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WATER BALANCE OF VIENNA AS FRAMEWORK FOR A SUBSTANCE FLOW ANALYSIS OF COPPER

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Abstract

Water management is one of the essential services that secure the viability of cities. An understanding of the interaction between urban systems and the environment is crucial for such management. In this thesis, water balances are developed based on different software tools and the results are compared. In addition, a balance of waterborne copper (Cu) is established in order to link the flow of water with the flows and stocks of a substance in an exemplary way.

The goals of this thesis are i) the identification and quantification of sources, pathways and sinks of water and Cu in Vienna, ii) the use of these results to develop pollution control measures particularly for Cu, and iii) a comparison of the software tools applied with respect to practicability and adaptability.

Water and Cu balances were established for the year 2008 in two steps based on the software tools UVQ (Urban Volume and Quality) and STAN (SToffflussANalyse – Substance Flow Analysis). The first step consisted of a rough simulation of the water balance to evaluate whether outcomes are promising or not. Results of these first simulations were used to provide a framework for the second step, where both models have been improved by more detailed and revised parameters and enhanced approaches. Finally, a generic STAN model was developed to establish both water and Cu balances.

Due to a lack of measured data, results are often based on literature values, several assumptions, and simplifications. Because of the fundamental differences of UVQ and STAN, the findings of these two tools vary, especially in the case of Cu. Each tool proved to have its advantages and disadvantages: UVQ is a grey box model well suited for planning purposes, demanding a high amount of input data. In contrast, STAN is a more research oriented model that facilitates a holistic understanding of the functions and behaviour of the urban water and Cu system.

Results indicate that in Vienna, 84 % of waste water is directed to the central treatment plant and 15 % is lost via spillways. In addition, 70 % of runoff generated by rainfall reaches the sewage treatment plant, which is more than required by the relevant directives proposing 40 to 60 %. 44 % of precipitation turns into surface runoff, and 56 % is evaporating. Regarding the distribution of urban surface runoffs, paved area and road area contribute 66 % to surface runoff. Private households and industry are major waste water producers. In comparison, tourism and trade are one magnitude smaller. 52 % of wastewater in the sewer system derives from consumers, 48 % is traced back to surface runoff. 35 % of Cu originates from surface runoff, and 65 % from consumers and industry. In total, 66 % of Cu flows are controlled, and 34 are emitted to the environment without control (24 % to atmosphere, 10 % to surface waters via overflow). The major Cu import (48 %) originates from consumer products of private households, of industry, tourism and trade. Another 21 % stems from dry atmospheric deposition, and 15 % are due to transportation activities.

In conclusion, despite a lack of data, the application of the models yielded plausible and useful results. For the future, improvement of the availability of data concerning waste water volumes and Cu content in Vienna soils is suggested. Moreover, an investigation of Cu retained in soil is recommended. Finally, a comprehensive investigation of wastewater and substance flows from private households, industry and trade is proposed for the sustainable management of urban metabolism.

Content

1. Introduction 1
2. Aim and tasks of this thesis 3
3. General background 4

3.1 Water Balance 4
3.1.1 Definition 4
3.1.2 Previous Case Studies in Urban Areas 4
3.1.2.1 Grimmond, Oke et al. (1986) 4
3.1.2.2 Van de Ven (1990) 5
3.1.2.3 Maier, Punz et al. (1995) 5
3.1.2.4 (Mitchell, Mein et al. 2001); Mitchell, McMahon et al. (2003) 8
3.1.2.5 Mitchell and Diaper (2006) 9
3.1.2.6 Huang, Bader et al. (2007) 9
3.1.2.7 Wolf, Klinger et al. (2007) 10
3.1.2.8 Martinez, Escolero et al. (2011) 10
3.1.2.9 Kenway, Gregory et al. (2011) 11
3.1.2.10 Case Study for the City of City-of-Berlin (2012) 12
3.1.3 Similarities of previous studies 14
3.1.4 Lessons learned 15

3.2 Substance Flow analysis 16
3.2.1 Definition 16
3.2.2 Previous Case Studies in Urban Areas 16
3.2.2.1 Malmquist and G. (1983) 16
3.2.2.2 Henseler, Scheidegger et al. (1992) 17
3.2.2.3 Bergbäck, Johansson et al. (2001) 17
3.2.2.4 Seelsaen, McLaughlan et al. (2007) 18
3.2.2.5 Chèvre, Gremaud et al. (2010) 18
3.2.3 Similarities of previous studies 19
3.2.4 Lessons learned 19

3.3 Software Tools 21
3.3.1 UVQ – General Introduction 21
3.3.2 UVQ - Results of the software 22
3.3.3 STAN - General Introduction 23
3.3.4 STAN - Results of the software 24

4. Material and Methods 26

4.1 Study Area Vienna 26

4.2 UVQ - Approach 30
4.2.1 Stage 1 30
4.2.2 Stage 2 31

4.3 UVQ Stage 1 - Parameters 32
4.3.1 Project Information 33
4.3.2 Physical Characteristics 33
4.3.3 Water Flow 39
4.3.4 Calibration Variables 39
4.3.5 Snow Variables 44
4.3.6 Land Block 45
4.3.7 Neighbourhood 46
4.3.8 Study Area 48
4.3.9 Climate Input File 48
4.3.9.1 Rainfall 49
4.3.9.2 Temperature 50
4.3.9.3 Evapotranspiration 50

4.4 UVQ Stage 2 – Revised Parameters 51
4.4.1 Project information 52
4.4.2 Physical characteristics 52
4.4.3 Calibration variables 58
4.5 STAN - Approach 62
4.5.1 Stage 1 62
4.5.2 Stage 2 62
4.6 STAN Stage 1 - Parameters 65
4.6.1 System Boundary 65
4.6.2 Import Flows 65
4.6.3 Export Flows 65
4.6.4 Internal Flows 66
4.6.5 Internal Processes 68
4.6.6 External Processes 69
4.7 STAN Stage 2 – Revised Parameters 70
4.7.1 System Boundary 70
4.7.2 Processes 70
4.7.3 Import Flows 71
4.7.4 Export Flows 76
4.7.5 Internal Flows 78
5. Results, Discussion and Interpretation 85
5.1 UVQ 85
5.1.1 Stage 1 – water balance 85
5.1.2 Stage 2 – water balance 87
5.1.3 Stage 2 – copper balance 90
5.2 STAN 94
5.2.1 Stage 1 – water balance 94
5.2.2 Stage 2 – water balance 96
5.2.3 Stage 2 – copper balance 102
6. Conclusion and Future Prospects 110
6.1 Conclusion 110
6.2 UVQ and STAN – a comparison 113
6.3 Future Prospects 115
7. Literature 116
8. Figures 122
9. Tables 124
10. Curriculum Vitae 125
11. Eidesstattliche Erklärung (declaration in lieu of oath) 127

1. Introduction

Supply with potable water and environmentally compliant treatment of wastewaters are major services in urban areas. These services are part of urban systems exhibiting unique water balances. Urban water balances are differ in their establishment compared to rural water balances due to a unique micro climate (oasis-type advection) influencing evaporation (Grimmond, Oke et al. 1986; Van de Ven 1990), complex supply systems with multiple reservoirs (Rozos and Makropoulos 2013) and other factors, such as water use patterns, water leakage within supply systems and more (Moglia, Perez et al. 2010). A holistic management approach puts a focus on paths water takes along its entire route through cities. The complexity of urban water systems and urban water balances in particular led to a high number of publications in these sectors. Scopes of these reach from a strict focus on water balancing (Mitchell, McMahon et al. 2003), across combined water balance – substance balance models (Chèvre, Guignard et al. 2011), combined water balance-management tools (Rozos and Makropoulos 2013) to complex heat-flux-material-water-balance models (Järvi, Grimmond et al. 2011). Many authors emphasize the importance of a holistic understanding of interactions between water and urban environment for water management purposes (Mitchell, McMahon et al. 2003; Mitchell and Diaper 2006; Martinez, Escolero et al. 2011; Charalambous, Bruggeman et al. 2012). Yet these studies differ widely in scope and limitations, study areas, goals and methods. water balances and cycles in recent studies have been modelled for catchments reaching from 29 km² (Semádeni-Davies and Bengtsson 1999) or 420 inhabitants (Grimmond and Oke 1986) up to several million inhabitants and thousands of hectares of study area (Kenway, Gregory et al. 2011; Martinez, Escolero et al. 2011). Each study is unique due to influences of parameters specific for each urban area. However, difficulties faced whilst performing an urban water balance were more uniform. The main problem for many authors was the lack of necessary data for proper performance of the used software or the applied model.

In this thesis the focus will be put on the city of Vienna, which manages its water-flows with a sectoral approach. Department 31 of the Viennese city administration is responsible for freshwater management, whereas department 30 deals with wastewater. Yet no complete picture revealing water-flow and waterborne material flows from source to sink exists. A large number of local studies focuses on selected parts of the water network, yet none of them pictures the entire water and waterborne substance flow system. Thitherto no holistic overview reflecting the system, starting with import of substances due to anthropogenic activities and goods into the city and ending with treatment and discharge into receiving waters, exists. It is essential to develop an improved understanding of the urban metabolism using the example of Vienna. Such an improved understanding serves as measure to identify sources and causes of material input to wastewater treatment plants and hence allows application of source-oriented measurement-approaches for emission reduction. Furthermore it reveals which released material-loads reach the wastewater network and which stay in urban soil, eluding the control of sewage management. Van de Ven Van de Ven (1990), lists 6 main reasons for carrying out such a study, of which two reasons are focused on in this thesis:

a. assessing the amount of flow along the (or certain) pathways;

b. assessing the pollutant loads along the (or certain) pathways;

To achieve a holistic view of Vienna's water system, its water balance will be modeled using and comparing results of two different software tools – STAN (SToffflussANalyse, the german word for substance flow analysis) and UVQ (Urban Volume and Quality). Comparisons of two software tools within the framework of a water balance of a single city are rare in previous studies which mainly focused on one software tool or one individual water balance model. The

only recent investigation, comparing the performance of two different software tools was achieved by Cleugh, Bui et al, who compared the two tools SUES (Single-source Urban Evapotranspiration-interception Scheme) and Aquacycle (Cleugh, Bui et al. 2005). Aquacycle (Mitchell, Mein et al. 2001) is the basis for the later developed software UVQ (Mitchell and Diaper 2006) which is used in this thesis.

It is expected that this thesis will provide a better insight into Vienna's water cycle and may provide assistance in future water management issues.

2. Aim and tasks of this thesis

Goal is the development of a water balance of Vienna for an assessment of the Viennese sanitation concept. Main focus is put on the identification of water and copper flows and their sources, as well as an assessment of their dimension and relevance. Further, control possibilities of anthropogenic copper-loads and the suggestion of measures for handling uncontrolled copper-flows are of concern.

According to this, following questions arise:

- Are there any case studies of other urban areas concerning a holistic water- and material-balance? What was the goal in these works, on which questions was focused on and which methods, respectively which data were used to answer these questions.
- Which processes and flows are necessary to picture the Viennese water and waterborne copper balance?
- Which part of copper-flows reaches thermal treatment or wastewater treatment plants and is therefore subject to a possible control? Which fraction reaches environmental-media untreated?
- To what extend are model-results of STAN and UVQ comparable? Where are the methodic and result-relevant differences?

To answer these questions, a holistic and cohesive water-balance of Vienna will be developed, followed by an identification of origins, paths and sinks of copper. For both steps STAN and UVQ will be used. STAN is a generic tool to picture material-balances with the application of an equation for balancing processes. It was developed by the Vienna University of Technology (FAR). UVQ is a process-based model serving simulation of urban water-balances. UVQ was developed by CSIRO in Australia. It determines water- and material-mass-flows from origin to depression within a water-cycle.

Below, the approach in this thesis is given:

1. Literature study of case studies – chapter 3, starting on page 4
2. Development of a rough water balance using UVQ and STAN (base year 2008, over the period of 1 year) – chapter 4, starting on page 26.
    a. Qualitative model-development (definition of processes and flows) and specification of the processes.
    b. Generation of model-equations
    c. Data-gathering
    d. Calculation of flows
    e. Balancing of the system
    f. Conclusion and identification of knowledge gaps
3. Development of a refined balance using results and new insights from the first UVQ and STAN models – chapter 4, starting on page 26.
4. Interpretation of results, comparison of the model-approaches of STAN and UVQ and conclusion – chapter 5 and 6, starting on page 85.

3. General background

This chapter will provide the reader with general background information of water balancing and Substance Flow Analysis and will analyse recent studies on both.

3.1 Water Balance

First, a definition of the term water balance used in this thesis will be given, followed by an analysis of a selection of previous studies on the subject, covering several decades. Selected studies were chosen due to their relation with the context of this thesis.

3.1.1 Definition

The water balance in this thesis is a mass balance which will be designed with the help of a material flow analysis as stated by Baccini and Brunner (2012), who describe such a balance as an “analysis of flows and stocks of goods”. The goal of a material flow analysis is “to determine the density, transformation, and flow of a material in a given system over a certain period of time” (Baccini and Brunner 2012).
In general a water balance can be explained as written by Mitchell, McMahon et al. (2003), who state that the principle of mass conservation is applied in a water balance, due to consideration of water movement in the land phase of the hydrological cycle for a given area and time period.

3.1.2 Previous Case Studies in Urban Areas

3.1.2.1 Grimmond, Oke et al. (1986)

The study by Grimmond, Oke et al. is one of the first dealing with the complex problem of an urban water balance. This study introduced a new model for calculation. To achieve the balance, the formula below was used:

$$p + I = r + E + \Delta S$$

p is the precipitation, I represents the piped in water, r is runoff, E stands for evapotranspiration and finally ΔS represents the change of the water storage.

The difference of the urban hydrological cycle to undeveloped areas was recognised and two urban subsystems were defined – the “internal system”, including water related to buildings and the “external system”, which includes all the remaining parts of the urban water cycle. Spatially the model was separated into impervious, pervious non-irrigated and pervious irrigated areas. Yet another innovation of this article was the introduction of a model to calculate evapotranspiration of urban areas, due to the fact that simply no model existed back in 1986. The model was an improvement of a well known combination model in order to take urban idiosyncrasies into account. It was possible to include variable surface types and to take the so called “oasis-type” advection into account. Two different equations for two different states of surface wetness were introduced: wet and moist/dry.

The sensitivity analysis revealed that the model which consists of a relative simple scheme for partitioning water and a complex model for evapotranspiration, is with two minor exceptions a linear one.

The model was then tested for a period of one year for a suburban site in Vancouver, British Columbia, which covered an area of approximately 21 hectares and was home to 420 residents. The model illustrated values for the internal and external system using the units L (litres) and mm (millimetres).

One of the difficulties in this study was to validate the model due to the lack of data for the study area. Grimmond states that all data used in this model was easily gathered, however, a hint was given that some necessary data may not be gathered periodically (heat flux and net radiation data).

This model was one of the first applied to investigate the water mass balance of an urban area, however it did not yet picture any flow paths, but presented values as a result.

3.1.2.2 Van de Ven (1990)

Van de Ven explains water balances of urban areas and correlated challenges in general. The article does not investigate a hydrological cycle of a specific urban catchment. Yet this article provides a good overview about the topic.

According to this article six objectives for application of an urban water balance exist, of which two are especially important in context of this thesis. These two are, as mentioned earlier, assessment of the amount of water-flow along a pathway and assessment of pollution loads – especially copper – along a pathway.

Furthermore, the author points out that despite differences between each urban water balance due to manifold variables (climate, stage of development, sewer system), the hydrological cycle of each city has two major water sources and two pathways, namely: the atmosphere and the public water supply and the surface/sewer pathway and the groundwater pathway.

Finally, Van de Ven also identifies weak points of urban water balances. Following listing summarizes the most important mentioned challenges:

- Estimation of evapotranspiration is seen by Van de Ven as the weakest point
- Availability of measured data on water budget of urban areas is limited
- Measurement of exact data is extremely difficult in urban environments, errors of 10 – 20% are common
- Water balances are not well suited for large urban areas due to spatial variability

3.1.2.3 Maier, Punz et al. (1995)

This study carried out in 1994 by Maier was the first to investigate the water balance of Vienna, however without application of any software tools. It is one of the most important studies with regards to this thesis due to its similarity. The major focus was put on determination of the distribution of precipitation water.

Two equations describing natural and anthropogenic water balances were used:

$$Z_o + A_o + Z_{GW} + A_{GW} + D_{Sp} + NS + ET_0 + S_0 = 0$$

For the natural water balance equation, following applies:

Z_o ... above-ground inflow

A_o ... above-ground discharge

Z_{GW} ... groundwater recharge

A_{GW} ... groundwater discharge

D_{Sp} ... change of natural water storage

NS ... areal precipitation

ET_0 ... actual natural evapotranspiration

S_0 ... natural transformation via metamorphosis and respiration

Several anthropogenic flows are added to the anthropogenic equation

$$Z_a + A_a + D_{Spa} + ET_a + V_a + E_{GW} + S_a$$

Z_a ... water supply and sanitation network inflow

A_a ... water supply and sanitation network discharge

D_{Spa} ... change of water storages

ET_a ... anthropogenic evapotranspiration due to irrigation

V_a ... anthropogenic caused percolation

E_{GW} ... groundwater extraction

S_a ... anthropogenic substance transformation

It is mentioned that knowledge of necessary parameters varies widely. Some are measured meticulously, others are calculated using rough assumptions. Further, inaccuracy in order of magnitude of 5 to more than 10 % is common.

As visible above, water flows entering and exiting the city and water flows within the city are considered. The major input flows are above-ground inflows, water supply and sanitation network inflow, precipitation and groundwater recharge. Water contained in food is mentioned as well, however this flow is of minor importance and could also be left unconsidered. Major export flows are natural and anthropogenic discharge and natural and anthropogenic evapotranspiration. The Danube is identified to dominate all other natural and anthropogenic flows by a factor of over 100. First results can be seen in Table 3.1 First water balance of Vienna by Maier (1995).

Table 3.1 First water balance of Vienna by Maier (1995)

Inflow		m³
Z_o	above-ground inflow (Rivers Wien & Liesing)	19560000
Z_a	water supply and sanitation network inflow	143847000
NS	precipitation	255056800
Discharge		
A_o	above-ground discharge (Rivers Wien & Liesing)	59483000
A_a	water supply and sanitation network discharge	182303000
D_{Spa}	change of water storages	399100
ET_a	anthropogenic evapotranspiration due to irrigation	12679000
ET_0	actual natural evapotranspiration	-

Actual natural evapotranspiration was not calculated in this first balance, this balance was actually used to approximate this parameter. The result for evapotranspiration determined with help of this first rough balance were 425 mm or 176 Million m³. Apparently, as many other authors, Maier had difficulties to estimate evapotranspiration. He mentions several studies and assumptions concerning this parameter which vary widely, however they all agree on the point

that evapotranspiration in urban areas is significantly smaller than in rural areas. This fact underlines the challenge of picturing correct values for evapotranspiration in urban areas.

A further difficulty Maier faced was the quantification of groundwater flows. However, he determined groundwater flows to be only a minor contributor to the Viennese water system and simply disregarded this factor.

Indoor water use was separated in nine categories, including toilet flush, shower and bathroom, laundry, cleaning, washing of hands and hair and more.

To determine stormwater discharge within the area of Vienna, a classification into several land use categories was carried out and assumptions about discharge coefficient and vegetation cover were taken. Six different land use categories were established:

- Residential area combined with garden
- Mixed residential area
- Trade and commerce
- Industrial area
- Railway traffic area
- General traffic area

Further, the so called “Wienerwaldbäche”, streams discharging from the surrounding forests into the sewer system, were considered, summing up to an annual discharge volume of 0.94 million m³. The stormwater discharge into the sewer system was calculated to be 40,379,801.5 m³.

Figure 3-1 illustrates the final water balance established by Maier (1995). Of 255.1 Million m³ precipitation water, 163.6 Million m³ evaporate, 50.3 Million m³ percolate, 15.7 Million m³ discharge into the sewer and 25.5 Million m³ stay in the system.

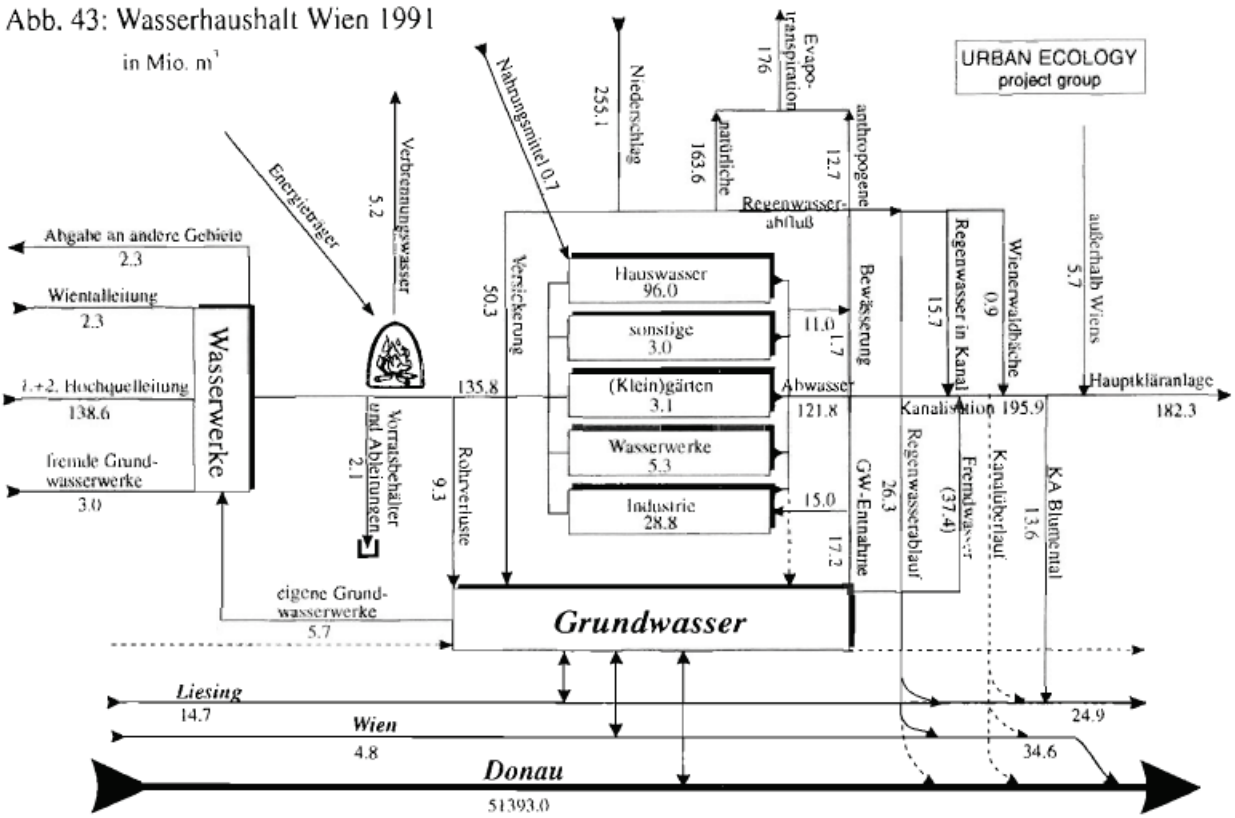


Figure 3-1 water balance Vienna 1991

This study was the first to establish a water balance of Vienna and it offers first reference points for this thesis. However, the software tools will differ widely from the approach used to achieve this balance. UVQ considers less indoor water use categories and needs detailed land use

information, however taking streams into account is not possible. Therefore STAN gives the opportunity to picture the entire water balance of Vienna more detailed in comparison with this study due to new data and the possibility of consideration of results calculated with UVQ.

3.1.2.4 (Mitchell, Mein et al. 2001); Mitchell, McMahon et al. (2003)

In this section two articles are analysed at once due to strong connection and interdependence. The former article deals with development of the water balance model “Aquacycle”, which is the framework for the later developed UVQ-model. The second article puts a focus on application of “Aquacycle” to a catchment in Australia.

Mitchell emphasizes the importance of a more holistic view of urban water systems, taking water supply, wastewater disposal and stormwater drainage into account, rather than focussing on detailed assessment of only components. To achieve such a more holistic view and picture available resources, the model “Aquacycle” was developed.

To picture spatial variability of an urban water system, three spatial scales were introduced in the developed model:

- The unit block – represents the smallest scale - a single household, industrial site or institution
- A cluster – is a group of uniform unit blocks and therefore represents a neighbourhood
- A catchment – is formed by a group of clusters, e.g. areas of single land use

Mitchell also states that the model is a continuous model, due to aspects of evaluation for water management purposes.

Input to the urban water cycle is given by precipitation and imported water, whereas output consists of evapotranspiration and stormwater or wastewater. Evaporation is considered as largest single output from a city and is calculated separately for pervious and impervious areas. Furthermore the model applies some simplifications, e.g. the assumption that all in-house water use becomes wastewater without any losses, the assumption that irrigation is fully effective and the simplification of modelling inflow and infiltration at a daily time step. Mitchell also states that several processes are not included in the Aquacycle model due to their rating as minor flowpaths, e.g. overflow of wastewater from sewers, stormwater pipe infiltration and others. Aquacycle is also not capable to simulate water quality.

Calibration and verification of the Aquacycle model was performed in Woden Valley, a region south west of Canberra City, covering 30 km². The same Valley inhibits the Curtis Catchment, which is subject of the latter article by Mitchell in 2003.

Mitchell defines the term “water balance” as “the comprehensive evaluation of the inputs, outputs and movements of water within an urban control volume”. To achieve this evaluation following formula is used:

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

ΔS represents the change in the catchment storage. On the input side, P stands for precipitation and I is imported water. On the output part E_a represents the actual evapotranspiration, R_s is stormwater runoff and R_w represents wastewater discharges.

Necessery input data for Aquacycle are:

- Precipitation - measured by three rainfall gauges,
- Potential evapotranspiration - calculated with use of Morton’s wet environment areal evapotranspiration formula
- Stormwater runoff - measured at four points in the catchment,
- Wastewater flow - recorded at one gauge,
- Water use - estimated from daily water use records of Canberra,
- Indoor water usage profile,

- Percentage area irrigated,
- Potable water leakage (estimated) and
- Surface coverage and land use, derived from Orthophoto-maps.

Calibration and validation was performed using the objective function SIM/REC, which is the sum of simulated flow (SIM) divided by the sum of recorded flow (REC). The result for SIM/REC was 1.03 with a standard deviation of 0.06 for water supply and 1.01 with a standard deviation of 0.07 for stormwater flow.

Like in other studies, Mitchell faced several challenges applying the newly developed model, the most important difficulties mentioned were:

- The blurring of natural catchment boundaries due to large infrastructure and impact of urban areas
- Evapotranspiration is described as more complex due to the highly variable microclimate of urban areas.
- Lack of data – in Mitchells case especially a lack of data concerning water use, therefore an estimation with data of a different city was necessary

Result of the development of a new model and its application were the calculation of a continuous daily water balance model in the Curtis Catchment. The articles concluded that evaluation of an urban water balance provides many advantages for urban water management and urban planning and helps to understand impacts of urbanization on the hydrological cycle.

3.1.2.5 Mitchell and Diaper (2006)

In this paper Mitchell presents the improvements of research in recent years, the so called “UVQ model”, which is a water and contaminant daily simulation model of the total water cycle. UVQ is the acronym for Urban Volume and Quality.

This model is an extension of the existing Aquacycle model by Mitchell, Mein et al. (2001) and was designed for simulation of urban water systems from source to discharge point. This includes estimation of pollution loads and concentrations as well as urban water flow volumes.

The major inflows within this model are imported water supplies and rainfall, whereas wastewater, stormwater and evaporation are the major outflows of the urban water cycle.

Mitchell explains that UVQ features a significant difference to other stormwater models: the linkage of rainfall-runoff network and water supply-wastewater network through processes such as garden-irrigation, stormwater inflow and infiltration into the wastewater system.

The model uses some simplifications, but Mitchell states that the major focus is put on integration and modelling of the complete urban water cycle, rather than on performing complex modelling of water or pollution flows.

A more detailed review of the programme UVQ will be given in Chapter 4 – “Material and Methods”.

3.1.2.6 Huang, Bader et al. (2007)

Huang, Bader et al. (2007) established a mathematically extended Material Flow Analysis for the city of Kunming, China, home to 2.4 million inhabitants, covering an area of 18000 hectares. The system boundary is the settlement of Kunming itself, situated in the catchment of lake Dianchi. The time period for the analysis was one year. For modelling the software SIMBOX® was used in this paper. The method was approached in four steps:

1. System analysis
2. Model approach
3. Data acquisition
4. Calibration and simulation – includes sensitivity and uncertainty analysis

The modelled system was classified into seven balance volumes and 23 flows, which are divided into input flows, internal flows and output flows. The authors developed several Input, Input-Output and specific equations to picture the system.

The data acquisition for the catchment proofed to be a challenge, due to the lack of available data. Therefore literature values as well as data from reference cases in Switzerland were used to estimate necessary variables. A water consumption pattern similar to Zurich was established: Bath:Kitchen:Laundry:Urine Flush:Faeces Flush = 7:4:4:4:1.

Due to a shallow groundwater table, sewer infiltration had to be considered in Kunming City and hence was estimated on basis of the dilution of inflow into the local waste water treatment plant.

The two main findings with regards to urban water balance were following:

- Kunming's wastewater collection has an efficiency of only 30%, leaving large amounts of water discharged untreated into receiving waters
- Sewer infiltration reaches the same quantity of sanitary wastewater discharged into the sewer network during dry weather conditions.

3.1.2.7 Wolf, Klinger et al. (2007)

This study is one of the most related ones to this thesis. In the course of the project AISUWRS (Assessing and Improving the Sustainability of Urban Water Resources and Systems) the authors applied the UVQ software to holistically quantify mass fluxes within the urban drainage system of the city of Rastatt, Germany. Rastatt has an approximated population of 50000, living in an area of 10.65 km². 30 % of sewers are considered to be situated below the shallow water table, which lies between 1 to 5 m below the ground. Water flows were expressed in m³/m²/a or in mm/a.

The authors faced difficulties to satisfy the large data demand posed by UVQ. Data was gathered using different methods, thus following data acquisition methods can be distinguished:

- Site specific measured data for the entire model area
- Site specific determined data via extrapolation
- Literature data with local context
- Literature data from international studies, therefore without local context

The authors also mention that for verification of the validation of model results, parameterization of assumptions on contaminant loading needs to be questioned. Therefore several adjustments were applied during the calibration process to reproduce the measured contaminations. This approach is also recommended in the UVQ User Manual (Mitchell and Diaper 2010). To assess uncertainty in pollutant load predictions from the sewer systems, the Monte Carlo Method was used.

Results illustrated that approximately 50 % of 1091 mm/a precipitation entered the pervious soil store directly. Road, roof and pavement runoff contributed an extra 51 mm/a, whereas 20 mm/a were supplied by leakage of water distribution systems. In total, 616 mm/a were added to the soil store, of which 269 mm/a or about 44 % evaporated and 347 mm/a or 56% infiltrated to the groundwater table. Irrigation only played a very minor role.

For the entire study area, 322 mm/a or 29.5 % of precipitation evaporated.

The results were pictured in a water balance diagram.

3.1.2.8 Martinez, Escolero et al. (2011)

The article of Martinez applies the UVQ model for San Luis Metropolitan Zone (ZMSLP) for reasons of quantification of water and contaminant balance and assessment of flow paths and pollution concentrations.

The study area has an estimated population of 1.1 million inhabitants and covers an area of 14754 hectares.

Martinez identifies the fact that the lumped parameter approach – which is used in UVQ – allows adequate reduction of the spatial complexity, while it still keeps major cause-effect relationships within the highly complex environment of an urban area. Martinez further draws the conclusion that this is the main reason behind the daily time step used in UVQ, which indeed underestimates peak floods, but in return provides a satisfying accuracy in the water balance.

In this study the UVQ Setup was established as follows:

To distinguish neighbourhood types in UVQ, two criteria were introduced: similar land use and similar sewer systems. Due to the fact that ZMSLP possesses a combined sewer system, neighbourhood similarity in this study was defined with the help of homogeneous water use and occupation rates. As a result, ten representative land uses for the urban area were classified. Distinction between pervious and impervious areas as well as the percentage of irrigated areas was achieved with help of aerial imagery and GIS data. The number of inhabitants for each block within a neighbourhood was calculated through official data of the National Institute INEGI. For estimation of indoor water consumption literature data was gathered. Water quality data was acquired conducting field measurements, gathering of local data and with help of the local water utility. For quality data of rainfall and its runoff, six measurement stations were installed.

Calibration of the model was achieved in two steps. During the first step, wastewater flows were compared with measurement studies. The second step included discharge measurements and chemical analysis of wastewater at the outlet of a smaller catchment which were then extrapolated to the area of ZMSLP to compare modelled and real contaminant concentrations.

One reference year was chosen to determine the daily urban water balance of the area. Calibration took place in the baseline scenario, which was the framework to develop and compare three further scenarios, reaching from water demand change to different recharge and supply strategies.

As in every study, challenges occurred, again especially a lack of data. In this paper the authors struggled with gathering of data for indoor water use, making them revert to literature values.

Results of the model delivered insight into the interdependencies within the water system of ZMSLP and emphasized the importance of an integration of urban water resources management.

3.1.2.9 Kenway, Gregory et al. (2011)

This journal article is one of the latest in the study-area of water balances and it considers the largest areas. Kenway analysed the urban areas of Sydney, Melbourne, South East Queensland and Perth using a mass balance method to quantify fluxes in and out of these areas. Units used were mm (millimetres) and GL (Gigalitres).

Following formula to evaluate the flows was used:

$$\Delta S = C + D + P - (W + R_S + G + ET)$$

ΔS is the change of storage, C represents imported or centralized water, D represents decentralized input from groundwater or rainwater tanks, P is input trough precipitation. Outputs are represented by W, which is wastewater discharge, R_S, stormwater runoff, G represents flows to groundwater and ET, which represents actual evapotranspiration.

Some major problems in this article were faced with acquisition and evaluation of data. Kenway mentions difficulties with the quantification of stormwater discharges as well as outflows to groundwater. Yet another challenge was faced in inconsistent characterization of the system

boundary due to vague land-use definitions. Finally, the determination of accurate Volumetric Runoff Coefficients proved to be a challenge.

The study did not use any software to assess the water balance.

3.1.2.10 Case Study for the City of City-of-Berlin (2012)

The city of Berlin, Germany operates an online digital environmental atlas picturing data concerning soil, water, air, climate, biotopes, land use, traffic and energy for the entire city. Water data is simulated using the ABIMO runoff model, a tool quite similar to UVQ. Figure 3-2 Flow Chart of the ABIMO model presents an illustration of the flow chart of the ABIMO model. According to the website of the city of Berlin following parameters are considered:

Mean annual values (mm/a)

$\overline{P}_1$	precipitation (1 m above the ground)
$\overline{P}$	precipitation at the soil surface
$\overline{KR}$	capillary rise from ground water near surface
$\overline{EP}$	potential evaporation $\left(\overline{EP} = 1{,}1 * \overline{EP}_{TURC}\right)$
$\overline{ETR}$	real evapo-transpiration of vegetation covered land areas
$\overline{EG}$	evaporation from bodies of water
$\overline{E}$	real evaporation of impervious areas and areas without vegetation (and from the surfaces of bodies of water)
$\overline{BER}$	amount of precipitation water
$\overline{Z} = \overline{P} - \left(\overline{E}, \overline{ETR}, \overline{EG}\right)$ $\left(\overline{E}, \overline{ETR}, \overline{EG}\right) \succ \overline{P}$	depletion of ground and surface water
$\overline{R}_v$	total runoff (impervious area)
$\overline{R}_{uv}$	total runoff (pervious area)
$\overline{ROW}$	rainwater and/or meltwater runoff from impervious area into the sewer system (or stream)
$\overline{RI}$	iinto the soil (below the zone influenced by evaporation)

Impervious areas (in %)

BAU	roof area
VGU	courtyard and parking areas (non-built-up impervious areas)
VER_STR	streets
BLK 1, ..., 4	impervious-coverage class of non-built-up impervious area
KAN	percentage of impervious areas connected to the rainwater drainage system

Land use of pervious areas

L	agricultural land use (incl. pastures)
W	forest land use (assuming of an even distribution of stocks with respect of age)
K	horticultural land use (programme intern: BER = 75 mm/a)
D	area without vegetation
G	area of surface water

Soil type

NFK	useable field-moisture capacity (moisture by volume [vol%] of field-moisture capacity minus vol% of permanent wilting point)
S, U, L, T	indication to soil type (sands, silts, clays;

N, H	low bog, high bog) for the determination of capillary ris
depth to ground water and capillary rise	
TG	depth to the water table (value in m - FLW) for the determination of K
TA	height of rise (m), TA = TG - TW
TW	mean effective root depth (m)

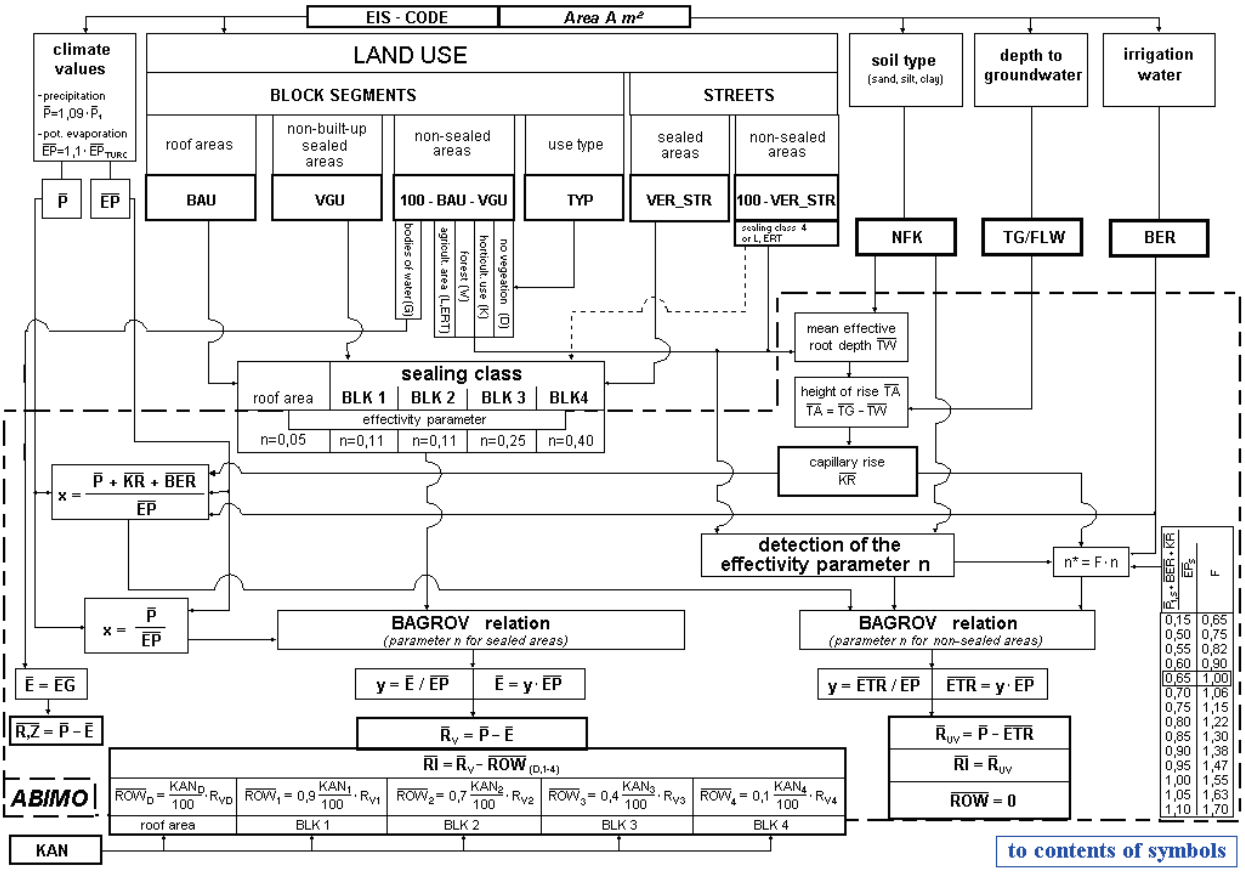


Figure 3-2 Flow Chart of the ABIMO model (www.stadtentwicklung.berlin.de, accessed 17.04.2013)

The most important results and findings of this case study regarding to this thesis concern surface runoff, percolation, total runoff and evaporation from precipitation.

