Project no. 4CE439P3

URBAN_WFTP

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

Water Footprint CEU common approach

Lead contractor for deliverable *D.3.5.4*: WUELS

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Start date of project: 1 November 2012 **Duration: 25 months**

Submission date: March 2014

CONTENS

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).

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 ,producer, process or product. 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). According to Hoekstra et al. 2011, Water Footprint methodology can effectively contribute also to local water management. Several application of these methodology have been published; however experiences at urban level are still limited and fragmented.

1.1 Goal and scope of the study

The overall goal of this work was to define a general Water Footprint Approach to be applied at urban level in the regions of Central Europe in order to reach a complete and clear knowledge of actual water use and management aspects. The results obtained using this model are based on available historic data for the urban areas especially primary data on water use. The approach can be used to develop a urban water footprint baseline and to monitor performance related to water use overtime

In this document guidelines and recommendation to assess Water Footprint at Urban level for the Central Europe Region is presented. 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.

The document is divided in three main sections: an introduction to the general model; a detailed description of the developed approach; a discussion and conclusion sections with recommendations for a consistent application of the presented methodology.

1.2 Project description and objectives

Nowadays water use has become a main issue discussed at international level. The continuous increase in population, which involves the expansion of urban areas, and the increase in water demand will lead to a worsening of the problem in the future. The lack of interaction between the diverse communities of users, decision-makers and isolated water managers has caused serious degradation of water resources and increased the risks to all the developmental sectors that depend upon them (WWAP, 2012).

The water, as a local resource, requires that its correct management is achieved in all dimensions, 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 model of common approach that will be used throughout the central Europe in order to study and optimize water civilian consumptions.

The document consists of three main sections: an introduction to the general model (Chapters 2); a detailed description of the developed approach (Chapters 3,4,5,6,7); a discussion and conclusion sections (Chapter 8) with recommendations for a consistent application of the presented methodology.

2. GENERAL DESCRIPTION

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

- local climate conditions and variables overtime,
- management of rainwater;
- collection of water from a catchment,
- storage of the water ,
- cleansing and purification,
- distribution through water supply network,
- carrying wastewater and storm water in the sewers,
- processing at a sewage treatment plant,
- returning treated water to the catchment,
- urban development (such as built area and green area).

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

Even if water consumption is highly influenced by agriculture and industrial activities, in this project the focus is on urban water use. Therefore, if not differently specified, only water that is used by citizens is considered

2.1 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. Elementary (basic) module is the smallest object for which one can apply water balance equation and calculate water footprint. The elementary module can be represented by an area of the city with homogenous coverage (built-up area, green area, road, water) or by a single building. To define the Blue, Green and Grey water indicators for each elementary module suitable characterization factors need to be determined.

2.2 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. In this context characterization factor refers to a variable that influence water use within the urban area such as total surface managed by the municipality, number of citizen, volume of withdrawn water etc..

Using the model water footprint baseline of the city will be computed considering general statistical data available for the whole city. Further study will enable to extend water footprint approach to more detailed elements of the urban area called elementary modules.

2.3 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.

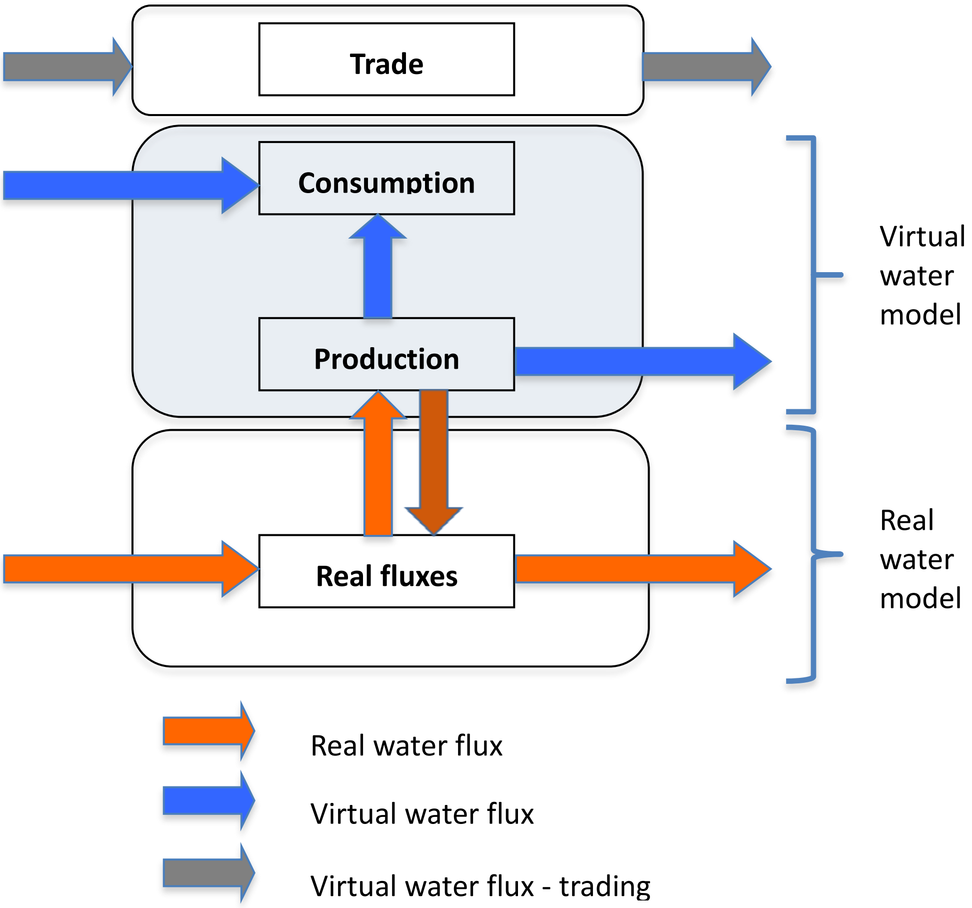

Figure 2: Water flux model on city level

The urban water footprint model was subdivided into real water model and virtual water model in order to reflect the different water fluxes occurring in the urban environment (Figure 3).

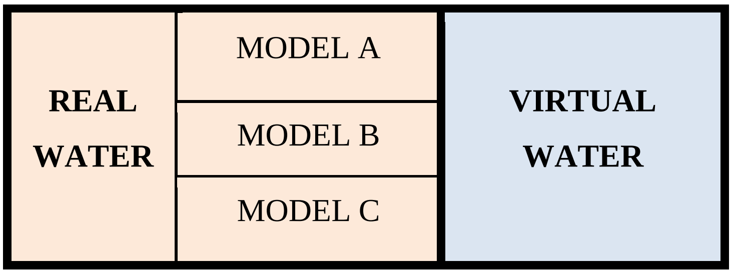

Figure 3: Structure of urban water footprint model

Moreover the real water model have been structured in three different levels of application. For each level a specific model has been drawn up (see chapter 3). Depending on specific needs only one level need to be applied for calculating part of water footprint resulting from real (direct) water flow model. The second part can be calculated from virtual (indirect) water flow model.

The three different levels are distinguished to reflect the degree of details, the information they provide and the load of input data that are required (Figure 4).

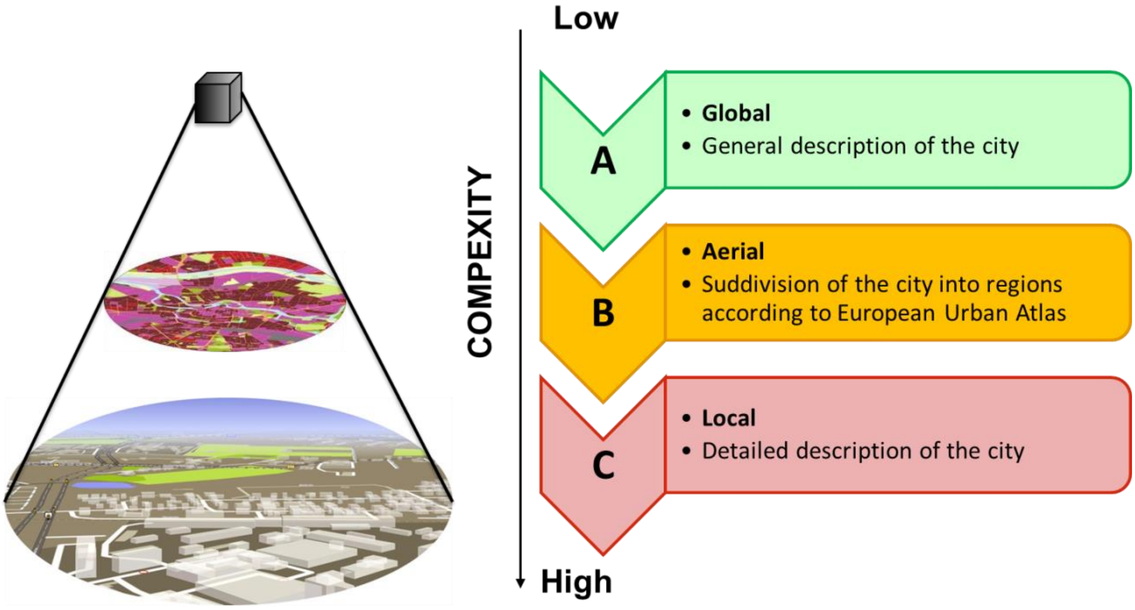

Figure 4: Three level model of Urban WFTP

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.

2.3.1 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. This relates to blue and green water that is used inside the city for production and grey water from the associated water pollution process.

Last, some of the produced goods are consumed inside the city. This leads to internal cycles of water but does not influence the import-export of virtual water.

2.3.2 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.

2.4 Characterisation of end-users and their needs

Water footprint can be applied in municipalities where water management is at different development level:

- municipality with no water management,
- municipality where water management started,
- municipality where water management practices are advanced.

In all cases water footprint will be addressed to end-users who will have specific objectives and will focus on different aspects of water use (Table 1).

Table 1: Characterisation of end-users

Targets	Objectives	Aspects considered*
Politician	Safe water supply Good Publicity	Mainly i and ii, then iii
Consumer	Reliability Low price (including redundancy)	Mainly i and ii, then iii
Public Operator	Service level	Mainly i then ii

* i – direct water consumption,
ii – infrastructure (water pipelines, wastewater treatment facilities etc.),
iii – product trade (virtual water).

