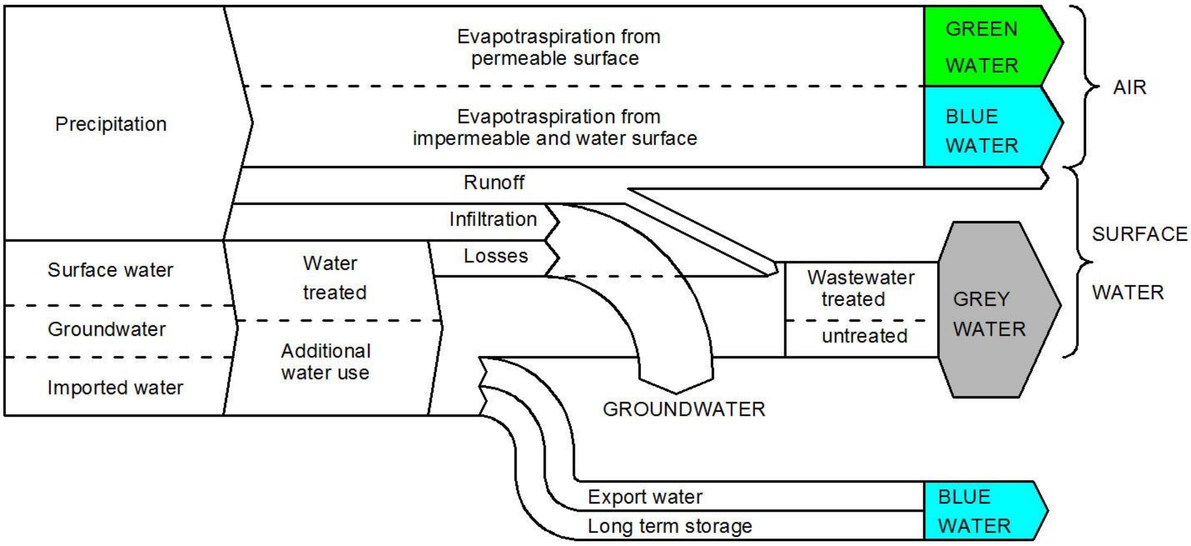


Figure 6: Real water fluxes in the urban area

3.5.2.1 *Water fluxes into the city indicators*

The water flowing into the city is originating from precipitation and natural water resources such as groundwater, surface water and imported water.

- Qprec = PREC * A [m3/year]

- Qsuppl = Qgw + Qsw + Qimp [m3/year]

- Qinflow = Qprec + Qsupl [m3/year]

3.5.2.2 *Water fluxes in the city indicators*

The main fluxes in the city which influence water footprint are related to withdrawal and discharge of water by industries and farms, heating and cooling, and runoff.

- QU = QId + QE [m3/year]

- Qrunoff = (Yperm * Aperm + Yimperm * Aimperm)*PREC [m3/year]

- Qrt = Qrunoff * Rtreat [m3/year]

- QUeff = QIe + QE [m3/year]

3.5.2.3 Water fluxes out of the city indicators

Water is leaving the city by:

- Evaporation and evapotranspiration

  Qetr =PREC (Kperm * Aperm + Kimperm * Aimperm + Kwater * Awater) [m3/year]

- Losses

  Qrl = Qrunoff * Rloss [m3/year]
  Qtl = Qsupl * Tloss [m3/year]

- Infiltration

  Qinfil = PREC * I [m3/year]

- Export

  Qexp [m3/year]

- Sewage

  Qsewage = Qsupl – Qtl – Qexp + Qrt [m3/year]

- Outflow

  Qoutflow = Qetr + Qrl + Qtl +Qinfil + Qexp + Qsewage [m3/year]

3.5.2.4 Water storage indicator

The difference between water inflow and outflow becomes long term freshwater storage:

- Qdel = Qinflow – Qoutflow

3.5.2.5 Water footprint indicators

The water footprint indicators related to real water fluxes are calculated using the following formulas:

WFTPgreen = PREC* Kperm * Aperm [m3/year]

WFTPblue = PREC*(Kimperm*Aimperm + Kwater*Awater) + Qdel + Qexp [m3/year]

WFTPgrey = c(i)* (Qsewage) /(cmax(i)-cnat(i)) [m3/year]

WFTPreal = WFTPgreen + WFTPblue + WFTPgrey

3.5.3 Urban water footprint

The overall urban water footprint is the sum of virtual part and real part:

WFTP = WFTPcons + WFTPreal

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