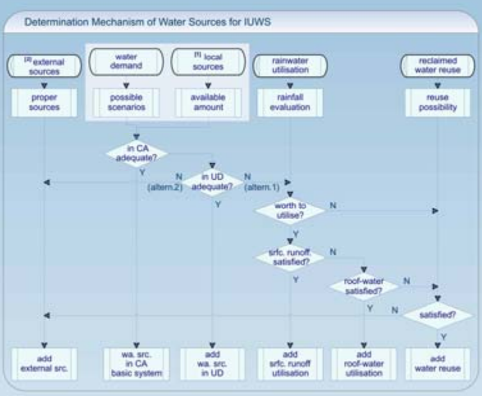
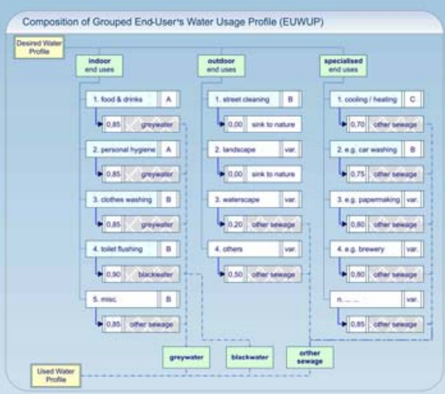
Hamburger Berichte zur Siedlungswasserwirtschaft

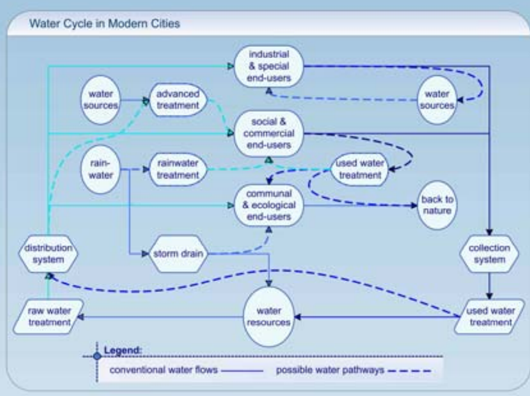
68

Yucheng Feng

New Conception and Decision Support Model for Integrated Urban Water System







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Band 68

Contents

TABLES IV

FIGURES VI

ABBREVIATIONS VIII

DEFINITIONS IX

ABSTRACT XI

CHAPTER 1 GENERAL INTRODUCTION 1

1.1 Urban water systems 1
1.1.1 Conventional concepts 2
1.1.2 New developing trends 3

1.2 Decision support systems (DSS) 4
1.2.1 General overview 4
1.2.2 Application to urban water systems 6

1.3 Scope of the research 7
1.3.1 Research objectives 7
1.3.2 System Boundaries 7
1.3.3 Application fields 7

CHAPTER 2 NEW CONCEPTION 9

2.1 Fundamentals of modern urban water systems 9
2.1.1 Water cycle in cities 9
2.1.2 Composition of water system 10
2.1.3 Hierarchy of urban water system 11
2.1.4 Essential components 12
2.1.4.1 water quality 13
2.1.4.2 intake and treatment facilities 17
2.1.4.3 conveying system 23
2.1.4.4 water fixtures 24

2.2 Subsystems 24
2.2.1 Water usage 25
2.2.1.1 water end-user 25
2.2.1.2 end-user’s water usage profile (EUWUP) 26

2.2.1.3 estimation 28
2.2.2 Water sources 29
2.2.2.1 categorisation 29
2.2.2.2 planning process 31
2.2.3 Desired water supply 32
2.2.3.1 options 32
2.2.3.2 planning process 33
2.2.4 Used water management 34
2.2.4.1 options 34
2.2.4.2 planning process 36
2.2.5 Rainwater utilisation 38
2.2.5.1 options 38
2.2.5.2 planning process 39