3. MODEL DEVELOPMENT

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 modelling approach.

3.1 Water footprint methodology

The Water Footprint is an ecological indicator that belongs to the family of “footprint indicators”. The underlying idea is here to relate the use and consumption of resources to the amount of space that is occupied by the consumers, i.e. a relation mass of consumed resources to area is specified (Rees, 1996).

The Water Footprint is based on the concept of virtual water, which has been developed app. 20 years ago by the British researcher J.A. Allen (Allen, 1998). Virtual water in this context is the total amount of water that is consumed and polluted during the production of goods, food or service. For the calculation of the total amount of virtual water, every step in the process is considered. Over the last two decades a huge amount of data has been gathered in databases that support the tedious process. 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). Hoekstra et al. (2011) have published a comprehensive manual that explains the concept in detail and supports its application. The following text is largely referring to this background material. For the definition regarding the computation of blue, green and grey water fluxes see also Hoekstra et al., 2011.

3.2 Definitions

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

In general the blue water footprint refers to consumption of blue water resources (surface and groundwater). “Consumption” means the 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 to the sea or is incorporated into a product. Within the urban context blue water footprint is defined as evaporation from impervious surfaces, long term storage and export of water outside the city boundary.

The green water footprint refers to consumption of rainwater insofar as it does not become run-off. It is therefore assumed that in the urban environment green water footprint covers this part of rainwater which is transferred from green surfaces to the atmosphere by evapotranspiration.

The grey water footprint refers to pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants given natural background concentrations and existing ambient water quality standards. For the urban conditions grey water footprint is calculated based on concentrations of treated runoff/waste water.

4. Virtual water model

The concept of Water Footprint relates to both real and virtual water fluxes. The aim of the following is to develop a schematic for presenting the mass balance of virtual water streams for an urban environment. This requires defining the relation of fluxes inside the city boundaries and exemplifying a model of virtual water fluxes that can be realistically applied. The mass balance of real water flows is treated in detail elsewhere. Note that all fluxes of blue, green and grey water that refer to physical processes and areas inside the city boundaries are seen here as real water fluxes.

4.1 Parameters

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

Table 2: Parameters of virtual water flow model

Notation	Unit	Name	Description	Source of Data
VW_i	m^3/year or lcd *	Virtual Water imported	Total virtual Water imported to city	Computed Formula (1)
$VW_{e,r}$	m^3/year or lcd	Virtual Water imported and re-Exported	Virtual water that is just passed through in trading goods	Statistic - Estimation
$VW_{e,d}$	m^3/year or lcd	Virtual Water exported goods produced with domestic water	Virtual water that is generated with domestic water for exported goods	Statistic – Estimation and Computed Formula (4)
VW_e	m^3/year or lcd	Virtual Water exported	Total Virtual water that is exported	Computed Formula (2)
$IWFTP_{cons}$	m^3/year or lcd	Internal Water footprint consumed goods	Water footprint of consumed goods produced with domestic real water	Statistic – e.g. Mekonen & Hoeckstra, 2011
$EWFTP_{cons}$	m^3/year or lcd	External Water footprint consumed goods	Water footprint of consumed goods produced with external real water	Statistic – e.g. Mekonen & Hoeckstra, 2011
$WFTP_{cons}$	m^3/year or lcd	Water footprint consumed goods	Total Water footprint of consumed goods	Computed Formula (3)

* lcd = litres per capita and day

4.2 Accounting

Until today the application of the Water Footprint approach as ecological indicator has been mainly restricted to a national level. Hardly any investigations have been reported in the literature on an urban scale. Even if, such studies usually take a broader picture and investigate the whole urban water metabolism (Huang et al., 2013; Wang et al., 2013; Stoeglehner et al., 2011). For the case of accounting only the virtual water fluxes – as it is the aim of this investigation – no detailed case study is currently reported.

Vanham et al., 2013 present a geographical WFTP accounting scheme based on earlier work from Hoekstra et al., 2011. This accounting scheme (Figure 5) is a more refined version of the water flux schematic presented earlier for an urban scale.

External WFTP of consumption $EWFTP_{cons}$	+	Internal WFTP of consumption $IWFTP_{cons}$	=	WFTP of consumption $WFTP_{cons}$
+		+		+
reExport VW_{er}	+	VW export produced with domestic water $VW_{e,d}$	=	VW Export VW_e
=		=		=
Import VW_i	+	WFTP of Production $WFTP_{prod}$	=	VW Balance

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
$IWFTP_{cons}$	Water Footprint consumed goods produced with domestic real water
$EWFTP_{cons}$	Water Footprint consumed goods produced external with external water
$WFTP_{cons}$	Water Footprint consumed goods
$WFTP_{prod}$	Water footprint produced goods

Figure 5: Geographical WFTP accounting scheme after Vanham et al., 2013

As the above scheme is already established in the literature it is most suitable for establishment of a virtual water balance for an urban environment (Figure 6). Note that in this context both “Virtual Water” and “Water Footprint” have the similar dimension of volume per time (e.g. m3/year or lcd – liter per capita per day).

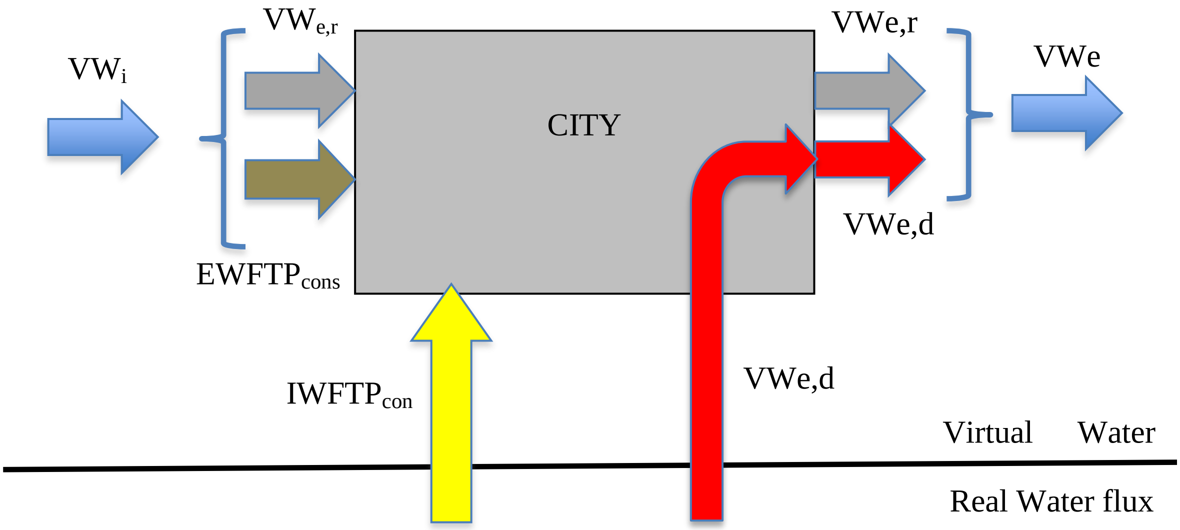

Figure 6: Virtual water flux model

An important point is here the relation with the real water fluxes. It is assumed that the real water fluxes going into the production of goods (in the virtual system) are net fluxes – stating that the waste fluxes running back are inherent subtracted – and covered in Model A as waste flows. Furthermore the aim is here to apply a scheme that provides the maximum information with minimum data requirements. Hence the Geographical WFTP accounting scheme is further simplified to only demonstrate the most important fluxes.

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

1. $VW_i = VW_{e,r} + EWFTP_{cons}$
2. $VW_e = VWe,r + VWe,d$
3. $WFTP_{cons} = EWFTP_{cons} + IWFTP_{cons}$
4. $VW_{e,d} + IWFTP_{cons} <$ Sum of real water fluxes (green, blue, grey)

4.3 Data for the virtual Water flux model on an urban scale

Water Footprint Database

An important information is the National Data of Water Footprint accounting after

Mekonnen & Hoeckstra (2011). Therein the data is compiled on a national level for the period 1996-2005. In the absence of more refined data on the urban level this data provides some basic information.

*Assumption 1: The following national accounting data are used as first approach (*Table 3*).*

Table 3: Some national data of Water Footprint accounting in m3/cap/year. Data Source: Mekonnen & Hoeckstra, 2011.

Country	Population (thousands)	Water footprint of consumption of agricultural products					
		Internal			External		
		Green	Blue	Grey	Green	Blue	Grey
Austria	8057	396,3	2,0	52,4	738,1	64,2	81,0
Germany	82139	311,4	1,0	85,9	741,9	56,9	62,3
Italy	57521	629,3	43,9	94,2	1091,2	117,0	82,4
Poland	38408	778,0	1,7	151,8	232,6	36,2	23,6
		Water footprint of consumption of industrial products					
			Internal		External		
			Blue	Grey	Blue	Grey	
Austria			5,1	8,0	18,3	190,5	
Germany			9,9	10,4	10,3	109,4	
Italy			8,7	47,7	9,1	97,8	
Poland			11,4	80,2	4,0	50,0	
		Water footprint of domestic water consumption					
			blue	grey			
Austria			9,2	32,5			
Germany			7,1	19,9			
Italy			14,0	67,7			
Poland			5,5	30,4			

Dominance of agriculture for virtual water fluxes

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 for an European dimension (Table 4).

Table 4: 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. But there is no information available if this relation also holds on an urban scale and if there are possibly significant differences in between cities. Most likely that is true as a specific city can be likewise dominated by e.g. industrial production or tourism. Both would render a significant difference in the virtual water fluxes. But in the absence of better information we assume as initial guess a dominance of agricultural products in the calculation of the virtual water fluxes.

*Assumption 2: In the absence of better information the following national relation (*Table 5*) between Industry Production and Agricultural Production can be assumed for the WFP.*

Table 5: National relation between Industry Production and Agricultural Production. Data Source: Mekonnen & Hoeckstra, 2011.