It is emphasized that knowledge of surface runoff, percolation and groundwater recharge is a condition for sustainable water management planning. Therefore a water balance is required in the area of Berlin for better response in case of water shortages.

It is further stated that urban evaporation differs considerably compared to rural areas due to buildings and large impervious areas causing decreased evaporation. This fact also causes an increased total runoff in urban areas, which directly flows to receiving waters via inflow points or wastewater treatment plants, regardless of the rate of connection to the sewer network. Remaining runoff infiltrates, thus recharging groundwater.

The water balance was calculated using ABIMO, providing results shown in Table 3.2.

Table 3.2 Long-term mean values of runoff formation

	area [km²]	mm/yr.	million cu.m./yr.
Total Berlin (without bodies of water)	840		
Precipitation (measured values, uncorrected)	840	570	478
Evaporation (Precipitation – Total Runoff)	840	312	262
Total Runoff	840	258	216,8
Surface Runoff	840	80	67,7
thereof			
Combined sewage system	81	256	20,7
Separate sewage system	310	151	46,9
Percolation	840	177	149,1
New Groundwater Formation	840	149	125,5
Bodies of Water	54		
Depletion (Precipitation – Evaporation)		-158	-9

Following findings were identified analysing Table 3.2:

- Approximately 55 % of precipitation evaporates, thus 217 million m³ or 45 % remains as total runoff
- Approximately 75 % of this available runoff percolates into sub-surface, 25 % reaches the sewer network
- An annual percolation of 150 million m³ faces a water use of 250 million m³, leading to a large deficit. However, compensation by surface seepage of river and sub-surface groundwater recharge is given.
- Finally, a comparison of figures for 2007 and 2001 was established, exhibiting an increase of long term surface drainage as well as increased runoff and percolation

Detailed maps are offered on the website published by the Senate Department for Urban Development and the Environment of Berlin, showing areal depths of surface runoff, percolation, total runoff and evaporation from precipitation.

3.1.3 Similarities of previous studies

To summarize previous articles, this part will review similarities of recent studies. The selection of articles given in chapter 3.1.2 is just a glimpse of studies available.

Not all articles on urban water balance actually use available software. This is due to the lack of suitable software tools capable of modelling the complexity of urban systems.

A major factor making this area of study so difficult is the lack of available data. In not a single recent study every required dataset was readily available. In some studies values taken from literature were used, others extrapolated data of smaller catchments to obtain estimations. Lack of data is the most common and most crucial challenge faced in the development of a water balance. Even the mathematically extended Material Flow Analysis of Huang, Bader et al. (2007) faced difficulties concerning data acquisition.

Furthermore, evaporation in urban areas turned out to be a difficult factor to determine. In some studies therefore models were developed by modifying well established evapotranspiration-models to calculate urban evaporation. In more recent studies estimation of evapotranspiration is quite simple due to software tools.

Also, some authors described difficulties with determination of system boundaries due to inconsistent data of land use and sewer networks.

A further important detail which was recognized is the preference to reduce spatial complexity while keeping most important cause-effect relationships with help of the lumped parameter

approach (Martinez, Escolero et al. 2011). This means that some processes within the urban system are ignored for the sake of simplicity of the model.

This finding leads to the next identified conclusion for urban water balances – a guideline for the approach of such an urban water balance model does not exist. Due to the large number of differences between each city such a guideline would not be a useful tool, because idiosyncrasies of cities could be lost.

3.1.4 Lessons learned

In conclusion, urban areas are highly complex systems, which are difficult to model due to a large number of idiosyncrasies of each city. Thus simplifications need to be applied in this thesis. Simplifications will have the difficult goal to simplify, but yet to provide a holistic and detailed picture of the urban water balance.

Analysis of previous studies in this research area exposed some important factors which will be considered in this thesis.

- First, a focus will be put on the acquisition of necessary data, therefore a close cooperation with the Viennese City Council and other data-gathering institutions is aspired.
- Second, evapotranspiration for the area of Vienna will be calculated meticulously to avoid major inaccuracy.
- Third, an accurate definition of the system boundary will be emphasized in this thesis.

One further similarity was revealed in previous studies. No detailed explanation concerning assumptions and data sources was provided. Only Wolf, Klinger et al. (2007) provided insight in data acquisition methods, but detailed explanations of taken assumptions were still missing. However, papers are supposed to present study results and short reviews. Nevertheless, this thesis will present detailed information about used methods and taken assumptions, as well as information concerning data sources, making it easier for the reader to comprehend.

3.2 Substance Flow analysis

This section will investigate progress made in the field of flow analysis with focus on substances, especially copper. To achieve this, several articles which possess a similar focus as this thesis will be reviewed. The similarities between previous studies will be identified and a conclusion with regards to this thesis will be drawn. Furthermore a definition of the term “flow analysis” as it will be used in this thesis will be given.

3.2.1 Definition

In this thesis the term flow analysis is a synonym for Material Flow Analysis (MFA) and Substance Flow Analysis (Lifset, Eckelman et al.). The following two paragraphs will give an overview of the definition of these terms as defined by Brunner and Merl (2002), Brunner and Ma (2009) and Baccini and Brunner (2012).

Material Flow Analysis or MFA is the analysis of flows and stocks of goods and materials with the result of picturing major flows and stocks of material and its changes over time. It is a very promising tool for decision making in environmental management. Further details about the steps of which a MFA consists and how it is achieved will be discussed in chapter 4 “Materials and Methods”.

Substance Flow Analysis or SFA is defined as the analysis of flows and stocks of substances and is an appropriate tool to identify missing information about defined systems (e.g. from where does a hazardous compound within the water supply system come from?). Likewise, SFA and its challenges will be explained in detail in chapter 4 “Materials and Methods”.

A practical reference work dealing with MFA Methodology is the “Practical Handbook of Material Flow Analysis” by Brunner and Rechberger (2004), which explains terms, definitions and procedures of MFA in detail.

3.2.2 Previous Case Studies in Urban Areas

3.2.2.1 Malmquist and G. (1983)

This 30 year old study deals with urban pollution and its sources, however it does not contain a flow analysis. New policies in Sweden in the 80s of the 20th century triggered the authors to investigate whether the assumption that stormwater is almost unpolluted justifies the introduction of separate sewer systems which would then perform more efficiently. Hence the paper tries to investigate stormwater quality by means of pollution sources.

With the aim to identify and quantify urban sources of stormwater pollution, four catchments were defined and quality monitoring of rainfall, air and dustfall was achieved as well as recording of stormwater runoff. Furthermore corrosion plates were installed and analysed for development of a stormwater model.

The authors found out that the major source of copper pollution in storm water was atmospheric fallout and corrosion. However, these results are eased by the fact that many errors existed due to a lack of knowledge concerning metal adsorption on different surfaces and metal extraction from tarmac and paints.

Malmquist and G. (1983) further emphasizes the importance of metal mass flows into groundwater and states that point sources (e.g. incineration plants) will cause higher pollution concentrations in stormwater and atmospheric fallout. Another finding was increased air quality and rainfall quality with distance from the city centre.

3.2.2.2 Henseler, Scheidegger et al. (1992)

This study can be seen as a major development step for substance flow analysis and the determination of a material flux for a region. The authors developed one of the first holistic material flow analysis, comprising the anthroposphere and the environment of an entire area.

Study area was the “Unteres Bünztal”, a valley situated in Switzerland including twelve communities, incorporating 28000 inhabitants and covering an area of approximately 66 km². The authors also distinguished between different land uses and presented a detailed description of the system boundaries.

Goal was to present a holistic picture of substance flows within the water balance for a single year of the entire study area. Flows were measured or approximated to identify major sources, transport-flows and sinks of goods. Indoor water use was assumed to equal between 200 and 300 litres per inhabitant and day, which is almost double the amount of water used indoor in Vienna. Major water stores are defined to be the atmosphere, groundwater and unsaturated soil.

Two different types of results were achieved: methodological findings and results concerning the importance of substance flow analysis. According to the authors it is possible to develop a balance of selected goods within the water balance with existing methods. However, it is important to carry out a system analysis and to set up a measurement – plan to identify major processes and flows and to keep measurement-efforts to a minimum.
The largest water flow through the study area was identified to be atmospheric humidity, only one to two percent of precipitation takes part in the actual regional water balance. Water flows of precipitation, evapotranspiration and surface water were identified to be of the same order of magnitude, however imported drinking water was one order of magnitude smaller.

The major source of metal imports within the water balance was identified to be precipitation, the largest exportflow is the regional stream “Bünz”. Soil was discovered to be a major sink for metals, retention of metals by soil is approximated to be larger than 80%. Further, metal flow to soil via sewage sludge was identified to be larger than metal flow via treated wastewater to the receiving water.

The authors emphasize the knowledge of following factors to achieve satisfying results determining a water balance:

- Groundwater
- Surface waters and linked catchment area
- Geology and pedology

If these factors are known, the determination of an accurate water balance with climate data and measurements concerning precipitation, surface waters, drinking water, wastewater and groundwater is possible.

Due to its similar methodology, this study is also very useful in the context of the water balance, however it was decided to present this article in context with Material Flow Analysis.

In conclusion, this first flow analysis was a very useful tool for future controlling of substance flows with regards to environmental sustainability.

3.2.2.3 Bergbäck, Johansson et al. (2001)

In 2001 the authors published a study analyzing the metal flows of Stockholm, Sweden. As spatial system boundary the administrative boarder of Stockholm City was selected, covering an area of 190 km² and an population of 700000 inhabitants. A holistic Substance Flow Analysis of several metals was established, including copper. The authors did not mention the use of any specific software.

This article presents some interesting findings which are helpful in accordance to this thesis.

The authors mention that point source pollutions are not significant any longer, the stock of goods represents the major source of metals. Most important emission sources for calculation of flows were emissions from goods, atmospheric deposition, industrial emissions and metal from food.

Major sources of copper emissions in Stockholm were found to be the tapwater system, followed by vehicle brakes and aerial lines as well as roofs and house fronts. Furthermore the authors discovered severely enhanced concentrations of metals in central parts of Stockholm, compared to park soils far from the city centre.

Diffuse emission from goods were identified to be the most contributing emissions for all observed metals.

3.2.2.4 Seelsaen, McLaughlan et al. (2007)

This paper examines copper flows related to stormwater runoff in the urban catchment of the Parramatta River in Sydney, Australia with help of Material Flow Analysis (MFA). A model was established using the software SIMBOX®.
Main parameters used for the calculation of copper flows were area, rainfall amount and copper concentration in goods. Processes within the system boundary were classified according to land use.

The author also determined land use types within the area, showing that 94% was urban land use, only 5% was open space and bushland and 1% was zoned rural.

The necessary data was mainly gathered through internet research, due to a highly developed online service of the Australian government. However, some data were acquired using published papers and interviews with Sydney Water and others.

As major pollution sources within the catchment, stormwater and sewage overflows discharging into the harbour embankments were identified. Goods containing most copper in the analysed stormwater pathway were rainfall, fertilisier, copper trace element, root killer, water supply and brake pad wearing.

Traffic was the main source of copper flows, followed by roof runoff and sewage overflows. Yet another significant contributor was identified to be copper in trace elements, which is caused by gardening and backyard cropping.

It is very interesting that fertilizer and root killer have such a strong impact on the copper cycle in Australia. According to Seelsaen, McLaughlan et al. (2007) such a high contribution of these factors is triggered by adding copper sulphate to heavily leached Australian soils.

The authors concluded that stormwater runoff is a major source of pollution within an urban system and that the established Substance Flow Analysis can be used by policy makers to identify priority locations for source control.

3.2.2.5 Chèvre, Gremaud et al. (2010)

In this study Chèvre, Gremaud et al. (2010) used substance flow analysis – SFA – to identify paths of copper, cadmium and zinc in Lausanne, Switzerland for a period of one year. The system consisted of the sewer catchment and the receiving water close to the city. The most important parts of the system were identified to be drainage systems, combined sewer overflows, the waste water system including the waste water treatment plant (WWTP), the sludge collector, surface water and sediment. Yet again, for modelling the software SIMBOX® was used. The fact that this study has a focus on a SFA of copper in an European city makes it helpful to draw conclusions regarding to this thesis.

The SFA was achieved following six iterative steps:

1. System analysis
2. Model approach

3. Data acquisition
4. Calibration
5. Plausibility check
6. Sensitivity analysis

A further interesting point are the thirteen inputs which have been taken into account. Drinking water, roof runoff, house sides runoff, car brakes and tires abrasion, particles of catenaries belonging to trolley busses, input from train catenaries, brakes and wheels, boats, dry deposition and finally motor oil residues were considered.

With help of iterative step 6, the sensitivity analysis, the authors identified the most sensitive parameters and their key variables. There are two key variables, the net input to surface water and the accumulation rate for sediment. Parameters most affected by these variables were identified to be roofs, trolleybus catenaries and the transfer coefficient from stormwater to separate sewer systems.

The study unveiled that the largest amount of the analysed heavy metals is imported to the system via stormwater. Furthermore, due to retention of metals in the waste water treatment plant sludge, the input of copper via WWTP discharge is five times lower than via stormwater.

The authors conclude that SFA is a promising tool for water management due to the possibility of detecting major system difficulties.

3.2.3 Similarities of previous studies

Even studies published decades ago emphasized the fact that the largest amount of heavy metals and pollution in general was brought into the systems by stormwater or precipitation. Further it is a common statement that diffuse pollution is one of the most relevant contributors to pollution. However, point sources can have some significant impact, at least locally, which can be seen in two studies not mentioned in the selection above (O'Sullivan, Wicke et al. 2012; Xiao, Bai et al. 2012). Xiao, Bai et al. (2012) found out that especially at construction sites heavy metal pollution is higher in shallow soil layers. This leads to yet another fact which was mentioned in some studies: The consideration of soils and groundwater is an important factor not to be underestimated.

The significant rise of metal-use in the 20th century due to industrialisation which triggered demand of more specific studies on urban pollution concerning heavy metals was also recognized in the majority of papers.

MFA and SFA seem to be promising tools for identification of substance flows due to their common use and positive experiences in anterior studies. The approach was similar in all studies.

Previous studies also concluded similar with regards to goods which contribute most to input of copper. These were identified to be drinking water systems, roofs and traffic. In some countries even fertilizer played a major role in the copper input.

Yet another interesting fact which was observed in several papers was the increased quality of soil and water with regards to heavy metals with increasing distance from city centres.

3.2.4 Lessons learned

To summarize, it was noticed that more recent studies commonly used the approach of an SFA to identify sources of pollution. The SFA in this thesis will be approached in accordance to Baccini and Brunner (2012) due to positive experiences in previous studies.

The sources of copper identified in recent studies will be taken into account meticulously in this thesis.

Only the first study on this topic by Henseler, Scheidegger et al. (1992) pointed out the importance of a system analysis and data acquisition, which will be considered detailed in this thesis.

Further it was identified that copper balances based on water balances are very uncommon and rarely, thus this thesis enters virgin territory with regards to this topic.

3.3 Software Tools

This chapter will introduce the software tools UVQ and STAN and present their characteristics.

3.3.1 UVQ – General Introduction

UVQ is an acronym for Urban Volume Quality and is a software tool developed by Mitchell for the Commonwealth Scientific and Industrial Research Organisation of Australia (CSIRO) to display holistic pictures of urban water cycles. The software is an extension of the Aquacycle Model, which was developed by Mitchell, Mein et al. (2001). It is a daily simulation model for water and contaminant flows within an urban area (Mitchell and Diaper 2005). Its main purposes are to:

- Analyse flows of water and contaminants in urban areas
- Determine the flowpaths from source to sink
- Picture the connections between the system parts water supply, stormwater and wastewater (Mitchell and Diaper 2010)

The major aim for development of this software was the idea of a holistic understanding of urban water and contaminant flows to better develop more sustainable urban systems (Mitchell and Diaper 2005; Mitchell and Diaper 2010).

The programme has several spatial scales, including the land block, the neighbourhood and the study area. The smallest scale is represented by the land block and describes a single property including buildings, paved area and garden area. It is distinguished between residential, commercial and industrial land blocks, defined through specified configurations. A Neighbourhood represents a cluster of several land blocks with similar properties, including road area and public open space. This spatial scale can also be separated into residential, commercial and industrial neighbourhoods. Finally, the spatial scale “study area” comprises all neighbourhoods, thus it defines the entire modelled urban area. The software also differentiates between pervious and impervious areas.

Furthermore, for sake of simplicity, a large number of assumptions are met, which can be looked up in the UVQ User Manual (Mitchell and Diaper 2010).

The software was used in several studies outside of Australia, four of which are listed in Table 3.3 below. Further studies are presented in chapter 3.1.2 on page 4.

Table 3.3 Previous studies outside of Australia utilizing UVQ

Author	Title	Study Area	Comments
Eiswirth, Wolf et al. (2004)	Balancing the contaminant input into urban water resources	Upper Rhine Valley (Rastatt), Germany 59 km² / 90 km² Population approx. 50000	First modelling results with UVQ – environmental effects of pipe leakage were investigated
Wolf, Klinger et al. (2007)	Quantifying Mass Fluxes from Urban Drainage Systems to the Urban Soil-Aquifer System	Rastatt, Germany 10.65 km² Population approx. 50000	Part of AISUWRS-Project: UVQ was used to calculate water and contaminant flows which were then used in another model to simulate network exfiltration and

			Infiltration
Vizintin, Souvent et al. (2009)	Determination of urban groundwater pollution in alluvial aquifer using linked process models considering urban water cycle	Ljubljana, Slovenia 275 km² / 903 km² Population approx. 270000	Part of AISUWRS-Project: UVQ was used to calculate water and contaminant flows which were then used in network exfiltration and infiltration models, unsaturated zone models and groundwater models
(Martinez, Escolero et al. 2011)	Total Urban Water Cycle Models in Semiarid Environments-Quantitative Scenario Analysis at the Area of San Luis Potosi, Mexico	San Luis Potosi, Mexico 147.54 km² Population approx. 1.1 Million	The results of the model delivered insight into the interdependencies within the water system and emphasized the importance of an integration of urban water resources management.

3.3.2 UVQ - Results of the software

Results of modelling are displayed via the programme interface and .csv files. The interface presents summary statistics, technology performance and user defined graphs. Following reports can be retrieved from the interface results:

1) Summary statistics
   - Water and contaminant balance
   - Climate statistics
   - Land block water use
   - Land block irrigation
   - Public open space and land block irrigation

In this thesis especially the water and contaminant balance will be the major points of interest from the summary statistics.

2) Technology Performance:
   - Rain tank
   - Sub surface greywater irrigation
   - On-site wastewater
   - Neighbourhood stormwater
   - Neighbourhood wastewater
   - Aquifer storage and recovery
   - Study area stormwater
   - Study area wastewater

3) User defined graphs

In this interface it is possible to choose between several options presenting flow paths and contaminant paths of different model scales.

The second output option beside interfaces are .csv files. Csv is an acronym for comma separated value. The output files in this format can be divided into contaminant and water files:

4) Contaminant files:
    - Cont Bal – Neighbourhood N
    - Cont Bal – Study Area

5) Water files:
    - StudyAreaBalance
    - DailyNeighbourhood*n*
    - DailyLandBlock*n*
    - MthlyStudyArea
    - MthlyNBH*n*
    - YearStudyArea
    - YearNBH*n*

The letters N and *n* represent neighbourhood numbers.

The user is able to choose which files should be generated by the software before running the simulation for the first time. The choice is between daily, monthly and yearly output files, depending on the period of simulation. Each file consists of several items, e.g. Precipitation depth in mm and Surface Stormwater outflow volume in m³/d.

The information provided in this chapter is taken from the UVQ User Manual (Mitchell and Diaper 2010), hence more detailed information concerning contents of each output file and further pieces of information can be found there.

3.3.3 STAN - General Introduction

STAN is an acronym for “SToffflussANalyse”, which is German and stands for Substance Flow Analysis. The programme was developed by Oliver Cencic of the Vienna University of Technology.
STAN is a generic software tool capable of picturing mass flows and material balances with graphic models and conduct simple balancing. It helps to perform Material Flow Analysis by giving users the possibility to define processes, flows and system boundaries and insert known data about these components, using these parameters to calculate missing quantities of flows or stocks (Cencic 2012). It is possible to picture different periods and layers and further data uncertainties can be considered. Such uncertainties can be calculated due to the use of “mathematical statistical tools such as data reconciliation, error propagation and gross error detection” (Cencic 2012).
According to Cencic (2012) and Baccini and Brunner (2012) the most important components of STAN are defined as follows:

- Substance: any chemical element or compound composed of uniform units
- Good: economic entities of matter with a positive or negative economic value that comprise one or several substances
- Material: expresses substances and goods – if metabolic processes are addressed in general or it is not yet clear whether the layer of substances or goods is focused, this term is appropriate
- Process: Transformation, transport or stock change of materials (goods and substances). It is distinguished between transformation processes, transport processes and storage processes.

- Flow: a material flow is a mass flow rate. Material flow is an amount of mass which flows through a conductor in a certain amount of time. The physical unit could be kg/y or m³/s.
- Flux: a material flux is defined as flow per time unit through a defined unit area. Units may be kg/(sec.m²).
- Stock: stock is defined as the mass of material residing in a process or system during the balancing period.
- System: in Material Flow Analysis a system is defined as processes and the interaction (flows) between these processes. Every good is clearly identified through an origin process and a target process.
- System Boundary: the system boundary has to be defined in time and space, taking into account scope and limitations of the project. Flows from outside the boundary into the system are imports, flows leaving the system are exports.
- Transfer Coefficient: transfer coefficients express the partitioning of materials within a process. Transfer coefficients are dimensionless values, equal or smaller than 1. The sum of all transfer coefficients within a process must be equal to 1.

STAN bases upon three principle equations which define the character of this software:

1. Mass Conservation

$$Sum\ of\ inputs\ =\ sum\ of\ outputs\ +\ change\ in\ stock$$

2. Linear relations

$$Ouput\ 1\ =\ Transfer\ coefficient\ 1\ \cdot\ Sum\ of\ Inputs$$

$$Output\ 2\ =\ Transfer\ coefficient\ 2\ \cdot\ Sum\ of\ Inputs$$

$$TC1\ +\ TC2\ =\ 1$$

3. Concentration Equation

$$Mass\ Substance\ =\ Mass\ Good\ \cdot\ Concentration\ Substance$$

3.3.4 STAN - Results of the software

As mentioned above, STAN pictures mass flows and material balances for a defined system, such as an urban area. The result of STAN is a graphical illustration of a Material Flow Analysis.

Figure 3-3 provides an example of how such a graphical illustration may look like. It is a very simple system for demonstration purposes only, which does not contain stocks. Imports, exports and change in stock are displayed by STAN as well as a holistic picture of the modelled MFA-system. Flows are illustrated by arrows proportional to its value, processes are rectangular boxes and the system boundary is a dashed outline.

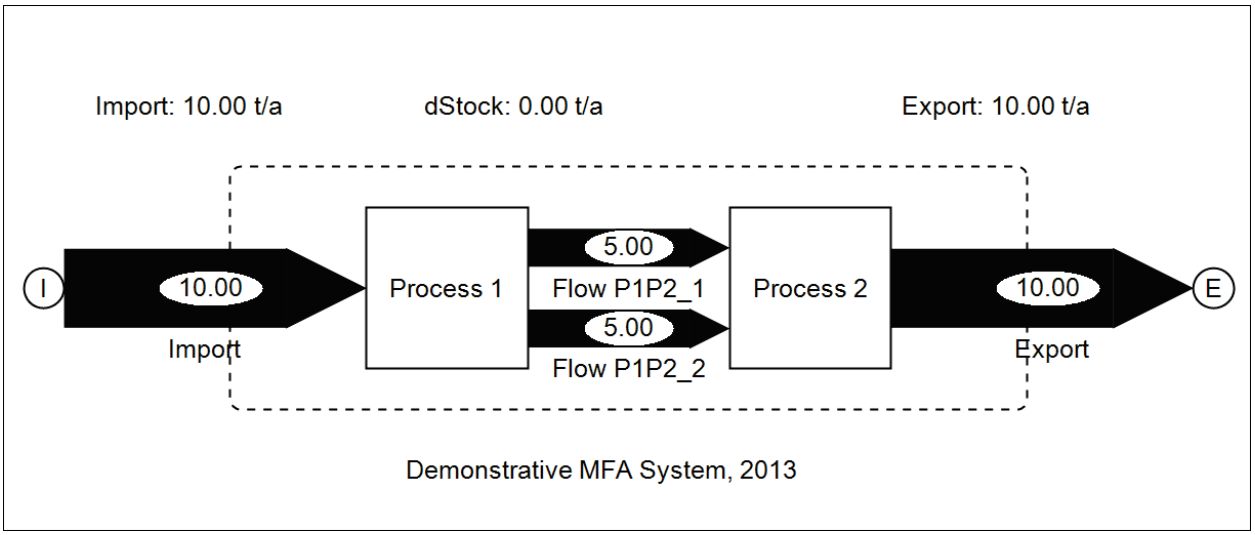


Figure 3-3 Result of STAN, a graphical illustration of “Demonstrative MFA System”

The illustrations produced by STAN help to get a better overview of complex systems and thus fits the need of picturing a holistic water balance of Vienna perfectly.

4. Material and Methods

This chapter will introduce the study area of Vienna and will furthermore define the modelling approach for each software and give an explanation of sources and assumptions taken for model parameters.

4.1 Study Area Vienna

Vienna is the capital of Austria, comprising approximately 41500 ha of space and is home to 1.7 Million inhabitants. In the West it is bordered by the Viennese Forest, to the North Vienna is limited by the Danube and eastwards and southwards it is bordered by the “Marchfeld”, the Danube Meadows and the Viennese Basin. Vienna has an altitude between 149 m, which is measured at the Danube close to the city limit and 542 m, reached at the mountain “Hermannskogel” (Maier, Punz et al. 1995). The city is divided into 23 administrative districts, only two of which are situated easterly of the Danube, as can be seen in Figure 4-1. Approximately 46 % of the entire area is taken by green space, 35 % is built area and 14 % is traffic space. The remaining 5 % is taken by surface waters.

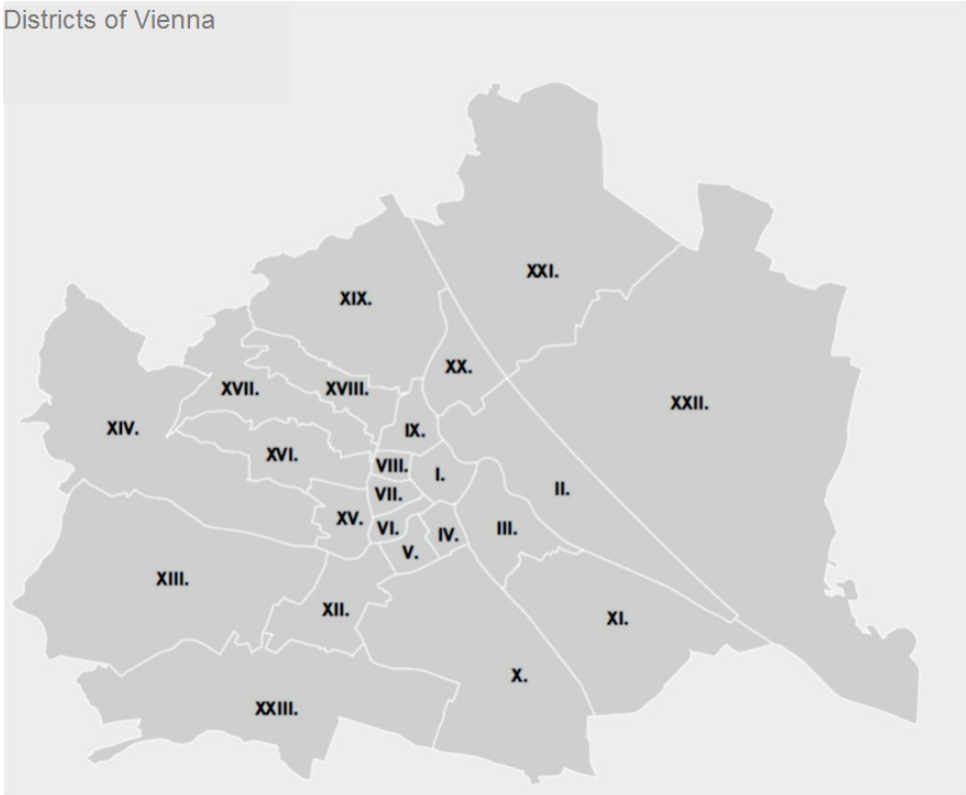


Figure 4-1 Districts of Vienna (Lebhart 2012), modified by Author

<u>Climate</u>

Vienna is situated at the border of the mid-european, the alpine and the pannonic climatic region or in the transition zone of oceanic and continental climate (Maier, Punz et al. 1995). It is further influenced by two factors: the landform which features increased altitude to the western city area and the microclimatic conditions caused by the city itself, which induces a heat-island, forcing air masses upwards (Lebhart 2012). The long term average precipitation was calculated to be 651 mm, based on data between 1950 and 2011 provided by MA23 (2013). However, there are regional differences within Vienna, eastern parts exhibit larger amounts of rainfall compared to western parts of Vienna.

Hydrology

The Danube is the major stream flowing through Vienna, dominating all water inputs and outputs to and from Vienna. Together with small rivers originating from the Viennese Forests in the West and the major channels “Wienfluss”, “Liesing” and Danube Channel it forms the flowing surface water parts of Vienna. Further the “Old Danube”, a former meander of the Danube and several other ponds complete the picture of surface waters in Vienna. Due to buildings, sealed surfaces and other factors originating from the city, a correspondence of surface water with groundwater is hardly given (MA45 (2008), cited by Grimm (2010)).

Groundwater in Vienna varies widely due to a very diverse Geology and Topography. According to Grimm, five different hydrological regions exist in Vienna:

- Area of Limestone Alps
- Flyschzone
- Danube Region
- Viennese Basin
- Riverbasins with alluvial gravel fillings

Figure 4-2 illustrates the various hydrological zones of Vienna.

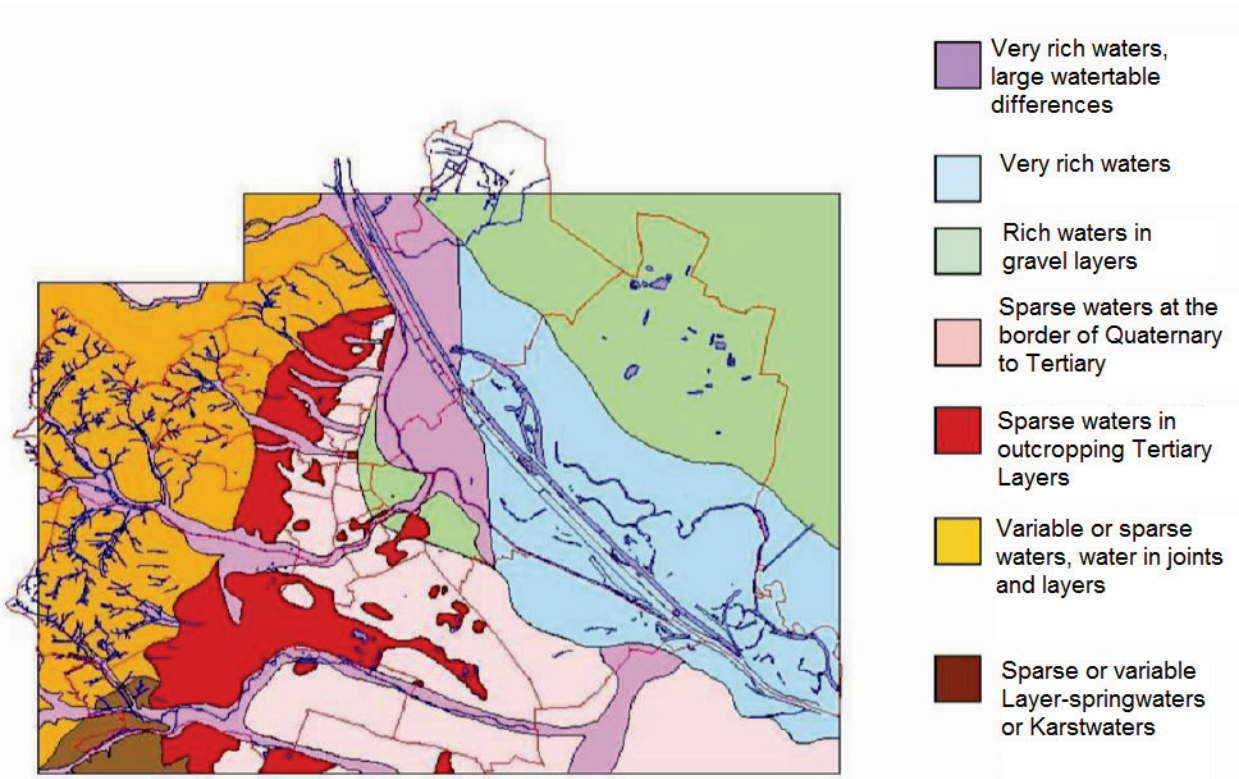


Figure 4-2 Hydrogeology of Vienna (MA45 (2008), cited by Grimm (2010)), translated by Author

Geology

Vienna is situated on the eastern foothills of the Alps, on the western end of the Viennese Basin and is traversed by the landscape-forming Danube (MA29 2013). There are three main areas in the geological underground of Vienna:

- Quaternary loose sediments
- Neogenic loose sediments of the Viennese Basin
- Solid rock of Flyschzone and Limestone Alps

Further Vienna is crossed by a system of north-south bound disruptions and faults. A detailed illustration of Vienna’s Geology is presented in Figure 4-3.

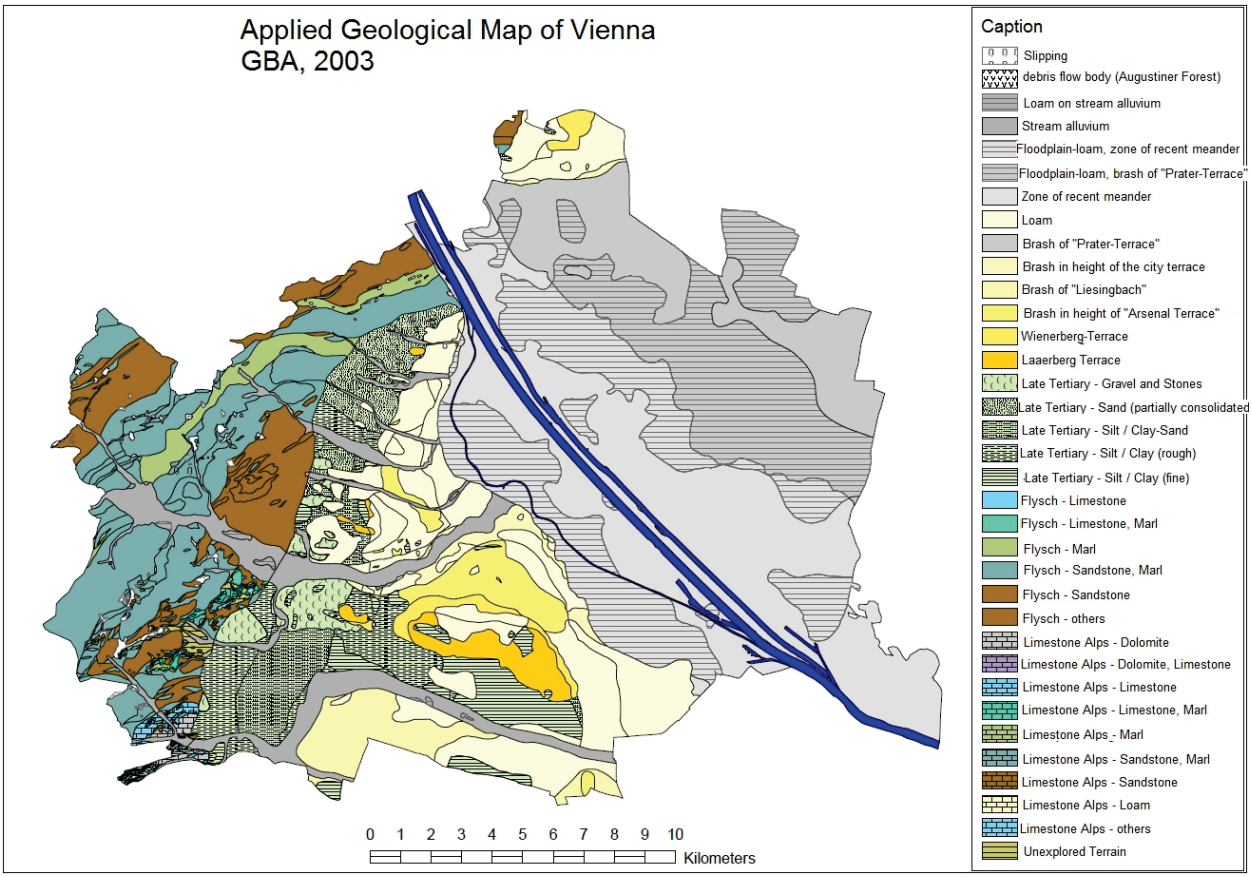


Figure 4-3 Geological Map of Vienna (MA29 2003), translated by Author

Water Supply and Sanitation

The majority of potable water in Vienna is supplied by two main supply pipelines, the first and the second Viennese Mountain Spring Pipeline. Water is pumped from Lower Austria and Styria to Vienna, providing enough highly qualitative water for the 1.7 Million inhabitants of the capital. Yet another source of water is groundwater, however, it only plays a minor role compared to the two supply pipelines. Figure 4-4 provides an overview of the supply network.

A city demanding two Mountain Spring Pipelines and groundwater extraction to satisfy its water needs also requires a sophisticated sewer system. According to Wien_Kanal (2013) 99 % of consumers are connected to the sewer system, which sums up to approximately 2400 km in length. The majority of Vienna is drained via a combined sewer system, however, separated and mixed sewer systems exist in the city as well. Further, Vienna is in possession of a sewer management system to provide water pollution control. This system is partially in the construction phase and not completely finished yet. Three major channels drain Vienna, the Danube Channel, the “Wienfluss” and the “Liesing”. Wastewater is treated in the centralized Viennese main wastewater treatment plant, situated in the 11th administrative district of Vienna.

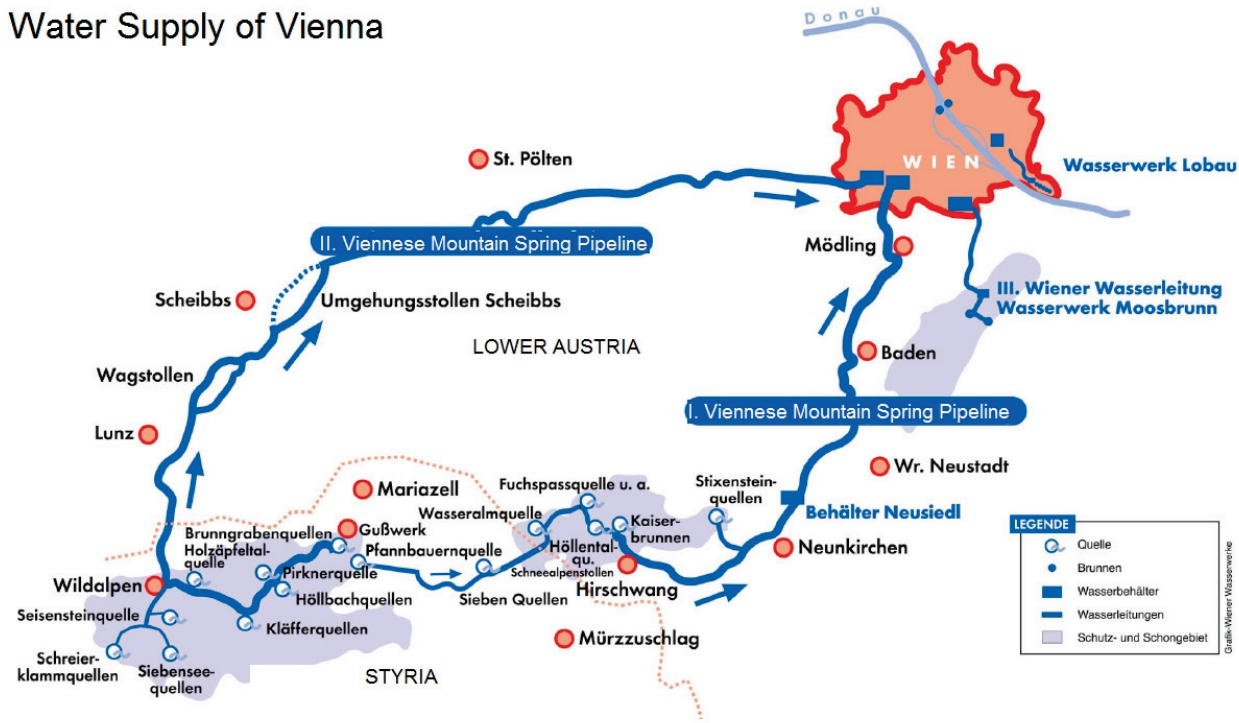


Figure 4-4 Water supply network of Vienna (MA31, cited by (Hlavac 2009)), partially translated by Author

4.2 UVQ - Approach

UVQ will be used in two steps which differ in level of detail. The two stages are explained in detail in the following two subchapters.