2.3 Integrated Urban Water System (IUWS) 41
2.3.1 Options 41
2.3.2 Planning processes 45
2.3.3 Demonstration 46

CHAPTER 3 DECISION SUPPORT MODEL (IUWS-DSM) 49

3.1 Architecture of IUWS-DSM 49

3.2 Planning procedure for water entities 50
3.2.1 General procedure 51
3.2.2 Planning of water entity of GROUP type 53
3.2.3 Planning of water entity of ZONE type 54

3.3 Decision making policies 55
3.3.1 Water sources 56
3.3.2 Water supply 58
3.3.3 Used water and rainwater collection 65
3.3.4 Used water 68
3.3.5 Rainwater 69

3.4 System evaluation 71
3.4.1 System sizes 71
3.4.2 Cost estimation 72
3.4.2.1 general methods 72
3.4.2.2 intake and treatment facilities 75
3.4.2.3 conveying system 75
3.4.3 Energy assessment 77

3.5 Option comparison 79
3.5.1 Water usage 80
3.5.2 Water infrastructure 83

3.6 Realisation Method in Software ... 86
3.6.1 Concepts ... 86
3.6.2 Model engine ... 87
3.6.3 Database ... 87

CHAPTER 4 DISCUSSION AND CONCLUSION ... 89

4.1 New conception ... 89

4.2 Decision support model (IUWS-DSM) ... 91

4.3 Uncertainty of urban water systems ... 92

4.4 Improvement of the IUWS-DSM ... 93

4.5 Prospect of further research for IUWSs ... 94

CHAPTER 5 SUMMARY ... 95

REFERENCES ... 99

APPENDICES ... 107

Appendix 1 Tables built up in database ... 107
Appendix 1.1 Water entities ... 107
Appendix 1.2 Water sources ... 108
Appendix 1.3 Treatment facilities ... 108
Appendix 1.4 Conveying system ... 109
Appendix 1.5 EUWUP ... 110
Appendix 1.6 Water standards ... 113

Appendix 2 Case study ... 114
Appendix 2.1 Basic information ... 114
Appendix 2.1.1 introduction to the city ... 114
Appendix 2.1.2 study area ... 114
Appendix 2.2 System planning ... 115
Appendix 2.3 System analyses and discussion ... 117
Appendix 2.4 Planning maps and calculation tables ... 119

CURRICULUM VITAE ... 146

Tables

Table 1: Rainwater quality in different streams (with secondary treated sewage for comparison) 14

Table 2: Categorisation of desired water quality....... 15

Table 3: Quality comparison of greywater and urban sewage....... 16

Table 4: Classification of the inflow of water treatment facilities....... 19

Table 5: Classification of water treatment steps....... 20

Table 6: Summation of common disinfection methods....... 21

Table 7: Classification of solids/sludge treatment steps....... 22

Table 8: Possible source water qualities and their applicability....... 32

Table 9: System options of desired water system....... 34

Table 10: System options of used water – WATER....... 37

Table 11: System options of used water – MATTER....... 37

Table 12: System options of rainwater water – Surface runoff management....... 40

Table 13: System options of rainwater water – Roof-water utilisation....... 40

Table 14: System types of water entities in IUWS....... 41

Table 15: General matrix for calculating cost and energy consumption of water entity....... 42

Table 16: Matrix for calculating cost and energy consumption of CA....... 43

Table 17: Matrix for calculating cost and energy consumption of UD....... 44

Table 18: Matrix for calculating cost and energy consumption of WUU....... 45

Table 19: Priority of water sources based on the type of water entity....... 57

Table 20: Rules for determining the type of distribution systems....... 59

Table 21: Water supply options for CA – with SINGLE system....... 60

Table 22: Water supply options for UD – with SINGLE system....... 61

Table 23: Water supply options for UD – with DUAL system....... 61

Table 24: Water supply options for WUU – with SINGLE system....... 63

Table 25: Water supply options for WUU – with DUAL system....... 63

Table 26: Possible collection systems and their general priorities....... 66

Table 27: General rules for determining collection system....... 67

Table 28: System options and general priorities of used water....... 68

Table 29: System options and general priorities of surface runoff management....... 70

Table 30: Evaluation of pipe assets based on statistical data (as pattern)....... 71