Nation	Relation Industry/Agriculture for WFP
Austria	0,17
Germany	0,11
Italy	0,08
Poland	0,12

Dominant food products for WFP

As a first approach to calculate the WFP of agricultural goods some data for Austrian consumption 2007-2010 and the amount of inland production are plotted in Table 6 (Statistik Austria). The last column gives global data for the virtual water footprint related to the production of those goods - Data from Mekonnen & Hoeckstra, 2011. Note that these values are only to be seen as an indication as the actual WFP can vary widely. This table and selection is related to Austria however, in other context, other products should be considered.

Table 6: Data on consumption of agricultural products in Austria and the connected WFP. Data Source – Statistik Austria and Mekonnen & Hoeckstra, 2011

Products	Austrian consumption in kg/cap/year	Austrian inland production in %	Global WFP for production in l/kg
Meat	102	121	7 000
Bovine	16.4	159	15 415
Pig	65.6	122	5 988
Poultry	17.9	84	4 325
Other	2	-	-
Eggs	14	75	3 265
Cheese	19	95	3 178
Butter	5	75	5 553
Milk	90	-	1 020
Cereals	85	100	1 644
Fruit and vegetables	180	55	600
Wine	29	100	870
Beer	105	100	298

Rauch (2013) plots the most dominant agricultural products in terms of WFP for national Austrian data (Figure 7). It is interesting to note that app. 50% of the WFP is attributed to animals and animal products such as milk, eggs, cheese, etc. Second largest group are consumption products such as coffee, tea, cacao and tobacco. Cereals (and related products such as bread and beer) make up for another 9% of the national WFP in Austria and the group fruit, vegetables and wine account for 7%.

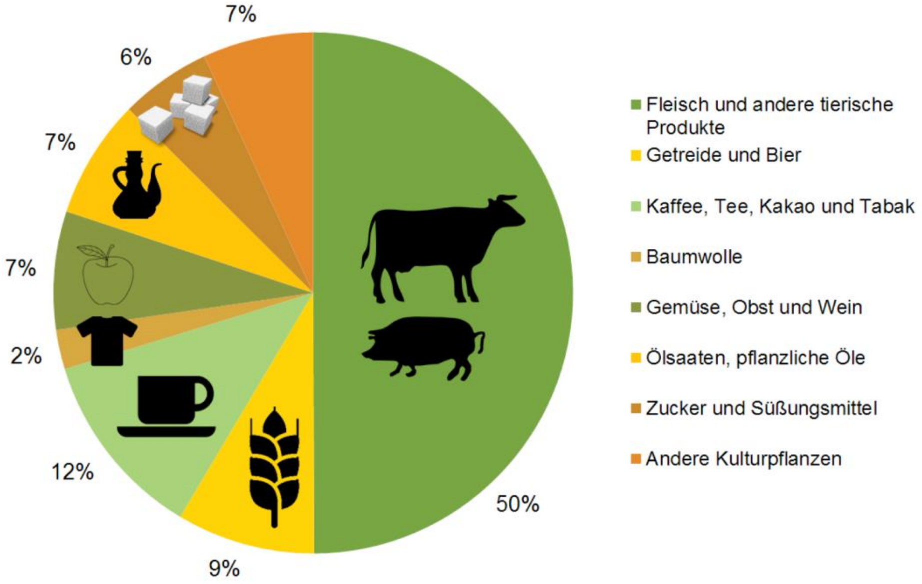

Figure 7: WFP for Austria for agricultural product groups after Rauch (2013) - based on Vanham (2012)

*Assumption 3: In the absence of more refined data on the urban level the following agricultural product groups (*Table 7*) are seen as most important for WFP accounting.*

Table 7: Agricultural product groups. *Data source Rauch (2013)*

Product groups	%
Animal Products	50
Consumption Products	12
Cereals	9
Fruit, vegetables, wine	7
Rest	22

Estimation of Export and Trade

For the Urban Virtual Water flux model it is necessary to estimate the WFP that is connected with trade ($VW_{e,r}$ - Virtual Water imported and re-Exported) and with export ($VW_{e,d}$ - Virtual Water exported goods produced with domestic water). The estimation of those values is complex even on the national level but even more so on the urban scale. It is to be expected that there are huge differences depending on the characteristic of the investigated urban environment.

Assumption 4: As a first guess the WFTP connected with trade and export is calculated with the following estimates for the Austrian national situation after Vanham et al., 2013

1. $VW_{e,r} = 0.5 * EWFTP_{cons}$
2. $VW_{e,d} = 0.5 * IWFTP_{cons}$

4.4 Urban Virtual Water flux model

Applying the urban water flux model as proposed, together with the national data from Mekonnen and Hoeckstra (2011) and using Formulas 1-6 gives the following results on the national level (Table 8).

Table 8: Urban water flux model for data on national level in lcd

Water Flux	Austria	Germany	Italy	Poland
VW_i	4488	4031	5743	1424
$VW_{e,r}$	1496	1344	1914	475
$VW_{e,d}$	692	610	2644	1451
VW_e	2188	1954	4558	1925
$IWFTP_{cons}$	1385	1221	5288	2901
$EWFTP_{cons}$	2992	2687	3829	949
$WFTP_{cons}$	4377	3908	9116	3851
Sum of real water fluxes	2077	1831	7931	4352

Note that the last relation (sum of real water fluxes) 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 IWF_{cons} is grossly overestimated – and likewise EWF_{cons} underestimated as the agricultural goods are not produced in the city boundaries but outside.

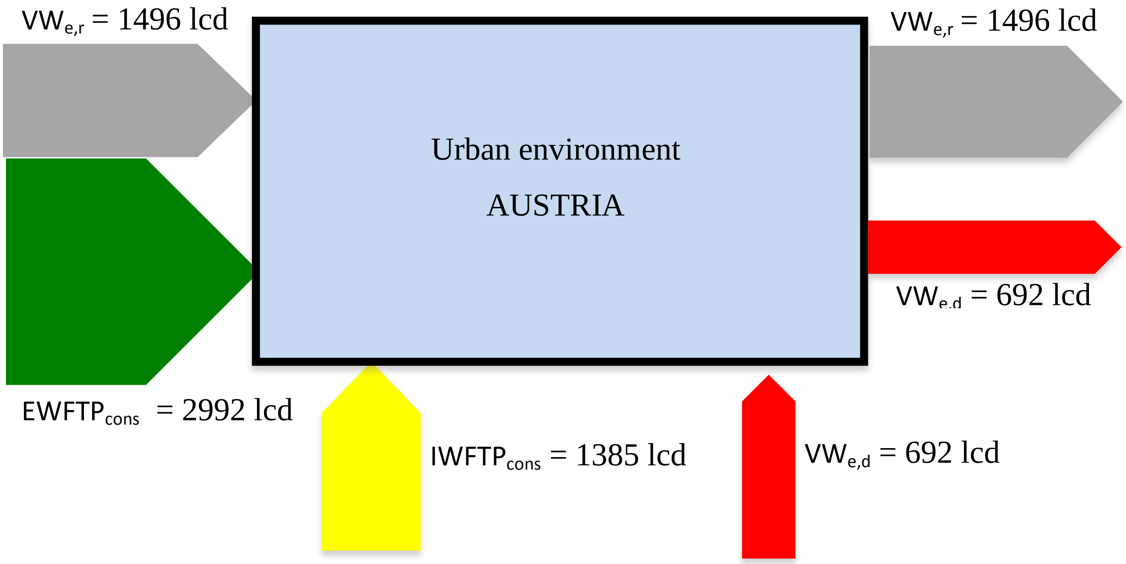

Figure 8: Sankey diagram of Virtual Water Flux model for an Austria city in lcd

In general the relations above (Figure 8) are based on many assumption and can only provide a rough estimate.

5. **Model A**

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 9, excluding the flux related to heating/cooling.

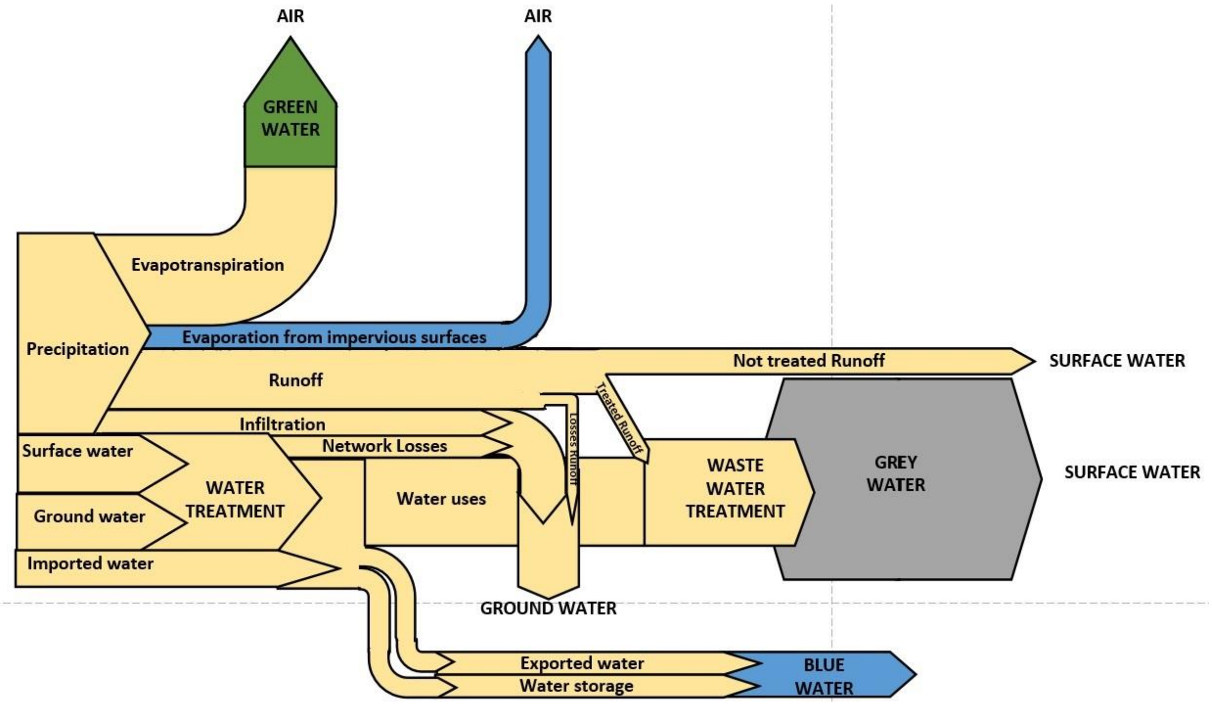

Figure 9: Real water fluxes in the urban area

5.1 *Parameters*

The parameters describing real water flow in the city are summarised in Table 9.