4.2.1 Stage 1

The first stage involves a simple model separated into 23 neighbourhoods which represent all districts of Vienna. However, the numbering of neighbourhoods will differ from the original district numbering in Vienna due to possible flows between districts which can only be considered by relabeling. The new arrangement is shown in Figure 4-5. The single districts only differ in some physical and calibration parameters, especially spatial parameters. Calibration parameters are assumed to be identical for all districts in phase one, except for districts not containing garden areas and not containing combined sewer systems. However, only one neighbourhood is modelled with a separated sewer system and only seven neighbourhoods do not include garden areas. Therefore the parameter “Effective Paved Area” is set to 100% in these seven neighbourhoods. In neighbourhood 21, representing the only district with a separate sewer system, surface inflow is assumed to be 40 %. In stage one only indoor water use by citizens is taken into account. Water use from industrial sites, tourism facilities and business infrastructure is not yet considered. Further, several assumption for not available data were taken.

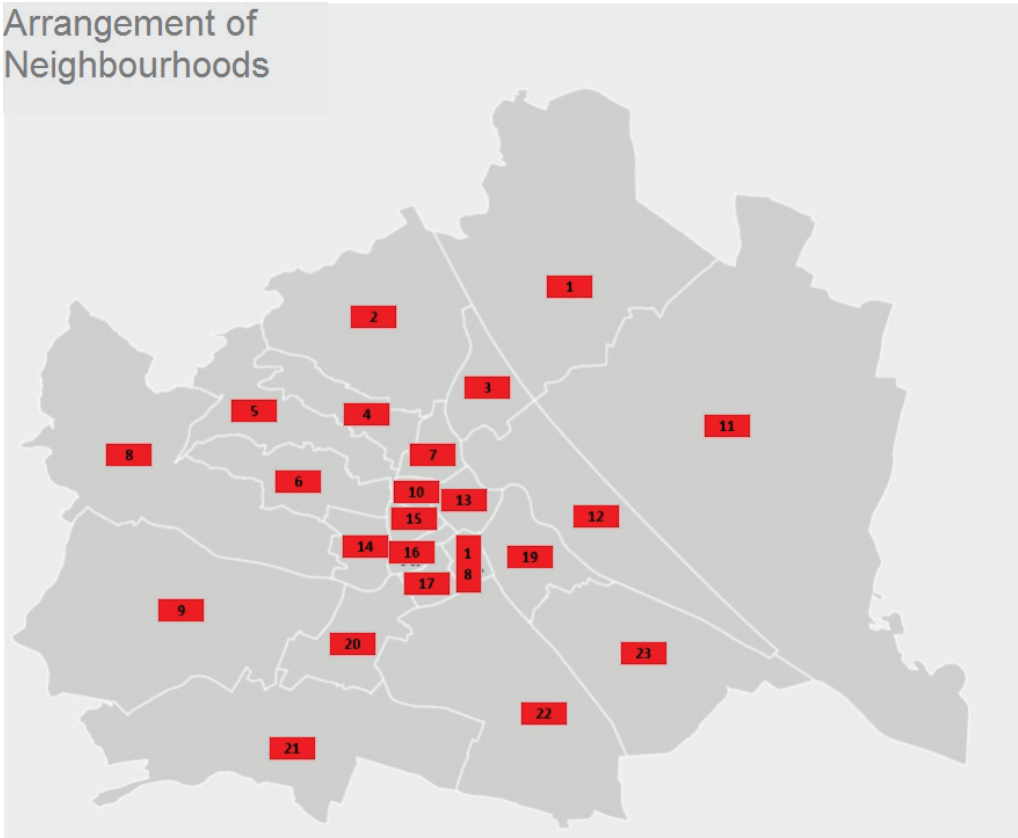


Figure 4-5 Arrangement of Neighbourhoods in UVQ

Stage 1 model is set up to determine whether UVQ delivers useful results concerning water and contaminant balance. If results are satisfying, some of the findings will be used to set up a first model in STAN, followed by initiation of stage two.

4.2.2 Stage 2

During stage two, the model is developed further to picture Vienna more detailed.

To achieve improvement, more data concerning the study year of 2008 is acquired. Further, new approaches for some parameters are considered and water used by Industry, Tourism and Trade is taken into account in the stage 2 model.

One of the main changes affects total area of the study area and of neighbourhoods due to omission of surface water areas. These areas are subtracted from total area, therefore study area decreases. The number of inhabitants decreases as well, from 1731236 to 1687271, thus average occupancy decreases slightly.

Yet another major difference to Stage 1 UVQ Model is an altered indoor water usage, especially toilet water use. Due to the inability of UVQ to picture industrial water use as an own component it has to be added to toilet flush. The same applies to tourism and trade water use. Thus, new approaches are developed to consider these water amounts and split them between inhabitants and neighbourhoods. Details concerning this approach are explained in chapter 4.4.

However, not only indoor water use, but also indoor contaminant loads change in the improved model. Due to new literature covering Vienna explicitly and several calibration calculations via UVQ itself, copper loads for kitchen, bathroom, toilet, road and pavement are altered. Furthermore, copper distributed by fertilizer is only taken into account in neighbourhoods with major agricultural land use and garden fertilizing is changed as well.

From above statements it can be clearly seen that several parameters have been revised, especially physical parameters are altered. However, due to a high level of detail already achieved in Stage 1 UVQ Model, changes are only minor, in hope of a more detailed model. A detailed description of each alteration is listed in chapter 4.4.

4.3 UVQ Stage 1 - Parameters

This section will review necessary parameters for UVQ. Values and source of values will be illustrated for each parameter, further an explanation for taken assumptions will be given. To provide a better overview, parameters will be classified according to input screen within the software tool. UVQ features eight input screens illustrated in Figure 4-6. Each of these screens demands a different number of input variables:

1) Project Information
2) Physical Characteristics
3) Water Flow
4) Calibration Variables
5) Snow Variables
6) Land Block
7) Neighbourhood
8) Study Area

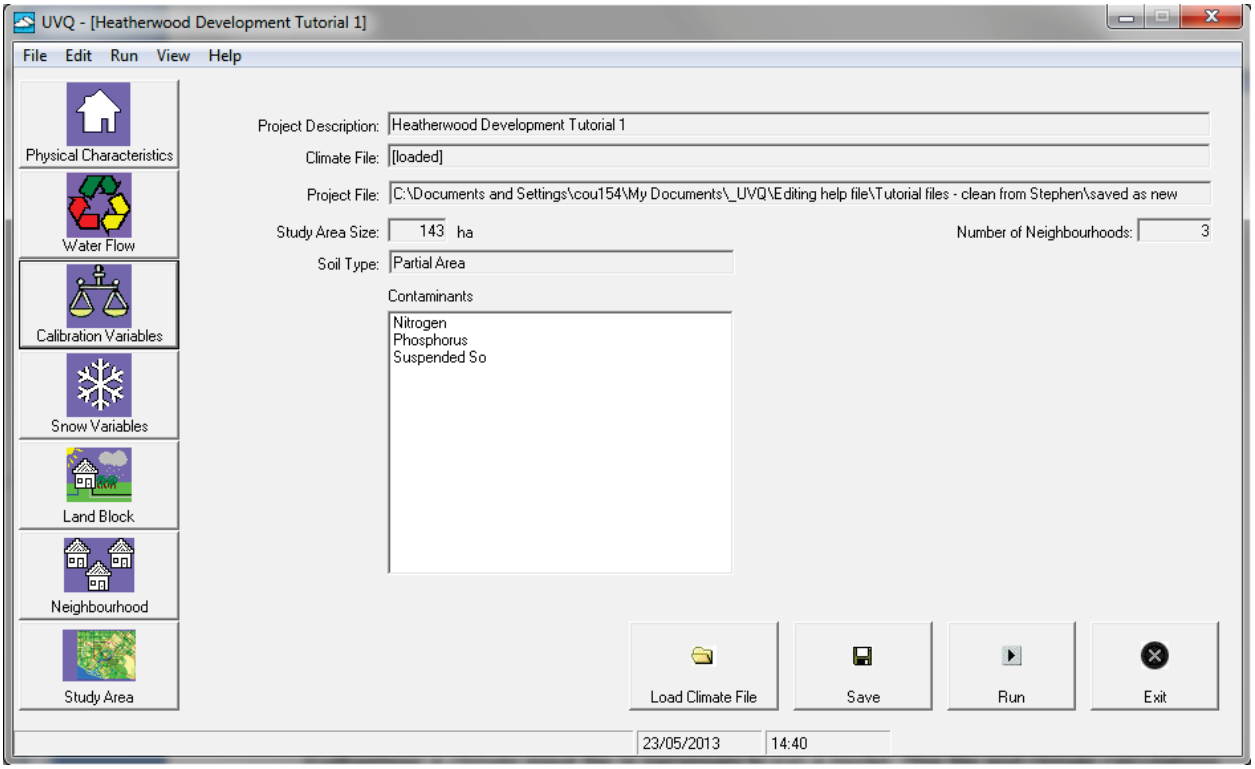


Figure 4-6 UVQ User Interface – on the left side in vertical formation are the input screens

In this chapter values of only one neighbourhood will be presented, however as mentioned before, each neighbourhood differs in several parameters. Below neighbourhood 23 will be illustrated, which represents district 11 “Simmering” of Vienna. Neighbourhoods are not labelled by original district number due to reasons of modelling water flows between neighbourhoods, which can only take place from lower neighbourhood numbers to higher ones.

Furthermore a climate input file is necessary to run a model. This file and climate calculations will be described in chapter 4.3.9, after explaining input screen specific parameters.

4.3.1 Project Information

The first input screen requires just a few inputs, which define some basic information of the project. Table 4.1 gives an overview of assumed values for the specific Project Information parameters, as well as their source and explanations of assumptions.

Table 4.1 Project Information for Stage 1

Parameter	Chosen Value	Source	Comment
Project Description			
Study Area Size	41487.4 ha	Statistisches Jahrbuch der Stadt Wien - Lebhart (2012)	This area includes the whole administrative district of Vienna
Number of Neighbourhoods	23	/	This is the actual number of districts in Vienna
Soil Store Type	Two Layer	/	/
Contaminants	Copper	/	/

4.3.2 Physical Characteristics

The largest data demand is displayed in this input screen. It describes physical characteristics of both, land block and neighbourhood. As mentioned before, values in the table below are representative for neighbourhood 23. Table 4.2 gives an overview of assumed values for the specific Physical Characteristics parameters, as well as their source and explanations of assumptions.

Table 4.2 Physical Characteristics for Stage 1 – the comment-points can be found below the table

Subscreen	Parameter	Chosen Value	Source	Comment
Neighbourhood	Total Area	2325.5 ha	Statistisches Jahrbuch der Stadt Wien - Lebhart (2012)	This area includes the whole administrative district 11 “Simmering “of Vienna
	Road Area	500 ha	Statistisches Jahrbuch der Stadt Wien - Lebhart (2012)	1) on page 36
	Open Space Area	990.7 ha	Statistisches Jahrbuch der Stadt Wien - Lebhart (2012)	2) on page 36
	Percentag e of Open	20 %	Statistisches Jahrbuch der Stadt Wien -	3) on page 37

	Space Irrigated		Lebhart (2012)	
	Imported Supply Leakage	8.5 %	Vienna water works	4) on page 37
	Wastewater Exfiltration	0.01	Fenz, Blaschke et al. (2005), Ruzicka, Zessner et al. (2011) and Zessner (2013)	5) on page 37
Land Block	Number of Land Blocks	7303	Statistisches Jahrbuch der Stadt Wien - Lebhart (2012)	6) on page 37
	Block Area	1143.1 m²	Statistisches Jahrbuch der Stadt Wien - Lebhart (2012)	7) on page 37
	Average Occupancy	12.5 Inhabitants	Statistisches Jahrbuch der Stadt Wien - Lebhart (2012)	8) on page 37
	Garden Area	113.7 m²	Statistisches Jahrbuch der Stadt Wien - Lebhart (2012)	9) on page 37
	Roof Area	335 m²	E-Mail Correspondance with Kubu and Kramer (2013)	10) on page 37
	Paved Area	694.4 m²	/	11) on page 38
	Percentage of Garden Irrigated	50 %	Assumption	Assumption
	Roof Runoff to Spoondrain	0	/	Assumption – 12) on page 38
Indoor Water Usage and Contaminants	Kitchen Water Use	17 L	Austrian Association for Gas and Water - OVGW	Retrieved online: http://www.wien.gv.at/wienwasser/verbrauch.html [Accessed 01.03.2013]
	Bathroom Water Use	53 L	Austrian Association for Gas and Water - OVGW	Retrieved online: http://www.wien.gv.at/wienwasser/verbrauch.html [Accessed

				01.03.2013]
	Toilet Water Use	40 L	Austrian Association for Gas and Water - OVGW	Retrieved online: http://www.wien.gv.at/wienwasser/verbrauch.html [Accessed 01.03.2013]
	Laundry Water Use	15 L	Austrian Association for Gas and Water - OVGW	Retrieved online: http://www.wien.gv.at/wienwasser/verbrauch.html [Accessed 01.03.2013]
	Kitchen Cu	3.2 mg/c/d	ZESSNER (1999; cited by Rebernig (2007)) and Vienna Water Works	13) on page 38
	Bathroom Cu	3.2 mg/c/d	ZESSNER (1999; cited by Rebernig (2007)) and Vienna Water Works	13) on page 38
	Toilet Cu	3.2 mg/c/d	ZESSNER (1999; cited by Rebernig (2007)) and Vienna Water Works	13) on page 38
	Laundry Cu	14.1 mg/c/d	ZESSNER (1999; cited by Rebernig (2007)) and Vienna Water Works	13) on page 38
Other Contaminants	Imported Cu	0.0015 mg/L	Vienna Water Works	Arithmetic Mean of four test sites
	Rainfall Cu	0.00259 mg/L	Nimmo and Fones (1997)	Rainfall weighted mean copper concentration for urban areas – study conducted in England
	Pavement Runoff Cu	0.0194 mg/L		14) on page 38
	Roof Runoff Cu	0.01 mg/L		14) on page 38
	Road Runoff Cu	0.0194 mg/L		14) on page 38
	Roof First Flush Cu	0.02 mg/L	Assumption	Doubled concentration of roof runoff is assumed

	Fertiliser to POS Cu	2000000 mg/ha	Etz and Baumgarten (2006)	15) on page 39
	Evaporation Cu	0	Assumption	It is assumed that the copper content in evaporation is negligible
	Groundwater Cu	0.0036 mg/L	Loishandl-Weisz, Wemhöner et al. (2012)	16) on page 39
	Fertiliser to Garden Cu	200 mg/m²	Etz and Baumgarten (2006)	Same value as 15), but calculated for m²
Water Outputs	Wasterwater from Neighbourhood goes to	Outlet	/	/
	Stormwater from Neighbourhood goes to	Outlet	/	/

1) Literature does not offer an exact value for road area but a percentage of total area, offered in Figure 4-7.

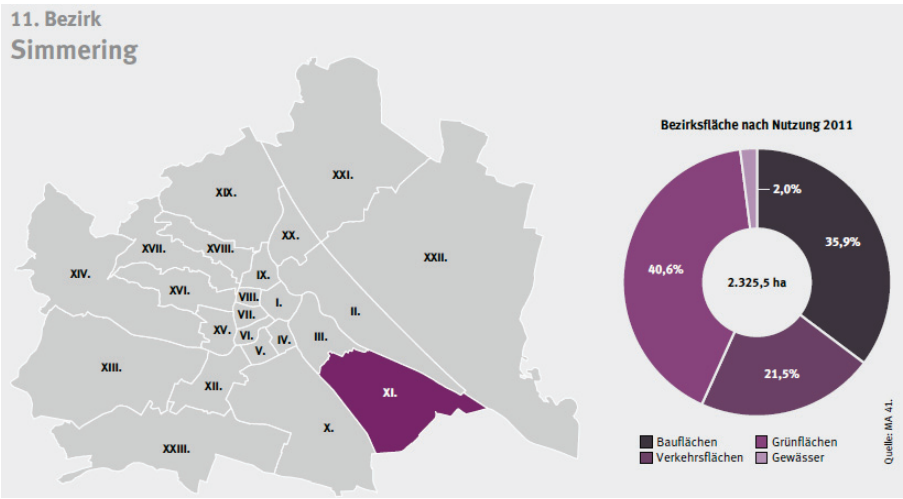


Figure 4-7 Spatial Distribution of Neighbourhood 23 or District 11 of Vienna (Lebhart 2012)

According to Figure 4-7 Spatial Distribution of Neighbourhood 23 or District 11 of Vienna (Lebhart 2012) Road Area is calculated as follows:

$$\text{Road Area} = \frac{21.5\ \%}{100} \cdot \text{Total Area}$$

2) Literature also does not offer an exact value for Open Space Area but a percentage of total area. Hence Open Space Area is calculated according to Figure 4-7 Spatial Distribution of Neighbourhood 23 or District 11 of Vienna (Lebhart 2012) as well:

$$Open\ Space\ Area = \frac{42.6\ \%}{100} \cdot Total\ Area\ \ .$$

Open Space Area also includes surface water areas, which only sum up to 2 % in this case. This inclusion is made due to no possibility of considering water areas in UVQ. Other neighbourhoods possess larger surface water areas.

3) The statistical yearbook of Vienna offers a table revealing land uses of open space in Vienna for each district. Areas of agriculture, public parks and sporting facilities were assumed to be irrigated by approximately 50%. There are 5958.1 ha of agricultural land use, 1702.7 ha of public park land use and 790.4 ha of sport facility land use. This sums up to an area of 8451.2 ha, taking up 40.5 % of the total Open Space Area of Vienna. Only 50 % of this Open Space Area is assumed to be irrigated, hence the value of 20 % was considered for this parameter in every neighbourhood.

4) The ratio of 8.5% for Imported Supply Leakage is an assumption made on the base of an email received by DI Anita Peintner on the 14.03.2013, who stated the Supply Leakage in Vienna can be assumed between 8 and 9 %.

5) Fenz, Blaschke et al. (2005) conducted two studies concerning sewage leakage, both resulting in an average exfiltration of 1%. Ruzicka, Zessner et al. (2011) published an article comparing the operation of a sewer system in two different years. In 2003, 1.8% of exfiltration were estimated, after a reconstruction five years later in 2008 this percentage decreased to 1.3%. Personal e-mail communication with Zessner (2013) revealed estimations between 0.5 and 1 %. Therefore a value of 0.01 (1 %) is assumed for wastewater exfiltration.

6) 7303 is the number of buildings in the district Simmering. It was assumed that each building forms a land block. All neighbourhoods sum up to a total of 168167 buildings respectively land blocks.

7) Land Block Area was calculated by dividing available building area by number of buildings:

$$Block\ Area = \frac{Total\ Neighbourhood\ Area - Road\ Area - Open\ Space\ Area}{Number\ of\ Land\ Blocks}$$

8) Average occupancy was calculated by dividing resident population of Vienna by number of Land Blocks.

$$Average\ Occupancy = \frac{Resident\ Population\ of\ Neighbourhood}{Number\ of\ Land\ Blocks\ in\ Neighbourhood}$$

9) Garden Area of Land Blocks was calculated using statistics of land use within Vienna's garden allotments. After subtracting garden road area from garden area, a division by the number of land blocks was conducted to receive an average garden area for each land block.

$$Block\ Garden\ Area = \frac{(Garden\ Area - Garden\ Road\ Area)}{Number\ of\ Land\ Blocks}$$

10) According to personal correspondence with Kubu and Kramer (2013) from Department 22 of the Viennese City Administration, roof area of Vienna sums up to approximately 5628 ha. To determine an area for each land block, this value was divided by the total number of Land Blocks, resulting in 335 m² of roof area for each land block. This value was assumed to be identical for each neighbourhood.

$$Block\ Roof\ Area = \frac{Total\ Roof\ Area\ of\ Vienna}{Total\ Number\ of\ Land\ Blocks\ in\ Vienna}$$

11) Land Block Paved Area is assumed to be the remaining area of a land block after subtracting roof and garden area.

$$Block\ Paved\ Area = Block\ Area - (Block\ Roof\ Area + Block\ Garden\ Area)$$

12) The value of 0 is an assumption based on several facts:

UVQ uses spoondrain water to add it directly to the lower soil store, however in Vienna allotments are connected to public sewer systems, spoon drains are very uncommon. They can be found in the outskirts of Vienna and even in these remote areas of Vienna it is uncommon not to be connected to the sewer system, which offers a connectivity rate of 99.5 % (Kommunalkredit_Public_Consulting 2012). Furthermore, UVQ-tutorials do not use this parameter.

13) Copper loads for kitchen, bathroom, toilet and laundry were estimated using Table 4.3 underneath:

Table 4.3 Reference values of household-wastewater-loads and atmospheric deposition ZESSNER (1999; cited by Rebernig (2007))

	Cd	Cu	Pb	Zn
	[mg/EW*a]	[g/EW*a]	[g/EW*a]	[g/EW*a]
Ausscheidungen und Speisereste	*9-20*	*0,6-1,7*	*0,02-0,2*	*3-8*
Leitungswasser	*8-15*	*0,5-3*	*0,09-1,00*	*1-8*
Reinigungswässer	*5-171*	*0,8-9,5*	*0,5-7,3*	*5-26*
	[mg/m²*a]	[mg/m²*a]	[mg/m²*a]	[mg/m²*a]
Atmosphärische Deposition (Land)	*0,14*	*5*	*2*	*30*
Atmosphärische Deposition (Stadt)	*0,6*	*25*	*27*	*100*

The arithmetic mean of copper loads from excretions and food leftovers (Ausscheidungen und Speisereste) was divided by 365 to receive daily loads. Further copper concentration of imported supply water multiplied by kitchen, bathroom or toilet water use was added. For laundry copper the arithmetic mean of cleaning water (Reinigungswässer) values was divided by 365 and further copper concentration of imported supply water multiplied by laundry water use was added. To demonstrate the equation behind these assumptions, calculation of Kitchen Copper is presented underneath:

$$Kitchen\ Copper = \left[\frac{\left(1700\frac{mg}{EW}\cdot a + 600\frac{mg}{EW}\cdot a\right)}{2}\cdot\frac{1}{365}\right] + [17L\cdot\frac{0.0015mg}{L}]$$

14) Copper concentrations for roof, road and pavement runoff are taken from a study dealing with storm water pollution in Genoa, Italy (Gnecco, Berretta et al. 2005). The mean values for road and roof runoff are taken from Table 4.4. Pavement runoff is assumed to be the same as road runoff.

Table 4.4 Event Mean concentration for road and roof runoff by Gnecco, Berretta et al. (2005)

	Road runoff				Roof runoff			
	Min	Max	Mean	Median	Min	Max	Mean	Median
TSS (mg/l)	15	377	140	119	0	42	19	18
COD (mg/l)	11	281	129	121	–	–	–	–
Cu (µg/l)	0.1	53.3	19.4	1.1	0.6	18.3	10	10.6
Pb (µg/l)	6.1	23.3	13.2	12.6	2.4	7.3	5.1	5.3
Zn (µg/l)	27.7	123.4	81.1	84.2	212.1	758.8	446.7	408

15) The Austrian Ministry of Agriculture, Forestry, Environment and Water Economy published a guideline for proper fertilizing. This guideline states that between 1 and 3 kg/ha copper should be used for soils with average copper content. Therefore the value of 2 kg/ha or 2000000 mg/ha was chosen.

16) According to a report published by the Austrian Ministry of Agriculture, Forestry, Environment and Water Economy concerning metals in Austria's groundwater, a concentration of 0.0036 mg/L represents the 90%-percentile of the median of all groundwater stations in Austria. However, it should be mentioned that a map offering an overview of copper in river sediments shows increased values around Vienna.

4.3.3 Water Flow

The water flow input screen does not demand any input in form of values. In this screen wastewater and stormwater reuse flows between neighbourhoods can be defined with a simple drag and drop procedure. In Vienna reuse of stormwater and wastewater between single districts is not of concern, thus this screen is negligible.

4.3.4 Calibration Variables

This screen is necessary to calibrate the model to the modelled area. It pictures observed and simulated wastewater and stormwater flows and contaminant loads and hence allows to vary specific components of the model for calibration. It is most likely that a model has to be run several times until a satisfying calibration can be achieved. Following listing presents necessary parameters for a modelling option with a 2-layer soil store, which was chosen in the model of Vienna. Table 4.5 gives an overview of assumed values for the specific Calibration Variables parameters, as well as their source and explanations of assumptions.

Table 4.5 Calibration Variables for Stage 1 – the comment-points can be found below the table

Subscreen	Parameter	Value	Source	Comment
Stormwater	Maximum Soil Storage Capacity	150 mm	Assumption based on Loiskandl and Strauss-Sieberth (2008)	17) on page 41
	Soil Storage Field Capacitiy	80 mm	Assumption	/
	Maximum Daily Drainage Depth	100 mm	Assumption	/
	Roof Area Maximum Initial Loss	1 mm	Assumption based on Mitchell and Diaper (2010)	18) on page 41
	Effective Roof Area	100 %	Assumption	19) on page 41
	Paved Area Maximum Initial Loss	2 mm	Assumption based on Mitchell and Diaper (2010)	20) on page 41

	Effective Paved Area	75 %	Assumption	21) on page 41
	Road Area Maximum Initial Loss	2 mm	Assumption based on Mitchell and Diaper (2010)	20) on page 41
	Effective Road Area	98 %	Assumption	22) on page 41
	Drainage Factor Ratio	0.1	Assumption	/
	Base Flow Recession Constant	0.00001	Assumption after calibration	23) on page 41
Contaminant Soil Store Removal	Contaminant Soil Store Removal of Cu	100 %	Assumption based on personal communication with Pfleiderer	24) on page 42
Wastewater	Infiltration Index	0.05	UVQ Tutorial	Assumption based on UVQ Tutorial
	Infiltration Store Recession	0.1	UVQ Tutorial	Assumption based on UVQ Tutorial
	Percentage Surface Runoff as Inflow	100 %	UVQ User Manual and Assumption	25) on page 42
	Dry Weather Overflow Rate	0	Assumption	/
	Wet Weather Overflow Trigger	Not enabled	Assumption based on email correspondence with Wienkanal	26) on page 43
Irrigation	Garden Trigger to Irrigate	0.5	Assumption	UVQ Tutorial
	Open Space Trigger to Irrigate	0.5	Assumption	UVQ Tutorial
Average Volumes Study Area	Observed Imported for Study Area	124301494 kL	Sailer (2009) and Tomenendal (2008)	27) on page 43
	Observed	205024907 kL	Gottschall (2013)	Personal

	Wastewater for Study Area			communication via telephone
	Observed Stormwater for Study Area	? kL	No Data Available	28) on page 44
Quality Study Area	Cu for Study Area	0.0015 mg/L	MA31 (2008)	29) on page 44
Average Volumes Neighbourhood	Observed Imported for Neighbourhood	/	No Data available	/
	Observed Wastewater for Neighbourhood	/	No Data available	/
	Observed Stormwater for Neighbourhood	/	No Data available	/
Quality Neighbourhood	Copper for Neighbourhood	0.0015 mg/L	MA31WienerWasser (2008)	29) on page 44

17) Loiskandl and Strauss-Sieberth (2008) lists storage capacity values suggested by the FAO. Medium Soils are assumed to have 140 mm/m capacity, heavy soils 200 mm/m. Thus 150 mm was assumed.

18) The amount of water it takes to wet the surface before runoff occurs was assumed to be 1 mm. The same value was used in a tutorial presented in the UVQ User Manual.

19) It is common to connect the entire roof area to a roof drainage system in Vienna, therefore this value was set to 100 %.

20) Due to mostly almost horizontal paved and road areas this value was assumed to be double the amount of roof area maximum initial loss which is affected by roof inclination. Further the same value was used in the UVQ tutorial.

21) Backyards and parking spots are usually connected to the public sewer system. Hence this value is set to 75 %, which implies that 25 % of paved-area-water is contributing to stormwater. In case of neighbourhoods not containing garden areas this parameter has to be set to 100 %. This is the case for neighbourhood 7, 10, 13, 15, 16, 17 and 18.

22) Due to a very high connection rate of private households to public sewers, the value representing public road area contributing to the stormwater system is assumed to be similarly high.

23) Vienna is supplied by several aquifers. According to the map presented in Figure 4-8, most important aquifers are “Marchfeld”, “Südliches Wiener Becken” and “Flyschzone”.

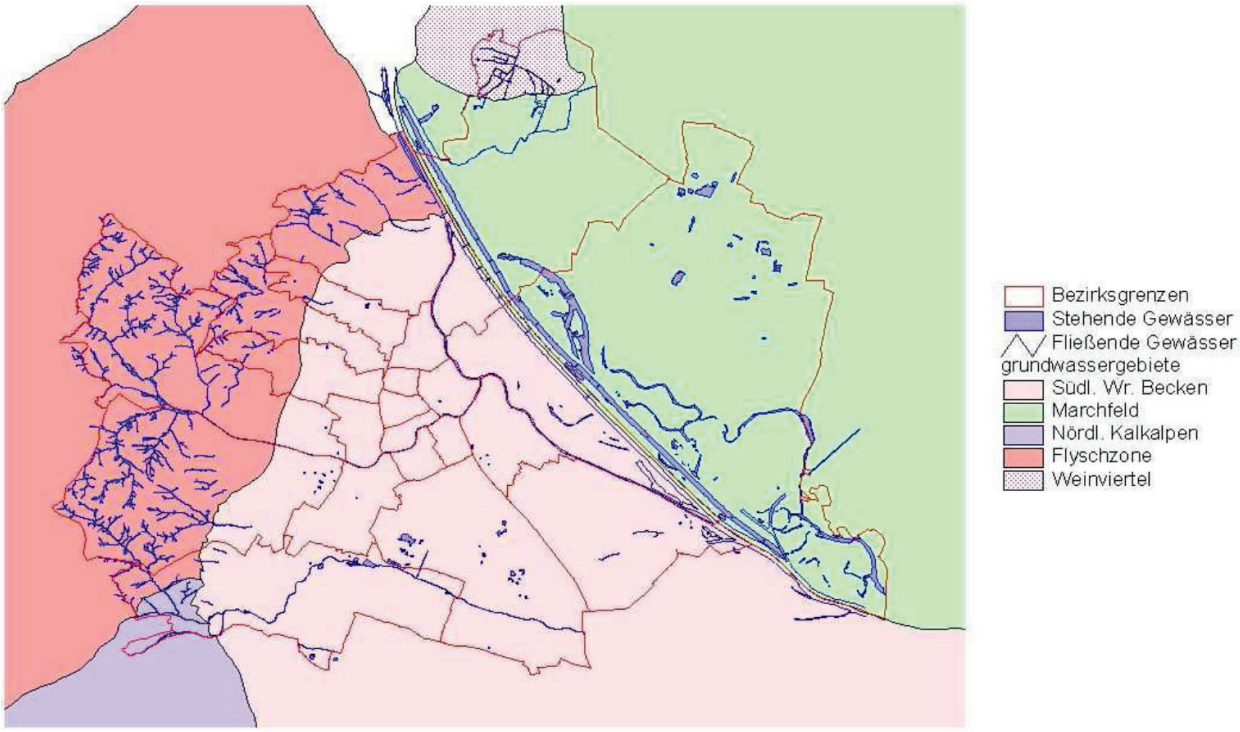


Figure 4-8 Aquifers in Vienna (MA 45 – Wiener Gewässer: Wasserwirtschaftsbericht Wien 2008. Magistrat der Stadt Wien. Wien 2008 cited by Grimm (2010))

Data for aquifers “Marchfeld” and “Südliches Wiener Becken” were available and thus these aquifers were used for calculation of the base flow recession constant. According to Grimm (2010) “Marchfeld” spreads over a total area of 947.7 km² and has an average depth of 20 m, whilst “Südliches Wiener Becken” covers an area of 1228.2 km² with an average depth of 30 m. Both aquifers are pore-groundwater, thus a porosity of 0.5 is assumed, comprising a range from sand to clay (Loiskandl and Strauss-Sieberth 2008). Therefore water storage sums up to 9.474 km³ and 18.432 km³.

To get a ratio for baseflow, an estimation of dry weather baseflow to the Viennese wastewater treatment plant was necessary, which was discovered in a report concerning optimization of substance-flow-monitoring in wastewater treatment of Vienna by Kroiss, Morf et al. (2008). The assumed value is 432.000 m³/d.

Thus the baseflow recession constant was estimated using following equation:

$$Base\ Flow\ Recession\ Constant = \frac{Dry\ Weather\ Baseflow}{(Marchfeld\ Aquifer\ Storage + Südl.Wiener\ Becken\ Aquifer\ \ Storage)}$$

$$Base\ Flow\ Recession\ Constant = \frac{0.0004\ km^3}{(9.474\ km^3 + 18.432\ km^3)} = 1.4 \cdot 10^{-5}$$

Hence this value was set to 0.00001. The same value was used by Mitchell and Diaper (2010) in a tutorial included in the UVQ User Manual. It is important to be aware of the fact that groundwater in Vienna is a highly complex system, thus making assumptions is a highly difficult task. Further pieces of information concerning groundwater conditions are listed at point 33).

24) Personal communication via telephone with Sebastian Pfleiderer of the Federal Agency of Geology revealed that copper is not yet accumulating in the groundwater of Vienna, therefore all copper has to be trapped in soil. Thus this value was set to 100%.

25) According to the UVQ User Manual, this value should be set to 100% in case of modelling a combined sewer system. However, Vienna’s sewer system combines three system approaches: combined sewer systems, separated sewer systems and partially combined sewer systems. The map presented in Figure 4-9 displays Vienna’s sewer network. Pink

areas reveal combined sewers, yellow areas represent partially combined sewers and green areas show separated sewers.

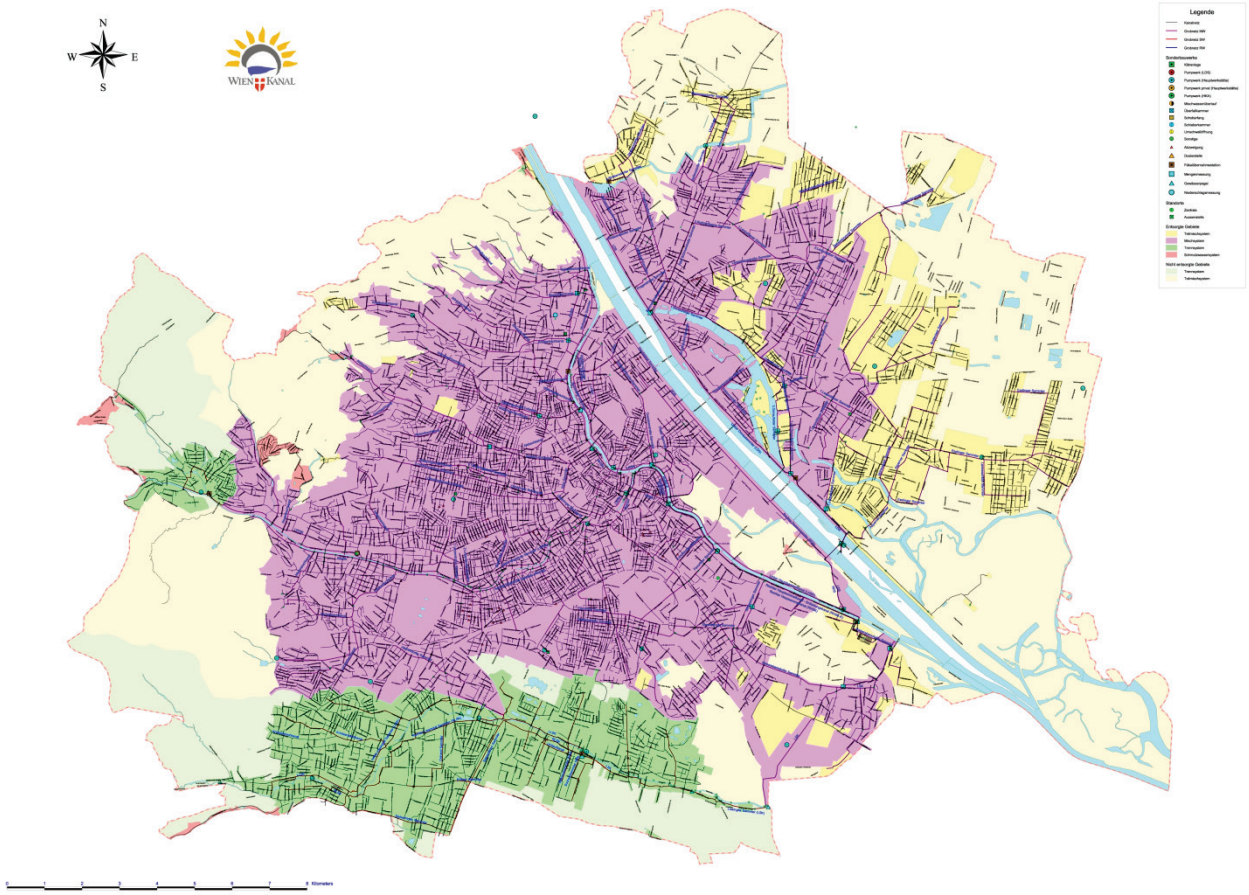


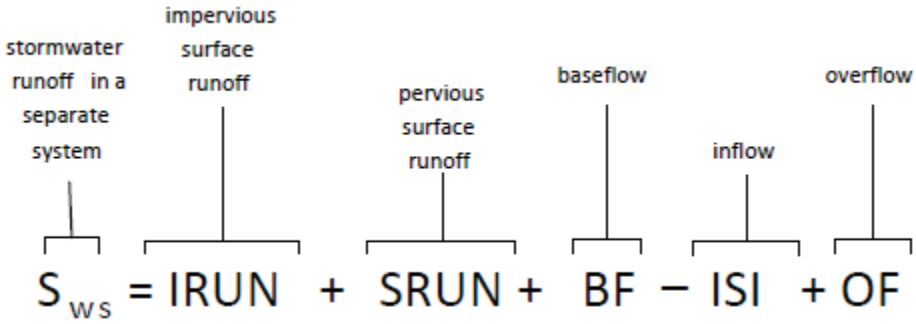
Figure 4-9 Sewer network Vienna (Wien_Kanal 2013)

A comparison of the sewer network map above with a map of Vienna offering a spatial division in districts showed that a separate sewer system operates dominantly only in district 23 (neighbourhood 21). In all remaining neighbourhoods, combined sewer systems by far outweigh other systems. As a result, this parameter was set to 100 % with neighbourhood 21 as exception. In neighbourhood 21 it was set to 40%, which is a simple assumption.

26) According to email correspondence with Wienkanal, the Viennese Sewer Network Administration, excess rain water management is very complex in Vienna. Several retaining pools have been built and are currently built to retain excess rain water in case of heavy rainfall events. After an event, retained water is sent to the central treatment plant in Simmering. Thus this option is yet disabled in the simulation.

27) Vienna imports water via two main water lines. Together these two pipelines imported 137461000 kL of water in 2008. However, this amount does not reflect the actual water use. A differentiation between revenue water and non revenue water is made in Vienna and further, a small percentage of water is exported to Lower Austria. Imported water in UVQ is only represented by revenue water, thus non revenue water and exports have to be subtracted. According to Tomenendal (2008) non revenue water in 2008 is calculated to be 7.6 %, water exports sum up to 2,712,470 kL. After subtracting these values, imported water for UVQ in 2008 results in 124,301,494 kL. A 3-year average value also by Tomenendal (2008) is 122,774,742 kL, showing that the calculated value in this thesis is quite similar.