Table 31: Table of cost functions (or coefficients) for different treatment steps (as pattern)....... 75

Table 32: Sheet of average pipe costs based on pipe diameters (as pattern) 76
Table 33: Option comparison – within water entities 84
Table 34: Option comparison – crossing levels 85
Table 35: Example projects of IUWSs 91
Table 36: Uncertainty of water usage along with city vicissitudes 93

Appendix.Table 1: Information of urban planning – for water entity of ZONE type (CA and UD) 107
Appendix.Table 2: Information of urban planning – for water entity of GROUP type (WUU and WUC) 107
Appendix.Table 3: Information of water resources 108
Appendix.Table 4: Information of treatment trains 108
Appendix.Table 5: Information of package plants 108
Appendix.Table 6: Information of pipes 109
Appendix.Table 7: Information of ancillary works 109
Appendix.Table 8: Information of the detailed EUWUP 110
Appendix.Table 9: Summation of the detailed EUWUP 112
Appendix.Table 10: General information of water standards 113
Appendix.Table 11: Controlled parameters and values of water standards 113
Appendix.Table 12: Basic information of CA and UDs 123
Appendix.Table 13: Basic information of WUUs and WUCs 123
Appendix.Table 14: Water demands and water sources of WUCs 130
Appendix.Table 15: Water demands and water sources of WUUs 138
Appendix.Table 16: Used water amounts of WUUs 140
Appendix.Table 17: Determination of the water system for WUUs (Scenario 1) 142
Appendix.Table 18: Water demands and water sources of CA and UDs 144
Appendix.Table 19: Used water amounts of CA and UDs 144
Appendix.Table 20: General end-user’s water usage profiles (general EUWUPs) 145

Figures

Figure 1: Evaluation of global water use – withdrawal and consumption by sector (UNESCO 1999) 1
Figure 2: The evolution of the DSS field (Arnott and Pervan, 2005) 5
Figure 3: Basic architecture for decision support systems (Holsapple 2008) 6
Figure 4: Water cycle in modern cities 10
Figure 5: Composition of modern urban water system 11
Figure 6: Hierarchy of the urban water system (demonstration) 12
Figure 7: Relationship between different types of water quality 13
Figure 8: Characteristics of domestic wastewater with no dilution for faeces and urine (Otterpohl *at al.* 2004) 17
Figure 9: Classification of urban water treatment processes 19
Figure 10: Flow schema of typical blackwater treatment (redrawn based on IAP) 22
Figure 11: Structure and process for determining subsystem options 25
Figure 12: Categorisation of grouped water end-users 26
Figure 13: Composition of grouped end-user's water usage profile (EUWUP) 27
Figure 14: Demonstration for the water usage of one WUU 28
Figure 15: Process for estimating water usage 29
Figure 16: Possible urban water sources and their classification 30
Figure 17: General priority of water sources 31
Figure 18: Process for planning water sources 31
Figure 19: Process for planning desired water system 33
Figure 20: Process for planning used water system 36
Figure 21: Process for planning rainwater system 39
Figure 22: Planning procedure for IUWS 46
Figure 23: Demonstration of the integrated urban water system (IUWS) 47
Figure 24: Architecture of the decision support model (IUWS-DSM) 50
Figure 25: General planning procedure for water entities 51
Figure 26: Planning procedure for water entities of type CA and UD 54
Figure 27: Systematic schemma of decision making process 56
Figure 28: Determination mechanism of water sources for IUWS 58
Figure 29: Matrix for determining the type of distribution systems 59
Figure 30: Decision making mechanism for collection system 65

Figure 31: Cost estimation methods for urban water infrastructure 74

Figure 32: Distribution of energy consumption in a waterworks (HDR 2001) and a WWTP (Metcalf & Eddy 2003)...77

Figure 33: Assessment methods of energy consumption for urban water infrastructure 78

Figure 34: Distribution of O&M costs in a typical waterworks and WWTP (Carns 2005)......79