Table 9: Parameters of real water flow model

Notation	Unit	Name	Description
PREC	mm/year	Annual Precipitation	Rainwater volumes per year per unit of surface
A	m^2	Total area	Total surface managed by the municipality
Q_{prec}	m^3/year	Total annual precipitation	Total rainwater volumes in the city

Q_{gw}	m^3/year	Groundwater uptake	Volume of freshwater intake from fresh ground-water resources
Q_{sw}	m^3/year	Surface water uptake	Volumes of freshwater uptaken from fresh surface-water resources
Q_{imp}	m^3/year	Imported water	Volume of fresh water imported from other basin (outside city boundary)
Q_{suppl}	m^3/year	Annual water supply inflow	Total volume of freshwater intake
Q_{civil}	m^3/ year	Civil use	Volume of water withdrawn for civil use
Q_{Id}	m^3/ year	Industry/farming demand	Volume of water withdrawn for Industry and farming use
Q_E	m^3/year	Water use for Energy (heating)	Volume of water withdrawn for heating and cooling
Q_{Ie}	m^3/year	Industry/farming effluent	Volume of water discharged from industries and farms
Q_{inflow}	m^3/year	Total water inflow	Total Volume of freshwater inflow
A_{perm}	m^2	Permeable area (Green)	Total permeable surface managed by the Municipality
A_{imperm}	m^2	Impermeable area (Build-up)	Total impermeable surface managed by the Municipality
Y_{perm}	-	Runoff coefficient	% of rainwater that becomes runoff from permeable surface
Y_{imperm}	-	Runoff coefficient	% of rainwater that becomes runoff from impermeable surface
Q_{runoff}	m^3/year	Total runoff	Total Volume of freshwater runoff
R_{treat}	-	Treated Runoff coefficient	% of total runoff that goes to treatment systems

Q_{rt}	m^3/year	Treated runoff	Total Volume of treated runoff
Q_{exp}	m^3/ year	Exported water	Volume of freshwater exported to another water basin or outside of the basin that the city uptake water from
$Q_{outflow}$	m^3/year		Total volume of freshwater that leave the city
A_{water}	m^2	Area under surface waters	Total surface water area
K_{perm}	-	Evapotranspiration coefficients	% of rainwater that evapotranspirates from permeable surface
K_{imperm}	-	Evaporation coefficients	% of rainwater that evaporates from impermeable surface
K_{water}	-	Evaporation coefficients	% of rainwater that evaporates from surfacewater
Q_{etr}	m^3/year	Evaporated volume	Total volume of water evaporated from the city
R_{loss}	-	Runoff loss coefficient	% of runoff water going to surface water
Q_{rl}	m^3/year	Loss	Total volume of runoff going to surface water
I	-	Infiltration coefficient	% of rainwater infiltrating in the ground
Q_{infil}	-	Infiltration volume	Total volume of rainwater infiltrating in the ground
T_{loss}	-	Transport loss coefficient	% of freshwater uptaken infiltrating in the ground
Q_{tl}	m^3/year	Transport loss	Total volume of freshwater losses during transportation
Q_{del}	m^3/year	Long term freshwater storage	Water does not return in the same period (e.g. it is withdrawn in a dry period and returned in a wet period)

$Q_{treated}$	m^3/year	Wastewater treated	Volume of water out of the wastewater treatment
Q_U	m^3/year	Additional water use	
Q_{Ueff}	m^3/year	Additional water discharge	Discharge from other uses such as industries, farms and energy
c(i)	mg/m^3or mg/l	Main pollutant concentration	Reference i-pollutant (after treatment)
c_{act}(i)		i-pollutant concentration of the intake water	Actual concentration of i-pollutant in the intake water
c_{max}(i)	mg/m^3or mg/l	Legal concentration of i-pollutant	Maximum acceptable concentration of i-pollutant in the receiving water body
c_{nat}(i)	mg/m^3 or mg/l	Natural concentration of i-pollutant	Natural concentration of i-pollutant in the receiving water body (c_{nat}(i)=0 for human made substances or when natural concentrationis are estimated to be low)

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

$K + Y + I \leq 1$

If the sum of K, Y and I is less than 1 it means that part of the precipitation is stored for future use.

5.2 Accounting

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.

- $Q_{prec} = PREC * A$ [m^3/year]
- $Q_{suppl} = Q_{gw} + Q_{sw} + Q_{imp}$ [m^3/year]

- $Q_{inflow} = Q_{prec} + Q_{supl}$ [m^3/year]

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.

- $Q_{civil} = Q_{suppl} – Q_U$ [m^3/year]
- $Q_U = Q_{Id} + Q_E$ [m^3/year]
- $Q_{runoff} = (Y_{perm} * A_{perm} + Y_{imperm} * A_{imperm})*PREC$ [m^3/year]
- $Q_{rt} = Q_{runoff} * R_{treat}$ [m^3/year]
- $Q_{Ueff} = Q_{Ie} + Q_E$ [m^3/year]

5.2.3 *Water fluxes out of the city indicators*

Water is leaving the city by:

- Evaporation and evapotranspiration

  $Q_{etr} =PREC (K_{perm} * A_{perm} + K_{imperm} * A_{imperm} + K_{water} * A_{water})$ [m^3/year]

- Infiltration

  $Q_{infil} = PREC * I$ [m^3/year]

- Losses

  $Q_{rl} = Q_{runoff} * R_{loss}$ [m^3/year]
  $Q_{tl} = Q_{supl} * T_{loss}$ [m^3/year]

- Export

  Q_{exp} [m^3/year]

- Sewage

  $Q_{sewage} = Q_{supl} – Q_{tl} – Q_{exp} + Q_{rt}$ [m^3/year]
  $Q_{sewage, civil} = Q_{sewage} – Q_{ueff}$ [m^3/year]

- Outflow

  $Q_{outflow} = Q_{etr} + Q_{rl} + Q_{tl} +Q_{infil} + Q_{exp} + Q_{sewage}$ [m^3/year]

5.2.4 Water storage indicator

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

- $Q_{del} = Q_{inflow} – Q_{outflow}$

5.2.5 Water footprint indicators

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

$$WFTP_{green} = PREC * K_{perm} * A_{perm} \quad [m^3/year]$$

$$WFTP_{blue} = PREC*(K_{imperm}*A_{imperm} + K_{water}*A_{water}) + Q_{del} + Q_{exp} \quad [m^3/year]$$

$$WFTP_{grey} = L/(c_{max}(i) - c_{nat}(i)) = (Q_{sewage} * c(i) – Q_{suppl} * c_{act}(i)) /(c_{max}(i) - c_{nat}(i)) \quad [m^3/year]$$

$$WFTP_{real} = WFTP_{green} + WFTP_{blue} + WFTP_{grey}$$

5.2.6 Urban and city water footprint

In many cases a city consists of agricultural and urbanized areas. In this document Urban WFTP refers to the calculated $WFTP_{real}$ with exclusion of agricultural areas whereas City WFTP means that agricultural areas were included in the calculation of $WFTP_{real}$. The overall urban/city water footprint is the sum of virtual and real parts:

$WFTP = WFTP_{cons} + WFTP_{real}$

6. Model B

Model B called also aerial model is design to present spatial distribution of water footprint indices. It assumes a division of the city area into homogenous regions called elementary modules. Moreover it is proposed to consider three types of components that significantly affect the water balance within the city:

- spatial pattern of precipitation,
- water and sewage distribution,
- land cover/use map.

The first component, spatial pattern of precipitation, will depend on numbers of precipitation stations within city and rain gauges installed on the water supply system. Information about the annual sum of precipitation recorded on each pluviometer will allow drawing isohyets. Isohyetal lines divide city area into regions with uniform amount of precipitation. Such areas can be described by P1, P2 … Pn, depending on the number of selected regions. Because amount of precipitation significantly impact on the water balance the number of regions referring to isohyets should be selected carefully. In cases when the amount of precipitation is known only for few locations Thiessen polygons can be constructed instead of isohyetal map.

The second component, water distribution area, is associated with the water treatment plants for which the water production is known. Amount of water distributed within city can be assigned to regions with uniform consumption. Such areas can be described by WD1, WD2 … WDn (WD – water distribution), depending on the number of selected regions. If more detailed data are available water consumption and sewage production can be assigned directly to the individual buildings and aggregated for each elementary module.

The last component, land cover/use map, is used to define the smallest areas (polygons) based on categories distinguished on the map. It is possible to utilize locally drawn maps or publically available European Urban Atlas [European Environment Agency]. The EUA’s main subdivision of land and water includes the artificial surfaces, surfaces with little or no human influence and waters within the city area (Figure 10).

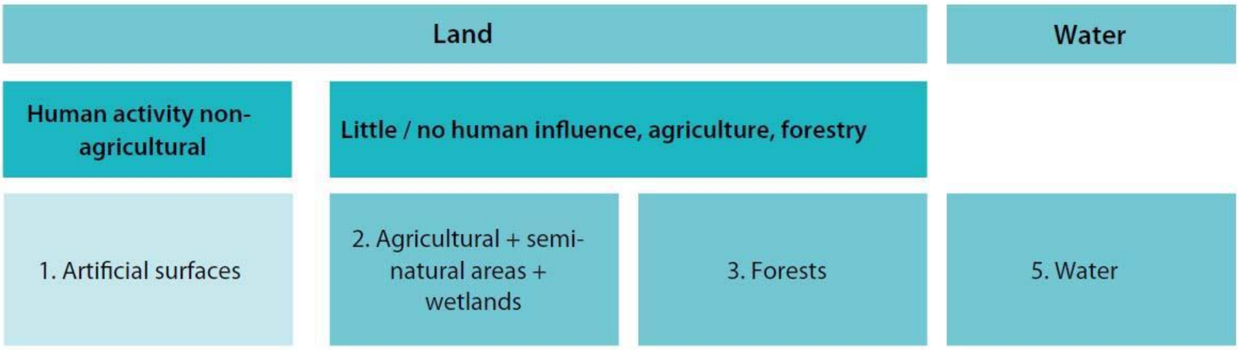

Figure 10: The main subdivision of city area

The finer subdivision of land found in EUA (Figure 11) allows to distinguish 20 mapping units which fall into the following groups:

- green areas,
- surface water,
- residential areas,
- transport areas,
- industrial areas.