28) Stormwater in UVQ is calculated by following equation:



This equation calculates stormwater for a separate sewer system. However, Vienna is mainly modelled with a combined sewer system. Therefore simulated stormwater is very small, consisting of impervious and pervious surface runoff which is also mainly received by the sewer system.

No data was available concerning this specific amount of water, hence calibration in this case is not constructive.

29) Data of copper concentrations were taken at four different sites in Vienna according to a table received from Department 31 of the Viennese City Administration "Vienna Water Works". An arithmetic mean of these values was calculated, resulting in 0.0015 mg/L Cu in imported water.

4.3.5 Snow Variables

The so called "Snow Accumulation and Redistribution" screen defines variables related to snowmelt and the amount of snow which can accumulate until action is taken to remove it. Table 4.6 gives an overview of assumed values for the specific Snow Variables parameters, as well as their source and explanations of assumptions.

Table 4.6 Snow Variables for Stage 1 – the comment-points can be found below the table

Subscreen	Parameter	Value	Source	Comment
	Snowfall Threshold	0°C	Kienzle (2008)	30) on page 45
	Snow Melt Threshold	0°C	Assumption based on Fürst (2008)	No significant discharge out of snow cover can take place below 0°C
	Melt Rate Factor	5 mm/d	Assumption based on Mitchell and Diaper (2010)	31) on page 45
Redistribution	Paved Area Redistribution	1 mm	Assumption based on Frybert (2011)	32) on page 45

	Threshold		and http://www.wien.gv.at	
	Road Redistribution Threshold	1 mm	Assumption based on Frybert (2011) and http://www.wien.gv.at	32) on page 45

30) Kienzle (2008) published an article concerning a new temperature based method to separate rain and snow. 15 climate stations were used, different methods were compared and several approaches were taken. However, it is mentioned that several studies on this topic use 0° C as threshold temperature and further literature study also revealed this value. Furthermore this temperature is the default value of UVQ. As a result, 0°C were chosen to be the snowfall threshold temperature.

31) Mitchell and Diaper (2010) states that values for this parameter range between 2 and 10 mm/d. Due to high buildings in urban areas, resulting in shaded spaces in which snow can resist sun for extended periods of time, this value was set to 5 mm/d.

32) Department 48 of the Viennese City Administration published a brochure concerning winter services in Vienna. This brochure and research on the homepage of the city of Vienna did not offer any results about this parameter. It was only possible to retrieve actions to be taken if snow falls and times for compulsory winter service. However, based on own experience, snow in Vienna is cleared very quickly and as soon as snow falls, cleaning vehicles are used immediately. Thus this value was set as low as possible, namely 1 mm.

4.3.6 Land Block

The “Land Block Water Management Features” screen defines the available water treatment and water storage processes of land blocks within a neighbourhood. Table 4.7 gives an overview of assumed values for the specific Land Block Water Management parameters. These parameters was not considered, an explanation is given below the table.

Table 4.7 Land Block Water Management Parameters for Stage 1 – an explanation is given below the table

Subscreen	Parameter	Value	Source	Comment
Rain Tank	Storage Capacity	0	/	/
	Initial Storage Level	/	/	/
	First Flush	/	/	/
	Storage Backup Trigger Level	/	/	/
	Stormwater Store in Neighbourhood Number	/	/	/

	Wastewater Store in Neighbourhood Number	/	/	/
	Contaminant Removal Efficiency	/	/	/
On Site Wastewater Unit	Storage Capacity	0	/	/
	Exposed Surface	/	/	/
	Initial Storage Level	/	/	/
	Contaminant Removal Efficiency	/	/	/

Due to the small number of on-site water management facilities in Vienna these features were not considered in the model.

According to a report on integrative rainwater management by Grimm (2010) for Department 22 of the Viennese City Administration, some projects on rainwater management were realised since the early nineties. The main concentration of these projects can be found in the 21st, 22nd and 23rd district of Vienna. However, evaluation of the percolation water data bank of Department 45 of the Viennese City Administration shows that only 27 rainwater tanks are currently used in Vienna (Grimm 2010).

Wastewater units are also obsolete in Vienna due to a connection ratio to the sewer network of 99.5% according to Kommunalkredit_Public_Consulting (2012).

4.3.7 Neighbourhood

This screen, called “Neighbourhood Water Management Features” contains water management options for the neighbourhood scale, divided in a “Stormwater and ASR (Aquifer Storage and Recovery)” tab, a “Wastewater” tab and a “Groundwater and Imported Water” tab. Table 4.8 gives an overview of assumed values for the specific Neighbourhood Water Management parameters, as well as their source and explanations of assumptions. The majority of these parameters was not considered, an explanation is given below the table.

Table 4.8 Neighbourhood Water Management Parameters for Stage 1 – an explanation is given below the table

Subscreen	Parameter	Value	Source	Comment
Stormwater Storage	Storage Capacity	0	/	/
	First Flush	/	/	/
	Exposed Surface	/	/	/

	Initial Storage Level	/	/	/
	Contaminant Removal Efficiency Cu	/	/	/
Aquifer Storage and Recovery	Storage Capacity	0	/	/
	Storage Level	/	/	/
	Maximum Recharge Rate	/	/	/
	Maximum Recovery Rate	/	/	/
Wastewater Store	Storage Capacity	0	/	/
	Exposed Surface	/	/	/
	Initial Storage Level	/	/	/
	Contaminant Removal Efficiency Cu	/	/	/
Groundwater and Imported Water	Initial Storage Level	9999999 kL	Assumption	33) on page 47

Stormwater Store in UVQ is explained to be a further supply source for the operations toilet flushing, garden and open space irrigation. However, in Vienna such stores do not exist, therefore these parameters are not taken into account. The same assumptions apply to Aquifer Storage and Recovery and Wastewater Store.

33) According to Wiener_Gewässer (2013) groundwater in Vienna comprises several different types, including pore groundwater, crack groundwater, non-stressed shallow groundwater and deep, stressed groundwater. Groundwater in Vienna may overlap, occur in different depths and may interact. This large amount of variability results in difficulties picturing groundwater in Vienna. Janac (2013) from Department 45 of the Viennese City administration, responsible for Hydrology, states that groundwater storage is not measured in Vienna. He further mentions that due to the lack of knowledge concerning porosity and aquifuges, joined by a severe inhomogenity of groundwater-conditions, a calculation of a storage level is not possible. Thus it is very difficult to assess the state of the initial storage level in Vienna. However, Grimm (2010) mentions a good quantitative state of groundwater in Vienna, hence the value for Initial Storage Level was set to its maximum, which is 9999999 kL for each neighbourhood. This amount of water in each neighbourhood sums up to 229999977 m³ of storage for the entire area of Vienna, which indicates in an average groundwater depth of approximately 0.6 m. This is definitely the case in Vienna.

4.3.8 Study Area

The Study Area Water Management screen defines characteristics of wastewater and stormwater storages which are capable of coping with the entire amount of storm- and wastewater accumulating at the study site. Table 4.9 gives an overview of assumed values for the specific Study Area Management parameters. These parameters were not considered, an explanation is given below the table.

Table 4.9 Neighbourhood Water Management Parameters for Stage 1 – an explanation is given below the table

Subscreen	Parameter	Value	Source	Comment
Wastewater Store	Storage Capacity	0	/	/
	Exposed Surface	/	/	/
	Initial Storage Level	/	/	/
	Contaminant Removal Efficiency	/	/	/
Stormwater Store	Storage Capacity	0	/	/
	Exposed Surface	/	/	/
	First Flush	/	/	/
	Initial Storage Level	/	/	/
	Contaminant Removal Efficiency	/	/	/

The same assumptions as for Neighbourhood stores explained in chapter 4.3.7 apply.

4.3.9 Climate Input File

As mentioned in chapter 4.3 the climate input file is a comma separated value file. It contains daily precipitation, evaporation and average temperature data. Evaporation and precipitation have to be provided in mm, average temperature in degrees Celsius. A climate series can cover a period of several years, however it has to start with the 1st of January and end with 31st of December.

In this thesis data from different stations across Vienna, containing the period between 2006 and 2012, were used to develop the climate input file.

Because daily rainfall values representative for the entire study area were unavailable, calculations of such values were necessary.

Following stations were considered for the calculation of daily rainfall, daily evapotranspiration and daily temperature:

- Station 5805 – Mariabrunn
- Station 5904 – Wien Hohe Warte
- Station 5917 – Wien Unterlaa
- Station 5925 – Wien Innere Stadt
- Station 5935 – Donaufeld

Due to the large study area it was not appropriate to select one single station to be representative for the entire area. As a result it was assumed that each station covers a specific spatial area to better calculate an average rainfall based on spatial scales. Table 4.10 below presents which districts of Vienna are assigned to which station.

Table 4.10 Assignment of Neighbourhoods to Climate Stations

Station Nr.	Assigned Viennese districts	Assigned neighbourhoods
5805	13, 14, 15, 16	9, 8, 14, 6
5904	17, 18, 19, 20	5, 4, 2, 3
5917	10, 11, 12, 23	22, 23, 20, 21
5925	1 to 9	13, 12, 19, 18, 17, 16, 15, 10, 7
5935	21, 22	1, 11

4.3.9.1 Rainfall

Rainfall of each station was multiplied by the percentage of the study area a station covers. The average daily rainfall was then calculated by building the sum of these spatial subsets. To demonstrate this approach, rainfall calculation for station 5805 will be shown:

$$Rain\ 5805 = Daily\ Rain\ 5805\ \cdot \frac{Area\ 13 + Area\ 14 + Area\ 15 + Area\ 16}{Total\ Area}$$

$$Total\ Daily\ Rain = \sum Rain\ 5805 + Rain\ 5904 + Rain\ 5917 + \ Rain\ 5925 + Rain\ 5935$$

Example with data from June the 8th, 2011:

$$Rain\ 5805 = 13.8mm\ \cdot \frac{3771.6\ ha + 3376.3\ ha + 392.4\ ha + 867.4\ ha}{41487.4} = 2.8\ mm$$

$$Rain\ 5904 = 4.4\ mm$$

$$Rain\ 5917 = 1.0\ mm$$

$$Rain\ 5925 = 8.2\ mm$$

$$Rain\ 5935 = 13.7\ mm$$

$$Total\ Daily\ Rain\ for\ 08062011 = 2.8\ mm + 4.4\ mm + 0.9\ mm + 8.2\ mm + 13.7\ mm = 30.0\ mm$$

This date was selected due to its heavy rainfall, which was the most severe rainfall event in 2011. It can be clearly seen that there is a wide spatial variability of rainfall within the urban area of Vienna.

Table 4.11 presents a comparison of officially published precipitation values between 2006 and 2001 by MA23 (2013) and calculated values with above method. The average error for the invented method equals 5.7 %, however for the observation year 2008 it is just 0.6 %. This error is satisfying and thus calculated values will be used.

Table 4.11 Comparison of official and calculated precipitation values

Year	Officially Observed Rainfall [mm]	Calculated Rainfall by Author [mm]
2006	694	642
2007	864	817
2008	669	665
2009	900	804
2010	838	799
2011	517	488

4.3.9.2 Temperature

Temperature data was available in form of 7am, 2pm and 7pm measurements, as well as minimum and maximum daily temperature measurements. To calculate a mean daily temperature for each station and day the formula below was used (Myszkowska 2012):

$$T_{mean} = \frac{(T_7 + T_{19} + T_{max} + T_{min})}{4}$$

After using this formula, the same spatial approach as for rainfall-calculations was used. This approach is explained in chapter 4.3.9.1.

4.3.9.3 Evapotranspiration

Evapotranspiration was calculated using the FAO Penman Monteith Method. This method is a universal standard for evapotranspiration calculation since the early nineties (Sentelhas, Gillespie et al. 2010). It uses air temperature, radiation, wind velocity and air moisture for calculation.

$$ET_0 = \frac{0.408 \cdot \Delta \cdot (R_n - G) + \frac{\gamma \cdot 900 \cdot (e_a - e_d)}{(t + 273)}}{\Delta + \gamma \cdot (1 + 0.34 \cdot U_2)}$$

ET_0 ... Reference Evapotranspiration in mm d^{-1}

Δ ... slope of the saturated vapor pressure curve in kPa C^{-1}
R_n ... net radiation in kJ m^{-2} s^{-1}
G ... soil heat flux density in kJ m^{-2} s^{-1}
γ ... psychrometric constant kPa C^{-1}
e_a ... saturation vapour pressure in kPa
e_d ... actual vapour pressure in kPa
(e_a-e_d) ... saturation vapour pressure deficit in kPa
t ... air temperature in °C
U_2 ... wind speed 2 m above the ground in m s^{-1}

<u>Calculation of e_a</u>

$$e_a = 0.611 \cdot e^{(\frac{17.27 \cdot t}{t + 237.3})}$$

Due to three temperature measurements throughout the day, e_a was calculated for each measurement.

Calculation of e_d

Usually e_d is calculated using maximum and minimum temperature and the associated relative air humidity. However, available data only included associated humidity with the three temperature measurements at 7am, 2pm and 7pm, thus these values were used. Just as e_a, three values for e_d were calculated.

$$e_d = e_a(t) \cdot \frac{RH(t)}{100}$$

RH(t) ... relative air humidity at time t in %

Calculation of Δ

$$\Delta = \frac{4098 \cdot e_a}{(t + 237.3)^2}$$

As the parameters before, Δ was also calculated for each measurement time.

Calculation of R_n

$$R_n = R_{ns} - R_{nl}$$

R_{ns} ... short waved net radiation in MJ m^{-2} d^{-1}
R_{nl} ... long waved net radiation in MJ m^{-2} d^{-1}

$$R_{ns} = (1 - 0.23) \cdot R_s$$

0.23 is the Albedo of the assumed plant.

R_s ... short waved solar radiation in MJ m^{-2} d^{-1}

$$R_{nl} = 2.45 \cdot 10^{-9} \cdot \left(0.9 \cdot \frac{n}{N} + 0.1\right) \cdot \left(0.34 - 0.14 \cdot \sqrt{e_d}\right) \cdot \left(T_{min}^4 + T_{max}^4\right)$$

n ... actual period of sunshine during the day in h
N ... maximum possible period of sunshine during the day in h
T_{min} ... minimum temperature of the day in K
T_{max} ... maximum temperature of the day in K

In this formula the arithmetic mean value for e_d was used, calculated with the three values mentioned before at calculation of e_d.

Calculation of G

The soil heat flux was set to 0 due to the daily time step in the UVQ software. The daily soil heat flux is very small for such short periods.

Finally, ET_0 was calculated for all three measurement times at 7am, 2pm and 7pm. The arithmetic mean of these values was computed for each station. After finishing this step, ET_0 was also averaged using the spatial approach from the calculation of rainfall and temperature (chapter 4.3.9.1 and 4.3.9.2), resulting in the value of ET_0 used for the UVQ model of Vienna.

4.4 UVQ Stage 2 – Revised Parameters

To increase the level of detail, further data was acquired. Data representing values for the simulation period of 2008 could be gathered and were used to enhance the UVQ model.

This section will introduce and explain changes in parameters conducted for development of UVQ Model Stage 2.

Only revised parameters will be described and represented in this chapter, variables not subject of modification were adopted from Stage 1 in chapter 4.3.

4.4.1 Project information

Table 4.12 presents changed parameters of the Project Information.

Table 4.12 Revised Parameters of Project Information

Parameter	Chosen Value	Source	Comment
Study Area Size	39706.9 ha	Statistical yearbook of Vienna 2009 by Hlavac (2009)	34) on page 52

34) The new study area is calculated by the summation of the new neighbourhood areas. In UVQ Model stage 2 surface water areas were not taken into account, hence the entire area decreased. A more detailed explanation is given in 35) in chapter 4.4.2.

4.4.2 Physical characteristics

As in chapter 4.3.2, values in Table 4.13 below apply for neighbourhood 23, representing the 11th district of Vienna, “Simmering”. The same neighbourhood as in Stage 1 is used for better illustration of revision.

Table 4.13 Revised Parameters of Physical Characteristics

Subscreen	Parameter	Chosen Value	Source	Comment
Neighbourhood	Total Area	2274.8 ha	Statistical yearbook of Vienna 2009 by Hlavac (2009)	35) on page 53
	Road Area	417.8 ha	Statistical yearbook of Vienna 2009 by Hlavac (2009)	36) on page 54
	Open Space Area	949.4 ha	Statistical yearbook of Vienna 2009 by Hlavac (2009)	37) on page 54
	Imported Supply Leakage	7.6 %	Tomenendal (2008)	38) on page 54
Land Block	Block Area	1242.7 m²	Statistical yearbook of Vienna 2009 by Hlavac (2009)	Change due to new total area
	Average Occupancy	7.3	Statistical yearbook of	39) on page 54

			Vienna 2009 by Hlavac (2009)	
	Garden Area	104.9 m²	Statistical yearbook of Vienna 2009 by Hlavac (2009)	40) on page 55
	Paved Area	802.8 m²	Statistical yearbook of Vienna 2009 by Hlavac (2009)	Changed due to new total area
Indoor Water Usage and Contaminants	Toilet Water Use	114.1 L/c/d	Neunteufel, Richard et al. (2012), Hlavac (2009)	41) on page 55
	Kitchen Cu	1.83 mg/c/d	Obernosterer, Reiner et al. (2003)	42) on page 56
	Bathroom Cu	1.83 mg/c/d	Obernosterer, Reiner et al. (2003)	42) on page 56
	Toilet Cu	1.83 mg/c/d	Obernosterer, Reiner et al. (2003)	42) on page 56
Other Contaminants	Road Runoff Cu	0.05 mg/L	Gnecco, Berretta et al. (2005)	43) on page 57
	Pavement Cu	0.05 mg/L	Gnecco, Berretta et al. (2005)	43) on page 57
	Fertiliser to POS	2000000 mg/ha	Etz (2006)	44) on page 57
	Fertiliser to Garden	50 mg/m²	Etz (2006)	45) on page 58

35) According to the Statistical Yearbook of Vienna 2009, the area of neighbourhood 23 was divided in 2008 as pictured in Figure 4-10.

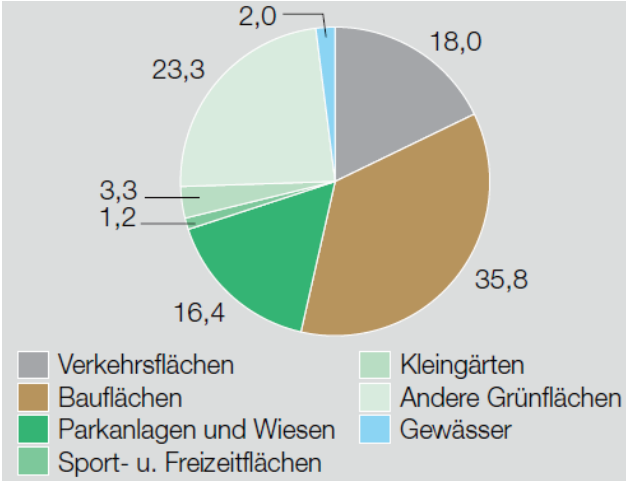


Figure 4-10 Areal division of neighbourhood 23

The entire area of neighbourhood 23 including surface water equals 2321.2 ha, however in UVQ model stage 2, surface waters were omitted. Thus, 2 % was subtracted from the entire area to obtain a new total area.

$$New\ Total\ Area = 2321.2\ ha - (2321.2\ ha \cdot 0.02) = 2274.8\ ha$$

The same approach was used in every single neighbourhood, some of them featured surface water areas comprising up to 20% of the entire neighbourhood area, resulting in severely decreased total areas.

Areas calculated using this approach were summed up to form the entire study area, as mentioned in 34).

36) Road area was calculated exactly as in UVQ Model Stage 1, only new values representing Vienna in 2008 were used:

$$Road\ Area = \frac{18.0\ \%}{100} \cdot Total\ Area\ incuding\ surface\ water\ area$$

Surface water area was included in this calculation, due to its solely influence onto total area.

37) Open Space area in stage 2 was calculated by omitting surface water area and garden areas, which were included in stage 1. The Statistical Yearbook of Vienna 2009 included explicit information about garden areas, which was used to calculate garden area within the land block. Open Space Area in stage 2 only includes “Other Green Area” OG, “Park Areas and Grassland” PG as well as “Sport- and Recreational Areas” SR. Below, calculation of Open Space Area in neighbourhood 23 is demonstrated:

$$Open\ Space\ Area = \left(\frac{23.3\%}{100} \cdot OG + \frac{1.2\%}{100} \cdot SR + \frac{16.4\%}{100} \cdot PG\right) \cdot Total\ Area\ including\ surface\ water\ area$$

38) A table by Tomenendal offered a calculated value of supply leakage of 7.6% for 2008. This value was calculated by the Vienna Water Works and includes non revenue water as well as leakage and personal water usage of the Vienna Water Works. During development of stage 1 it was not known that this percentage already includes former mentioned water-flows.

39) In 2008 Vienna was home to only 1687271 inhabitants compared to 1731236 used in UVQ model stage 1. This results in decreased values for average occupancy, however, calculation is still the same as demonstrated in point 8) in chapter 4.3.2. The Number of Land Blocks, representing the number of buildings, did not change.

40) Figure 4-10 illustrates that 3.3 % of the total area (including surface waters) is dedicated to garden area. Hence garden area is calculated with following equation:

$$Garden\ Area = \frac{\frac{\%\ of\ Total\ area\ taken\ by\ Garden}{100} \cdot Total\ Area\ including\ surface\ water}{Number\ of\ Land\ Blocks}$$

41) According to the UVQ User Manual, the software is only able to consider industrial , touristic and commercial water use by adding the necessary amount of water to toilet water of indoor water use. The previous toilet water use of 40 L per capita and day therefore changed severely in each district. Calculations behind new values are explained below.

Tourism water use

According to Neunteufel, Richard et al. (2012) a hotel room uses an average of 345 L of water each day. Because room numbers of each district in Vienna were not available, but only a total quantity of rooms for entire Vienna, a simple formula was invented to approximate a room number for every neighbourhood:

$$Neighbourhood\ Room\ Quantity = \frac{Number\ of\ Nights\ spent\ in\ Neighbourhood}{Total\ Number\ of\ Nights\ spent\ in\ Vienna} \cdot Total\ Quantity\ of\ Rooms\ in\ Vienna$$

To obtain a value for used water, following formula was used:

$$Total\ Tourism\ Water\ Use\ in\ Neighbourhood = 345\ L \cdot Neighbourhood\ Room\ Quantitiy$$

However, UVQ demands a value per capita, hence Total Tourism Water Use was divided by residents of the neighbourhood:

$$Added\ Water\ Use\ to\ Toilet\ by\ Tourism = \frac{Total\ Tourism\ Water\ for\ Neighbourhood}{Number\ of\ Residents\ of\ Neighbourhood}$$

In case of neighbourhood 23, which is not a district known for tourism, 0.81 L were added to Toilet water. The highest added amount of tourism water was calculated for neighbourhood 13, representing the inner city of Vienna, the major contributing district to tourism. There, almost 93 L were added to toilet water to consider tourism water use.

Commerce and Trade water use

Neunteufel, Richard et al. (2012) investigated water use of shopping centres and achieved to present a value for water use of 3.08 L per m² and day. The Statistical Yearbook of Vienna 2012 by Lebhart (2012) offered values concerning the space taken by the most important trade zones in Vienna. However, for neighbourhood 11 a very rough estimation via Google™ Earth was achieved, resulting in 200000 m² of trade area. After gathering data for trade area, following calculation was conducted:

$$Neighbourhood\ Trade\ Water\ Use = \frac{Neighbourhood\ Area\ of\ Trade\ \cdot 3.08\ L}{Number\ of\ Inhabitants\ of\ Neighbourhood}$$

Industrial water use

Industrial water use was approximated by using findings of STAN Model Stage 1. These results are presented in chapter 5.2.1. It was calculated that industry used approximately 44,190,513,000 L of water in 2008. This value was partitioned onto each inhabitant using following equation:

$$Industrial\ Water\ Use\ Per\ Capita = \frac{Approximated\ STAN\ Annual\ Industrial\ Water\ Use}{365 \cdot Number\ of\ Inhabitants\ of\ Vienna}$$

Thus, 71.8 L per capita and day are added to Toilet Water Use in every single neighbourhood.

Finally, Toilet Water Use in UVQ Model Stage 2 is calculated by adding the components Industry, Tourism and Trade to the common Toilet Water Use.

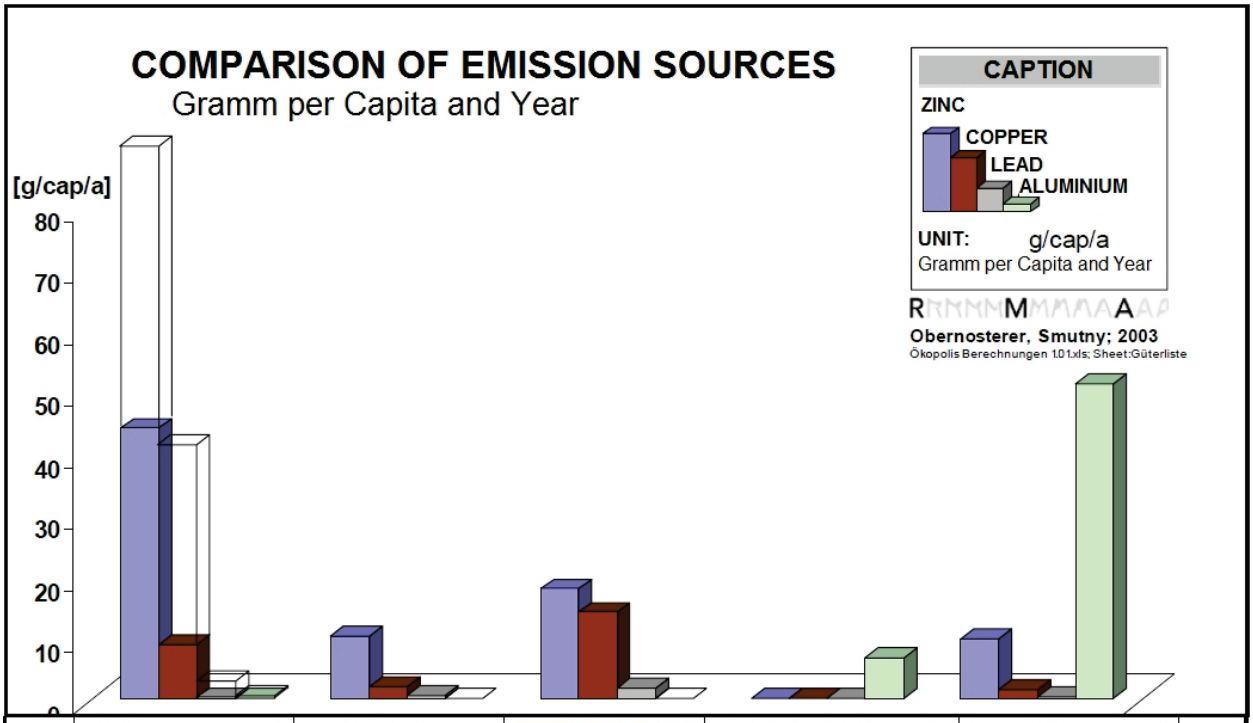
$$Toilet\ Water\ Use = Toilet\ Flush + Industrial\ Water + Tourism\ Water + Trade\ Water$$

For neighbourhood 23, the total “toilet water use” sums up to 114.1 Litres per capita and day.

$$Toilet\ Water\ Use\ Neighbourhood\ 23 = 40 + 71.8 + 1.5 + 0.8 = 114.1 \frac{L}{c \cdot d}$$

42) In 2003, Ressourcen Management Agentur [Resource Management Agency] published a report on pollution management of diffuse metal-emissions in Vienna. This report contained information concerning copper emissions from buildings, nourishment and cleaning, traffic, waste incineration and wastewater treatment. Several calibration calculations were taken with these new values in UVQ Model stage 2 to approximate the simulated copper load to observed values. However, only copper loads for nourishment and cleaning seemed reasonable for the UVQ model, because separation of dry and wet deposition was not possible. Thus approximated traffic copper loads with values taken from this study would have resulted in severe overestimation. Figure 4-11 presents estimated copper loads per capita and year for different anthropogenic fields. The outer left column exhibits a transparent and a coloured fraction. The transparent parts represent the maximum of the measured diffuse pollution in a settlement area, the coloured fraction presents the actual diffuse emission. The column “Ernährung und Reinigung” represents nourishment and cleaning, where a value of 2.0 g/cap/a Cu can be observed. To obtain a representative value for kitchen, bathroom and toilet copper concentration, the load was divided by the number of days and the number of water use sections, which is three (toilet, bathroom and kitchen).

$$Kitchen, Bathroom, Toilet - Copper\ Load = \frac{2000 \frac{mg}{cap \cdot a}}{365\ d \cdot 3} = 1.83\ mg/cap \cdot d$$



g /cap /a	BUILDING (balances settlement area)				NOURISHMENT & CLEANING				TRAFFIC				WASTE INCINERATION				WASTEWATER TREATMENT				g /cap /a
	Zn	Cu	Pb	AL	Zn	Cu	Pb	AL	Zn	Cu	Pb	AL	Zn	Cu	Pb	AL	Zn	Cu	Pb	AL	
Ist	44	8,9	0,2	0,03	10	2,0	0,53	n.b.	18	14	1,7	n.b.	0,08	0,02	0,01	6,7	10	1,4	0,41	51	Ist
Max.	92	41	2,4	0,40																	

Figure 4-11 Comparison of Emissions within Vienna – loads in g per capita and year (Obernosterer, Reiner et al. 2003), translated by Author

Laundry copper load did not change and copper load arising from imported water used indoor was omitted, because it is already considered as a parameter.

43) During calibration with new copper values from Obernosterer Richard (2003), it was discovered that an increasement of copper concentration in road runoff is necessary compared to UVQ model stage 1. Hence the same study as in stage 1 was considered, however, this time values representing the upper limit of measured concentration were assumed. In Table 4.4, pictured at point 14) in chapter 4.3.2, copper loads for road runoff can be observed. The upper measured limit in the study by Gnecco, Berretta et al. (2005) was 53.3 µg/L or 0.05 mg/L. The same value was assumed for pavement runoff. This value still underruns the legal threshold value of 0.5 mg/L published in AAEV (1996), the General Decree concerning Wastewater Emissions in Austria.

44) The value of the parameter “Fertilizer to Public Open Space (POS)” did not change in stage 2, however, consideration of this factor did. Fertilizer to POS in UVQ Model stage 2 is only taken into account in neighbourhoods with significant agriculture. Thus neighbourhood 1, 2, 11, 22 and 23 still consider this parameter, whereas in all other neighbourhoods the value is set to 0.

45) It is often mentioned that urban soils contain high amounts of copper and the fact that no increase in copper in Vienna's groundwater is measured confirms this assumption. Therefore it is assumed that copper in gardens is only distributed via leaf-fertilizing. In this case, Etz (2006) suggests a value of 50 mg/m².

4.4.3 Calibration variables

Just as Stage 1 UVQ Model, calibration variables are mostly identical for all neighbourhoods. Changed parameters are listed in Table 4.14 below and if a parameter is different for other districts, it is mentioned explicitly in the descriptive comments.

Table 4.14 Revised Parameters of Calibration Variables

Subscreen	Parameter	Chosen Value	Source	Comment
Stormwater	Maximum Soil Storage Capacity	140 mm	Loiskandl, Klik et al. (2010), eBOD (2006)	46) on page 58
	Soil Store Field Capacity	100 mm	eBOD (2006)	47) on page 59
	Maximum Daily Drainage Depth	80 mm	Assumption	48) on page 60
	Drainage Factor Ratio	0.05	Assumption	49) on page 60
Wastewater	Dry Weather Overflow Rate	0 %	Assumption	50) on page 61
	Wet Weather Overflow Trigger	variable	Assumption based on	51) on page 61

46) Advanced literature research and correspondence with Pfleiderer from the Geological Survey of Austria offered the cognition that soil parameters demanded by UVQ are hardly available for Vienna. The Ministry of Agriculture, Forestry, Environment and Water Management offers a service called eBOD, a digital online version of soil maps in Austria. This map illustrates different soil parameters, however measurements of soils in Vienna are only available in outskirts, due to the lack of measurements for areas covered with buildings. Thus assumptions are based on findings from surrounding areas and geological maps. Assumptions made in Stage 1 UVQ Model were satisfying, however, several calibration runs, as well as literature and online research, made slight adjustments necessary. LOISKANDL W. (2010) mentions 140 mm of soil storage capacity as a first orientation for medium soils. Figure 4-12 Soil types surrounding Vienna (eBOD 2006) presents a map by eBOD (2006), illustrating that Vienna is mostly surrounded by medium soils. Further, calibration indicated that this value fits best for simulation. Thus 140 mm is assumed to be the Maximum Soil Storage Capacity.

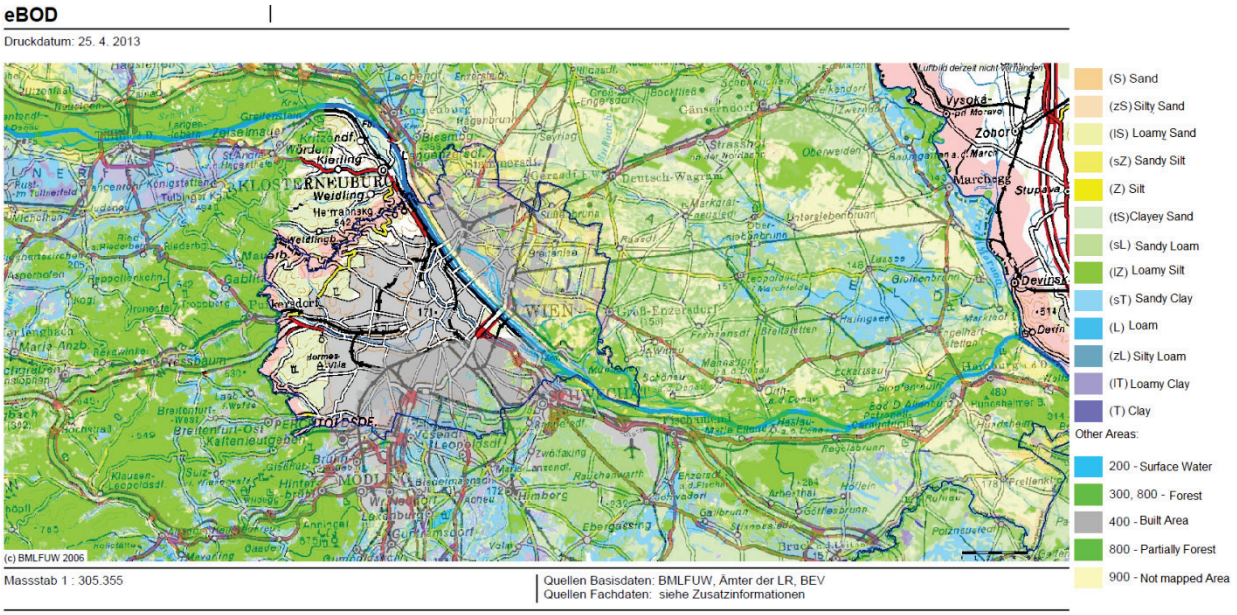


Figure 4-12 Soil types surrounding Vienna (eBOD 2006), translated by Author

47) Figure 4-13 illustrates areas of measured available field capacity in the Vienna Region. It can be clearly seen that eastern parts feature areas with medium to high field capacity, whereas southern parts of Vienna exhibit medium to low field capacity. Eastern areas and the central region are not mapped due to the lack of data, however Figure 4-14 offers a different geological background in these sections. Thus field capacity is likely to be low in central and eastern parts. Therefore the arithmetic mean of low field capacity of the map shown in Figure 4-13 is assumed for Stage 2 UVQ Model. In comparison with UVQ Model Stage 1 (chapter 4.3.4), a slight increase of field capacity is carried out, from 80 mm up to 100 mm.

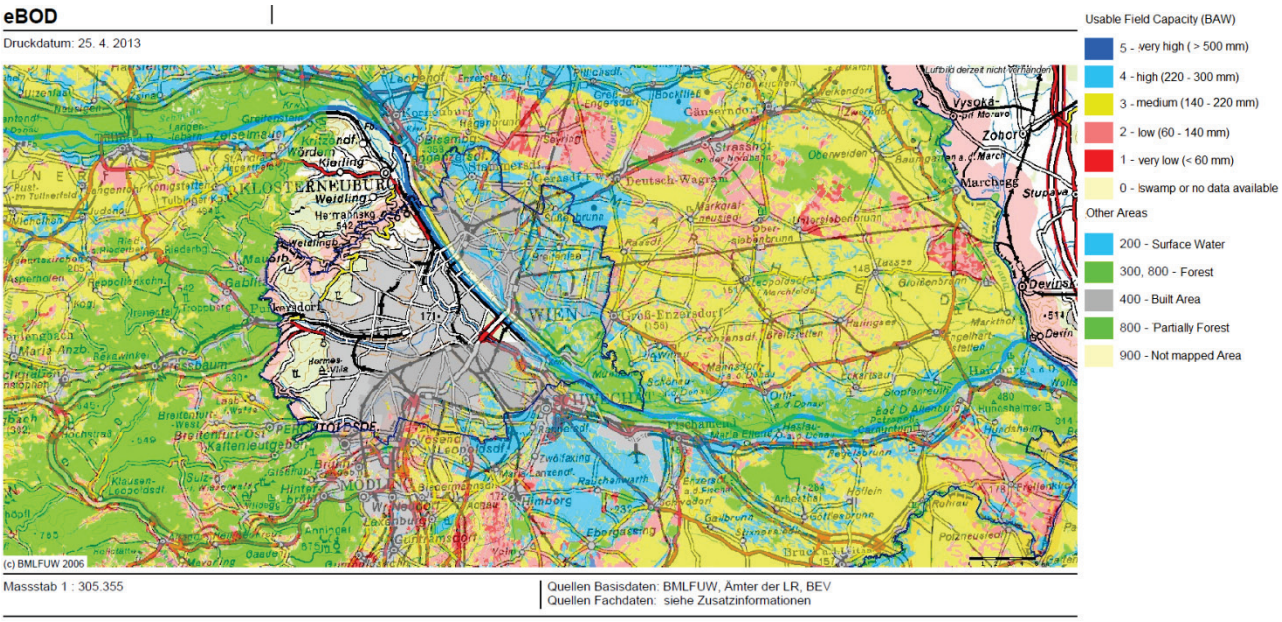


Figure 4-13 Available Field Capacity in the Vienna Region (eBOD 2006), translated by Author

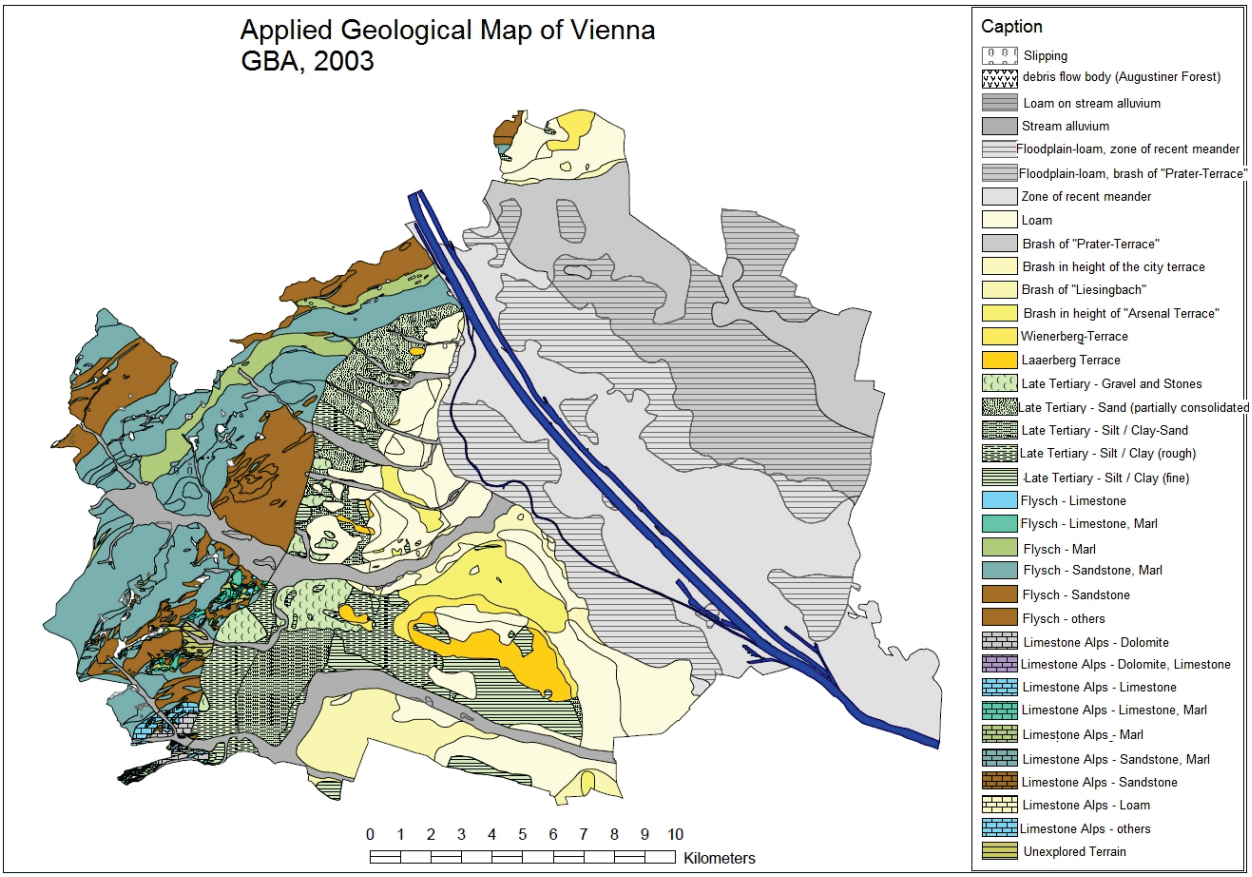


Figure 4-14 Geological Map of Vienna (MA29 2003), translated by Author

48) As mentioned above, several calibration runs were carried out during development of Stage 2 UVQ Model. During this calibration, a Maximum Daily Drainage Depth of 80 mm was found to fit observations best.