Figure 35: Water usage of WUU (demonstration)..80

Figure 36: Water usage of UD (demonstration) 81

Figure 37: Water usage of CA (demonstration) 82

Figure 38: Strategic view of total water demand vs. water sources in IUWS (demonstration) 83

Figure 39: System architecture of the software (IUWS-DSM)..86

Figure 40: Structure of Database in the Software 87

Figure 41: Systematic structure of the Dissertation 96

Appendix.Figure 1: The detailed EUWUP (demonstration) 111

Appendix.Figure 2: Summation of the EUWUP (demonstration).......................................112

Appendix.Figure 3: Water usage of UDs 118

Appendix.Figure 4: Water usage of CA 119

Appendix.Figure 5: Water balance between demands and sources.................................119

Appendix.Figure 6: Total planned Luqiao area in Taizhou city (lang-range plan).............120

Appendix.Figure 7: Case study area in Luqiao with the division of WUUs 121

Appendix.Figure 8: 3-D map of the case study area..122

Abbreviations

BOD	Biochemical Oxygen Demand
CA	City Area
CCI	Construction Cost Index
DSM	Decision Support Model
DSS	Decision support systems
EcoSan	Ecological Sanitation
Eq.	Equation
EU	European Union
EUWUP	End-user’s Water Usage Profile
GIS	Geological Information System
IUWS	Integrated Urban Water System
IUWS-DSM	Integrated Urban Water System - Decision Support Model
IS	Information Systems
NTU	Nephelometric Turbidity Units
O&M	Operation and Maintenance
PPI	Producer Price Index
SS	Suspended Solids
SSCS	Source Separated Collection System
UD	Urban District
WIS	Water Infrastructure System
WUU	Water Utilisation Unit
WUC	Water Utilisation Cell
WWTP	Wastewater Treatment Plant

Notice: following the German Standards, in this dissertation the comma “,” is used as the decimal separator, where the period “.” is used as the digit group separator.

Definitions

term	definition & explanation
blackwater	flushing water from toilets
brownwater	faeces with flushing water but without mixing with urine
City Area (CA)	represents the whole urban water system or one absolute independent water system in urban area, which is going to be the final IUWS.
construction cost index (CCI) [1]	a business cycle indicator showing the evolution of costs incurred by the contractor to carry out the construction process
Conveying system	water transport media including water transmission, distribution, sewer, storm drain, and their ancillary works
desired water	water has the quality satisfying the requirements of end uses.
direct non-potable reuse	pipe-to-pipe to reuse the reclaimed water for non-drinking purpose. If it is possible to be contacted by human beings, it must be hygienic safe.
dual water system	consists of dual separate mains (pipelines from separate sources) and designed to concurrently provide two separate water supplies to the consumer. One main conveys drinking (potable) water, the other conveys appropriately treated non-drinking water (WSA 2002).
end-user's water usage profile (EUWUP)	each type of water end-user has specified and standardised information of water usage including water demand with required water qualities and used water amounts from different streams.
greywater	the used water coming from household activities other than toilets
indirect potable reuse	after being buffered in nature for certain period, the reclaimed water is used as raw water supply.
producer price index (PPI) [2]	a family of indexes that measures the average change over time in the selling prices received by domestic producers of goods and services
raw water	directly coming from the nature, such as surface water, groundwater and rainwater
roof-water	rainfall that is gathered from roofs of buildings
sewage	used to substitute for *wastewater* in the context
source separated collection system (SSCS)	the different used water streams from domestic activities are collected separately, whereby greywater and blackwater (or brown water + urine) are formed.
reclaimed water	treated wastewater that meets certain water standards or satisfy the quality requirements of water end-users

[1] http://europa.eu.int/estatref/info/sdds/en/ebt/ebt_cons_pri_sm.htm (Statistical Office of the European Communities)