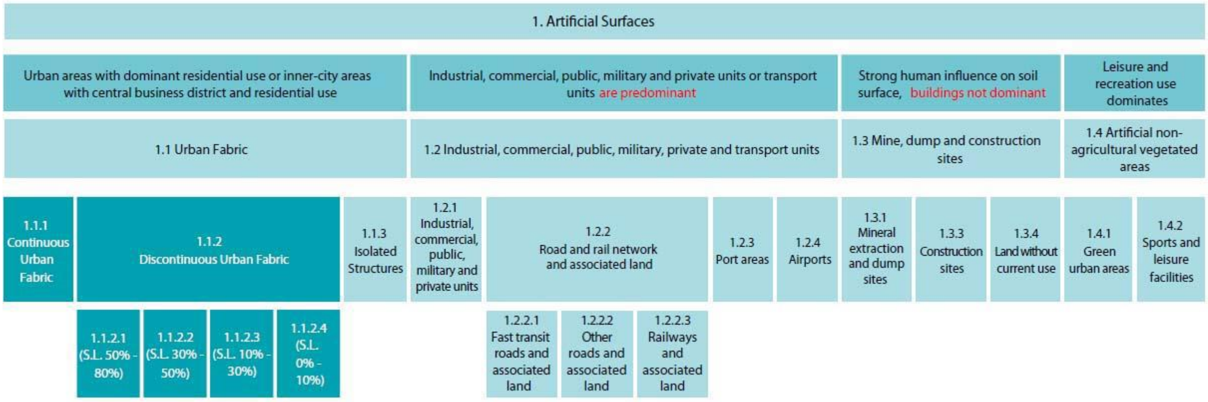

Figure 11: Subdivision of artificial surfaces within the city

Using GIS techniques elementary modules will be created by overlaying thematic maps containing information about distribution of precipitation, water use, sewage production and land units (Figure 12). Elementary modules will be represented on the intersected layer with polygons characterized by volume of precipitation (PREC), volume of water used (W), volume of sewage production (S) and type of land use (LU). Each elementary module (EM) can thus be described by:

$EM_i = f(PREC_j, W_k, S_m, LU_n)$ $(i=1,\dots I;\ j=1,\dots J,\ k=1,\dots K;\ m=1,\dots M;\ N=1\div20)$

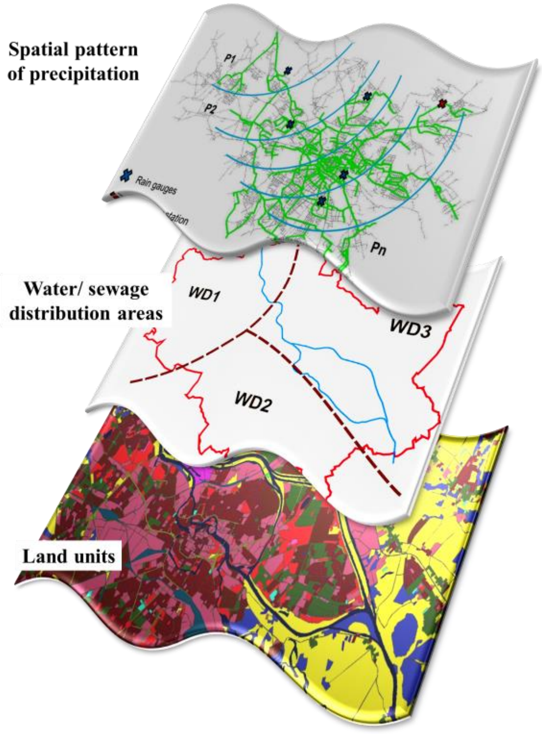

Figure 12. Determination of homogeneous regions in the city

Every elementary unit needs to be described with additional parameters such as infiltration coefficient, evaporation coefficient, runoff coefficient etc. All the characterization factors are following:

- the area of EM_i,
- total volume of precipitation falling on EM_i,
- total volume of water conveyed to EM_i and abstracted in place,
- total volume of wastewater produced by all objects located in EM_i and discharged into the sewerage system,
- pollutant concentration of outflow water discharged from a wastewater treatment plant to the receiving water body (EM_i can route wastewater to only one treatment plant),
- legal concentration of pollutant (one value for the whole region),
- natural concentration of pollutant (one value for the whole region).

6.1 Parameters

For each land unit, defined on the land cover/use map, the specific set of parameters will be determined to assess evaporation, runoff and infiltration. For this purpose the appropriate evaporation coefficients, runoff coefficient and infiltration coefficient should be chosen.

These coefficients mainly refer to elementary modules. Coefficients vary within a certain range. Especially evaporation coefficient depending on the climatic region within the Europe can differ for different types of surfaces, both permeable and impermeable. Proposal of coefficients limits found in technical literature are given in Table 10. However values of all three coefficients for each elementary module should be assigned carefully and their sum should not exceed unity.

Table 10: Runoff, infiltration and evaporation coefficients

Elementary module description	Runoff coefficient (Y)	Infiltration coefficient (I)	Evaporation coefficient (K)
Continuous Urban Fabric (S.L.>80%)	0,80 – 0,90	0,05 – 0,10	0,05 – 0,10
Discontinuous Dense Urban Fabric (S.L.: 50% - 80%)	0,65 – 0,80	0,10 – 0,20	0,05 – 0,15
Discontinuous Medium Density Urban Fabric (S.L.: 30% - 50%)	0,55 – 0,65	0,20 – 0,30	0,10 – 0,25
Discontinuous Low Density Urban Fabric (S.L.: 10% - 30%)	0,45 – 0,55	0,30 – 0,35	0,15 – 0,25
Discontinuous Very Low Density Urban Fabric (S.L.: < 10%)	0,30 – 0,40	0,40 – 0,50	0,20 – 0,30
Isolated structures	0,85 – 0,90 or 0,15 – 0,20	0,05 – 0,10 or 0,35 – 0,45	0,05 – 0,10 or 0,35 – 0,45
Industrial, commercial, public, military and private units	0,70 – 0,80	0,15 – 0,20	0,10 – 0,15
Fast transit roads and associated land	0,85 – 0,90	0,02 – 0,10	0,08 – 0,15
Other roads and associated land	0,55 – 0,65	0,20 – 0,30	0,20 – 0,30
Railways and associated land	0,50 – 0,65	0,25 – 0,30	0,15 – 0,20
Port areas	0,55 – 0,65	0,20 – 0,35	0,20 – 0,25
Airports	0,60 – 0,70	0,20 – 0,30	0,15 – 0,20

Mineral extraction and dump site	0,45 – 0,55	0,35 – 0,40	0,15 – 0,25
Construction sites	0,30 – 0,50	0,40 – 0,45	0,20 – 0,25
Land without current use	0,10 – 0,20	0,45 – 0,55	0,40 – 0,45
Green urban areas	0,00 – 0,10	0,50 – 0,60	0,40 – 0,50
Sports and leisure facilities	0,10 – 0,20	0,45 – 0,55	0,40 – 0,50
Agriculture, semi-natural areas, wetlands	0,05 – 0,15	0,45 – 0,55	0,40 – 0,50
Forests	0,05 – 0,10	0,55 – 0,65	0,40 – 0,50
Water bodies	0,90 – 1,0	0,00	0,00 – 0,10

Because there is no information how ‘isolated structures’ should be treated, coefficients are of two types: the first values as for roof surface, the second ones as for land with one structure/building.

6.2 Accounting

The calculation of WFTP using Model B should be done in the following steps:

1. division of the city area into elementary modules (EM_i) based on land use map,
2. determination of characterization factors for each EM_i,
3. determination of specific parameters for each EM_i,
4. calculation of water balance within each EM_i,
5. calculation of WFTP within each EM_i,
6. aggregation of WFTP for the whole city.

6.2.1 Water fluxes indicators

Real water balance within each elementary module (EM_i) can be calculated using the following formulas:

$Q_{inflow} = Q_{prec} + Q_{suppl}$

$Q_{outflow} = Q_{etr} + Q_{rl} + Q_{tl} + Q_{infil} + Q_{exp} + Q_{sewage}$

$Q_{del} = Q_{inflow} - Q_{outflow}$

where:

Q_{prec} – annual precipitation in EM_i

Q_{suppl} – annual water supply inflow in EM_i

Q_{etr} – evaporated volume in EM_i

Q_{rl} – runoff losses going to surface water in EM_i

Q_{tl} – freshwater losses during transportation in EM_i

Q_{infil} – rainwater infiltrating into the ground in EM_i

Q_{exp} – exported water in EM_i

Q_{sewage} – total volume of sewage in EM_i

Each component of water balance will be determined on a level of elementary module:

$Q_{runoff\_i} = (A*PREC*Y)_{\_i}$

$Q_{runoff} = \Sigma\ (Q_{runoff\_i})$

$Q_{infil\_i} = (A*PREC*I)_{\_i}$

$Q_{infil} = \Sigma\ (Q_{infil\_m})$

$Q_{evap\_i} = (A*PREC*K)_{\_i}$

$Q_{evap} = \Sigma\ (Q_{evap\_i})$

For the cities where areas of agricultural use are present, evapotranspiration can be calculated more precisely using one of available models of evapotranspiration, for example the SWAP model.

6.2.2 *Water footprint indicators*

Within each elementary module Water Footprint indicators are determined using the following formulas:

$WFTP_{green,\ i} = PREC* K_{perm} * A_{perm}$ [m^3/year]

$WFTP_{blue,\ i} = PREC*(K_{imperm}*A_{imperm} + K_{water}*A_{water}) + Q_{del} + Q_{exp}$ [m^3/year]

$WFTP_{grey,\ i} = c(i)* (Q_{sewage}) /(c_{max}(i)-c_{nat}(i))$ [m^3/year]

$VWFTP_i = WFTP_{cons} * N_{inhab}$ [m^3/year]

6.2.3 *City water footprint*

The total WFTP of the city can be obtained by aggregating WFTP indicators calculated for all homogeneous regions constituting the whole city area. The resulting formula can be written as:

$WFTP_{city} = \Sigma\ (WFTP_{green,\ i} + WFTP_{blue,\ i} + WFTP_{grey,\ i} + VWFTP_i\ )$

It is also possible to aggregate each WFTP component separately to get green, blue and grey WFTP for the whole city.