49) Compared to Stage 1 UVQ Model the parameter Drainage Factor decreased from 0.1 down to 0.05. Figure 4-15 presents hydraulic conductivity in the Vienna region and proves that conductivity is mostly moderate. Thus and due to calibration this parameter was decreased.

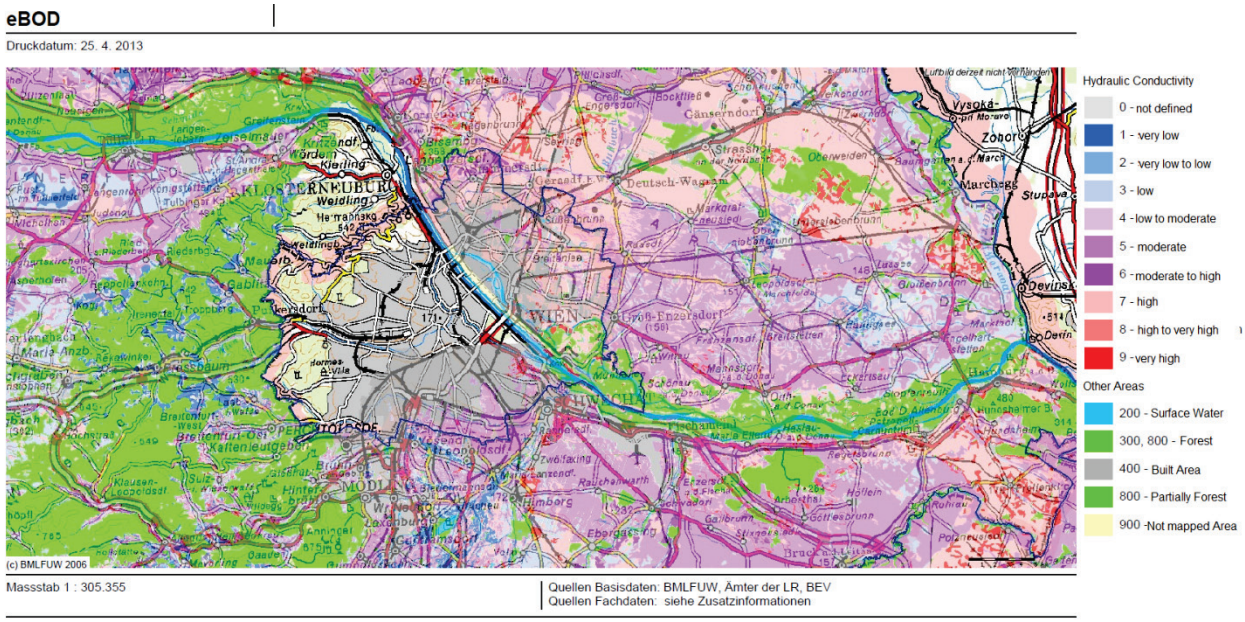


Figure 4-15 Hydraulic Conductivity in the Vienna Region (eBOD 2006), translated by Author

50) This parameter was not explained in detail during Stage 1, however, due to further data acquisition it has become clear that overflow caused by pipe chokes in the sewer system of Vienna are negligible. The sewer system comprises approximately 2400 km of pipes, demonstrating the minor importance of this parameter.

51) The Wet Weather Overflow Trigger was not considered in neighbourhood 23, however it was taken into account in other neighbourhoods, thus an explanation of the used approach will be given.

Stormwater Management is a complex task in Vienna. Several basins, channels and pipes serving as retention volume were built in former years, creating a unique and highly complex stormwater management system. Three main drainage channels exist, namely the "Donaukanal" [Danube Channel], the "Wientalkanal" [Wiental Channel], and the "Liesingtalkanal" [Liesingtal Channel]. All serve as important storage volumes for stormwater. Overflows are spread mostly in districts bordering one of the main drainage channels in Vienna. However, acquisition of data concerning this system is as difficult as the system itself. Only spare information was available, but it was possible to identify number and volume of some of the most important storage possibilities.

According to Kimmersdorfer (2013) from Wienkanal, 24 combined wastewater spillovers exist alongside the Danube Channel and 47 alongside the Wientalkanal. The Wiental Channel is capable to store up to 1 Billion Litres of water, the Liesingtal Channel has a capacity of 20 Million Litres. Storage Volumes for the Danube Channel could not be retrieved, thus it is not considered in UVQ Model Stage 2.

To take Wiental Channel and the Liesingtal Channel into account, following assumptions were made in the model:

<u>Wiental Channel</u>

The Channel is situated alongside neighbourhoods 8, 9, 13, 14, 16, 17, 18, 19, 20 and comprises 1 Billion Litres or 1,000,000 kL. Kimmersdorfer (2013) mentioned a similar distribution of spillovers on each side of the Channel, 23 on the left and 24 on the right side. Thus the storage capacity is divided by two, resulting in 500,000 kL available for each side. Neighbourhood 8 and 9 both share approximately half of the length of the Channel within Vienna, thus one half of storage capacity is distributed between those two districts. Hence in both, neighbourhood 8 and 9, the Wet Weather Overflow Trigger was set to 250,000 kL. Therefore 250,000 kL for each side of the remaining channel are left. Distribution was assumed to be even, thus neighbourhood 13, 14, and 16 to 20 possess 71,429 kL of Wet Weather Overflow Trigger in Stage 2 Model.

<u>Liesingtal Channel</u>

This channel flows in neighbourhood 21, thus 20,000 kL Wet Weather Overflow Trigger were assumed for this specific neighbourhood.

4.5 STAN - Approach

Similar to UVQ, STAN will be used in two steps. The first stage of modelling will include a rough water balance of Vienna to improve the first UVQ model by detecting missing quantities of water. The second stage will be produced with help of the detailed Stage 2 UVQ model and will consider more complex processes and flows than STAN model stage 1.

4.5.1 Stage 1

This model will be produced using outputs of the first UVQ model and calculations made by the author. The model will consider similar flows as UVQ to provide information about missing flows for improvement of UVQ model in stage 2.

Major import flows are precipitation and imported water. Groundwater extraction is considered as well, but it is only of minor importance. Precipitation is separated in pervious and impervious surface runoff and evaporation. Impervious surface runoff consists of roof runoff, road runoff and paved area runoff. Impervious surface runoff is runoff occurs from open space areas such as gardens or parks. It is assumed that this runoff percolates into the groundwater. Evaporated water is released into the atmosphere.

Beside the process surface, also private households, tourism, trade and industry are runoff producing processes, however they produce runoff in shape of wastewater. This process is supplied by Imported Water which is separated in the Network Distribution Process. The flows exiting the processes surface and private households are entering the sewer system which is connected to the wastewater treatment plant. Leakage from the sewer system to groundwater is also considered. Treated wastewater is the final flow between the wastewater treatment plant and the major final storage, the Danube.

Export flows are exported water and non-revenue water, which is water used for purposes not considered in final accounting of Vienna Water Works. They exit the Network Distribution process.

A detailed description of system parameters can be found in chapter 4.6, results of Stage 1 STAN model are presented and discussed in chapter 5.2.1.

4.5.2 Stage 2

This model represents a major improvement of the Stage 1 Model. A generic model was set up in STAN which is capable of illustrating both, a copper and a water balance via two different layers. However, the main focus was still put on the water balance, thus no copper-specific processes such as break-wear from traffic was pictured. Copper originating from such sources is considered via specific input flows. Due to the improved foundation, the UVQ Model Stage 2 and newly considered flows, this model will illustrate a better holistic picture of Vienna's water balance and will be a valuable framework for the copper balance. Outputs from UVQ Model Stage 2 are utilised to set up flows of this model. Yet another improvement is the use of runoff coefficients for optimization of flows discharging from urban surfaces.

For better understanding, flows based on outputs by UVQ are coloured in light blue, flows calculated by STAN are illustrated in green and finally, flows based on calculation or assumptions made by the Author of this thesis are black. Further enhancement for distinguishing processes is made by colouring processes outside the system boundary orange, processes within the boundary grey and processes linked to wastewater treatment green. For a better visualisation of the newly achieved system, an illustration is given in Figure 4-16.

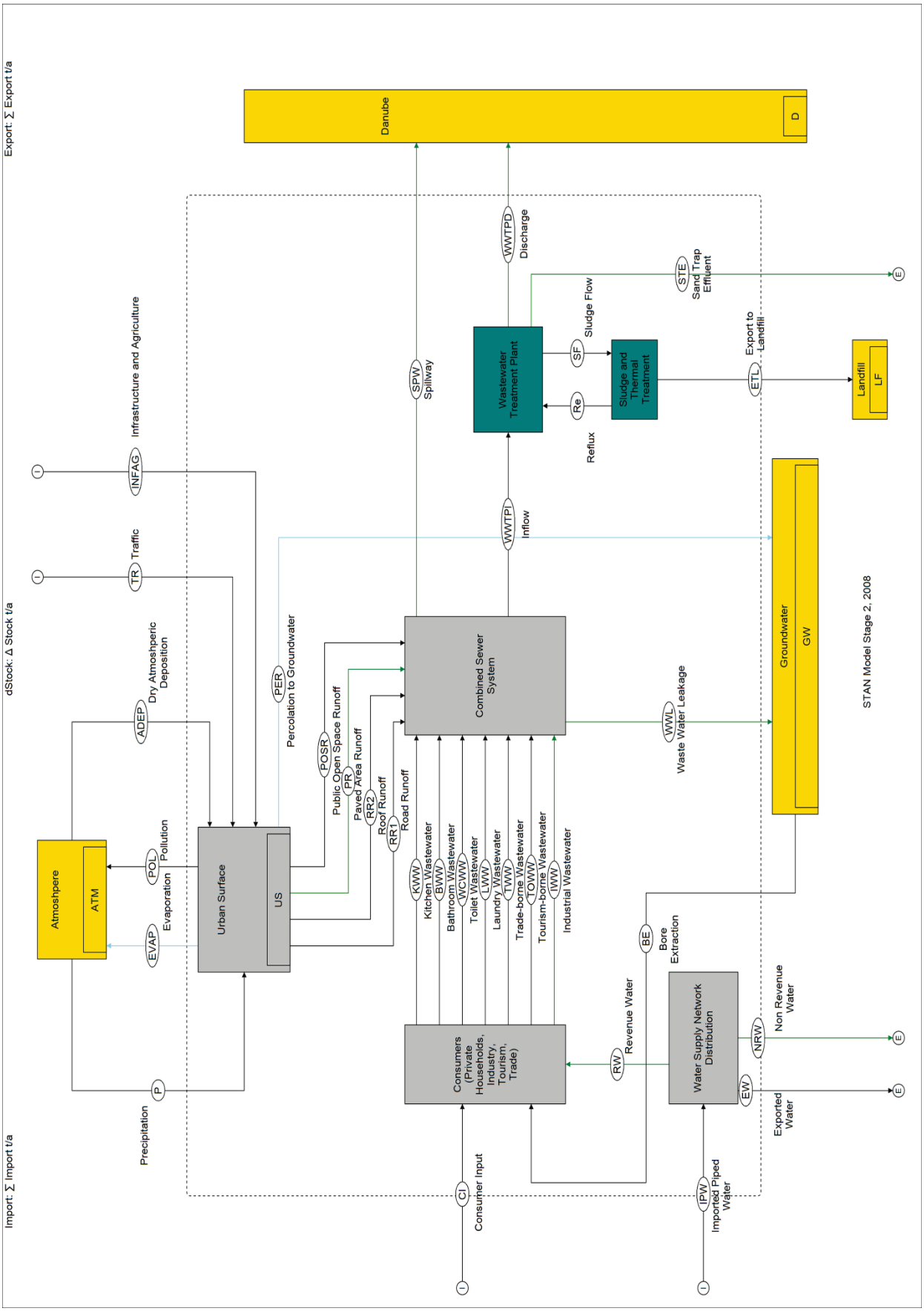


Figure 4-16 STAN Model Stage 2 generic model setup

In general, this model is similar to stage 1, however differences are noticeable in details. New information concerning percolation enhances accuracy of surface runoff flows. Further, spillway water was considered. To take this factor into account, inflow to the treatment plant was not calculated by STAN but set to the definite value of 2008. By taking this step, STAN was able to calculate Spillway water. Yet another innovation is the consideration of sewage sludge and export to thermal treatment, which are important for the copper balance. Copper inputs from traffic, roofs, buildings and other sources which do not directly take part in the water balance are considered via four import flows:

- Atmospheric Deposition
- Traffic
- Infrastructure
- Consumer Input

Copper leaving the wastewater treatment plant through sewage sludge is simulated by the export flow “Export to Thermal Treatment”, further copper trapped in the sand trap and exported is simulated by the export flow “Sand Trap Effluent”.

More details concerning STAN Model Stage 2 and specific information about parameters are treated in chapter 4.7.

4.6 STAN Stage 1 - Parameters

This chapter will review parameter used in STAN Model Stage 1. Assumed Values and appropriate explanations will be given to demonstrate the approach.

4.6.1 System Boundary

The system boundary is defined as the administrative district of Vienna in 2008. However, some parameter-values could not be acquired for the specific year, thus values from different years had to be considered. The system boundary includes 41487.4 ha of urban area, 1731236 inhabitants and 168167 buildings (Lebhart 2012). The vertical limit is set by the highest situated building in Vienna.

4.6.2 Import Flows

Import flows enter the system past the system boundary.

Precipitation

Precipitation was calculated using the same climate values as in UVQ. A description of how the areal depth of precipitation was calculated can be found in chapter 4.3.9.1. The value of areal depth for 2008 is 665 mm. To convert this value into a flow it has to be multiplied by the considered area of Vienna, which equals 41487.4 ha.

$$Precipitation = Rainfall\ Depth\ [mm] \cdot Area\ of\ Vienna\ [ha]$$

$$Precipitation = 0.665\ m\ \cdot 414{,}874{,}000\ m^2 = 275{,}891{,}210\ m^3\ or\ kL$$

Imported Piped Water

According to Sailer (2009) the two main water supply lines in Vienna imported 137,461,000 m³ of potable water in 2008.

Groundwater Extraction

A statistic on water supply in Vienna by Sailer (2009) offers a value of 3,540,000 m³ of groundwater extraction for 2008.

4.6.3 Export Flows

Export flows in this model are all flows leaving the system boundary, even if they have a target process outside the system boundary.

Exported Water

Tomenendal (2008) provides a table offering an value of 2,712,470 m³ of exported water to the Hinterland of Vienna.

Water Losses

Tomenendal (2008) states that according to a benchmarking system developed by the University of Natural Resources and Life Sciences Vienna, the water loss in 2008, consisting of non-revenue water, equal 7.6 % of imported piped water. This results in 10,447,036 m³ of water loss.

Evaporation

The value for actual evaporation was taken from Stage 1 UVQ model and equals 388 mm, as can be seen in Table 5.1. Calculation approach is the same as in every flow calculation.

$$Evaporation = 0.388\ m\ \cdot 414{,}874{,}000\ m^2 = 160{,}971{,}112\ m^3\ or\ kL$$

Leakage

Leakage of the sewer system is assumed to be 1%. This value was also taken in Stage 1 UVQ Model, an explanation of the taken assumption can thus be found in chapter 4.3.2.

4.6.4 Internal Flows

These flows are situated in the system boundary.

Revenue Water

Revenue water is calculated by STAN, it equals the remaining amount of water after subtracting Exported Water and Water Losses from Imported Piped Water.

Kitchen Wastewater

Kitchen Wastewater is calculated by multiplying the average kitchen water demand of 17 L per capita and day by the number of inhabitants in Vienna and the number of days.

$$Kitchen\ Wastewater = 0.017 \frac{m^3}{c \cdot d} \cdot 365d \cdot 1{,}731{,}236c = 10{,}742{,}319\ m^3$$

Bathroom Wastewater

Bathroom Wastewater is calculated by multiplying the average bathroom water demand of 53 L per capita and day by the number of inhabitants in Vienna and the number of days.

$$Bathroom\ Wastewater = 0.053 \frac{m^3}{c \cdot d} \cdot 365d \cdot 1{,}731{,}236c = 33{,}490{,}760\ m^3$$

Toilet Wastewater

Toilet Wastewater is calculated by multiplying the average toilet water demand of 40 L per capita and day by the number of inhabitants in Vienna and the number of days.

$$Toilet\ Wastewater = 0.04 \frac{m^3}{c \cdot d} \cdot 365d \cdot 1{,}731{,}236c = 25{,}276{,}046\ m^3$$

Laundry Wastewater

Laundry Wastewater is calculated by multiplying the average laundry water demand of 15 L per capita and day by the number of inhabitants in Vienna and the number of days.

$$Kitchen\ Wastewater = 0.015 \frac{m^3}{c \cdot d} \cdot 365d \cdot 1{,}731{,}236c = 9{,}478{,}517\ m^3$$

Tourism Wastewater

Wastewater produced by tourism is calculated using a value of 345 L of water per day for one hotel room, which was determined by Neunteufel, Richard et al. (2012). According to Lebhart (2012) the number of guestrooms in Vienna equalled 25609 in 2008. Therefore Tourism Wastewater is calculated with following equation:

$$Tourism\ Wastewater = 0.345\ \frac{m^3}{Room \cdot d} \cdot 365d \cdot 25{,}609\ Rooms = 3{,}224{,}813\ m^3$$

Trade Wastewater

To determine a value for wastewater produced by trade, data is acquired from Neunteufel, Richard et al. (2012) and Lebhart (2012). The former offers a value of 3.08 L per m² and day as water use of a shopping centre, the latter provides data for store areas in Vienna. Store Area in Vienna sums up to 1,079,600 m², however, not every shopping centre is considered in this value. Hence a rough estimation based on Google™ Earth was conducted, adding another 200,000 m² which take shopping centres in the 22nd district of Vienna into account.

$$Trade\ Wastewater = 0.00308 \frac{m^3}{m^2 \cdot d} \cdot 365d \cdot 1{,}279{,}600m^2 = 1{,}438{,}526\ m^3$$

Industry Wastewater

Industrial wastewater is calculated by STAN, it equals the remaining amount of water after subtracting all other wastewater flows from Revenue Water.

Roof Runoff

To calculate roof runoff, data of roof area was acquired from Department 22 of the Viennese City Administration (Kubu and Kramer 2013). According to this department, roof area of Vienna sums up to 5628 ha. The runoff is calculated by multiplying this area with precipitation depth of 665 mm.

$$Roof\ Runoff = 56{,}280{,}000\ m^2 \cdot 0.665\ m = 37{,}426{,}200\ m^3$$

Road Runoff

Road runoff was calculated using Figure 4-17 Land use in Vienna, published by Lebhart (2012), which represents the percentage each land use covers in Vienna.

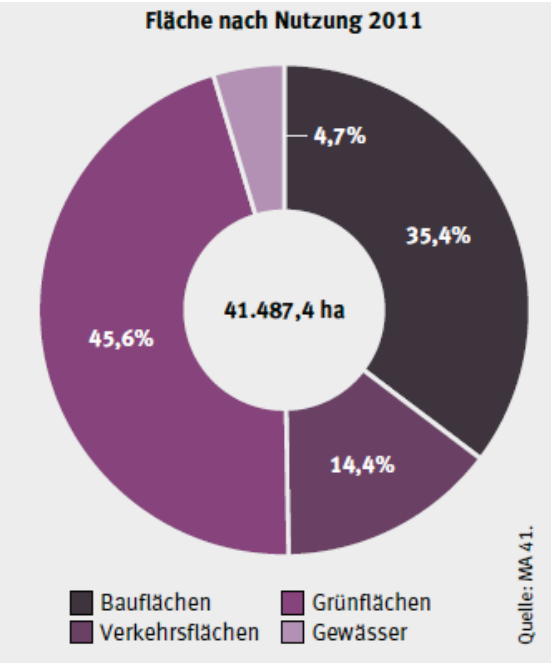


Figure 4-17 Land use in Vienna

According to this figure, 14.4 % or 5974 ha is “Traffic Area”. “Traffic Area” is considered to be road area, thus road runoff is calculated by multiplying this area with rainfall depth.

$$Road\ Runoff = 59740000\ m^2 \cdot 0.665\ m = 39727100\ m^3$$

Paved Area Runoff

Paved area runoff is calculated by STAN. It is the value which remains after subtracting Evaporation, Road Runoff, Roof Runoff and Pervious Surface Runoff from Precipitation.

Pervious Surface Runoff

Pervious surface runoff is calculated by using the areal depth value of storage change of Table 5.1 Annual water balance of UVQ Model Stage 1. This value was calculated by UVQ and is assumed to be pervious surface runoff in this model, due to the possible infiltration into groundwater and change in store through pervious areas.

$$Pervious\ Surface\ Runoff = 414{,}874{,}000\ m^2 \cdot 0.085\ m = 35{,}264{,}290\ m^3$$

4.6.5 Internal Processes

This chapter explains processes situated within the system boundary.

Process Surface

This process represents all surfaces of the urban area Vienna. Precipitation is the only flow entering this process. Runoff from roofs, roads and paved areas exits this process to the sewer system. Pervious surface runoff exits to percolate into groundwater. Evaporation exits to nourish the storage of the process Atmosphere. The unknown value in this process was Paved Area Runoff.

Process Network Distribution

Network distribution represents the Viennese Water Works which distribute the water to consumers. It is entered by Imported Piped Water. The flows Revenue Water, Export Water and Water Losses leave this process. Only Revenue water is a flow within the system boundary, all over flows are export flows. The unknown value linked to this process was Revenue Water.

Process Private Households, Industry, etc.

Representing all water consumers in Vienna, this process is entered by Revenue Water and left by seven different flows. Four of these belong to private households, namely Toilet Wastewater, Bathroom Wastewater, Kitchen Wastewater and Laundry Wastewater. The other streams are Tourism Wastewater, Trade Wastewater and Industry Wastewater. The unknown stream in this process was Industry Wastewater.

Process Sewer System

The sewer system process catches all pervious surface runoff and all wastewater from revenue water consumers. The major flow leaving this process is wastewater, directed to the wastewater treatment plant. The second, minor flow, is sewer system leakage.

Process Treatment plant

This process represents the treatment plant, however it does not have any significance for the model.

4.6.6 External Processes

This chapter explains processes situated outside of the system boundary.

Process Atmosphere

This process acts as storage for evaporation.

Process Groundwater

Groundwater stores pervious surface runoff and supplies the Private Household and Industry process.

Process Danube

The Danube is the receiving water of Vienna's treatment works, therefore it is simulated as a storage for treated wastewater.

4.7 STAN Stage 2 – Revised Parameters

This chapter will explain all flows and processes involved in the generic model for both, water and copper. Each flow will be divided in two subchapters, water and copper. Each subchapter will deal with calculations and assumptions for the specific substance.

4.7.1 System Boundary

As in Stage 1, the system boundary is assumed to be the administrative district of Vienna in 2008. However, due to further data acquisition it was possible to determine the exact area in 2008, which equals 41488.5 ha (Hlavac 2009). This value is slightly larger compared to STAN Model Stage 1. The study area comprises 1687271 inhabitants, the number of buildings did not change, thus it still equals 168167 (Lebhart 2012). The vertical limit is set by the highest rise above sea level in Vienna. The chronological system boundary is the year of 2008, thus an annual water balance is simulated.

4.7.2 Processes

STAN Model Stage 2 comprises 10 processes, of which five feature storage. The processes are written in the colours they exhibit in the model. Orange processes are external processes, situated outside the system boundary, grey processes act within the system boundary and green processes are part of the wastewater treatment plant which is also located inside of the system boundary.

-Atmosphere

The process Atmosphere is the origin of the flow Precipitation and receives the flow Evaporation and Pollution. This process contains storage, which stores evaporation.

-Groundwater

Groundwater supplies the process -Consumers with the flow Bore Extraction. The process Groundwater receives two inflow, Waste Water Leakage, emanating from the process -Combined Sewer System and Percolation to Groundwater, originating from the process -Urban Surface. Groundwater is in possession of a storage.

-Danube

The process Danube is storage for two inflows. The major inflow is Waste Water Treatment Plant Discharge, followed by Spillway Water.

-Landfill

Representing the final sink of copper after Thermal Treatment, the process Landfill receives Cu from the flow Export to and deposits the load in its stock.

-Water Supply Network Distribution

This process distributes the imports Imported Piped Water and Groundwater Extraction between the export flows Exported Water and Non Revenue Water and the system flow Revenue Water, which supplies the process -Consumers. Non Revenue Water is considered in this process via a transfer coefficient of 0.076 for water and copper, Revenue Water is calculated as well.

-Urban Surface

This process represents all urban surfaces, from green space to sealed surfaces such as roads or roofs. As the city itself it is supplied by Precipitation. For copper further import flows were

considered, namely Dry Atmospheric Deposition, Traffic and Infrastructure. The major output of this process in the water balance is Evaporation, the remaining volume is divided between different urban surfaces and groundwater. In the copper balance, the flow Pollution exports Cu from the urban system to the Atmosphere. Surface runoffs are considered via Roof Runoff, Road Runoff, Paved Area Runoff and Public Open Space Runoff, the discharge to groundwater is represented by Percolation to Groundwater. Surface runoffs discharge to the process -Combined Sewer System.

-Consumers

Representing all water consumers - households, industry, tourism and trade - this process comprises the largest amount of outflows. The process is supplied by Revenue Water, Groundwater Extraction and Consumer Input for copper. Its seven outflows are Kitchen Wastewater, Bathroom Wastewater, Toilet Wastewater, Laundry Wastewater, Tourism-borne Wastewater, Trade-borne Wastewater and Industrial Wastewater, which is calculated by STAN.

-Combined Sewer System

Almost all discharging flows within the system boundary are captured by the process Combined Sewer System. It collects all flows emerging from the process -Consumers and with exception of Percolation to Groundwater and Evaporation all flows which originate the process -Urban Surface. The main outflow emanating from this process is Waste Water Treatment Plant Inflow. The outflow Waste Water Leakage is considered in this process via a transfer coefficient of 0.01 for water and copper, further Spillway Water is calculated by STAN as well.

-Wastewater Treatment Plant

This process illustrates the central treatment plant of Vienna. Inflow to this process is Waste Water Treatment Plant Inflow and Reflux from - Sludge, outflows are Sludge Flow and Waste Water Treatment Plant Discharge.

- Sludge and Thermal Treatment

Representing Sewage Sludge and Thermal Treatment, this process has only one inflow, the Sludge Flow. Its outflows are Reflux and Export to Landfill.

4.7.3 Import Flows

a) Precipitation

a1) Water

The amount of annual precipitation was calculated to be 275,898,525 m³, a slight plus of 7315 m³ due to enlarged area. The calculation approach was taken from Stage 1.

$$Precipitation = Rainfall\ Depth\ [mm] \cdot Area\ of\ Vienna\ [ha]$$

$$Precipitation = 0.665\ m\ \cdot 41{,}4885{,}000\ m^2 = 275{,}898{,}525\ m^3\ or\ kL$$

a2) Copper

Nimmo and Fones (1997) conducted a study concerning rainfall in urban areas, according to which 0.00259 mg Cu per Litre are assumable. The same value was used in both stages of UVQ modelling. Thus, copper imported by precipitation sums up to 714.6 kg per annum.

$$Precipitation\ Copper = 275{,}898{,}525{,}000\ L\ \cdot 0.00259 \frac{mg}{L} = 714.6\ kg$$

This calculated value is very close to the value of 684.3 kg, simulated UVQ, illustrated in chapter 5.1.3.

b) Imported Piped Water

b1) Water

The basic value of this parameter did not change. According to Sailer (2009) the two main water supply lines imported 137,461,000 m³ of potable to Vienna water in 2008, as presented in Figure 4-18.

b2) Copper

The arithmetic mean of four test sites of imported piped water by the MA31 (2008), equals 0.0015mg Cu per Litre. The identical concentration was used in both UVQ simulations. Copper imported to Vienna by the two Mountain Spring Pipelines hence equals 206.2 kg in 2008.

$$Imported\ Piped\ Water\ Copper = 137{,}461{,}000{,}000\ L\ \cdot 0.0015 \frac{mg}{L} = 206.2\ kg$$

In this case too, the calculated value comes very close to the by UVQ simulated value of 204.79 kg, presented in chapter 5.1.3.

c) Groundwater Extraction

c1) Water

A statistic on water supply in Vienna by Sailer (2009) presented in Figure 4-18 offers a value of 3,540,000 m³ of groundwater extraction for 2008.

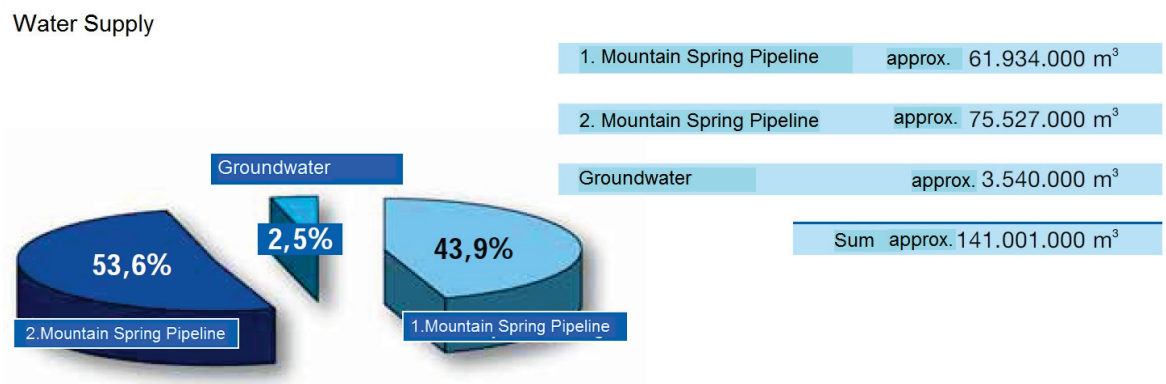


Figure 4-18 Water Supply Vienna 2008 (Sailer 2009)

c2) Copper

At point 16) in chapter 4.3.2 it is stated that a report published by the Austrian Ministry of Agriculture, Forestry, Environment and Water Economy suggests a concentration of 0.0036 mg/L to be the 90%-percentile of the median of all groundwater stations in Austria. This concentration was assumed in UVQ and it will also be used in this model. Therefore copper imported by groundwater bore extraction sums up to 12.7 kg for 2008.

$$Groundwater\ Extraction\ Copper = 3{,}540{,}000{,}000\ L\ \cdot 0.0036 \frac{mg}{L} = 12.7\ kg$$

d) Dry Atmospheric Deposition

d1) Water

In case of water, atmospheric deposition is considered in the flow precipitation, thus this flow is set to 0 for water.

d2) Copper

Table 4.3 was used to determine copper concentrations of indoor use in Vienna for UVQ. This table also offers values of atmospheric deposition over countryside and cities. Figure 4-19 offers a distribution of space in Vienna. According to this Pie Chart, approximately 52.9 % of Vienna's entire area is green space or surface waters. Thus an atmospheric deposition of countryside is assumed for these areas. According to Table 4.3, 5 mg/m²a of Cu are deposited over countryside and 25 mg/m²a are distributed over cities. Thus, atmospheric copper deposition in Vienna is calculated according to following equation:

$$\begin{aligned} Atmospheric\ Copper\ Deposition \\ &= [Copper\ concentration_{country} \cdot Green\ Space_{Vienna}] \\ &+ [Copper\ concentration_{city} \cdot Built\ Space_{Vienna}] \end{aligned}$$

$$\begin{aligned} Atmospheric\ Copper\ Deposition \\ &= \left[\frac{5\ mg}{m^2 a} \cdot 0.528 \cdot 414{,}885{,}000 m^2\right] + \left[\frac{25 mg}{m^2 a} \cdot 0.472 \cdot 414{,}885{,}000 m^2\right] = 5990.9\ kg \end{aligned}$$

Precipitation already imports 714.6 kg Cu via wet deposition, as a result, 5276.3 kg of copper are assumed to be deposited via dry atmospheric deposition over Vienna in 2008. This load represents industrial emissions and partially copper originating from traffic. Traffic emissions which are deposited directly onto urban surfaces and do not reach the atmosphere are calculated in the import flow "Traffic".

e) Traffic

e1) Water

In case of water this flow is set to 0. Traffic is not directly considered in the water balance.

e2) Copper

This import flow considers two main copper sources of traffic:

- Break wear and other emissions of motorized individual transport
- Break and wheel wear of public transport

According to Laschober, Limbeck et al. (2004), the mean copper emission of vehicles equals 30.2 µg per kilometre, which is illustrated in Table 4.15. Further, Statistik_Austria (2009) published a value for the level of motorisation of 480.1 vehicles per 1000 inhabitants for Vienna in 2008. Thus in 2008, 810,059 vehicles were licensed in Vienna. Finally Herry, Sammer et al. (1997) states that 87 % of all persons in Vienna are mobile, displaying an average daily travel distance of 21.6 km. Hence it is assumed that all vehicles in Vienna travel the suggested distance of 21.6 km. As a result, copper emissions of motorized vehicles sum up to 192.9 kg per annum. This value is rather small. The equation behind this consideration and the following ones is presented below:

$$Annual\ Cu\ Load\ Traffic = \frac{Cu\ emission}{km} \cdot Number\ of\ Vehicles \cdot \frac{Kilometres}{day} \cdot 365\ days$$

However, according to a study conducted in Stockholm (Westerlund 2001), cars emit 84 mg of goods per kilometre. 27.3 mg of 1 kg brake linings, which are considered as goods, are copper. Thus 2.3 mg of copper are emitted each km. Using this value, copper emissions in Vienna sum up to 14689 kg. This value is rather high.

UVQ suggests a value of 1339.93 kg of copper imported by traffic.

This discrepancy featured in the values above indicates that a quantification of copper emissions is a very difficult task, thus an average value of above given three values will be assumed in STAN Model Stage 2 for copper input by motorized individual transport. The average value of given calculations equals 5407.3 kg.

Table 4.15 Average emissions in µg/vehicle*km

	Mean (AV)	SD	Workday
Zn	34.2	29.9	33.4
Cu	30.2	20.2	32.3
Pb	9.5	6.7	9.5
Ni	1.8	2.1	1.8
V	1.0	0.7	1.0

AV average; SD standard deviation

According to a report concerning substance emissions during operation of railways in Switzerland (Burkhardt, Rossi et al. 2005), 5.3 kg of copper are emitted each rail-kilometre. The network length of the Viennese Public Transport tramway network comprises approximately 422 kilometres of rails (Wiener_Linien 2012). Another 226 km of rails are added by the subway network. The network of the Austrian Federal Railway in Vienna comprises 170 km of rails (Herry, Sedlacek et al. 2011), further private rail tracks in Vienna sum up to 4 km. Thus 4356.6 kg of copper are imported via railways.

As a result, the copper imports from motorized vehicles and railways add 9763.9 kg copper. However, 5990.9 kg of this load are already included in atmospheric deposition, hence the copper import flow “Traffic” adds only 3773 kg of Cu to the system. This load represents copper deposited directly onto the urban surface, thus not reaching the atmosphere.

f) Infrastructure and Agriculture

f1) Water

In case of water this flow is set to 0. Infrastructure and Agriculture is considered via different flows in the water balance.

f2) Copper

The import flow “Infrastructure and Agriculture” comprises three copper sources:

- Roofs
- Fertilizer
- Catenary wear

To consider an amount of copper emitted by roofs, the value calculated by UVQ Model Stage 2 was utilised in this STAN model. According to UVQ, approximately 218.6 kg of copper are emitted by roofs in Vienna.

Fertilizer represents input via agriculture and hence is assumed to be only used in areas with agricultural land use. A representative value for agricultural land use is the area used to cultivate vine. Mentioned area comprises approximately 611 ha (Hlavac 2009). According to point 15) on page 39, 2 kg of Cu per ha are suggested for fertilizing, as a result import to the system by fertilizer sums up to 1222 kg. Furthermore, fertiliser is also used in gardens, however,

only 0.5 kg Cu per ha are assumed to be used, as mentioned at point 45) on page 58. According to the Statistical Yearbook of Vienna (Hlavac 2009), 3 % or 1244.65 ha of Vienna is garden area. Hence, 622.3 kg of Cu are added via garden fertilising.

Catenaries are immobile, hence they are considered to be Infrastructure and are not counted in the import flow Traffic. Catenaries consist mainly of copper, hence emissions from this source cannot be neglected. It is known that approximately 71 % of the railway network of the Austrian Federal Railways is electrified (ÖBB-Infrastruktur-AG 2013), thus 120.7 km of catenary is in service at the Austrian Federal Railways in Vienna. It is further assumed that the tramway and subway network is fully electrified, comprising 648 km of catenary. According to Müller, Schöller et al. (2008), approximately 1.1 kg copper per kilometre and year are imported to the system via percolation water originating from the ballast bed of rails. Thus 845.6 kg of copper are imported via catenaries each year.

In sum, the import flow “Infrastructure” adds 2908.5 kg copper to the system.

g) Consumer Input

g1) Water

In case of water this flow is set to 0, because consumed water is considered via Revenue Water.

g2) Copper

The Consumer Input is taken from results of UVQ Model Stage 2. According to the model, 12105.1 kg of copper are imported via consumers.