[2] http://www.bls.gov/ppi/ppifaq.htm#1 (U.S. Department of Labor)

term	definition & explanation
Urban District (UD)	the city area is divided into certain small sections, whereby each section has its independent water entity that is defined as *Urban District*.
used water	corresponding to the conventional term “wastewater”, involving different types of urban sewage
water end use	the final water use, or the place that water leaves the distribution system, e.g. toilet flushing, laboratory
water end-user	grouped water consumer, e.g. university, hospital
water entity of GROUP type	holds the grouped water end-users that form the functional units of cities. It includes WUU and WUC.
water entity of ZONE type	is planned and designed in the holistic perspective based on the area. It includes CA and UD.
water infrastructure system (WIS)	including all kinds of urban infrastructure for water intake, water treatment and water conveying
water subsystem	in conception of the IUWS, several subsystems are built up, i.e. water usage, water sources, desired water system, used water system, and rainwater system, which are finally constructed together as one IUWS.
water usage	contains the water information of water end-users, including water demands associated with required water qualities, and used water amounts with their water qualities.
water usage scenario	water end-user can have different water usages profiles, which results in different kinds of water usage, and they are named as the water usage scenarios.
Water Utilisation Unit (WUU)	in general, it is the certain functional unit in cities and consequently, its water system can be managed and coordinated within one entity.
Water Utilisation Cell (WUC)	It has the same structure as WUU but on a small scale that mostly focuses on the single big buildings or mono water end-users.

Abstract

Traditionally, water supply, wastewater disposal, and rainwater elimination systems are three separate systems in cities. It has been realised that urban water systems must be planned, designed, and managed as one integrated urban water system (IUWS). As the emerging direction of development, there is still a lack of conception, models and experiences to consider and deal with IUWSs. Therefore, this research conceives the new thoughts and methods for IUWSs. The urban water system is structured into a four-level hierarchy. Water end-users and their water usage profiles are re-defined in the hierarchy. As two key elements, rainwater utlisation and water reuse are integrated. A special planning procedure for IUWS is developed based on the hierarchical system. Consequently, the decision support model IUWS-DSM is developed as a planning tool for IUWSs in the early project phase. Then, a method to realise the IUWS-DSM in the software is proposed.

Keywords: urban water cycle, hierarchy, water entity, water usage, water infrastructure

Traditionell sind Wasserversorgung, Abwasserentsorgung und Regenwasserbeseiti-gung drei getrennte Systeme im urbanen Raum. Es ist erkannt worden, dass Wasser- und Abwassersysteme in der Stadt als ein integriertes urbanes Wassersystem (IUWS) geplant, entworfen und betrieben werden müssen. Noch immer gibt es zu wenig Konzepte, Modelle und Erfahrungenzu IUWSe. Daher schlägt diese Forschungsarbeit neue Ansätze und Methoden für IUWSe for. Das städtische Wassersystem wurde in vierStufen unterteilt, die Wasser-Endbenutzer und ihre Wasserverbrauchsprofile wurden neu definiert und als zwei Schlüsselelemente werden die Regenwassernutzung und die Wasserwiederverwendung in diese Hierarchieintegriert. Ein spezielles Planungsverfahren für die IUWSe wurde auf der Basis des hierarchischen Systems entwickelt. Darauf aufbauend wurde ein Prototyp für das entsprechende Entscheidungsfindungssystem IUWS-DSM entwickelt, das für die Planung des IUWSs in der frühen Projektphase vorgesehen ist. Abschließend wird eine Methode vorgeschlagen, um das IUWs-DSM als Software zu realisieren.

Schlagwörter: städtischer Wasserkreis, Hierarchie, Wasserentität, Wasserverwendung, Wasserinfrastruktur