7. **Model C**

Model C represents the methodology to assess the “Local Water Footprint” of the city adopting a bottom up approach; in fact starting from the analysis of a single representative neighbourhood and its elementary modules (buildings, roads, green areas etc.), the whole city water footprint is estimated adopting a multi-linear modelling approach.

The objectives of this model are:

- to describe the water use within the municipality under study adopting a bottom-up approach and identify water use hotspots;
- to predict the water use according to new urban development (e.g. definition of new building requirements or different water management practices) and different climatic condition;
- to assess the impacts of local policies on water use;
- to take decision on more suitable local development strategies that minimizes water footprint.

This chapter present the parameters and give guidance on the application of the Local Water Footprint model.

7.1 Parameters

In this section the parameters to be used for the assessment of Local Water Footprint are presented (Table 11). Parameters consist in the data to be collected to assess the Local Urban Water Footprint.

Table 11: Local Water Footprint parameters.

Notation	**Unit**	**Name**	**Description**
$WFTP_{Blue}$	m^3/year	Blue Water Footprint of the whole city	Measures the amount of water available in a certain period that is consumed (not immediately returned within the same catchment)
$WFTP_{Blue,Buildings}$	m^3/year	Blue Water	Overall buildings present

		Footprint of buildings	in the whole city to be considered
$WFTP_{Blue,roads}$	m^3/year	Blue Water Footprint of roads	Overall roads considered
$WFTP_{Blue\ Green\ areas}$	m^3/year	Blue Water Footprint of the green areas	Overall green areas considered
$WFTP_{Blue\ surfaces}$	m^3/year	Blue Water Footprint of blue surfaces	Overall blue surfaces considered
$WFTP_{Blue\ Other\ imp\ surfaces}$	m^3/year	Blue Water Footprint of other impervious surfaces	Other impervious surfaces not considered as buildings or roads
$WFTP_{Green}$	m^3/year	Green Water Footprint of the whole city	Is the volume of the precipitation on land that does not run off or recharge the groundwater
$WFTP_{Green,\ Buildings}$	m^3/year	Green Water Footprint of buildings	Overall buildings present in the whole city with green surfaces
$WFTP_{Green,\ Green\ areas}$	m^3/year	Green Water Footprint of green areas	Overall green areas considered
$WFTP_{Grey}$	m^3/year	Grey Water Footprint of the whole city	Is the volume of water that is required to assimilate waste, quantified as the volume needed to dilute pollutants to such an extent that quality of the ambient water remains above agreed water quality standards (as model A)
$WFTP_{Grey,\ Buildings}$	m^3/year	Grey Water	Overall buildings present

		Footprint of buildings	in the whole city to be considered
$WFTP_{Grey,\ Roads}$	m^3/year	Grey Water Footprint of roads	Overall roads considered
$WFTP_{Grey,\ Green\ areas}$	m^3/year	Grey Water Footprint of green areas	Overall green areas considered
$WFTP_{Grey,\ Blue\ surfaces}$	m^3/year	Grey Water Footprint of blue surfaces	Overall blue surfaces considered
$WFTP_{Grey,\ Other\ impervious\ surfaces}$	m^3/year	Grey Water Footprint of other impervious surfaces	Other impervious surfaces not considered as buildings or roads
$WFTP_{Grey,\ not\ connected}$	m^3/year	Grey Water Footprint of the all discharges from structures not connected with wastewater treatment plants	Relevant to the structures not connected with wastewater treatment plants or facilities
Q_{exp}	m^3/year	Exported water	Volume of freshwater exported to another water basin
Q_{del}	m^3/year	Long term freshwater storage	e.g. it is withdrawn in a scarce period and returned in a wet period
$Blue_{LWF\ Buildings,i}$	m^3/year	Blue Local Water Footprint of i-esime Building	Blue water footprint of the specific i-esime building under study i= specific type of buildings

$Blue_{LWF\ roads}$	m^3/year	Blue Local Water Footprint of roads	Blue water footprint associated with the processes of washoff of all the roads that are located in the city
$Blue_{LWF\ Green\ areas}$	m^3/year	Blue Local Water Footprint of green areas	Blue water footprint associated with the processes of irrigation of the green areas
$Blue_{LWF\ Blue\ surfaces}$	m^3/year	Blue Local Water Footprint of blue surfaces	Blue water footprint considering standard evaporation from water surfaces
$Blue_{LWF\ Other\ imp\ surfaces}$	m^3/year	Blue Local Water Footprint of other impervious surfaces	Blue water footprint of other impervious surfaces not considered as buildings or roads
$Green_{LWF\ Buildings}$	m^3/year	Green Local Water Footprint of i-esime Building (private green areas)	Green water footprint of the private green areas
$Green_{LWF\ Green\ areas}$	m^3/year	Green Local Water Footprint of public green areas	Green water footprint of parks and other green public areas
$Grey_{LWF\ Buildings}$	m^3/year	Grey Local Water Footprint of i-esime Building	Grey water footprint of the different buildings located in the city
$Grey_{LWF\ Roads}$	m^3/year	Grey Local Water Footprint of roads	Grey water footprint resulting from washoff of the roads when pollutants are mobilised from surfaces during rainfall (and washing)

$Grey_{LWF\ Green\ areas}$	m^3/year	Grey Local Water Footprint of green areas	Grey water footprint of the green areas
$Grey_{LWF\ not\ connected}$	m^3/year	Grey Local Water Footprint of all structures not connected with any wastewater treatment plant	
$Q_{withdrawal,i}$	m^3/year	Water withdrawal from the i-esime Building	
$Q_{discharge,i}$	m^3/year	Water discharged from the i-esime Building	
$Q_{PREC,Evap,Building\ Impervious\ Surfaces}$	m^3/year	Rainwater evaporation from building impervious surfaces	
$constant_i$	m^3/year	Numerical constant of the multi linear regression model	Constant generates from the multi linear regression model for the specific type of elementary module
$Q_{evaporation,i}$	m^3/year	Water evaporation from domestic use	e.g.: cooking water, cleaning, evaporation of the irrigation water for the garden..
$PREC$	mm/year	Annual precipitation	Rainwater volumes per year per unit of surface
$K_{imperm-Building\ Impervious\ Surfaces}$	-	Evaporation coefficients of the i-esime building	Evaporation coefficient for the buildings respect to the rainwater volumes
$K_{imperm-roads}$	-	Evaporation	Evaporation coefficient for

		coefficients for the roads	the roads respect to the rainwater volumes
$K_{perm,i}$	-	Evaporation coefficients for the green areas	Evaporation coefficient for the green areas respect to the rainwater volumes
K_{water}	-	Evaporation coefficients for water surfaces	Evaporation coefficient for the blue surfaces that represents the normal water evaporation flow
K_{imperm}	-	Evaporation coefficients for the other impervious surfaces	Evaporation coefficient for the other impervious surfaces respect to the rainwater volumes
$A_{imperm-Building\ Impervious\ Surfaces}$	m^2	impermeable area of the i-esime building	Extension of the entire district area covered by buildings
$A_{imperm-neighborhood-roads}$	m^2	road area	Extension of the entire district road network
$A_{water-neighborhood}$	m^2	Water area	Extension of the district blue surfaces
$A_{imperm,OIS}$	m^2	Area of the other impervious surfaces	Extension of the entire district area covered by other impervious surfaces
$A_{perm,i}$	m^2	Green area	Extension of the entire district area covered by green surfaces
$Q_{PREC,Evap,R}$	m^3/year	Rainwater evaporation from roads	Volume of rainwater water that evaporates from all the roads surfaces
$Q_{first\ rain\ water}$	m^3/year	First flush rain water	Volume of runoff from a storm event with the highest concentration of contaminants
$Q_{Washing}$	m^3/year	Volume of water	Annual volume of water

		used to wash the roads	used for street cleaning
$Q_{Washing,Evap,R}$	m^3/year	Water evaporation from $Q_{Washing}$	Part of water used for street cleaning which evaporates
$Q_{Irrigation,i}$	m^3/year	Volume of water used for irrigation of green areas	Annual volume of irrigation water
$Q_{Irrigation,Evap,i}$	m^3/year	Water evaporation from $Q_{Irrigation,i}$	Part of irrigation water that evaporates before the water reaches the water basin
$Q_{Evap,BS}$	m^3/year	Water evaporation from water surfaces	Annual volume of freshwater that evaporates from blue surfaces
$Q_{PREC,Evap,OIS}$	m^3/year	Rainwater evaporation from other impervious surfaces	Annual volume of rainwater that falls on other impervious surfaces and evaporates
$Q_{PREC,Evap,Private\ green\ area}$	m^3/year	Evapotranspiration from private green areas	
$Q_{PREC,Evap,GA}$	m^3/year	Evapotranspiration from public green areas	

7.2 Accounting

The assessment of the Local Water Footprint of the city according to model C is based on the following procedure:

1. Analysis of the territory managed by the Municipality. The main characteristics of the city should be identified, such as: water management practices and technologies, water uses, characteristics of buildings, climatic conditions etc.; the objective of this step is

to determine the distinguishing characteristics of the city that influence water use; application and definitions of Model A answer these requirements;

2. Identification of relevant buildings' categories and other elementary modules (roads, water surface, green areas, other impervious surfaces etc.) representative of the territory;
3. Identification of a neighbourhood were representative elementary modules are located; this neighbourhood will be used as reference for data collection and for the assessment of blue, green and grey water footprint;. This neighbourhood in this guideline is called "pilot district".
4. Selection of a representative sample for each identified elementary module ;
5. Data acquisition: relevant inventory data on blue, green and grey water footprint for each elementary module should be collected accordingly; data acquisition can be performed using data acquisition model (see Urban water Footprint Project output 4.3.1 – Model C).
6. Definition of the multi-linear regression model based on the analysis of the collected data; such model is built on parameters representative for the water use profile of the city understudy; these are chosen based on data availability but also considering their relevance. Potential parameters can be chosen based on literature review such as from Schleich and Hillenbrand (2009) or Bennet et al. (2013); these can be for example: income, age of the building and age of the inhabitants, family size, access to private wells; (Schleich J., Hillenbrand T., 2009. Determinants of residential water demand in Germany. Ecological Economics n.68 pp 1756-1769; Bennet C., Stewart R.A., Beal C.D., 2013. ANN-based residential water end-use demand forecasting model. Expert systems with Applications n. 40 1014-1023.
7. Quantification of blue, green and grey water footprint for each basic module through the application of formula reported in this chapter;
8. Quantification of blue, green and grey water footprint of the city under study using multi-linear regression. Such results should be compared with model A results in order to assess their consistency.