4.7.4 Export Flows

h) Evaporation

h1) Water

Results of UVQ Model Stage 2 indicate that actual evaporation equals an areal depth of 372 mm, which is presented in chapter 5.1.2. Multiplied by the study area this sums up to 154,337,220 m³.

$$Evaporation = 0.372\ m\ \cdot 414{,}885{,}000\ m^2 = 154{,}337{,}220\ m^3\ or\ kL$$

The calculated amount of evaporation comprises 55.94 % of precipitation.

h2) Copper

It is assumed that no copper is exported via evaporation, thus this flow is set to 0 in the copper balance model.

i) Pollution

i1) Water

This flow is not considered in the water balance, thus it is set to 0.

i2) Copper

As already explained at the flow Dry Atmospheric Deposition, 5990.9 kg Cu originating from the Atmosphere, are deposited over Vienna each year. This load has to reach the atmosphere before deposition, hence it is assumed that the same amount of copper is emitted from the Process “Urban Surface” to the atmosphere.

j) Exported Water

j1) Water

A table by Tomenendal (2008) offers a value of 2712470 m³ of exported water to the Hinterland in 2008. The same value was assumed for this parameter in Stage 1.

j2) Copper

As mentioned at Imported Piped Water, the arithmetic mean of four test sites of imported piped water by the MA31 (2008), equals 0.0015mg Cu per Litre. Exported water origins from the same pipes, thus the identical concentration is assumed. copper exported by this flow therefore equals 4.1 kg.

k) Non Revenue Water

k1) Water

As mentioned at point 38) in chapter 4.4.2, imported supply leakage or “Non Revenue Water” is assumed to be 7.6 %, which is considered via a transfer coefficient in the process “Water Supply Network Distribution”. Thus 7.6 % of all imports to this process is directed to the flow “Non Revenue Water”. The volume is calculated by STAN.

k2) Copper

For copper, it is also assumed that 7.6 % of the import by the two main pipelines is distributed to the flow Non Revenue Water. STAN calculates the load.

l) Waste Water Leakage

l1) Water

Leakage from the sewer system was not altered, thus it is still set to 1% and is considered as Transfer Coefficient in the process “Combined Sewer System”. It is calculated by STAN.

l2) Copper

As in the case of water, it is assumed that approximately 1% of the entire copper load from the sewer system leaks into groundwater.

m) Percolation to Groundwater

m1) Water

Percolation to Groundwater is also newly added in Stage 2. This flow represents percolation from pervious areas to the groundwater. Due to revision and analysis of generated result files of UVQ, annual groundwater recharge calculated by UVQ was discovered to be 10.78 mm for the entire study area. This is a significant reduction compared to Stage 1 Model due to analysis of the generated result files, which were neglected in Stage 1 modelling of UVQ and STAN. In Stage 1 the “Change in Storage” was assumed to be groundwater recharge, which turned out to be a false assumption.

Thus groundwater recharge in STAN Model Stage 2 represented by “Percolation to Groundwater” – flow is calculated with the equation presented below:

$$Percolation\ to\ Groundwater = 0.01078\ m \cdot 414{,}885{,}000\ m^2 = 4{,}472{,}460\ m^3 or\ kL$$

m2) Copper

According to Pfleiderer (2013), groundwater monitoring stations do not offer any evidence for percolation of copper into groundwater, thus this flow is set to 0 in the copper balance.

n) Spillway Water

n1) Water

Spillway water volume is calculated by STAN itself. Due to known input to the wastewater treatment plant and known percentage of leakage, the remaining volume of the process Combined Sewer System is assumed to belong to overflows. According to Guideline 19 of the ÖWAV (2007), the Austrian Association of Water Management and Waste Management, at least 40 % to 60 % of annual stormwater should reach the first biological treatment stage of the wastewater treatment plant.
Spillway water in Vienna is distributed between the main drainage channels, however in the model it is assumed that spillway water directly enters to the Danube, due to the fact that all drainage channels discharge into the Danube.

n2) Copper

Copper entering the Danube via Spillways is calculated by STAN, equal to the way the water flow is calculated.

o) Waste Water Treatment Plant Discharge

o1) Water

This flow is calculated by STAN and is the remaining Volume after subtracting Sludge Flow from Waste Water Treatment Plant Inflow.

o2) Copper

In Figure 4-20 on page 83, approximately 9.8 % or 1584 kg of copper reaches the discharge of the wastewater treatment plant, however this copper flow is calculated by STAN to identify whether the model is satisfying or not.

p) Export to Landfill

p1) Water

This flow is exclusively established for copper contained in sewage sludge, thus its value in the water balance is 0.

p2) Copper

The export flow to Thermal Treatment is calculated by STAN.

q) Sand Trap Effluent

q1) Water

This flow is also exclusively established for copper contained in sewage sludge, thus its value in the water balance is 0.

q2) Copper

According to Figure 4-20 on page 83, approximately 6 % of copper from the Treatment Plant is disposed via the Sand Trap Effluent. This flow is calculated by STAN, the 6 % is taken into account via a Transfer Coefficient in the Process -Wastewater Treatment Plant.

4.7.5 Internal Flows

r) Revenue Water

r1) Water

Revenue water is again calculated by STAN, it equals the remaining amount of water after subtracting Exported Water and Water Losses from Imported Piped Water and Bore Extraction.

r2) Copper

For copper too, Revenue water is calculated by STAN.

s) Kitchen Wastewater

s1) Water

Due to a change in number of inhabitants, Kitchen Wastewater decreased. Calculation stayed the same and is presented below:

$$Kitchen\ Wastewater = 0.017\,\frac{m^3}{c \cdot d} \cdot 365d \cdot 1{,}687{,}271c = 10{,}469{,}517\ m^3$$

s2) Copper

As mentioned in the section Consumer Input, 12105.1 kg of copper are added to the system by consumers. Furthermore copper added by bore extraction and revenue water has to be considered. The total load of 12304.2 kg is distributed to each flow according to its proportion of the entire flow. Therefore kitchen wastewater transports 1007.6 kg of copper.

$$Kitchen\ Wastewater\ Copper = \frac{10{,}469{,}517\ m^3}{127{,}841{,}494\ m^3} \cdot 12{,}304.2\ kg\ Cu = 1007.6\ kg\ Cu$$

t) Bathroom Wastewater

t1) Water

This parameter also changed due to decreased number of inhabitants.

$$Bathroom\ Wastewater = 0.053 \frac{m^3}{c \cdot d} \cdot 365d \cdot 1687271c = 32{,}640{,}258\ m^3\ or\ kL$$

t2) Copper

As mentioned above, 12304.2 kg of copper are added to the process -Consumers. This load is distributed to each flow according to its proportion of the entire flow. As a result, bathroom wastewater transports 3141.5 kg of copper.

$$Bathroom\ Wastewater\ Copper = \frac{32{,}640{,}258\ m^3}{127{,}841{,}494\ m^3} \cdot 12{,}304.2\ kg\ Cu = 3141.5\ kg\ Cu$$

u) Toilet Wastewater

u1) Water

Toilet Wastewater experienced a decrease as well. Other than in UVQ, Toilet wastewater per capita stays identical in STAN, due to a separate consideration of Industry, Tourism and Trade.

$$Toilet\ Wastewater = 0.04 \frac{m^3}{c \cdot d} \cdot 365d \cdot 1{,}687{,}271c = 24{,}634{,}157\ m^3$$

u2) Copper

As mentioned above, 12304.2 kg of copper are added to the system. This load is distributed to each flow according to its proportion of the entire flow. Therefore toilet wastewater transports 2370.9 kg of copper.

$$Toilet\ Wastewater\ Copper = \frac{24{,}634{,}157\ m^3}{127{,}841{,}494\ m^3} \cdot 12{,}304.2kg\ Cu = 2370.9\ kg\ Cu$$

v) Laundry Wastewater

v1) Water

Finally, Laundry Wastewater dropped slightly too.

$$Laundry\ Wastewater = 0.015 \frac{m^3}{c \cdot d} \cdot 365d \cdot 1{,}687{,}271c = 9{,}237{,}809\ m^3\ or\ kL$$

v2) Copper

As mentioned above, 12304.2 kg of copper are added to the system. This load is distributed to each flow according to its proportion of the entire flow. Therefore laundry wastewater transports 889.1 kg of copper.

$$Laundry\ Wastewater\ Copper = \frac{9{,}237{,}809\ m^3}{127{,}841{,}494\ m^3} \cdot 12{,}304.2\ kg\ Cu = 889.1\ kg\ Cu$$

w) Tourism-borne Wastewater

w1) Water

Tourism Wastewater did not change compared to STAN Model Stage 1 and is calculated with following equation:

$$Tourism\ Wastewater = 0.345\ \frac{m^3}{Room \cdot d} \cdot 365d \cdot 25{,}609\ Rooms = 3{,}224{,}813\ m^3\ or\ kL$$

w2) Copper

As mentioned above, 12304.2 kg of copper are added to the system. This load is distributed to each flow according to its proportion of the entire flow. Therefore tourism wastewater transports 310.4 kg of copper.

$$Tourism\ Wastewater\ Copper = \frac{3{,}224{,}813\ m^3}{127{,}841{,}494\ m^3} \cdot 12{,}304.2\ kg\ Cu = 310.4\ kg\ Cu$$

x) Trade-borne Wastewater

x1) Water

This parameter did not experience any alterations as well, thus it still equals 1,438,526 m³. Calculation is visible in chapter 4.6.4.

x2) Copper

As mentioned above, 12304.2 kg of copper are added to the system. This load is distributed to each flow according to its proportion of the entire flow. Therefore trade wastewater transports 138.5 kg of copper.

$$Trade\ Wastewater\ Copper = \frac{1{,}438{,}526\ m^3}{127{,}841{,}494\ m^3} \cdot 12304.2\ kg\ Cu = 138.5\ kg\ Cu$$

y) Industrial Wastewater

y1) Water

As in Stage 1, Industrial Wastewater is subject to calculation by STAN.

y2) Copper

Copper carried by Industrial Wastewater is also calculated by STAN.

z) Roof Runoff

z1) Water

For STAN Model Stage 2 a slightly altered approach was chosen to calculate roof runoff. The basic calculation stays the same, however a runoff coefficient is added to consider different surfaces. As mentioned in chapter 4.6.4, roof area comprises 5628 ha in Vienna and precipitation depth is assumed to be 665 mm. According to Imhoff (2007), Metal- and Shiverroofs display a runoff coefficient of 0.95, flat roofs exhibit a value between 0.5 and 0.7. A report on integrative rainwater management in Vienna states a value of 0.8 to 1.0 for steep

roofs and 0.7 for flat roofs (Grimm 2010). Thus for Stage 2 a roof runoff coefficient of 0.8 was assumed for the entire study area.

$$Roof\ Runoff = 56{,}280{,}000\ m^2 \cdot 0.665\ m \cdot 0.8 = 29{,}940{,}960\ m^3 or\ kL$$

Roof runoff decreased significantly by 7,485,240 m³ or kL due to the newly added runoff coefficient.

z2) Copper

Copper contained in roof runoff is assumed to equal 1.35 g/m² and year, based on Wallinder and Leygraf (1997). According to Kral, Lin et al. (2013), who interviewed local tin smiths in Vienna, approximately 5% of the entire roof area is taken by copper roofs. The roof area of Vienna equals 5628 ha, as mentioned at point 10) in chapter 4.3.2. Thus copper entering the sewer system via roof runoff sums up to 3798.9 kg.

$$Roof\ Runoff\ Copper\ 1 = 0.00135 \frac{kg\ Cu}{m^2} \cdot (0.05 \cdot 56{,}280{,}000\ m^2) = 3798.9\ kg\ Cu$$

Another option to calculate copper transported by roof runoff is via Table 4.4 on page 38. The table offers an average concentration of 10 µg Cu per Litre for roof runoff. If this value is multiplied by the calculated volume above, 299.4 kg of copper are carried by roof runoff.

$$Roof\ Runoff\ Copper\ 2 = 1 \cdot 10^{-8} kg\ Cu/L \cdot 29{,}940{,}960{,}000 L = 299.4\ kg\ Cu$$

This example shows the difficulty involved in presenting estimations of copper transported by runoff. In this model, the mean value between above calculated values is taken, equalling 2049.2 kg.

aa) Road Runoff

aa1) Water

For Road Runoff a runoff coefficient was added as well to the calculation approach. Further study area and its distribution changed, an illustration is given in Figure 4-19. Imhoff (2007) approximates the runoff coefficient for concrete and tarmac roads to be between 0.85 and 0.9. For Stage 2, a value of 0.9 was assumed to be the road runoff coefficient.

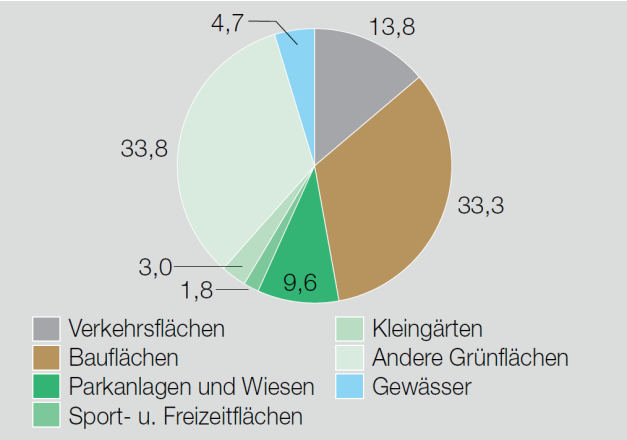


Figure 4-19 Areal Distribution of Vienna

Traffic areas comprise 13.8 % of the entire study area, this equals 5725.4 ha. Thus road runoff is calculated as stated below:

$$Road\ Runoff = 57{,}254{,}130\ m^2 \cdot 0.665\ m \cdot 0.9 = 34{,}266{,}597\ m^3\ or\ kL$$

Because of decreased traffic space and the added runoff coefficient, road runoff decreased by 5,460,503 m³ or kL.

aa2) Copper

Results by UVQ offer a value for road copper load of 1339.9 kg, a calculation with Table 4.4 on page 38 sums up to 664.8 kg.

$$Road\ Runoff\ Copper = 19.4 \cdot 10^{-9} \frac{kg\ Cu}{L} \cdot 34{,}266{,}597{,}000\ L = 664.8\ kg\ Cu$$

For STAN Model Stage 2 the average mean value of 1002.4 kg was assumed.

bb) Paved Area Runoff

bb1) Water

Paved area runoff is again calculated by STAN.

bb2) Copper

For copper, paved area runoff cannot be calculated by STAN due to involved storage in the copper model. Therefore it will be calculated using UVQ results, findings from the STAN water balance and concentrations of Table 4.4 on page 38. The same runoff concentration as for road runoff is assumed, 19.4 µg Cu per Litre. The water balance of STAN Model Stage 2 calculates a value of 43,725,098 m³ for paved area runoff.

$$Paved\ Area\ Runoff\ Copper = 19.4 \cdot 10^{-9} \frac{kg\ Cu}{L} \cdot 43{,}725{,}098{,}000\ L = 848.3\ kg\ Cu$$

UVQ results suggest a value of 1965 kg Cu load for this runoff. The mean value between those options equals 1406.7 kg Cu, which is considered in the model.

cc)Public Open Space Runoff

cc1) Water

The newly added flow “Public Open Space Runoff” considers only Public Open Space Area and its runoff to the sewer system. Public Open Space area is assumed to be Open Space Area connected to sewer system. To approximate this value, agricultural used space was subtracted from the sum of Parks and Green Areas, Sport and Recreational Areas, Garden Areas and Other Green Space. The entire green area of Vienna takes up 48.2% or 19,997.5 ha of the entire study area. Literature offered two values for agricultural used area, in 2005 this parameter comprised 6499.6 ha (Hlavac 2009), in 2011 this value decreased to 5958.1 ha (Lebhart 2012). Assuming linear reduction, each year 90.25 ha of agricultural area disappear, thus agricultural used space in 2008 equalled 6228.75 ha. Subtracting this value from the entire green space, 13768.7 ha of “Public Open Space” are left. Runoff coefficients from vegetated areas are significantly lower than for sealed surfaces. Imhoff (2007) suggests a runoff coefficient of 0.1.

$$Public\ Open\ Space\ Runoff = 137{,}687{,}070\ m^2 \cdot 0.665\ m \cdot 0.1 = 9{,}156{,}190\ m^3 or\ kL$$

9,156,190 m³ represents the Public Open Space Runoff contributing to sewer discharge.

cc2) Copper

Public Open Space Runoff is clearly smaller compared to other urban surface runoffs, however Public Open Space comprises 48.5 % or 20,121.9 ha of the entire study area. Assuming an atmospheric deposition of 5 mg/m²a as suggested in Table 4.3 on page 38, 1006.1 kg of copper are deposited over Public Open Space each year. Furthermore, at least 1222 kg of copper are added due to fertilizing (look up at Infrastructure) , summing up to 2228.1 kg Cu in total for Public Open Space. Usually the majority of copper is incorporated by plants or stored in soil, thus not reaching runoff. However, due to large uncertainty for Public Open Space Copper it is assumed that the entire copper load reaches runoff. According to this assumption, Public Open

Space, which comprises almost 50 % of the entire study area adds 2228.1 kg of copper to the sewer system, which is only 33.3 % of copper from urban surface.

dd) Waste Water Treatment Plant Inflow

dd1) Water

In STAN Model Stage 2 wastewater treatment plant inflow was not calculated by STAN but set to be 205,024,907 m³ or kL (Gottschall 2013). This allows STAN to calculate the unknown flow Spillway Water.

dd2) Copper

According to Kroiss, Morf et al. (2008), approximately 16,165 kg of copper enter the central wastewater treatment plant in Vienna. Thus this value is considered for the copper model.

ee) Sludge Flow

ee1) Water

According to ebswien (2011), 68,000 tons of sewage sludge dry mass are produced each year. Assuming that dry substance takes approximately 10 % [ATV (1996): ATV Handbuch der Abwassertechnik, Klärschlamm, 4. Auflage, Verlag Ernst& Sohn, cited by Haberl (2009)] of sludge, whereas the other 90 % is taken by water, 612,000 tons or m³ of water are “lost” to sewage sludge each year.

ee2) Copper

According to Figure 4-20 by Kroiss, Morf et al. (2008), the Input to the treatment plant comprises 97.4 %, thus the entire copper load within the Treatment Plant equals 16,596.5 kg. 84.2 % or 13,974.3 kg of copper reaches sewage sludge each year. DS is an acronym for “Dünnschlamm”, which is the German word for a composition of primary and secondary sludge. This mixture is also passed to a Thermal Treatment Plant after condensing.

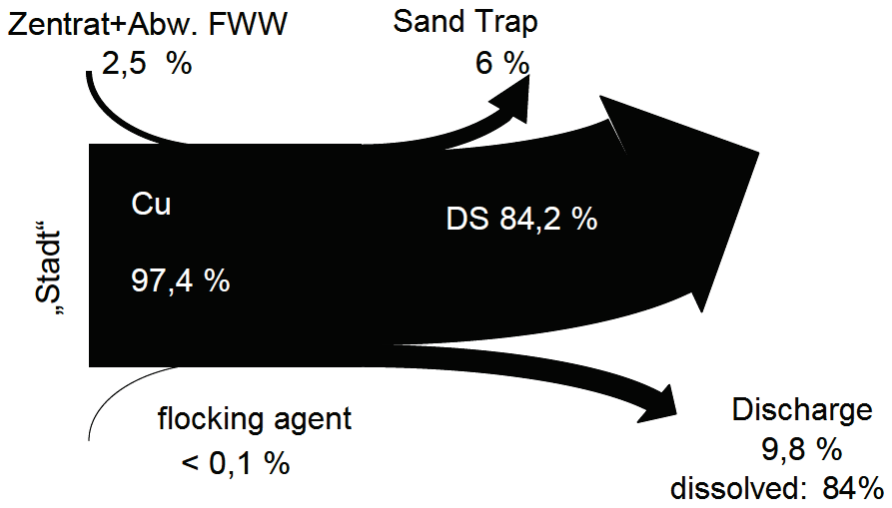


Figure 4-20 Distribution of copper in the central wastewater treatment plant

ff) Reflux

ff1) Water

It is assumed that the entire input water to sewage sludge is recycled within the wastewater treatment plant, thus 612,000 tons or m³ of water are added to the flow Reflux.

ff2) Copper

Figure 4-20 shows that 2.5 % of copper reflows to the treatment plant from sludge condensing. The Input to the treatment plant comprises 97.4 %, thus the entire copper load within the treatment plant equals 16,596.5 kg. 2.5 % of the entire copper load equals 414.9 kg Cu, which represents the Reflux.

5. Results, Discussion and Interpretation

5.1 UVQ

5.1.1 Stage 1 – water balance

The first model was set up to determine whether modelling results are satisfying or not. Simulation was run from 2006 until 2012, however only 2008 is of concern in this thesis and thus results of 2008 will be presented in this chapter. Further only results of the entire study area will be presented, detailed results of each neighbourhood are not of concern.

Input to the model was an annual precipitation of 665 mm, an indoor water usage of 125 L per capita and day and a certain amount of baseflow, as well as extraction for irrigation purposes taken from groundwater. The rough model only considers indoor water use of private households. Water used by industry, tourism and trade are not taken into account yet. Simulated imported water and wastewater thus were expected to be smaller than observed.

Copper is considered via precipitation, imported water, groundwater, surface runoff (roads, roofs, pavements) and fertilizer. It is known that approximately 16 tons of copper are treated in Vienna's wastewater treatment plant each year. The software was expected to calculate lower Cu values than observed, due to smaller water flow volumes.

Table 5.1 and Table 5.2 present results retrieved from UVQ Model Stage 1:

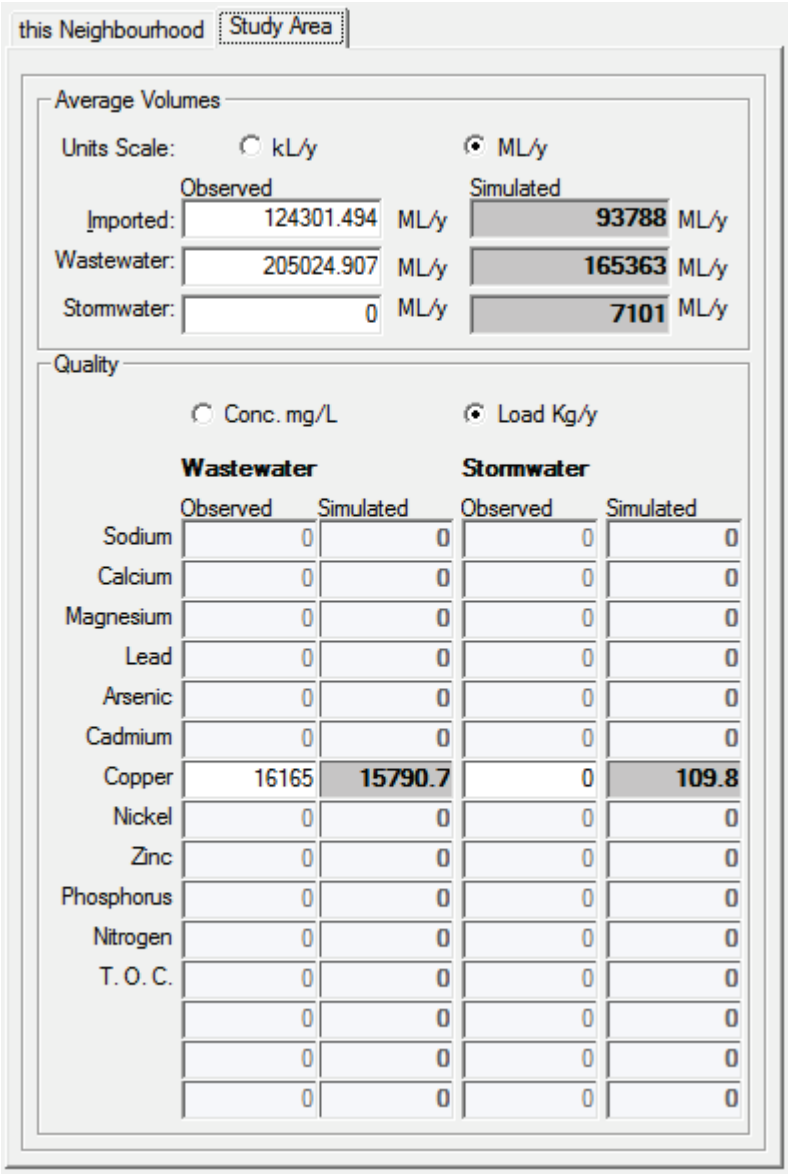
Table 5.1 Annual water balance of UVQ Model Stage 1 – Imports and exports/sinks are balanced. The neglectable difference of sums occurs due to rounding errors.

Imports	
Precipitation	665
Imported water	225
Stormwater inflow	0
Wastewater inflow	0
Sum Imports	890
Exports/Sinks	
Evaporation	388
Stormwater runoff	18
Wastewater discharge	400
Change in storage	85
Transfer of water (+ve means net input)	0
Sum Exports/Sink	891

Table 5.2 Wastewater flow and waterborne copper load reaching the wastewater treatment plant for the entire study area in Stage 1

	FLOW (kL/y)	Copper (kg/y)
Study Area Total	170348662.8	15794.3

Table 5.1 Annual water balance of UVQ Model Stage 1 illustrates the annual water balance of 2008 for Vienna. Water amounts are given as areal depths in mm. It can be identified that UVQ calculates a change in storage of plus 85 mm/y, which equals 35,264 ML/y. This is a rather large change in storage and therefore this value needs to be further investigated in stage 2. Maybe improvement of the model will result in a decrease of this value.



this Neighbourhood | Study Area

Average Volumes

Units Scale: kL/y ML/y

	Observed		Simulated	
Imported:	124301.494	ML/y	93788	ML/y
Wastewater:	205024.907	ML/y	165363	ML/y
Stormwater:	0	ML/y	7101	ML/y

Quality

Conc. mg/L Load Kg/y

	Wastewater		Stormwater	
	Observed	Simulated	Observed	Simulated
Sodium	0	0	0	0
Calcium	0	0	0	0
Magnesium	0	0	0	0
Lead	0	0	0	0
Arsenic	0	0	0	0
Cadmium	0	0	0	0
Copper	16165	15790.7	0	109.8
Nickel	0	0	0	0
Zinc	0	0	0	0
Phosphorus	0	0	0	0
Nitrogen	0	0	0	0
T. O. C.	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0

Figure 5-1 Comparison of observed and simulated water volumes and contaminant loads, Stage 1

A better picture of UVQ results is given in Figure 5-1, which presents the comparison of observed and simulated water volumes and contaminant loads. As expected both, simulated imported water and simulated wastewater are lower than observed, due to not taking industry, tourism and trade into account. However, simulated values are promising, indicating that after inclusion of before mentioned waste water producers, UVQ should deliver very plausible values. Very promising is also the fact that both, imported water and wastewater combined with stormwater still lack approximately the same amount of water to reach observed values. If UVQ proves to deliver plausible values in stage 2, it is a promising tool to be used in Vienna for water management purposes.

Table 5.2 and Figure 5-1 display that simulated copper loads are yet too large. 15,790.7 kg almost match the observed amount of Cu in Vienna with inclusion of all water-consumers. In stage 2, an improvement of imported copper values might change the outcome of copper load. Hence a revision of imported copper concentration is aspired.

Results of UVQ Model Stage 1 provide an informative basis and will be used to set up the first rough STAN model.

5.1.2 Stage 2 – water balance

UVQ Model Stage 2 was improved by a meticulous revision of parameters from UVQ Model Stage 1 and with several calibration runs. This chapter will review results and findings achieved by the improved model. This time, simulation was only run for the year 2008.

Major differences to stage 1 are following:

- Industrial, Trade and Tourism Water Use was considered
- Changed copper inputs
- Changed Study Area and changed Neighbourhood Areas
- Spillovers considered partially

These changes, explained in detail in chapter 4.4, resulted in findings illustrated in Table 5.3, Table 5.4 and Figure 5-3.

Table 5.3 Annual water balance of UVQ Model Stage 2 – Imports and exports/sinks are balanced. The neglectable difference of sums occurs due to rounding errors.

Imports	
Precipitation	665
Imported water	344
Stormwater inflow	0
Wastewater inflow	0
Sum Imports	1009
Exports/Sinks	
Evaporation	372
Stormwater runoff	37
Wastewater discharge	529
Change in storage	72
Transfer of water (+ve means net input)	0
Sum Exports/Sink	1010

Table 5.4 Wastewater flow and waterborne copper load reaching the wastewater treatment plant for the entire study area in Stage 2

	FLOW (kL/y)	Copper (kg/y)
Study Area Total	209925229.7	15866.8

Both, Table 5.3 and Table 5.4 already indicate differences to UVQ Model Stage 1. Imported water and wastewater discharge increased, as well as Stormwater runoff. Change in storage decreased. Further, copper load only increased by 72.5 kg or 0.46 %, whereas wastewater discharge increased by approximately 39,600,000 kL or 23.2 %. This was achieved by revision of Cu import parameters, as well as validation and calibration. Consideration of spillways caused a change in assumptions taken for sewer storage, which caused Stormwater to increase. In Stage 1 sewer storage was assumed to be infinite, which was not the case in this stage. Figure 5-2 illustrates the major model flows presented in Table 5.3, allowing an easy comparison.

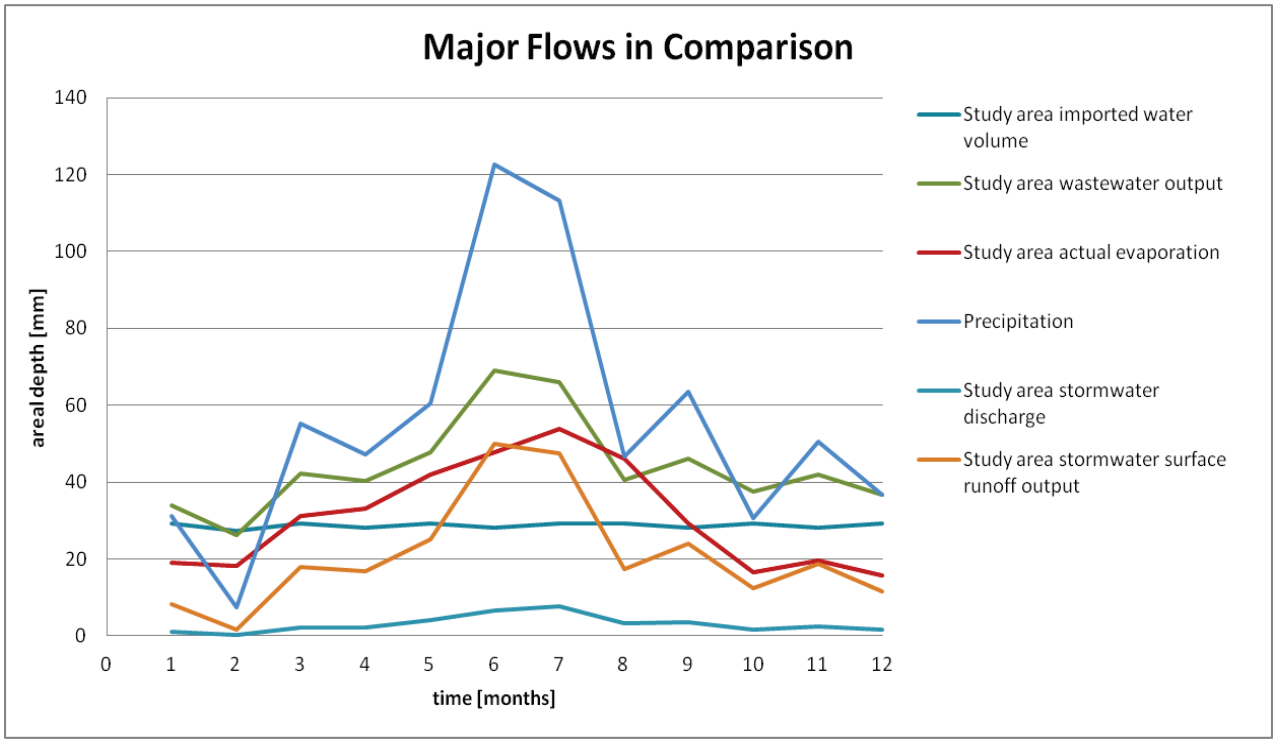


Figure 5-2 Hydrographs of major export and import flows from Table 5.3 in comparison

The figure indicates that precipitation is the largest input flow to the system, featuring significant variation throughout the year, displaying large amounts of precipitation during the late spring and early summer months. In contrast, the second largest import flow, imported water, is constant during the year, exhibiting no significant peaks. In sum 665 mm or 264,050,884 m³ of precipitation and 344 mm or 136,523,462 m³ of piped water were imported to the system. Piped water is calculated by UVQ itself, using indoor water use and irrigation patterns. The wastewater-hydrograph follows the shape of the precipitation-hydrograph, however, it is way smaller because a large amount of precipitation evaporates. This fact indicates that UVQ offers good results in combined sewer system simulation. Evaporation is represented by the red hydrograph, displaying a peak during the summer months, which are also the hottest. In 2008, Evaporation exceeds precipitation only in February. Surface runoff is presented by the orange curve, which clearly follows the shape of the precipitation graph. The light blue hydrograph on the bottom of the figure represents stormwater discharge, which is actually water lost via spillways. It can be observed that this graph exhibits a similar shape as the precipitation- and wastewater- and stormwater-hydrographs, yet the peaks are by far not as distinctive.

Although areal rainwater depth remained constant, rainwater volume decreased in comparison with UVQ Model Stage 1 due to a decreased total area. Actual Evaporation turns out to be 372 mm or 147,709,668 m³. The decrease in volume of evaporation is caused by the same reason precipitation volume dropped. Actual Evaporation equals approximately 56 % of rainfall, a percentage very similar to the Case Study for the City of City-of-Berlin (2012), which claims that 55 % evaporate.
Due to taking spillover possibilities within the study area into account, which rejects the assumption of infinite sewer storage in some neighbourhoods (see point 51) in chapter 4.4.3), stormwater discharge increased and now equals 37 mm or 14,585,250 m³. Stormwater in UVQ comprises base flow supplied by groundwater and excess flow of spillways. This amount is a first indication of a possible spillway volume for the final STAN model, however, not all spillovers were considered. Change in storage decreased by 13 mm, resulting in a value of 72 mm.

Figure 5-3 compares observed and simulated water volumes and copper loads for UVQ Model Stage 2 for Vienna in 2008.

this Neighbourhood | Study Area

Average Volumes

Units Scale: kL/y ML/y

	Observed		Simulated	
Imported:	137461.000	ML/y	136523	ML/y
Wastewater:	205024.907	ML/y	209925	ML/y
Stormwater:	0	ML/y	14585	ML/y

Quality

Conc. mg/L Load Kg/y

	Wastewater		Stormwater	
	Observed	Simulated	Observed	Simulated
Sodium	0	0	0	0
Calcium	0	0	0	0
Magnesium	0	0	0	0
Lead	0	0	0	0
Arsenic	0	0	0	0
Cadmium	0	0	0	0
Copper	16165	15866.8	0	1323.8
Nickel	0	0	0	0
Zinc	0	0	0	0
Phosphorus	0	0	0	0
Nitrogen	0	0	0	0
T. O. C.	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0

Figure 5-3 Comparison of observed and simulated water volumes and contaminant loads, Stage 2

Observed imported water was corrected and hence increased in comparison to stage 1. This is due to the omission of supply leakage in the observed value of stage 1, which only pictured revenue water. Supply leakage also includes non-revenue water, thus it was considered in UVQ Model Stage 2, resulting in a slight rise of this value. Observed Stormwater Cu-load is 0, because this value is not known.

The accordance of simulated and observed values is very satisfying. The SIM/OBS-functions, created by dividing simulated values by observed values, show following results:

- SIM/OBS Imported Water = 0.993
- SIM/OBS Wastewater = 1.024
- SIM/OBS Copper = 0.982

These values illustrate a definite improvement of the UVQ Model in this stage.

In addition to above pictured figures and tables, UVQ also provided more detailed contamination results and several .csv output files containing information which will be utilised in STAN Model Stage 2 and the copper model of Vienna.

5.1.3 Stage 2 – copper balance

In UVQ Model Stage 1 only a glimpse in shape of a final load reaching the treatment plant was caught of the copper balance, however, Stage 2 Model features revised and improved parameters, hence a more detailed picture of the copper balance will be given in this chapter. UVQ uses its own water balance calculations to set up a copper balance. Dry atmospheric deposition and input via traffic is not considered in detail, only road runoff concentrations and roof runoff concentrations are input to the model, considering these emission sources. Further information can be found in chapter 3.3.1.

A very promising feature of UVQ for the later development of a final copper balance in STAN is the “Simple Sludge Operation”. This operation calculates copper loads within a process in which both, input and output is already known. The “Simple Sludge Operation” determines missing loads between inputs and outputs, providing an assumed value for missing loads. This operation is used for assumed loads onto road, roof and pavement. Detailed information concerning this and further contamination operations used in UVQ can be found in the UVQ User Manual (Mitchell and Diaper 2010).

UVQ provides result files presenting copper loads for each neighbourhood and land block and for the entire study area. However, contaminant flows of land block and neighbourhood scale are calculated differently from study area flows. This causes variations in contaminant loads calculated for different areal scales. One example are contaminants from imported water – If results from Land Block scale are summed up for all Neighbourhoods, about 189 kg of copper are imported, however, a look at the study area file offers a value of approximately 205 kg of copper. The “missing” load from land block scale is very likely to be caused by the assumed 7.6 % imported supply leakage which is considered for the study area flow. This 7.6 % is the exact difference between these values. This example shows that the balance presented in Table 5.5 is a composition of different output files generated by UVQ, analysed to achieve a satisfying picture of the simulated waterborne copper flows.

Table 5.5 Simulated copper loads of specific flows for the entire study area in UVQ Model Stage 2

Simulated Flows	Copper load [kg]
Import Flows	
Imported Water	204.79
Precipitation	684.3
Internal Flows	
Roof Runoff	218.62
Road Runoff	1339.93
Pavement Runoff	1964.98
Kitchen Effluent	1130.81
Bathroom Effluent	1130.81
Laundry Effluent	8712.66
Toilet Effluent	1130.81
Export Flows	
Stormwater (Excess Water + Baseflow)	1323.82
Wastewater	15866.81

Table 5.5 shows that UVQ identifies precipitation to be the largest waterborne copper import flow in this simulation. Kitchen, Bathroom and Toilet loads are identical due to the calculation approach used by UVQ. Indoor copper loads are demanded in mg per capita and day, which in case of these sections, were assumed to be the same. Therefore UVQ does not use provided indoor water flows to calculate a load for this sections. Toilet flow in this simulation also considers Industry, Tourism and Trade, for this reason load from this flow should actually be the largest. However, the approach used by UVQ neglects this factor because copper loads are not linked to water flows for indoor water use. Hence copper emitted from laundry is the largest load due to the largest Cu-concentration value.
UVQ also assumed copper loads for roof, pavement and roads by using a “Simple Sludge Operation”. Pavement and road copper loads are assumed to be 1965 kg and 1340 kg. Roof load is one order of magnitude smaller, summing up to 219 kg.

UVQ also creates graphics illustrating sources of copper for neighbourhood stormwater outputs, which are presented and compared in Figure 5-4 and Figure 5-5. The numbers in front of the fraction-description are the flow labelling of UVQ.