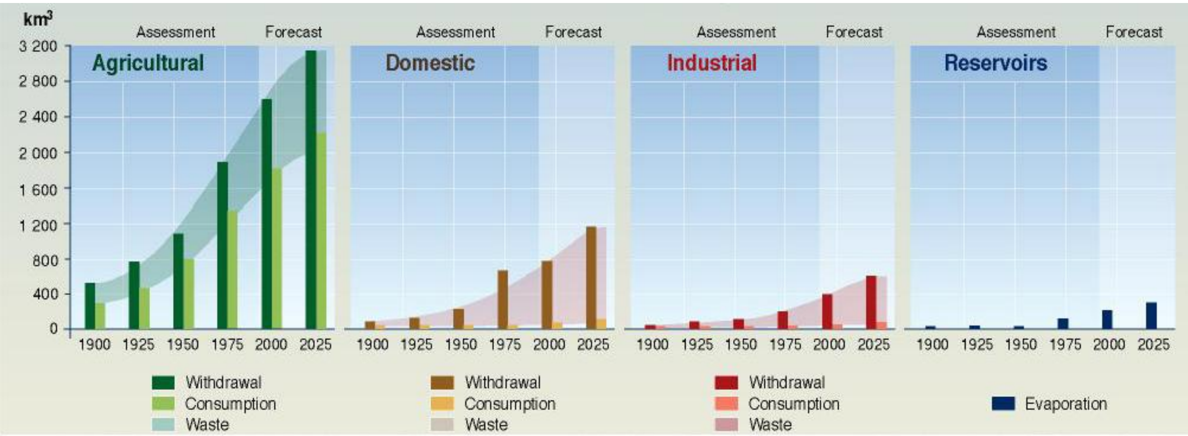
Chapter 1 General Introduction

The water scarcity is becoming the global issue. Meantime, the situation is getting worse caused by many reasons, especially by population explosion, industrialisation and urbanisation, as well as the climate change. This chapter draws the general overview of current urban water systems, shows the development trend of urban water systems, and gives a short introduction to the decision support systems. Subsequently, the scope and objectives of this research work are presented.

1.1 Urban water systems

Along the development of human beings' society, more and more people are going to live in cities. The world urban population had reached 3,15 billion as 48,7% of the global population in 2005, and till 2030 this will increase to 4,91 billion as 59,9% of the total population (UN 2006). As the highly condensed settlement areas, modern cities are the complicated giant aggregate with miscellaneous functions.

The water, as the essentials of life, must be fully and safely supplied in modern cities. It has been clearly realised that fresh water is the limited resource. It is even predicted by the World Meteorological Organisation that our water resources will be rapidly depleted by the explosive growth of cities (Obasi 1997). Figure 1 pictures an overview of worldwide water use based on the sectors. Clearly, water use in all sectors is dramatically increasing till 2025. The very low use efficiency in domestic and industrial sectors is constently kept that is the serious problem.



Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational,Scientific and Cultural Organisation (UNESCO, Paris), 1999.

Figure 1: Evaluation of global water use – withdrawal and consumption by sector (UNESCO 1999)

Standing at the crossroads of the new millennium, we have to find out the appropriate and sustainable solutions to resolve our overall water crisis.

1.1.1 Conventional concepts

Aiming to satisfy the demands of water consumers and maintain a proper water environment in the meantime, urban water systems generally involve three systems, water supply, wastewater disposal and rainwater elimination. Conventionally, three systems are planned, constructed and administrated individually. The water supply system consists of water intake, waterworks, and distribution networks. The wastewater system consists of sewage sewer and treatment plants. The rainwater system is mainly composed of storm drain, where certain processing facilities can be involved, if rainwater is heavily polluted. Besides, there are ancillary works, such as pumping stations in both distribution and collection systems.

Today's urban water supply and wastewater disposal systems in most countries are based on the experience of the 19th century in Europe (Eiswirth 2000), which have the main goals of safely supplying clean water, disposing wastewater, and simultaneously preventing waterborne diseases. Urban water systems enlarged step by step along with the expansion of cities. The centralised systems of both water supply and wastewater disposal are therefore formed, which means the water is treated centralised to the highest required water quality and distributed to users by one set of networks, and the wastewater is collected together and transported to the centralised wastewater treatment plants (WWTP). Centralised systems have many advantages, such as simple system structure, easy construction and operation, etc. As they were born in Europe, i.e. the advanced developed area, and have century-long successful operation experience, the centralised water systems are adapted worldwide, and still act as the standard patterns of urban water system in many countries and regions.