A representative list of basic modules to be identified and studied follows:

- Buildings
- Roads
- Green Areas

- Blue surfaces
- Other impervious surfaces

Even if cultivated area are out of the scope of the URBAN WFTP project, this model give guidance on its water footprint assessment.

7.2.1 Local blue water footprint

The blue water footprint of the city is estimated starting from the blue water footprint of the basic modules located in the representative neighbourhood under-study. It is therefore the sum of different components and can be expressed as follows.

With this approach the basic modules can be dividend in:

1. Buildings
2. Roads
3. Green areas
4. Blue surfaces
5. Others impervious surfaces

The consistency among the Global model A and the Local model C is to be checked through the use of following equations:

$$\boldsymbol{WFTP_{Blue}} = WFTP_{Blue,\ Buildings} + WFTP_{Blue,\ Roads} + WFTP_{Blue,\ Green\ areas} + WFTP_{Blue,\ Blue\ surfaces} + WFTP_{Blue,\ Other\ imp\ surfaces} + Q_{exp} + Q_{del}$$

[m^3/year]

The contribution of the overall buildings to the total Water Footprint of the city is estimated from the contributions of the specific neighbourhood under study.

$$\boldsymbol{WFTP_{Blue,\ Buildings}} = \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Blue_{LWF,Buildings,i,j}\right)\right) = \sum_{j=1}^{nPilot}\left(\sum_{i=1}^{k}\left(Blue_{LWF,Buildings\ Pilot\ District,i,j}\right)\right) + \sum_{j=1}^{N-nPilot}\left(\sum_{i=1}^{k}\left(Blue_{LWF,Buildings\ Rest\ of\ the\ city,i,j}\right)\right)$$ [m^3/year]

k= number of different types of buildings

n= number of buildings in the whole city for the specific type

$$N = \sum n(k\ types) = number\ of\ buildings\ in\ the\ whole\ city$$

For the other basic modules, the following equations should be applied:

$$\boldsymbol{WFTP_{Blue,\ Roads}} = \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Blue_{LWF,Roads,i,j}\right)\right) = \sum_{j=1}^{nPilot}\left(\sum_{i=1}^{k}\left(Blue_{LWF,Roads\ Pilot\ District,i,j}\right)\right) + \sum_{j=1}^{N-nPilot}\left(\sum_{i=1}^{k}\left(Blue_{LWF,Roads\ Rest\ of\ the\ city,i,j}\right)\right) \quad [\mathrm{m}^3/\mathrm{year}]$$

$$\boldsymbol{WFTP_{Blue,\ Green\ areas}} = \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Blue_{LWF,Green\ areas,i,j}\right)\right) = \sum_{j=1}^{nPilot}\left(\sum_{i=1}^{k}\left(Blue_{LWF,Green\ areas\ Pilot\ District,i,j}\right)\right) + \sum_{j=1}^{N-nPilot}\left(\sum_{i=1}^{k}\left(Blue_{LWF,Green\ areas\ Rest\ of\ the\ city,i,j}\right)\right) \quad [\mathrm{m}^3/\mathrm{year}]$$

$$\boldsymbol{WFTP_{Blue,\ Blue\ surfaces}} = \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Blue_{LWF,Blue\ surfaces,i,j}\right)\right) = \sum_{j=1}^{nPilot}\left(\sum_{i=1}^{k}\left(Blue_{LWF,Blue\ surfaces\ Pilot\ District,i,j}\right)\right) + \sum_{j=1}^{N-nPilot}\left(\sum_{i=1}^{k}\left(Blue_{LWF,Blue\ surfaces\ Rest\ of\ the\ city,i,j}\right)\right) \quad [\mathrm{m}^3/\mathrm{year}]$$

$$\boldsymbol{WFTP_{Blue,\ Other\ imp\ surfaces}} = \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Blue_{LWF,Other\ imp\ surfaces,i,j}\right)\right) = \sum_{j=1}^{nPilot}\left(\sum_{i=1}^{k}\left(Blue_{LWF,Other\ imp\ surfaces\ Pilot\ District,i,j}\right)\right) + \sum_{j=1}^{N-nPilot}\left(\sum_{i=1}^{k}\left(Blue_{LWF,Other\ imp\ surfaces\ Rest\ of\ the\ city,i,j}\right)\right) \quad [\mathrm{m3}/\mathrm{year}]$$

7.2.1.1 Buildings

Blue Water Footprint of a generic building:

$$\boldsymbol{Blue_{LWF\ Buildings,i}} = Q_{withdrawal,i} - Q_{discharge,i} + Q_{PREC,Evap,Building\ Impervious\ Surfaces}$$

i = types of buildings (e.g. schools, offices, services, domestic).

$$Q_{withdrawal,i} = constant_i + f(parameters)_i$$

$$Q_{discharge,i} = Q_{withdrawal,i} - Q_{evaporation,i}$$

E.g. of different uses that generate evaporation need to be listed here (cooking water, cleaning, gardening evaporation..)

$$Q_{PREC,Evap,Building\ Impervious\ Surfaces} = PREC \cdot K_{imperm-Building\ Impervious\ Surfaces} \cdot A_{imperm-Building\ Impervious\ Surfaces}$$

It is assumed that no water- losses take place in buildings.

7.2.1.2 Roads

$$\boldsymbol{Blue_{LWF\ roads}} = Q_{PREC,Evap,R} - Q_{Washing,Evap,R}$$

$$Q_{PREC,Evap,R} = PREC \cdot K_{imperm-roads} \cdot A_{imperm-neighborhood-roads}$$

$$Q_{Washing,Evap,R} = Q_{Washing} \cdot K_{imperm-roads} \cdot A_{imperm-neighborhood-roads}$$

7.2.1.3 Green areas

$$\boldsymbol{Blue}_{\boldsymbol{LWF\ Green\ areas}} = Q_{Irrigation,Evap,i}$$

$$Q_{Irrigation,Evap,i} = Q_{Irrigation,i} \cdot K_{perm,i} \cdot A_{perm,i}$$

7.2.1.4 Blue surfaces

$$\boldsymbol{Blue}_{\boldsymbol{LWF\ Blue\ surfaces}} = Q_{Evap,BS}$$

$$Q_{\ Evap,BS} = K_{water} \cdot A_{water-neighborhood}$$

7.2.1.5 Other impervious surfaces (e.g. parking)

$$\boldsymbol{Blue}_{\boldsymbol{LWF\ Other\ imp\ surfaces}} = Q_{PREC,Evap,OIS}$$

$$Q_{PREC,Evap,OIS} = PREC \cdot K_{imperm} \cdot A_{imperm,OIS}$$

7.2.2 Local green water footprint

In this case the equation to assess green water footprint can be formulated as follow:

$$\boldsymbol{WFTP}_{\boldsymbol{Green}} = WFTP_{Green,\ \ Buildings} + WFTP_{Green,\ \ Green\ areas} \ [\mathrm{m}^3/\mathrm{year}]$$

Following the previous approach, it is possible to write this identity equation:

$$\boldsymbol{WFTP}_{\boldsymbol{Green,\ \ Buildings}} = \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Green_{LWF,Buildings,i,j}\right)\right) = \sum_{j=1}^{nPilot}\left(\sum_{i=1}^{k}\left(Green_{LWF,Buildings\ Pilot\ District,i,j}\right)\right) + \sum_{j=1}^{N-nPilot}\left(\sum_{i=1}^{k}\left(Green_{LWF,Buildings\ Rest\ of\ the\ city,i,j}\right)\right) \quad [\mathrm{m}^3/\mathrm{year}]$$

$$\boldsymbol{WFTP}_{\boldsymbol{Green,\ \ Green\ areas}} = \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Green_{LWF,Public\ \ Green\ areas,i,j}\right)\right) + \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Green_{LWF,Cultived\ areas,i,j}\right)\right) = \sum_{j=1}^{nPilot}\left(\sum_{i=1}^{k}\left(Green_{LWF,Public\ green\ areas\ Pilot\ District,i,j}\right)\right) + \sum_{j=1}^{N-nPilot}\left(\sum_{i=1}^{k}\left(Green_{LWF,Public\ green\ areas\ Rest\ of\ the\ city,i,j}\right)\right) +$$

$$\sum_{j=1}^{nPilot}\left(\sum_{i=1}^{k}\left(Green_{LWF,Cultived\ areas\ Pilot\ District,i,j}\right)\right) + \sum_{j=1}^{N-nPilot}\left(\sum_{i=1}^{k}\left(Green_{LWF,Cultived\ areas\ Rest\ of\ the\ city,i,j}\right)\right)\ [m^3/year]$$

7.2.2.1 Buildings (private green area, green roofs)

$$\boldsymbol{Green_{LWF\ Buildings}} = Q_{PREC,Evap,Private\ green\ area}\ [m^3/year]$$

7.2.2.2 Green areas (public and cultivated)

$$\boldsymbol{Green_{LWF\ Public\ green\ areas}} = Q_{PREC,Evap,Public\ GA}\ [m^3/year]$$

$$\boldsymbol{Green_{LWF\ Cultived\ areas}} = Q_{PREC,Evap,GA}\ [m^3/year]$$

7.2.3 Local grey water footprint

The grey water is calculated considering the volume and the quality parameters of the water in input to the wastewater treatment plants. The quality of this water is the result of mixing of the discharges of:

- Civil buildings
- Industrial buildings
- Public buildings

Other important aspects are represent by the grey water generated by the processes of run-off from squares, streets and cultivated areas. Therefore it is important to estimate the different qualities of wastewater that is generated in the various cases.