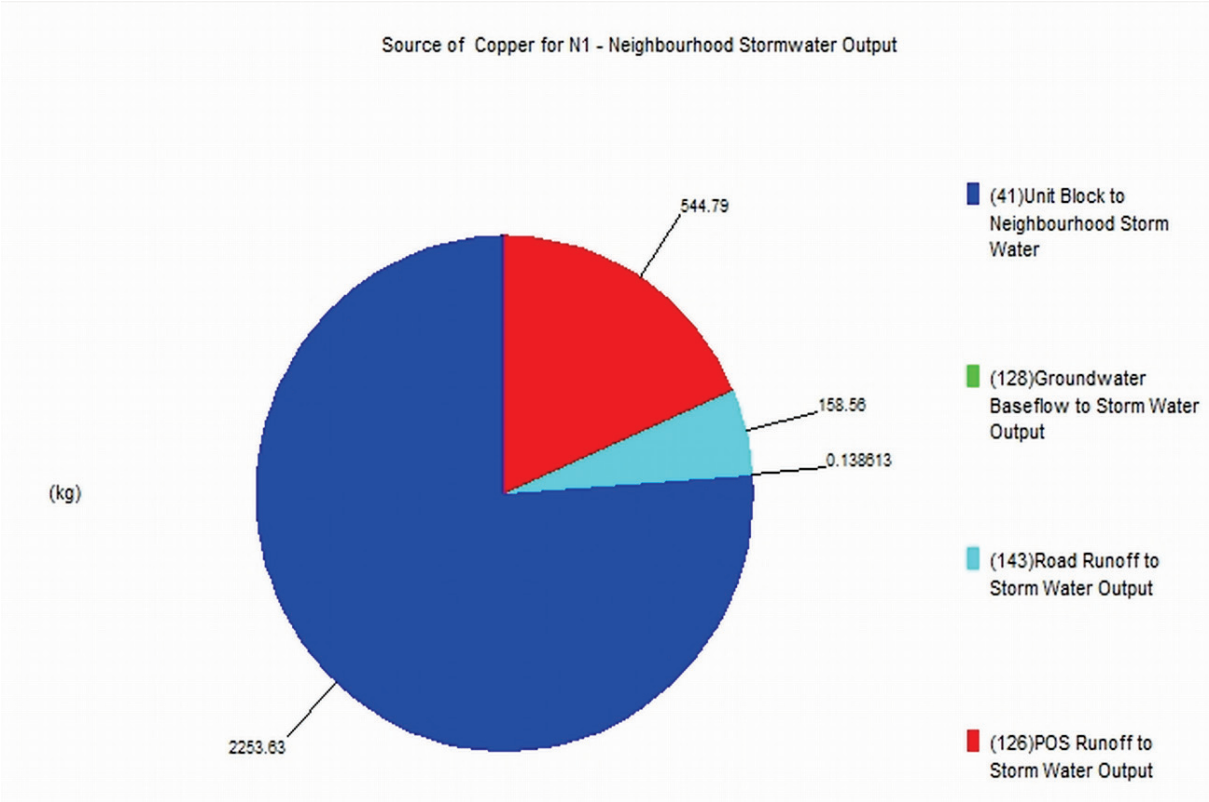


Figure 5-4 Source of copper for Neighbourhood 1 – Neighbourhood Stormwater Output

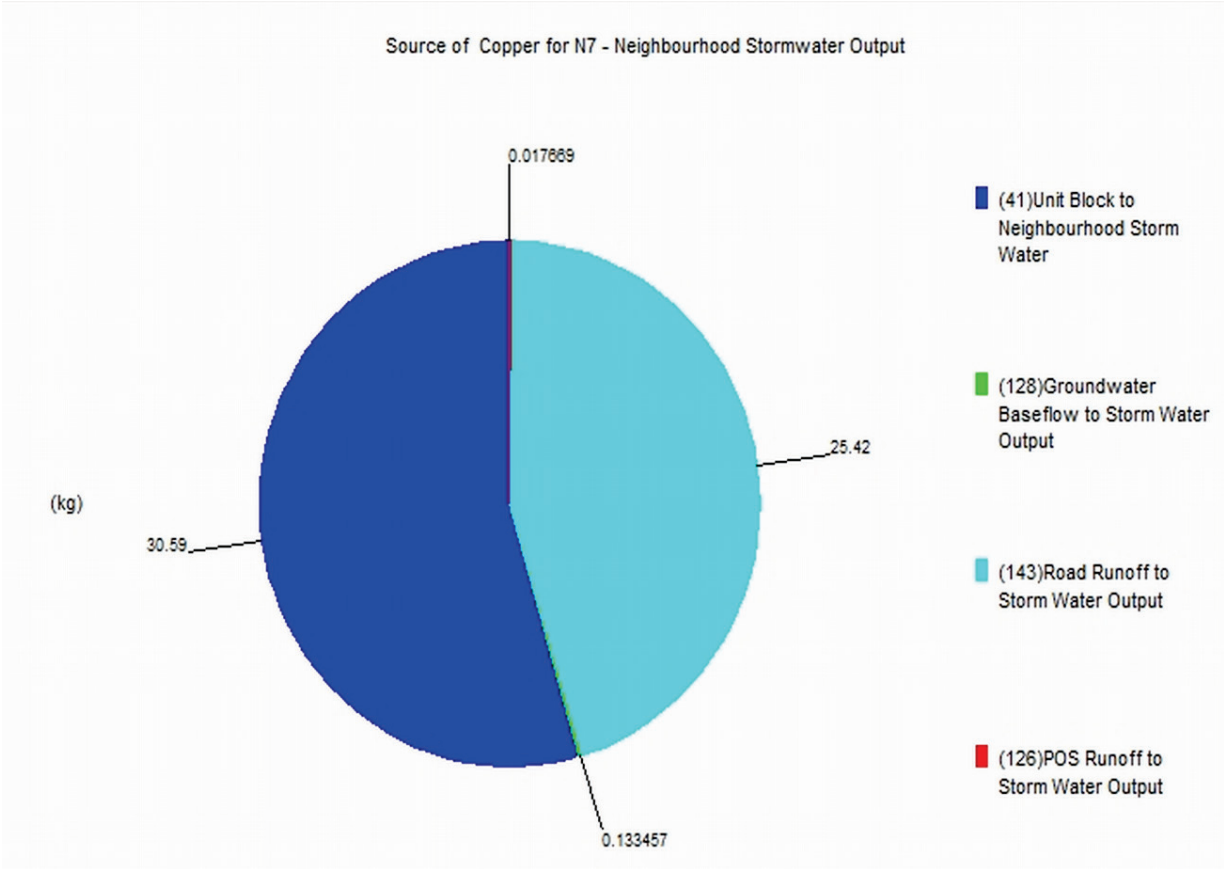


Figure 5-5 Source of copper for Neighbourhood 7 – Neighbourhood Stormwater Output

Figure 5-4 represents Neighbourhood 1, displaying large agricultural areas, whereas Figure 5-5 represents Neighbourhood 7, an inner city district in Vienna with large impervious areas and hardly Public Open Space. Differences are obvious: In Neighbourhood 1 Fertilizer plays a significant role as contributor to copper-load. The major contributor in Neighbourhood 1 are buildings and households, illustrated by the dark blue partition in the pie chart. Road Runoff only plays a minor role in Neighbourhood 1. In comparison, Neighbourhood 7 offers a picture in which fertilizer contributes almost nothing to copper loads, it is replaced by Road Runoff which comprises almost 50 % of Cu . Buildings and households are still the major contributors. Groundwater baseflow does not play any role in both districts.

UVQ may demand a large amount of input data concerning copper, however simulated balance seems rather vague, due to the missing linkage between indoor water flows and copper. It still provides useful and important indications for creation of the future copper balance in STAN. Especially the possibility to analyse sources of copper and its distribution is a promising tool.

5.2 STAN

5.2.1 Stage 1 – water balance

As mentioned before, STAN model stage 1 is based on results from UVQ model stage 1 and calculations explained in chapter 4.6. The model of this stage was used to calculate the missing flow “Industrial Wastewater” and to investigate, whether results are satisfying or not.
In conclusion, results were very satisfying considering the roughness of the model and the lack of exact data.

Figure 5-6 illustrates results from STAN model stage 1. Some clear differences can be spotted compared to UVQ values and observed values.

One difference is discovered at the amount of wastewater flow, which sums up to 205,422,329 m³ for 2008. This value is very close to the observed value of the wastewater treatment plant in Vienna equal to 205,024,907 m³.

A major step for modelling of UVQ Model stage 2 is provided by the calculation of industrial wastewater through STAN. The value determined in STAN Model stage 1 will be used in UVQ Model stage 2.

Private household water use sums up to 78,987,642 m³, whereas water used by industry, tourism and trade sums up to 48,853,852 m³. Impervious surfaces combined produce 79,655,808 m³ of runoff, pervious surfaces only 35,264,290 m³.

Sewer leakage is assumed to be 1% respectively 2,074,973 m³, supplying the groundwater storage.

Considerations behind the first model and the model itself may not be very detailed yet, however it already illustrates a simple yet clear water balance of Vienna, displaying a large variety of water flows and their dimensions, which can be used for water management purposes.

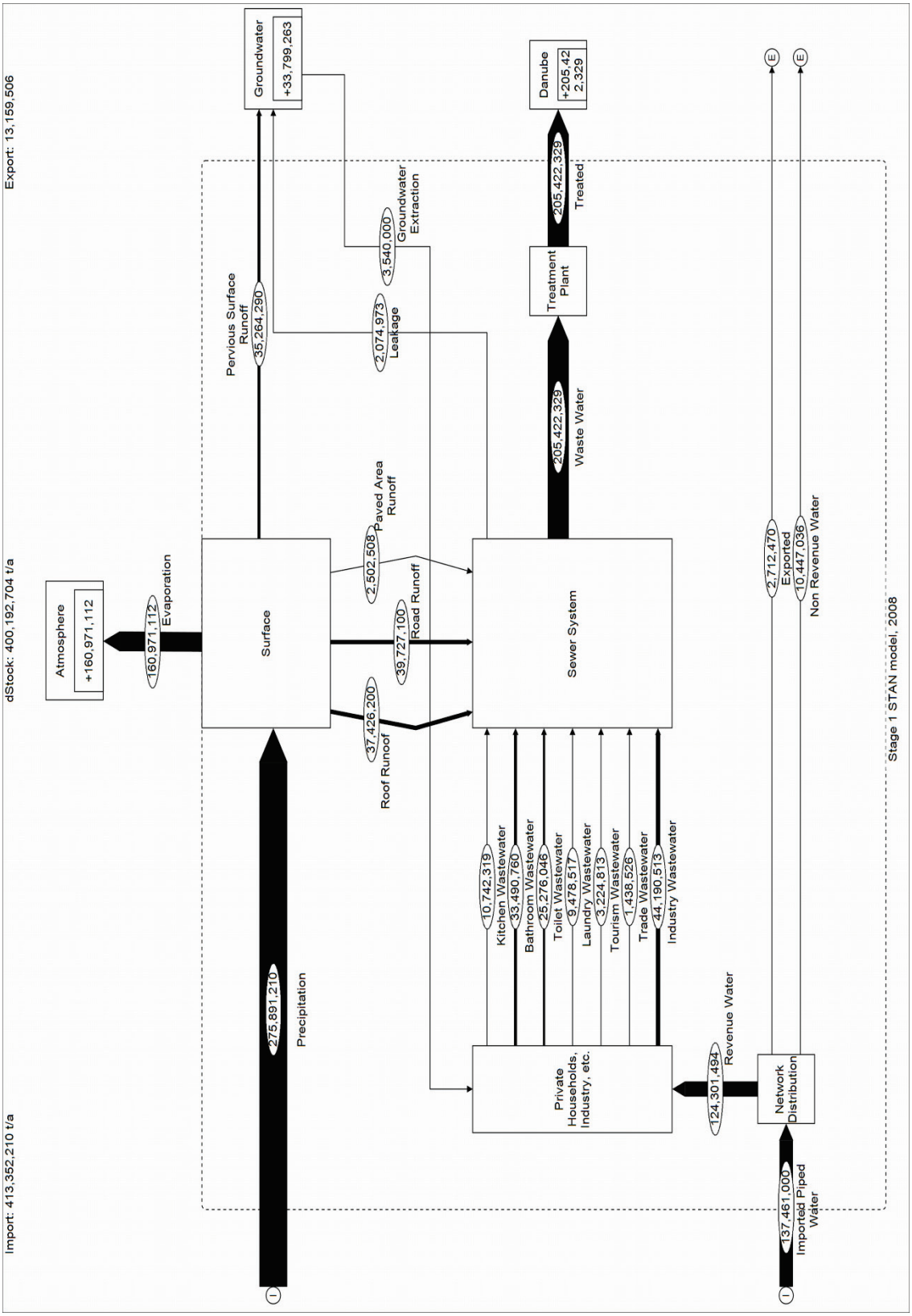


Figure 5-6 Result of STAN model stage 1 simulating the urban water balance of Vienna

5.2.2 Stage 2 – water balance

The final water balance model delivered satisfying results, an illustration is given in Figure 5-7.

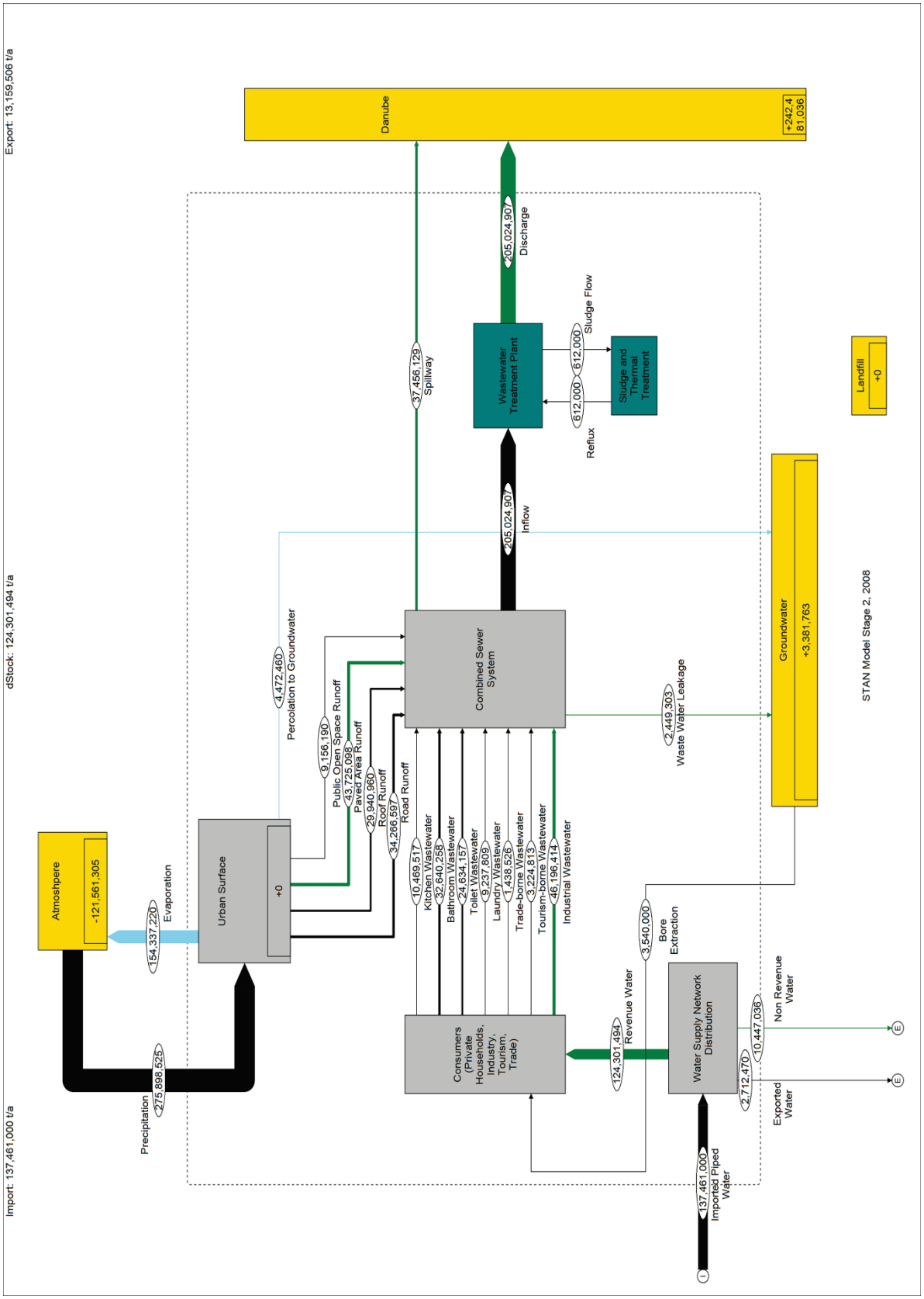


Figure 5-7 STAN Model Stage 2 water balance – flows are given in m³/a

Several stages of model development and data improvement were necessary to develop a model which illustrates important flows and processes to represent a simplified, yet holistic picture of the water balance of Vienna. The final water balance, represented by STAN Model Stage 2, gives an idea of how complex such an urban water system actually is. The most important improvements of the water model in comparison with STAN Model Stage 1 are following:

- Consideration of Spillway Water
- Consideration of sludge treatment
- Correction and improvement of many flows

It is very important to understand that results illustrated by the developed model are only simplified static simulations, a detailed picture of such a complex system is barely possible to develop. Consideration of all influences and dynamic factors would go beyond scope. Moreover, measuring errors already generate significant uncertainties, not to mention the dimension of such a holistic system. Similar difficulties were already identified in previous literature, e.g. in the article “water balances of Urban Areas” (Van de Ven 1990), which was analysed in chapter 3.1.2.2.

The final water balance identifies two major inputs to the urban water system, with exception of the Danube. The first, precipitation, comprises 66 % of all inputs. The second largest input is represented by water imports originating from the two mountain spring pipelines and sums up to approximately 33 % of inputs. This percentage is in strong accordance with a study on the water balance of Vienna by Maier, Punz et al. (1995), who calculated imported water to comprise approximately 34 % of inputs.

The vast majority of precipitation is evaporated, which is presented in Figure 5-8. Thus only 44 % of precipitation generates runoff from different urban surfaces or percolate, which strongly correlates with the Case Study for the City of City-of-Berlin (2012), in which approximately 45 % of precipitation is available for runoff. It is assumed that no water is stored on urban surface, thus the largest runoff is represented by Paved Area Runoff, followed by Road Runoff and Roof Runoff. Due to rough surface and hence a different runoff coefficient, runoff originating from Public Open Space, which takes up 48.5 % of Vienna’s entire area, only comprises approximately 8 % of Urban Surface Runoff. This finding is documented in Figure 5-9. Remaining water, which sums up to only 2 % of precipitation, percolates to groundwater. Runoff from the Urban Surface is collected in the sewer system.

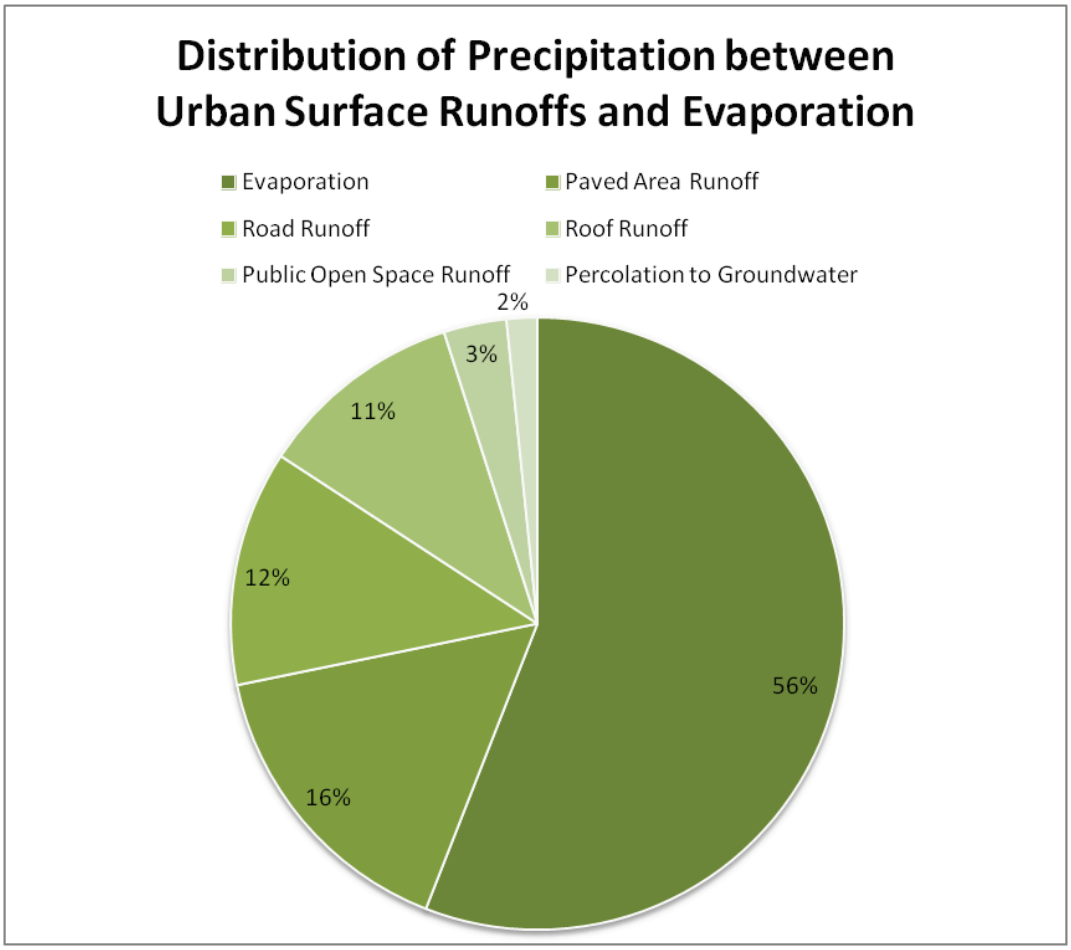


Figure 5-8 Distribution of Precipitation between redirecting flows

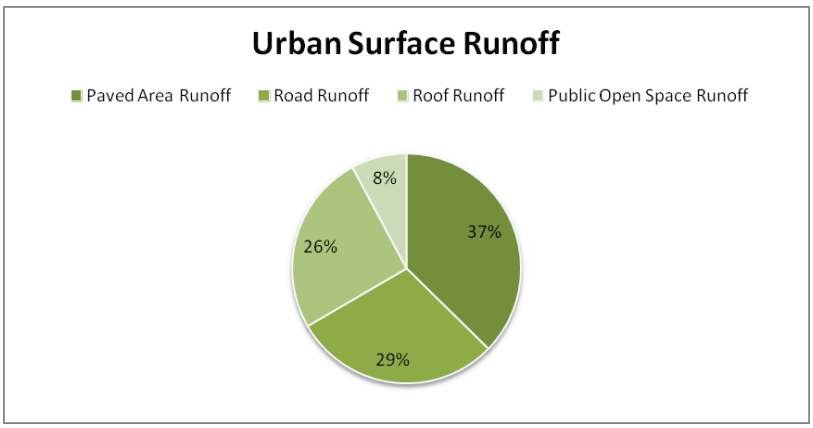


Figure 5-9 Distribution of urban surface runoff

Paved Area Runoff seems to comprise large amounts of total surface runoff, however this runoff includes all sealed areas not considered in traffic area, e.g. private parking, sealed backyards, sealed industrial sites, etc. Roof Runoff comprises 26 % of urban surface runoff, despite roof area only takes up 13.6 % of the entire study area. Taking a look at precipitation, 11 % of precipitation contributes to roof runoff, which is close to the areal ratio. Considering the fact that sealed surfaces exhibit a significant higher runoff compared to impervious, vegetated areas, calculated flows do not seem to be too far off reality. Percolation of only 2 % of precipitation seems to be rather small, other studies in Vienna concluded that approximately 20 % percolate (Maier, Punz et al. 1995), the case study “Case Study for the City of City-of-Berlin (2012)“

exhibits 31 % of percolation. Such a discrepancy may be caused by the lack of available soil data, differences in the system boundary, differences in used software tools and the used approach or idiosyncrasies of each city.

Imported water is split up too, however, the majority of roughly 90 % stays in the system and is distributed to consumers. Private households, tourism, trade and industry represent consumers. Non Revenue Water was assumed to export 7.6 % of Imported Piped Water. STAN calculated this percentage to equal approximately 10.5 million m³.
The largest water volume to the sewer system originates from private households, which is subdivided into four flows of indoor water usage. Overall, about 60 % respectively 76,981,741 m³ of water input to consumers is used by private households. Of this volume, 42 % is used in the Bathroom, 32 % for Toilet Flush, 14 % in the Kitchen and 12 % for Laundry, as demonstrated in Figure 5-11. This water use pattern is different to other studies, such as the water use pattern of Zurich (Huang, Bader et al. 2007), which has a ratio of Bath : Kitchen : Laundry : Urine Flush : Faeces Flush = 7 : 4 : 4 : 4 : 1. This difference once again underlines the idiosyncrasies of each urban area. The second largest waste water producer is industry, which was calculated to contribute 36 % to consumer wastewater. Tourism and trade only sum up to 4 %, which can be seen in Figure 5-10.

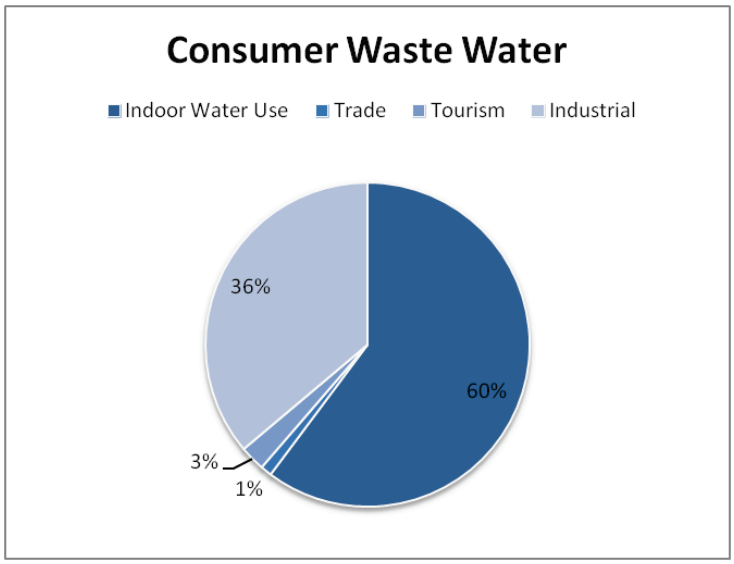


Figure 5-10 Distribution of waste water generated by Consumers

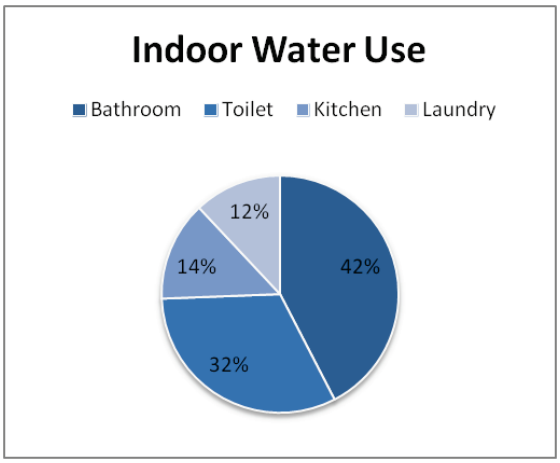


Figure 5-11 Distribution of waste water flows generated by Private Households

Figure 5-10 confirms expectations that private households in Vienna produce the majority of wastewater, followed by industry. However, it was not expected that tourism and trade would play such a minor role, especially the trade sector was expected to contribute more to

wastewater production. This result is based on assumptions, thus in future studies a more detailed investigation of water use in the trade Sector in particular is suggested to reveal more specific water use patterns.

Wastewater from Urban Surface or Consumers collected in the sewer system is further directed either to the Wastewater Treatment Plant or leaves the system via Spillways or Leakage. As illustrated in Figure 5-13, calculations indicate that roughly 15 % of the water volume transported in the sewer system overflows via spillways and 1 % is lost via sewer leakage. Spillway volume equals about 37.5 million m³, a value which is very close to the 34.6 million m³ calculated by Maier in 1995. Compared to the value calculated in UVQ, which totals about 14,6 million m³, this results seems rather large. However, by far not all possible spillways were considered in UVQ, hence the calculated value is very satisfying. The missing 84 % of the entire wastewater volume is treated in the central wastewater treatment plant of Vienna. Figure 5-12 indicates that about 48 % of water in the sewer system is traced back to surface runoff. This percentage equals about 117.1 million m³ of water. Assuming that Spillway Water is entirely rainwater, 79.6 million m³ of stormwater reach treatment. Hence, approximately 70 % of runoff generated by rainfall reaches the treatment plant. Since the actual composition of spillway water is not known, the effective percentage of stormwater reaching treatment is very likely to outreach 70 %. These values exceed suggestions from Austrian guidelines (ÖWAV 2007), which suggest 40 to 60 % of rainwater should reach treatment.

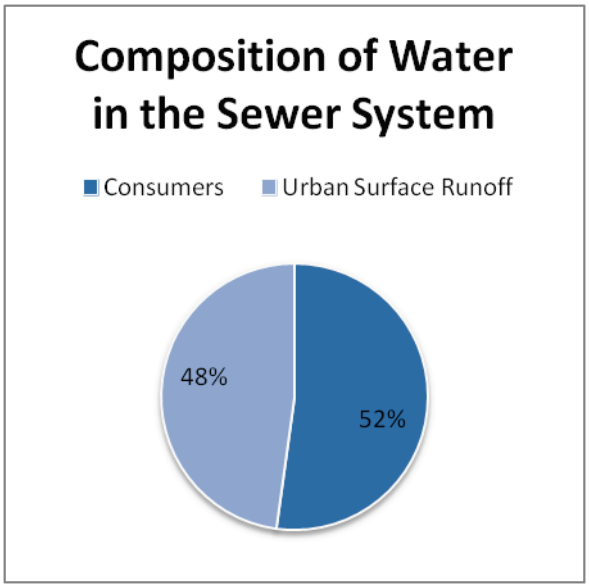


Figure 5-12 Composition of water in the sewer system

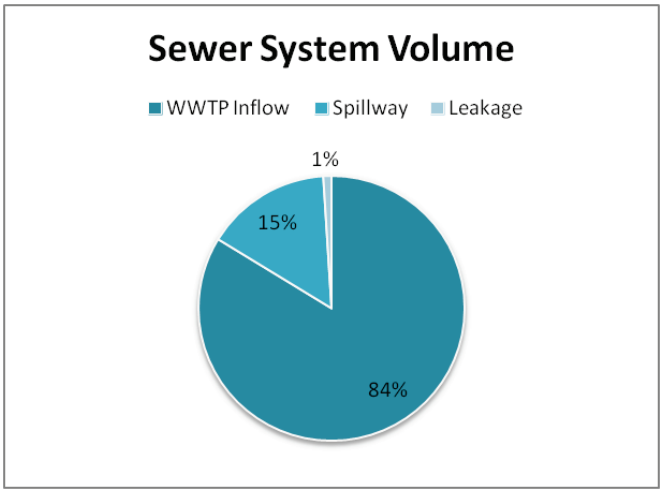


Figure 5-13 Redirection of sewer system volume flow

In the simulation it is assumed that all wastewater directed to the wastewater treatment plant is treated and discharged into the Danube.

It is known that not all of treated wastewater is discharged into the Danube, some water stays in the treatment process, little is exported via sludge or sand trap effluent. These flows were assumed to be negligible due to their small volume. It is further known that some water is used for irrigation, however, this flow was also ignored, based on results of UVQ which indicated that this amount of water is negligible.

It is important to understand that all calculations are based on assumptions and available data. Many simplifications had to be considered and not all necessary data was available, thus some input values were assumed, based on literature and experience. Calculated Spillway volume is also based on assumptions made in advance, thus it is possible that this flow is larger or smaller in reality. The same applies to all calculated flows and the entire model.

A recommended task for future studies is the gathering of more detailed data about wastewater flows in the Viennese sewer system. The establishment of monitoring equipment would improve the investigation of wastewater flows and their source. Thus tracing of major wastewater producers and of leakage in the sewer system could be enhanced, improving accuracy and effects of measures against wastewater production and leakage. Especially for large industrial facilities and large shopping centres a wastewater monitoring system would deliver detailed information about water use patterns of these consumers. This could improve political and technical measures to mitigate wastewater production and enhance the preparation of the central wastewater treatment plant for special wastewater contents.

Moreover an improvement of available soil data for Vienna is necessary to develop more detailed models in future. Hydrological data of Vienna at present is very satisfying and readily available, a combination of available data in an hydrological model as established in the case study “Case Study for the City of City-of-Berlin (2012)“ would even enhance knowledge of the urban system and may improve prediction about runoff and wastewater patterns.

Further it would be desirable to update existing information concerning spillways. The sewer information system KANIS should be improved by making profiles accessible for public and by marking spillways on the map.

Recommendation for future studies and stakeholders:

- Soil of Vienna – Improvement of available data
- Wastewater Monitoring System – establishment in the sewer system, at industrial sites and shopping centres
- Establishment of an hydrological model using the example of Berlin
- Improve public available data of sewer network

5.2.3 Stage 2 – copper balance

The copper balance is based on the same generic model as the water balance, hence it is also based on the water flows. However some import and export flows exclusively for copper had to be established, because import of this heavy metal on the waterway only plays a minor role. An illustration of the final results are presented in Figure 5-14 .

Due to the lack of available data of copper in Vienna, results of this model are based mainly on assumptions or literature values, not on actual observed data. Furthermore a comparison with other studies is difficult, due to the fact that this copper balance is based on a generic model of a water balance, which is a very unique approach. This approach was barely used in literature, however, some results may be comparable with other studies.

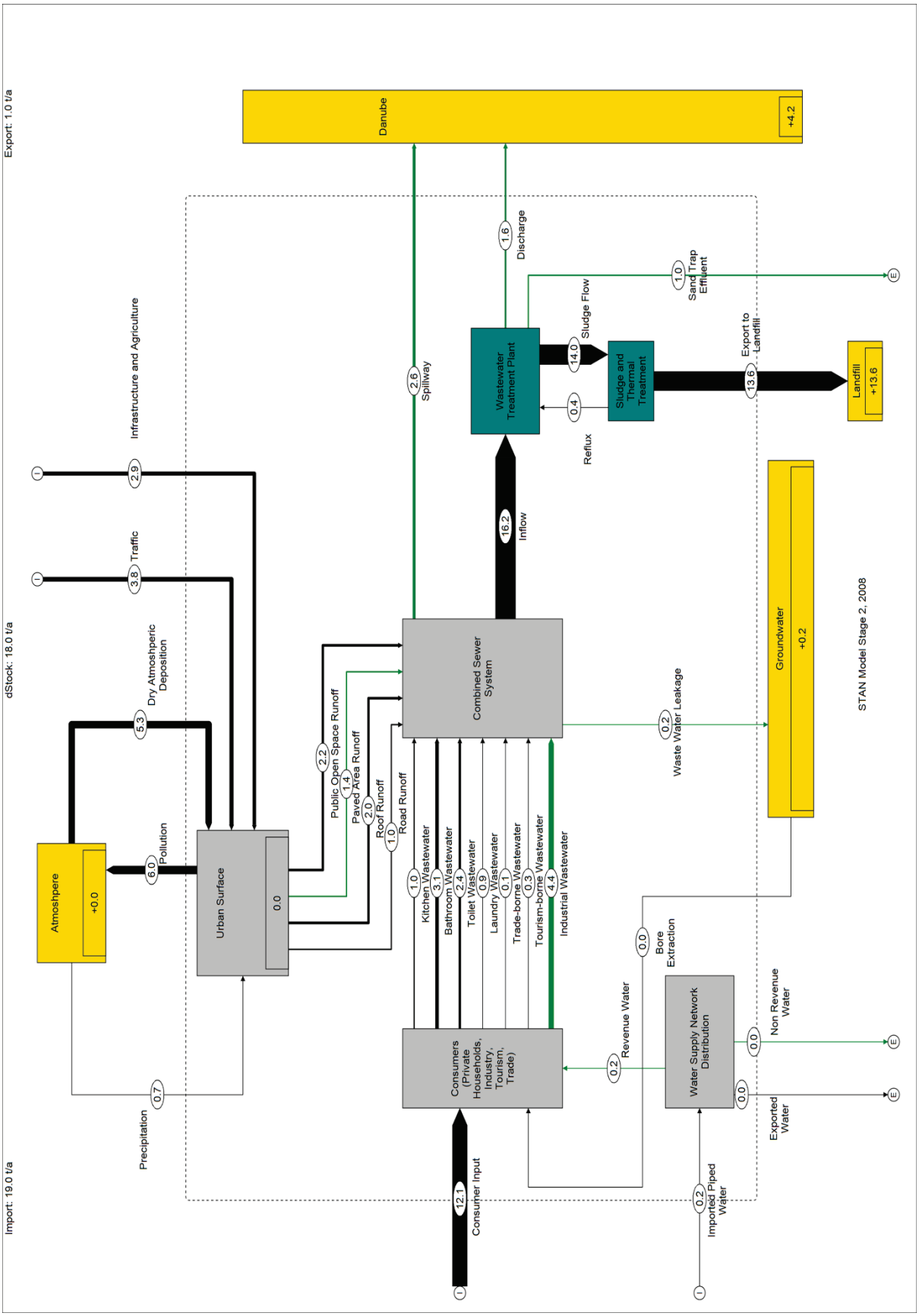


Figure 5-14 STAN Model Stage 2 copper balance, flows in t/a

During development of the model the major sources of copper were identified to be the input via Consumers, Traffic, Atmospheric Deposition, as well as Infrastructure and Agriculture. In total, about 25,000 kg Cu are imported to the system. Infrastructure includes parts of the copper-stock, such as copper emitted by Roofs. Figure 5-15 draws a clear picture of imported copper to the simulated system and identifies copper imported on the waterway to sum up to only 4 %. This minor proportion is due to low copper concentrations in Imported Piped Water and Precipitation. This is a contradiction to UVQ Model Stage 2 which identified Precipitation to be the largest waterborne import flow to the system. However, due to its preset equations, UVQ is not capable to consider waterborne input by Consumers, as it is the case in this final generic model setup. UVQ does not consider copper imports via concentrations in water, it does so by concentrations per capita and day, which draws a different picture, which will be investigated further later.

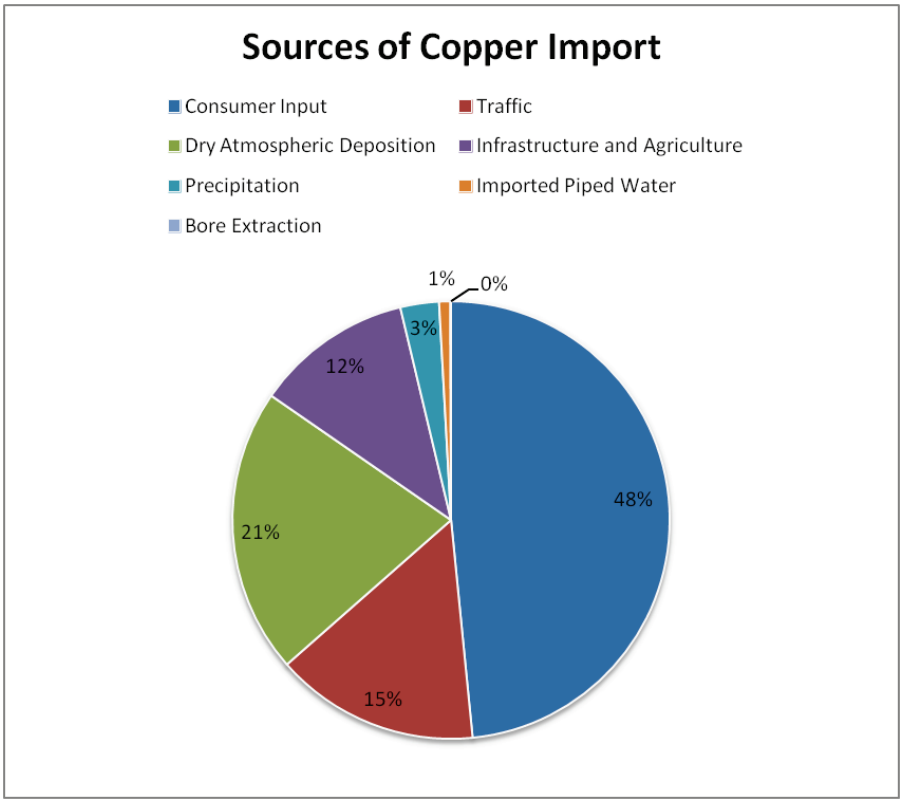


Figure 5-15 Sources of copper import to the copper model in STAN

Copper loads transported with runoff from urban surfaces offer a different picture compared to the water balance. Hence, the major contributor to copper transported with runoff is not Paved Area Runoff. Public Open Space Runoff carries about 2230 kg of copper, followed by Roof Runoff transporting 2050 kg, Paved Area Runoff containing 1410 kg and Road Runoff contributing 1000 kg. The distribution of total copper emitted by Urban Surfaces is illustrated in Figure 5-16.

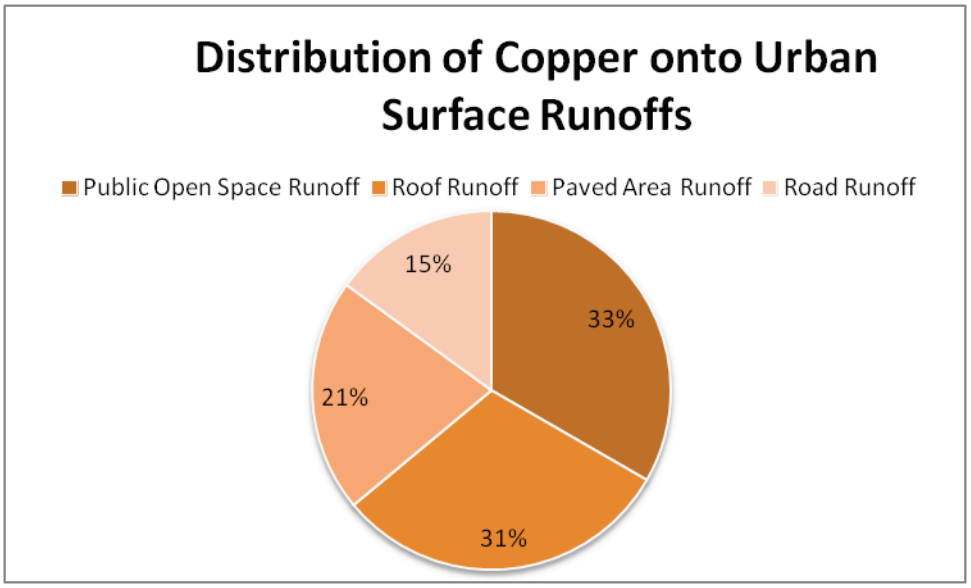


Figure 5-16 Distribution of total copper in urban surface runoff

Public Open Space is assumed to be partially fertilized and comprises 48.5 % of the entire study area. This vast area catches large amounts of atmospheric deposition, hence copper in its runoff exceeds other sources. Roof Runoff seems to be rather large, taking into account that only about 5 % of roofs are copper-roofs (Kral, Lin et al. 2013). As mentioned in chapter 4.7.5 at the calculation of Roof Runoff, it is very difficult to assess the real value due to large uncertainty. Therefore an average value was taken, but results still show the influence of uncertainty. Contribution of Road Runoff seems to be rather small, taking into account the number of personal motorized vehicles, tramways, subways and public busses emitting Cu. Road Runoff copper was calculated using a copper concentration in road runoff of Genoa and results from UVQ, thus a discrepancy with reality is possible due to idiosyncrasies of each urban area. Actual data of Vienna was not available, indicating that measurements of copper concentration in road runoff in Vienna would be very desirable for future studies. The ratio of 33 % of total runoff copper transported via Paved Area Runoff is in accordance with Figure 5-9, in which 37 % of surface runoff is comprised by this flow. These results are slightly different to other studies, however no major discrepancy is discovered. Seelsaen, McLaughlan et al. (2007) identified Traffic to be the major contributor, followed by Roof Runoff. Thus the large value for Roof Runoff might be not too far off.

For copper transported with the specific wastewater flows originating from Consumers, copper was distributed according to the flows proportion on total wastewater flow by Consumers. Hence no surprises in STAN were investigated in this section, Figure 5-17 offers the same distribution for copper load as Figure 5-10 for water.
However, this approach differs significantly from the UVQ approach. This explains the large discrepancy of Private Households Cu loads in UVQ and STAN, which is observed in Table 5.5 and Figure 5-14. The best example is Laundry Copper, which equals about 8700 kg in UVQ, but only 890 kg in STAN. UVQ determines the Cu-load without taking the water flow into account. The input demanded by UVQ is in the unit mg/c/d, hence the laundry copper value is simply calculated by multiplying the entered 14 mg/c/d with the inhabitants of Vienna and the number of days of the simulation. UVQ does not demand a Cu-concentration for water. In STAN, the total household copper-load calculated by UVQ was partitioned according to the proportion each flow takes of the total Consumer waste water volume. Thus these results differ significantly between the used software tools, which can be seen in Figure 5-18. However in total, they are equal.

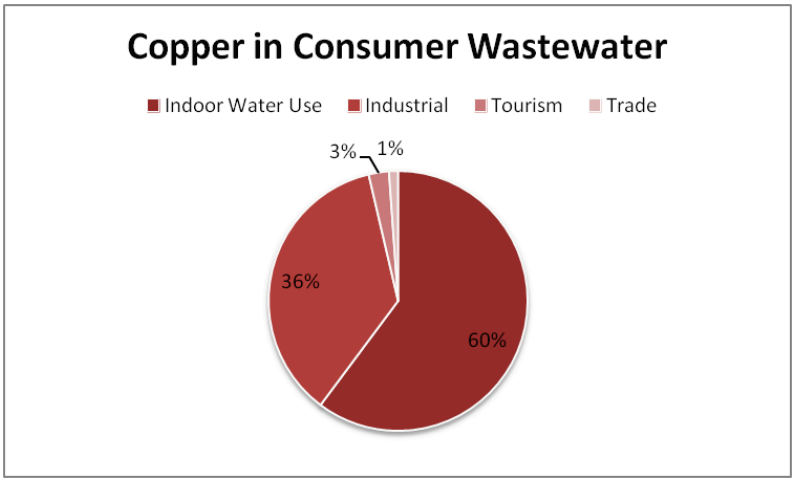


Figure 5-17 Distribution of copper load in Consumer wastewater

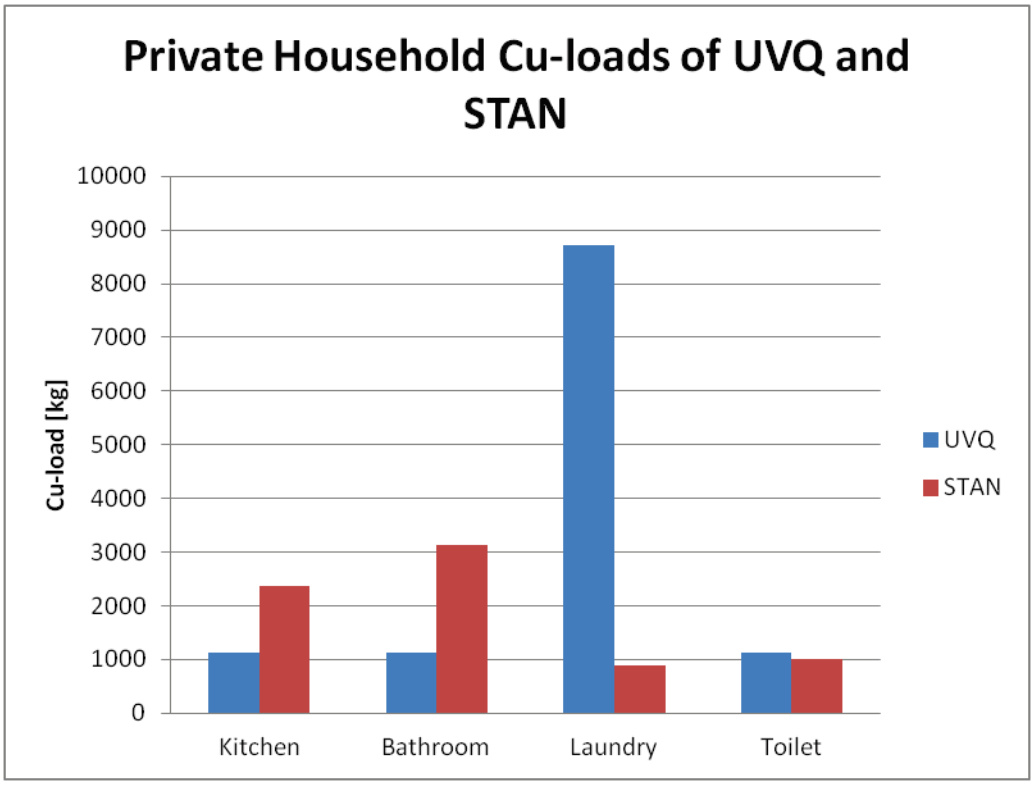


Figure 5-18 Private Household Cu-loads of UVQ and STAN in comparison – STAN also includes copper originating from tourism, industry and trade in private households, which is not pictured, hence total Cu of households in UVQ is larger than in STAN.

Due to many simplifications and assumptions it is not necessarily true that private households contribute most of copper to the sewer system, however it was not possible to investigate copper concentrations for private households and all individual industrial sectors as part of this thesis. Thus, to develop a more detailed picture of copper transported by the individual flows, measurements of copper concentrations in runoffs originating from households and industry should be considered in future. Also, assuming an average value for copper concentration for Industry would simply be wrong due to the large variety of industrial sections and their individual wastewater compounds.

In total, approximately 19,000 kg of Cu enter the sewer network, 12,300 kg or 64.8 % originating from Consumers, 6700 kg respectively 35.2 % from the Urban Surface, as can be seen in Figure 5-19. These values differ significantly from the distribution of wastewater which enters

the sewer system. For wastewater, only 52 % of water originates from Consumers and 48 % is added by urban runoff.

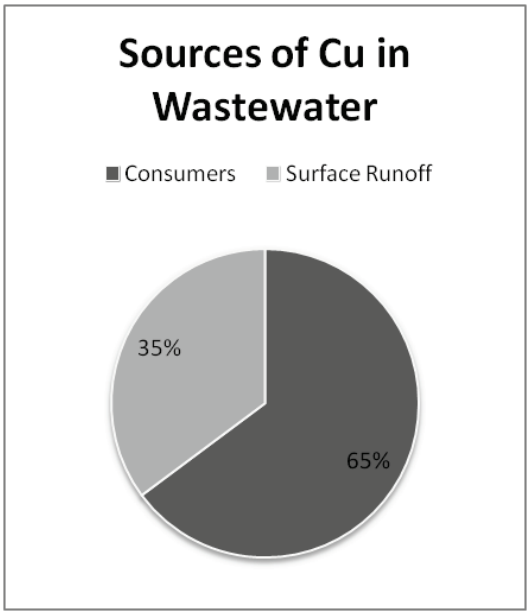


Figure 5-19 Sources of Cu in wastewater

As in the water balance, the sewer system offers three options for copper to escape. The Wastewater Treatment Plant Inflow, Spillway and Leakage. Figure 5-20 offers a fragmentation of the total sewer system copper load. The distribution is very similar to Figure 5-13. The Cu-input to the wastewater treatment plant was known, leakage was assumed to be 1 %, Cu in spillway was thus calculated by STAN. It is satisfying that the distribution of copper is in accordance to the distribution of wastewater, despite a different distribution of Cu sources. Only 1 % difference in the distribution was observed. Therefore copper concentrations in Wastewater Treatment Plant Inflow and in Spillway Excess Water are almost the same, which indicates a satisfying simulation of copper in the sewer system. However, the actual composition of spillway water is not known, hence a variability of these values is possible. Seelsaen, McLaughlan et al. (2007) came to the conclusion that sewage overflows are major contributors to copper flows, which in this case is true for the Danube, but not for the entire system.

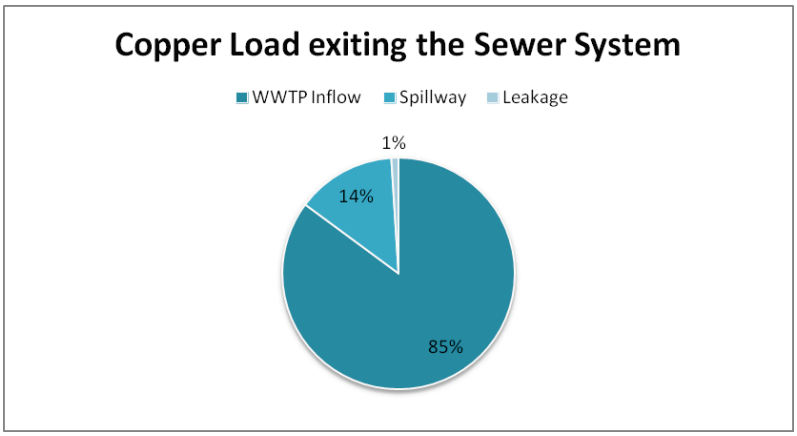


Figure 5-20 Distribution of copper load exiting the sewer system

For copper, yet another aspect of the system is of interest. Treatment in the wastewater treatment plant and further deposition are important points. Figure 5-21 illustrated that of Cu entering the wastewater treatment plant, 84 % is exported to landfill after thermal treatment, 6 % ends up in the Sand Trap Effluent and about 10 % is discharged into the Danube. Hence approximately 90 % of copper in wastewater is removed.

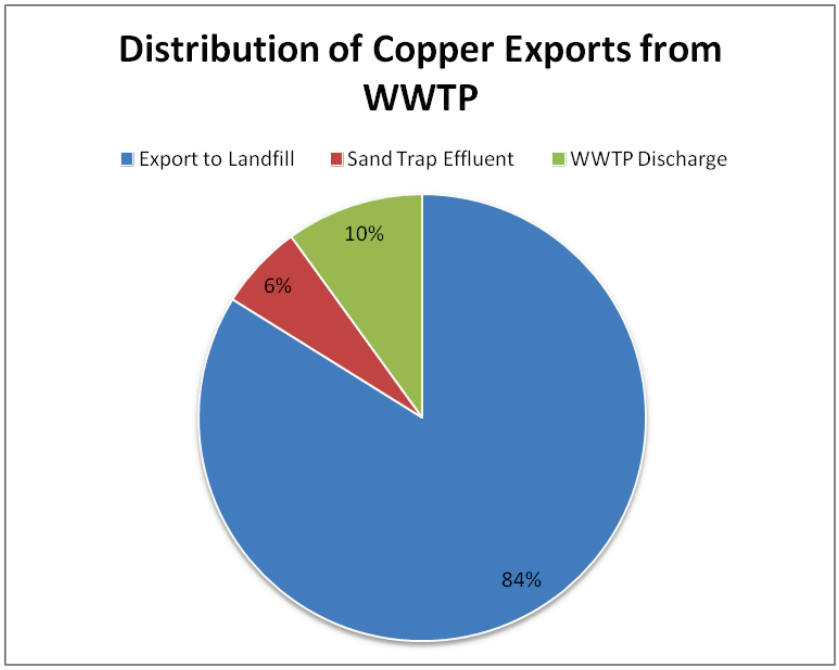


Figure 5-21 Distribution of wastewater treatment plant copper leaving the system

However, if taking a look at total copper contained in the sewer system, more flows have to be considered. If Spillway and Leakage are taken into account as well, distribution changes. Figure 5-22 shows the changed distribution of copper exports. If approached this way, only about 71 % of copper is treated in Thermal Treatment and exported to Landfill, 14 % leaves the sewer system via Spillways, 9 % is discharged by the WWTP, 5 % is contained in Sand Trap Effluent and 1 % exits via Leakage. According to this distribution, approximately 23 % or 4330 kg of total Cu from the sewer system enters the Danube annually. 60.9 % of this load is not treated in processes of the wastewater treatment plant because it is transported in spillway water.

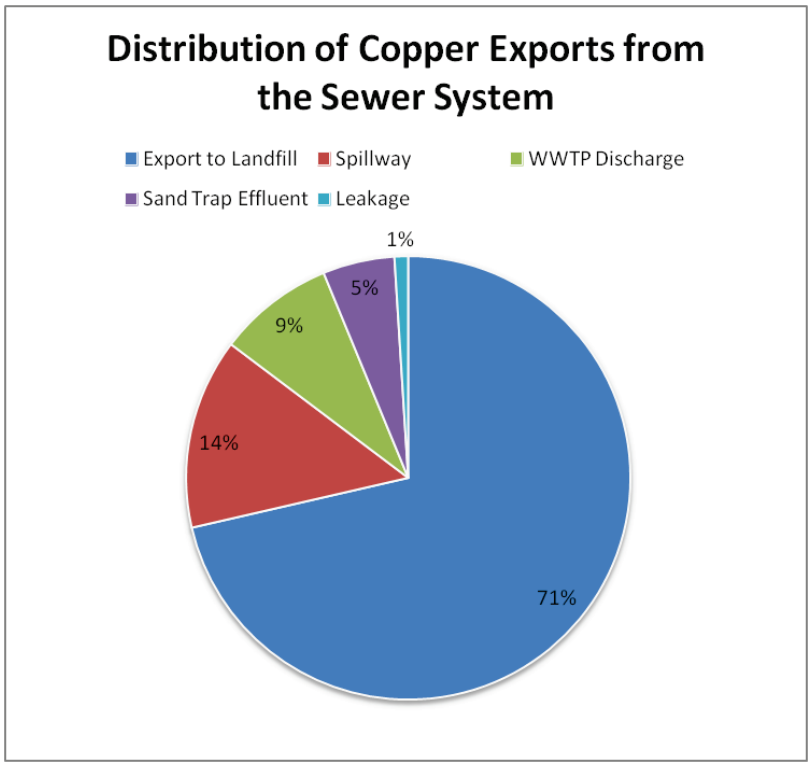


Figure 5-22 Export flows of total copper in the sewer system

The copper balance is based on a generic model which was designed for a water balance, therefore the level of detail of the water balance is out of reach. The focus in this thesis was the establishment of a holistic water balance which provides a framework for a copper balance. To consider more Cu sources and to enhance details, it would be necessary to develop a generic model which fits the requirements of a copper balance. This would also give the possibility to better consider copper transported outside of the waterway. Identification of sources and thus tracing of the metal on its path through the urban system would also be an advantage of a Cu-specific generic model. Such a model was developed by Kral, Lin et al. (2013) from the Institute of Water Quality, Resources and Waste Management of the Vienna University of Technology.

Moreover, availability of copper related data for Vienna was poorly. Many Cu loads and concentrations had to be assumed based on literature values or UVQ results. Further, even literature offers highly variable values, making an exact calculation of copper loads impossible. To decrease uncertainty in copper values, additional measurements of Cu concentrations in diverse runoffs are emphasized.

For measurement of Cu concentration in Road and Paved Area Runoff, filters in manholes in different locations could be established. To enhance results for Roof Runoff, a detailed recording of copper roof areas could bring improvement. An investigation of idiosyncrasies in Cu use and disposal of private households and industry could enhance future models too.

There is also one question which is worth asking for Vienna: What happens with copper that remains in the sewer system? How much Cu can be found in debris of spillways and deposition in pipes and is there a procedure to remove or treat these loads?

Recommendation for future studies and stakeholders:

- Further research concerning the identification and relevance of Cu sources in urban areas (e.g. Measurements of copper loads and concentrations in runoffs, Investigation of Idiosyncrasies of Private Households and Industry with regards to Cu)
- Investigation of copper remaining in the sewer system

All results and models are also available on CD-ROM.

6. Conclusion and Future Prospects

This chapter will assess the final accomplishment of aims and goals of this thesis based on results and interpretation of chapter 5. Additionally, necessary future prospects will be given.

6.1 Conclusion

Literature research revealed a well developed field of research for water balances, however, copper balances based on water balances were identified to be mostly virgin territory.

To picture a holistic balance for the year 2008 of both, water and copper, a generic model had to be developed, including all necessary flows and processes. Several development steps in the used software tools UVQ and STAN were necessary to achieve a holistic picture of Vienna. The final generic model which was developed in STAN comprised 10 processes and 32 flows. 7 flows were exclusively established for copper - water is not considered in these flows, thus they do not appear in the water balance.

Results showed that approximately 84 % of the entire wastewater transported via the sewer network reaches the treatment plant, only 15 % enters receiving waters untreated via Spillways. Further 1 % enters environment directly and untreated due to sewer leakage.

The major results of this thesis with regards to water flows are presented below:

- Evaporation in Vienna adds up to approximately 56 % of precipitation, 44 % is available for runoff.
- 33 % of water in the urban system of Vienna (not including the Danube) is imported via the two main High Mountain Spring Pipelines.
- The major contributors to wastewater production were identified to be Private Households and Industry.
- Runoff from Impervious Areas (Paved Areas, Road Space and Roof Areas) comprises 92 % of surface runoff to the sewer system, whereas runoff from Public Open Space to the sewer system adds up to only 8 %.
- The annual volume of wastewater which enters receiving waters untreated for the year 2008 was calculated to be approximately 37,500,000 m³ or 15 % of the entire waste water volume, respectively 29.5 % of rainfall runoff reaching sewers.
- 70 % of rainwater reaching the sewer system is directed to the wastewater treatment plant.

These results indicate a well managed sewer network of Vienna, which overtops suggestions of relevant literature with regards to rainwater reaching treatment.

A similar picture was obtained for copper. 85 % of copper transported via the sewer network reaches wastewater treatment, 14 % is lost via Spillways and 1 % leaks into groundwater or soil. This indicates that the vast majority of copper transported by water is subject to possible control due to known sources such as consumers and urban surfaces. However, as stated before, several options for improvement of control are emphasized. Approximately 16 % of copper reaches environment untreated. The majority of treated copper leaves the system as landfill, only 10 % is discharged into the Danube and 6 % is caught in the Sand Trap.

The heavy metal copper has mainly anthropogenic sources, which were identified during development of the model. It was detected that the majority of inputs origins from the process Consumers (mainly private households and industry), followed by Traffic, Atmospheric Deposition and Infrastructure. The natural input to the urban system via waterway (Precipitation and Imported Piped Water) was identified to be ridiculously small compared to anthropogenic Cu-import. All natural copper import flows sum up to only 1 % of total Cu import, because Cu comprised in precipitation and dry deposition mainly originates anthropogenic sources. The explained distribution is illustrated in Figure 5-15. This caused the introduction of copper-

specific import flows during development of the generic model, otherwise it would not have been possible to consider all imports of Cu.

Major results of this thesis with regards to copper flows are following:

- 99 % of Cu-Input to the water system is anthropogenic
- Approximately 65 % of total Cu import reaches the wastewater treatment plant and 10 % leaves the system without treatment through spillways or leakage. A visualisation of this and the previous point gives Figure 6-1.
- 24 % of Cu is exported to the Atmosphere via Pollution

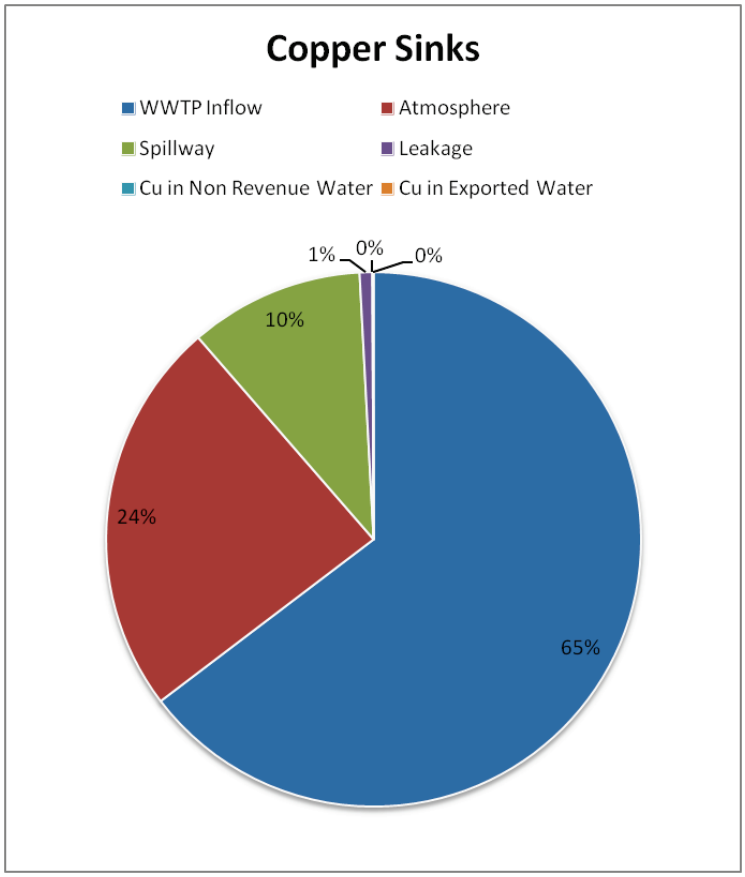


Figure 6-1 Sinks of copper in the urban water system of Vienna

- If processes following the wastewater treatment plant are taken into account 54 % of Cu in Vienna reaches Landfill as the final sink, 6 % is contained in the effluent of the treatment plant, 4 % leaves the system via the sand-trap and 2 % is recycled within the treatment plant. This distribution and loads are illustrated in Figure 6-2 and Figure 6-3.
- Due to its large area in Vienna, Public Open Space is the largest Cu-contributor of surface runoffs, followed by Roof Runoff, Paved Area Runoff and Road Runoff.
- 85 % of Cu in the sewer system reaches treatment, 15 % of sewer system Cu enters receiving waters untreated.

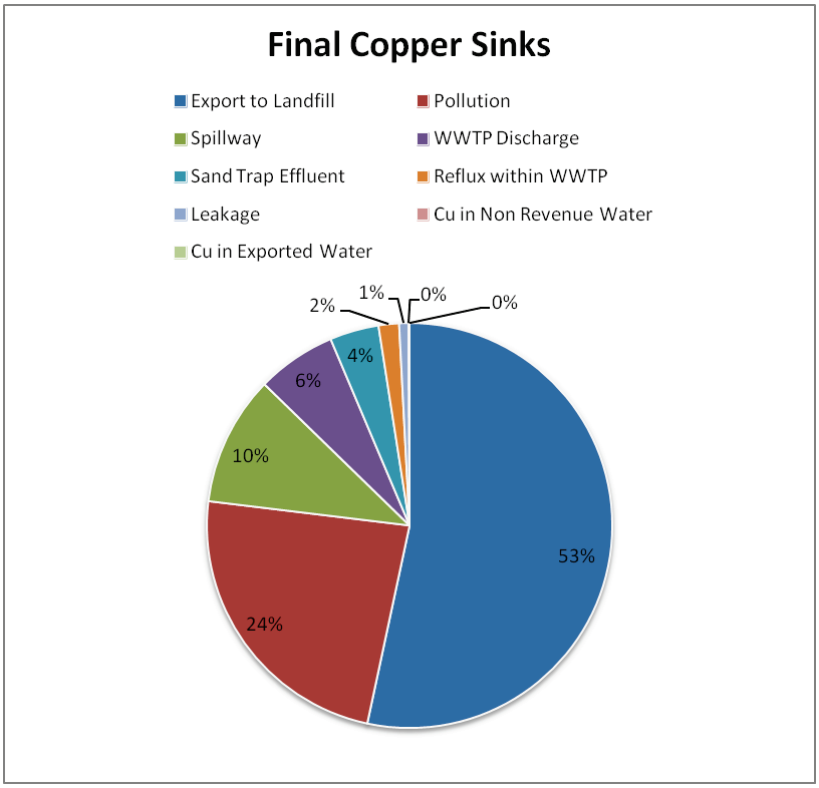


Figure 6-2 Distribution of Final Cu-Sinks, if processes following the wastewater treatment plant are taken into account as well.

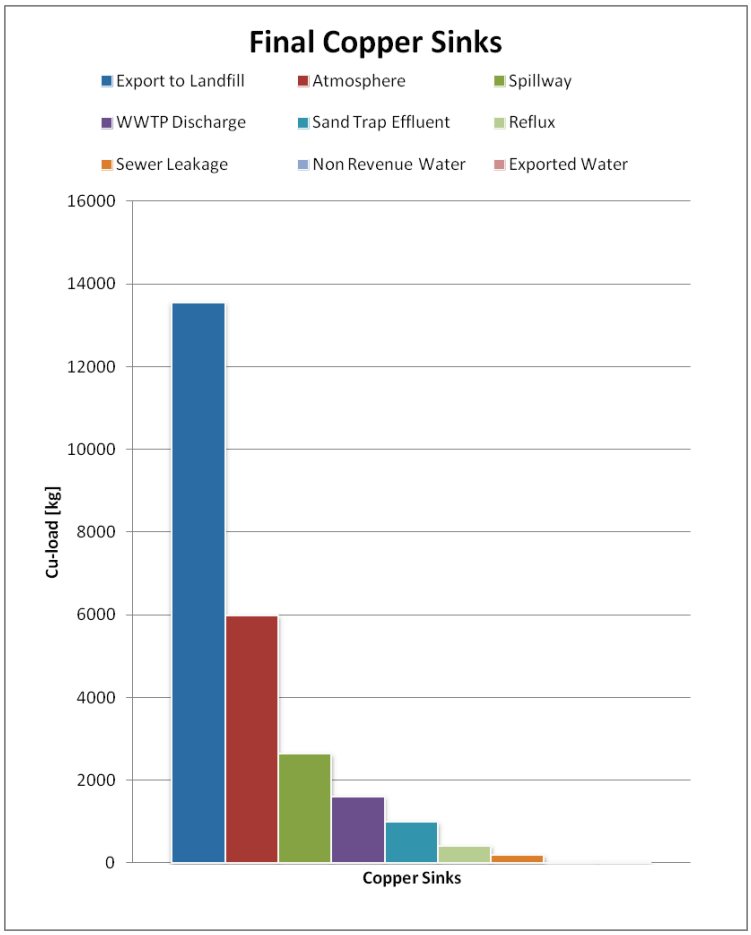


Figure 6-3 Final Cu-Sinks as columns representing the copper-load each sink takes.

Findings indicate that 85 % of copper comprised in waste water is subject to possible control.

All values and percentages given in this thesis are valid for 2008. The development of an Urban water balance is a highly complex task and picturing the entire urban water system is not possible. An urban system is utterly dynamic and changes each second. Thus simplifications are necessary to achieve a simple, yet satisfying simulation of all important processes. Due to the lack of available data, time and for the sake of simplicity, not every possible process and flow was considered in this thesis. Yet results are very satisfying, even if comparison with other studies is always a difficult task due to idiosyncrasies of each city and different scopes and aims.

6.2 UVQ and STAN – a comparison

After using both software tools to develop a water and a copper balance, it is concluded that UVQ and STAN are quintessentially different.

UVQ is a lumped grey box model which requires large amounts of input data. A lumped grey box model is a simulation which is fed by data averaged for the entire area and which is based on simplified physical laws by representing physical elements as storages (Nachtnebel 2007). This gives little reach of play for the user. All equations are preset, the only option to alter the model is via input data. However, this software cannot be used without knowledge of simulated processes and the simulation itself. Only feeding input data does not result in a good model, it is necessary to understand how UVQ works. This leads to a disadvantage of UVQ – while developing a model, the user tries to fit the model to the simulated reality, however during this process, the user deepens his or her understanding of UVQ but does not intensify efforts to understand reality. The step which arises comprehension of the real system is missing in UVQ.
UVQ was developed in Australia and thus it offers several options to include water management alternatives which are of concern for dry climates (rainwater harvesting). Hence this software is an ideal tool for planning purposes of future water supply and sanitation networks, offering the ability to compare different alternatives such as combined and separated sewer systems or assessing future water management options. However it is difficult to simulate already existing water systems in detail using UVQ. Due to its large data demand and predefined background calculations it may not be able to consider all relevant idiosyncrasies of existing systems. UVQ is capable of simulating a system holistically, however it is difficult to describe specific parts in detail. This fact caused some researchers to combine UVQ with other software tools to model a system more detailed (Wolf, Klinger et al. 2007). Further it does not include the option to consider industrial water use and indoor substance loads are calculated based on inhabitants, not on used water volumes.
UVQ represents a solid yet complex tool for planning and thus its advantages could be used in the area of planning all around the globe.

In contrast, the generic tool STAN requires a holistic understanding of the simulated system to be able to develop a less complex, yet satisfying model. The level of detail is based on abilities and desire of the user, even uncertainties can be considered if necessary. The approach and required input data is provided by the operator. The system is not preset, hence it is designed and easily altered by the user. This software tool does not offer any hidden calculations, with exception of simple mass balance equations.
STAN implies a comprehension-awakening step for the user. This is a major advantage, however it also holds the disadvantage of time consumption. Due to the requirement of system comprehension and input data, development of a simulation in STAN takes more time than in UVQ. STAN is still a promising tool for both, research purposes and civil engineering market purposes. Pictures generated with STAN can be used to easily demonstrate processes, making complex relations accessible to a wide audience, including stakeholders and politicians. Premise for this access is a developer who comprehends reality, making it accessible with help of STAN.

To conclude, each software has its advantages and disadvantages in specific fields of application. However, combination of both turned out to be very promising for development of a holistic water and copper balance. UVQ is easy to use and does not need a highly qualified operator, however gathering of necessary input data is crucial, which makes this software ideal for the field of planning. STAN requires deep comprehension of the subject, in return it rewards the user with understandable illustrations, which can be used to explain complex contents to a wide audience. Hence STAN should be utilised in various areas of research and implementation.

Some examples of the application of STAN can be found in studies of the Institute of Water Quality, Resources and Waste Management of the Vienna University of Technology, such as “Identification of copper sources and pathways entering railway track ballast” (Müller, Schöller et al. 2008) or as part of the research project SCUDE (Sinks as constraints of Urban Development), which is led by O.Univ.Prof. Dipl.-Ing. Dr.rer.nat. Paul H. Brunner.

6.3 Future Prospects

Results show that the ratio of wastewater forwarded to the wastewater treatment plant is very satisfying, indicating no difficulties for wastewater treatment in future, even under circumstances such as climate change and population growth due to urbanisation and immigration. This finding should not encourage stakeholders to neglect the field of Water Management, it proves that decisions made in the past were necessary and correct and that further development and research in the field of Water Management is absolutely essential for a bright future of Vienna as a modern urban agglomeration.

Chapter 5.2.2 and 5.2.3 already offered some suggestions and recommendations for improvement, this chapter will give further hints especially for future research fields.

Quite a few challenges were faced during development of a suitable model. A lack of data for both, water and copper, caused difficulties for approximation of parameters, leaving no other choice than making assumptions based on literature values or estimations. Still, the goals of this thesis were achieved.
The lack of data leads to the first suggestion, the improvement of available data for water and copper in Vienna. More detailed measurements concerning soil data, wastewater volumes of specific wastewater producers and public available sewer network data would enhance the level of detail in future studies.

Due to the focus on water, this thesis does not deal with processes of copper in soil. According to Pfleiderer (2013) from the Geological Survey of Austria, soil in Vienna still retains Cu. But it is not known for how long this state will sustain and which quantity of copper enters soil annually. This field is identified to be worth of future investigations due to its possible impact on groundwater. Currently, promising research in this direction was conducted by Kral, Lin et al. (2013).

Another future option is to further increase the level of detail of the water balance. It would be interesting to investigate the sources of waste water in each district in detail and to identify major contributors to waste water for every single district in Vienna. A combination of these results would then draw an entirely advanced picture of the water balance of Vienna and has the potential to trigger development of more specific measures in waste water mitigation and prevention.

Spillway water volume and the flow “Industrial Wastewater” are calculated by simple balancing in this thesis. A detailed research of these flows would enhance knowledge about actual untreated waste water leaving the sewer network on one hand and increase knowledge about waste water composition and variability on the other hand. Knowledge of these components would improve waste water management and research in this direction may even cause new directives.

The most important conclusion learned in this thesis is the fact that each new development and improvement in the field of urban system research will cause new questions and with each answered question, life in the cities of the world will be more liveable.

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8. Figures

Figure 3-1 water balance Vienna 1991 7

Figure 3-2 Flow Chart of the ABIMO model (www.stadtentwicklung.berlin.de, accessed 17.04.2013) 13

Figure 3-3 Result of STAN, a graphical illustration of “Demonstrative MFA System” 25

Figure 4-1 Districts of Vienna (Lebhart 2012), modified by Author 26

Figure 4-2 Hydrogeology of Vienna (MA45 (2008), cited by Grimm (2010)), translated by Author 27

Figure 4-3 Geological Map of Vienna (MA29 2003), translated by Author 28

Figure 4-4 Water supply network of Vienna (MA31, cited by (Hlavac 2009)), partially translated by Author 29

Figure 4-5 Arrangement of Neighbourhoods in UVQ 30

Figure 4-6 UVQ User Interface – on the left side in vertical formation are the input screens 32

Figure 4-7 Spatial Distribution of Neighbourhood 23 or District 11 of Vienna (Lebhart 2012) 36

Figure 4-8 Aquifers in Vienna (MA 45 – Wiener Gewässer: Wasserwirtschaftsbericht Wien 2008. Magistrat der Stadt Wien. Wien 2008 cited by Grimm (2010)) 42

Figure 4-9 Sewer network Vienna (Wien_Kanal 2013) 43

Figure 4-10 Areal division of neighbourhood 23 54

Figure 4-11 Comparison of Emissions within Vienna – loads in g per capita and year (Obernosterer, Reiner et al. 2003), translated by Author 57

Figure 4-12 Soil types surrounding Vienna (eBOD 2006), translated by Author 59

Figure 4-13 Available Field Capacity in the Vienna Region (eBOD 2006), translated by Author 59

Figure 4-14 Geological Map of Vienna (MA29 2003), translated by Author 60

Figure 4-15 Hydraulic Conductivity in the Vienna Region (eBOD 2006), translated by Author 60

Figure 4-16 STAN Model Stage 2 generic model setup 63

Figure 4-17 Land use in Vienna 67

Figure 4-18 Water Supply Vienna 2008 (Sailer 2009) 72

Figure 4-19 Areal Distribution of Vienna 81

Figure 4-20 Distribution of copper in the central wastewater treatment plant 83

Figure 5-1 Comparison of observed and simulated water volumes and contaminant loads, Stage 1 86

Figure 5-2 Hydrographs of major export and import flows from Table 5.3 in comparison 88

Figure 5-3 Comparison of observed and simulated water volumes and contaminant loads, Stage 2 89

Figure 5-4 Source of copper for Neighbourhood 1 – Neighbourhood Stormwater Output 92

Figure 5-5 Source of copper for Neighbourhood 7 – Neighbourhood Stormwater Output 92

Figure 5-6 Result of STAN model stage 1 simulating the urban water balance of Vienna 95

Figure 5-7 STAN Model Stage 2 water balance – flows are given in m³/a 96

Figure 5-8 Distribution of Precipitation between redirecting flows 98

Figure 5-9 Distribution of urban surface runoff 98
Figure 5-10 Distribution of waste water generated by Consumers 99
Figure 5-11 Distribution of waste water flows generated by Private Households 99
Figure 5-12 Composition of water in the sewer system 100
Figure 5-13 Redirection of sewer system volume flow 100
Figure 5-14 STAN Model Stage 2 copper balance, flows in t/a 103
Figure 5-15 Sources of copper import to the copper model in STAN 104
Figure 5-16 Distribution of total copper in urban surface runoff 105
Figure 5-17 Distribution of copper load in Consumer wastewater 106
Figure 5-18 Private Household Cu-loads of UVQ and STAN in comparison – STAN also includes copper originating from tourism, industry and trade in private households, which is not pictured, hence total Cu of households in UVQ is larger than in STAN. 106
Figure 5-19 Sources of Cu in wastewater 107
Figure 5-20 Distribution of copper load exiting the sewer system 107
Figure 5-21 Distribution of wastewater treatment plant copper leaving the system 108
Figure 5-22 Export flows of total copper in the sewer system 108
Figure 6-1 Sinks of copper in the urban water system of Vienna 111
Figure 6-2 Distribution of Final Cu-Sinks, if processes following the wastewater treatment plant are taken into account as well. 112
Figure 6-3 Final Cu-Sinks as columns representing the copper-load each sink takes 112

9. Tables

Table 3.1 First water balance of Vienna by Maier (1995) 6

Table 3.2 Long-term mean values of runoff formation 14

Table 3.3 Previous studies outside of Australia utilizing UVQ 21

Table 4.1 Project Information for Stage 1 33

Table 4.2 Physical Characteristics for Stage 1 – the comment-points can be found below the table 33

Table 4.3 Reference values of household-wastewater-loads and atmospheric deposition ZESSNER (1999; cited by Rebernig (2007)) 38

Table 4.4 Event Mean concentration for road and roof runoff by Gnecco, Berretta et al. (2005)38

Table 4.5 Calibration Variables for Stage 1 – the comment-points can be found below the table 39

Table 4.6 Snow Variables for Stage 1 – the comment-points can be found below the table 44

Table 4.7 Land Block Water Management Parameters for Stage 1 – an explanation is given below the table 45

Table 4.8 Neighbourhood Water Management Parameters for Stage 1 – an explanation is given below the table 46

Table 4.9 Neighbourhood Water Management Parameters for Stage 1 – an explanation is given below the table 48

Table 4.10 Assignment of Neighbourhoods to Climate Stations 49

Table 4.11 Comparison of official and calculated precipitation values 50

Table 4.12 Revised Parameters of Project Information 52

Table 4.13 Revised Parameters of Physical Characteristics 52

Table 4.14 Revised Parameters of Calibration Variables 58

Table 4.15 Average emissions in µg/vehicle*km 74

Table 5.1 Annual water balance of UVQ Model Stage 1 – Imports and exports/sinks are balanced. The neglectable difference of sums occurs due to rounding errors. 85

Table 5.2 Wastewater flow and waterborne copper load reaching the wastewater treatment plant for the entire study area in Stage 1 85

Table 5.3 Annual water balance of UVQ Model Stage 2 – Imports and exports/sinks are balanced. The neglectable difference of sums occurs due to rounding errors. 87

Table 5.4 Wastewater flow and waterborne copper load reaching the wastewater treatment plant for the entire study area in Stage 2 87

Table 5.5 Simulated copper loads of specific flows for the entire study area in UVQ Model Stage 2 91

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