In this case the equation of consistency is the following:

$$\boldsymbol{WFTP_{Grey}} = WFTP_{Grey,\ Buildings} + WFTP_{Grey,\ Roads} + WFTP_{Grey,\ Green\ areas} + WFTP_{Grey,\ Other\ imp\ surfaces} + WFTP_{Grey,\ not\ connected}\qquad [m^3/year]$$

Following the previous approach, it is possible to write this identity equation:

$$\boldsymbol{WFTP_{Grey,\ Buildings}} = \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Grey_{LWF,Buildings,i,j}\right)\right) = \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Grey_{LWF,Civil\ buildings,i,j}\right)\right) + \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Grey_{LWF,Industrial\ buildings,i,j}\right)\right) + \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Grey_{LWFPublic\ buildings,i,j}\right)\right)\ [m^3/year]$$

$$\boldsymbol{WFTP_{Grey,\ Roads}} = \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Grey_{LWF,Roads,i,j}\right)\right)\ [m^3/year]$$

$$\boldsymbol{WFTP}_{\boldsymbol{Grey},\ \boldsymbol{Green\ areas}} = \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Grey_{LWF,Green\ areas,i,j}\right)\right) = \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Grey_{LWF,Public\ green\ areas,i,j}\right)\right) + \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Grey_{LWF,Cultived\ areas,i,j}\right)\right)\ [\mathrm{m}^3/\mathrm{year}]$$

$$\boldsymbol{WFTP}_{\boldsymbol{Grey},\ \boldsymbol{Blue\ surfaces}} = \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Grey_{LWF,Blue\ surfaces,i,j}\right)\right) = 0\ [\mathrm{m}^3/\mathrm{year}]$$

$$\boldsymbol{WFTP}_{\boldsymbol{Grey},\ \boldsymbol{Other\ impervious\ surfaces}} = \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Grey_{LWF,Other\ impervious\ surfaces,i,j}\right)\right)\ [\mathrm{m}^3/\mathrm{year}]$$

$$\boldsymbol{WFTP}_{\boldsymbol{Grey},\ \boldsymbol{not\ connected}} = \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Grey_{LWF,not\ connected,i,j}\right)\right)\ [\mathrm{m}^3/\mathrm{year}]$$

7.2.3.1 Buildings

Even if industries are out of the scope of the projects, these need to be addressed when looking at waste water treatment municipal facilities. Therefore its contribution to grey water needs at least to be estimated and the subtracted from the whole grey water assessed at the global level (Model A).

$$\boldsymbol{Grey}_{\boldsymbol{LWF\ Buildings}} = Grey_{LWF\ inhabited\ buildings} + Grey_{LWF\ industry\ buildings} + Grey_{LWF\ public\ buildings}$$

$\boldsymbol{Grey}_{\boldsymbol{LWF\ inhabited\ buildings}} = \frac{\left(\sum_1^j L_j\right)\cdot c_j}{(c_{max}-c_{nat})}$ j is the j-esime building

$\boldsymbol{Grey}_{\boldsymbol{LWF\ industry\ buildings}} = \frac{\left(\sum_1^h L_h\right)\cdot c_h}{(c_{max}-c_{nat})}$ h is the h-esime industry

$\boldsymbol{Grey}_{\boldsymbol{LWF\ public\ buildings}} = \frac{\left(\sum_1^m L_m\right)\cdot c_m}{(c_{max}-c_{nat})}$ m is the m-esime public building

7.2.3.2 Roads

$$\boldsymbol{Grey}_{\boldsymbol{LWF\ Roads}} = \frac{Q_{first\ rain\ water}\cdot c_{first\ rain\ water}}{(c_{max}-c_{nat})} + \frac{Q_{Washing}\cdot c_{first\ rain\ water}}{(c_{max}-c_{nat})}$$

7.2.3.3 Green areas

$$\boldsymbol{Grey}_{\boldsymbol{LWF\ Public\ Green\ areas}} = \left(Q_{PREC} + Q_{Irrigation}\right)\cdot I_{ground}\cdot C_{removal,i}$$

i is the i-esime pollutant

$$\boldsymbol{Grey}_{\boldsymbol{LWF\ Cultived\ areas}} = \left(Q_{PREC} + Q_{Irrigation}\right) \cdot I_{ground} \cdot C_{removal,i}$$

i is the i-esime pollutant

7.2.3.4 Other impervious surfaces (e.g. parking…..)

$$\boldsymbol{Grey}_{\boldsymbol{LWF\ Other\ imp\ surfaces}} = \frac{Q_{first\ rain\ water} \cdot c_{first\ rain\ water}}{(c_{max} - c_{nat})}$$

7.2.3.5 Structures not connected with any wastewater treatment plant

$\boldsymbol{Grey}_{\boldsymbol{LWF\ not\ connected}} = \frac{(\sum_{1}^{z} L_z)\cdot c_z}{(c_{max}-c_{nat})}$ z is the z-esime structure not connected

NB: the coefficients c and the volumes of water discharged L are specific for each of the models listed.

Instead, c_{max} e c_{nat} are specific for the for the receiving water body.

8. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

In order to properly use the methodology developed to asses water footprint in the urban area it is important to first clarify the goal of a water footprint assessment. If a water footprint is aimed at understanding the behaviour of the whole city as a single entity, application of Global Model A will be most helpful. Those who need to know how water footprint is distributed over the area of the city Aerial Model B will produce the relevant maps. In cases when detailed assessment of water footprint is needed for a small urban area (district, estate a parcel), Local Model C will be the most appropriate. Application of models A, B or C will result in calculation of real (direct) water use in the city. To get total water footprint of a city one need to calculate virtual water consumed within the city. Because obtaining appropriate data at this level will in most cases be difficult or impossible, the use of national statistics is recommended.

First applications of proposed methodology revealed some exceptional cases which are not covert directly by the models. The following section give explanation and suggestions how to take into consideration the fact that some cities import/export sewage, the influence of stormwater runoff and the energy consumption during the whole urban water cycle.

8.1 Import/export of sewage

Some cities do not have a wastewater treatment plant within the city boundaries but they export wastewater to the plant located in the immediate vicinity. It means that there are cases when a city is processing the imported wastewater from the neighbouring cities. This situation implies that the sewage flux entering the wastewater treatment plant is calculated as:

$$Q_{\mathrm{sewage}} = \sum_{i=1}^{n} Q_{\mathrm{sewage,i}}$$

where n represents number of cities utilising one wastewater treatment plant.

The grey WFTP of each city can be thus calculated by using the volume of sewage produced by each $Q_{\mathrm{sewage,i}}$.

8.2 Stormwater runoff

Due to pollutant washoff, stormwater runoff from impervious surfaces should be considered in the grey WFTP of an urban area. In a separate sewer system, stormwater runoff is often discharged directly into the receiving water, or to specific treatment facilities (detention and/or infiltration basins). In combined sewer systems, stormwater is discharged together with domestic and industrial waste water. The total volume of treated water thus comprises both, waste water and storm water. However, to avoid flooding due to overloading of the sewer system and to ensure a sufficient efficiency of treatment plants, storage facilities and combined sewer overflow (CSO) structures are built in the drainage system. At CSO structures, a part of the total runoff is discharged directly into the receiving water without any treatment. The actual volume of this overflow discharge to the receiving water is rarely measured and difficult to estimate on a yearly basis, as it depends on the rainfall characteristics. It is thus not directly related to the total annual rainfall. A reliable estimation of overflow discharge requires a detailed dynamic simulation model.

Implementation:

It was decided to consider the amount of treated stormwater in the grey water footprint. This volume is estimated based on the following relation:

$Q_{sewage} = Q_{du} + Q_{cu} + Q_{rt}$

As the volumes of drinking water for domestic and commercial uses, Q_{du} and Q_{cu}, are known from the water supply, the treated runoff Q_{rt} can be calculated as follows:

$Q_{rt} = Q_{sewage} - (Q_{du} + Q_{cu})$

Measurements of the total treated waste water volume Q_{sewage} are available from the central waste water treatment plant.

For consistency, the runoff coefficient for treated runoff R_{treat} must be adjusted in order to fulfil the following equation:

$Q_{rt} = Q_{runoff} * R_{treat}$

This implementation allows to investigate the effects of changes in impervious area and effective impervious area on the grey water footprint.

8.3 Energy

Processes related with water production, distribution and wastewater treatment consume energy. To include the energy consumption during the main urban water flow stages the following components of water footprint can be calculated:

$$WFTP_{water\_prod} = Q_{suppl} * E_{water\_prod} * E_{wftp}$$

$$WFTP_{water\_distr} = Q_{suppl} * E_{water\_distr} * E_{wftp}$$

$$WFTP_{wastewater\_treat} = Q_{sewage} * E_{wastewater\_treat} * E_{wftp}$$

where:

$WFTP_{water\_prod}$ – water footprint resulting from energy consumption during the production processes at the water treatment plants

$WFTP_{water\_distr}$: – water footprint resulting from energy consumption during the distribution of water to consumers

$WFTP_{wastewater\_treat}$: – water footprint resulting from energy consumption during the wastewater treatment

Q_{suppl} – volume of water produced by the water treatment plants

Q_{sewage} – volume of sewage entering the wastewater treatment plants

E_{water_prod} – specific energy consumption for the production of 1 m^3 of drinking water

E_{water_distr} – specific energy consumption for the distribution of 1 m^3 of water

$E_{wastewater\_treat}$ – specific energy consumption for the treatment of 1 m^3 of water

E_{wftp} – energy to water footprint convergence factor (Table 12)

Table 12: Energy to water footprint convergence factors*

Primary energy carriers		**Global average water footprint (m^3/GJ)**
Non-renewable	Natural gas	0.11
	Coal	0.16
	Crude oil	1.06
	Uranium	0.09
Renewable	Wind energy	0.00
	Solar thermal energy	0.27
	Hydropower	22
	Biomass energy	70 (range: 10-250)

Source: http://www.waterfootprint.org/?page=files/Water-energy

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