Tracing back the history, engineers have different philosophies in different periods to deal with the wastewater, from direct discharge to end-pipe treatment till today's source separated collection systems (Hahn and Song 2006). Due to its flooding risks, rainwater is conventionally eliminated from urban area as soon as possible, which effects the large storm water drains. Meanwhile, both seen as unwanted water, the collection systems of rainwater and wastewater can be merged, whereby several forms of urban drainage are have several prevailing forms, i.e. combined, separate, and hybrid systems, etc. (Butler and Davies 2000). Combined and hybrid collection systems often occurs in old cities.

Nonetheless, such conventional urban water systems have many intrinsic deficiencies, such as high water consumption rate, low water use efficiency, and high environmental loads, etc. Currently, the water scarcity is becoming the problem in many regions of the world, where many man-made reasons exacerbate it, such as population explosion, industrialisation and urbanisation, as well as the climatic changes, etc. The conventional water systems are most often neither sustainable nor optimal systems. Therefore, the better solutions for our urban water systems are needed urgently.

1.1.2 New developing trends

Until the end of last century, our society realised that the earth cannot support us any longer if we keep the existing way of development. Consequently, the concept of *sustainable development* came up. Probably one of the most cited definition of sustainable development is from the Brundtland Commission as “*a development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (WCED 1987). The definition is ambiguous and non-operable as it is hard to define what the real needs of the present and it is impossible to know what the future needs. However, the idea is clear and correct, i.e. the world should not be exhausted for only satisfying the requirements of one or few generations. It needs to be sustainable based on our current knowledge and technology.

Several directions have been investigated and experimented in order to resolve the problems of water scarcity in urban area. Improving the efficiency of water fixtures is one of the simplest and most effective ways. Some countries like China (MOHURD 2002) even issue the national standards in order to progress the application of water saving fixtures.

Water demand management is another angle to manage and improve effectiveness and efficiency of urban water systems (Baumann *et al.* 1998). In the last two decades, water demand management has been extensively focused especially in the areas with water scarcity, such as Australia (e.g. White and Fane 2002), China (e.g. Chen *et al.* 2005), Greece (e.g. Kolokytha *et al.* 2002), Malawi (e.g. Mulwafu *et al.* 2003), and southern Africa (e.g. Gumbo 2004), etc. Different methods have been used for demand management as well, such as the artificial neural network (e.g. Liu *et al.* 2003), the least cost planning (e.g. Fane and Mitchell 2004), the multi-criteria decision analysis (e.g. Durga Rao 2005), and the genetic algorithm (e.g. Lavric *et al.* 2005), and so on. Certain models and software tools are developed, too, e.g. IWR-MAIN[1], IWCM[2].

Water reuse is the old new topic as it can be traced back to ancient time and it regained the huge attention in the last decades due to the water shortage in many regions of the world. Concepts and techniques of water reuse are extensively discussed and investigated. Water reuse is an indispensable part of modern urban water system, which is going to be also discussed and integrated into the model of this work later on.

The form of urban water systems is being investigated for decades, as well. Opposite the centralised systems, the decentralised water system has been trailed worldwide. Even semi-centralised systems come forth that has the medium-size. Nonetheless, due to their inherent limits, neither decentralised nor semi-centralised system can in all cases entirely substitute the conventional systems acting as the better solutions for urban water systems.

The ancient Chinese philosophy believes that everything on the earth is a cycle, so that the world can run endless. It also believes that the nature should be followed but not for being conquered. In ancient Chinese philosophy, there is no word of sustainable develop-

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[1] Camp Dresser & McKee (CDM), http://www.iwrmain.com/

[2] Department of Energy, Utilities and Sustainability, New South Wales, Australia, http://www.deus.nsw.gov.au/publications/publications.asp

ments, but it clearly points out how we could/should live in and with the nature. Such kinds of idea are now fully comprehended and represented in the concept of the sustainable development. Consequently, three separate water systems in the urban area, i.e. water supply, wastewater disposal and rainwater elimination, should be integrated together to complete the cycle.

The modelling of the urban water cycle can be traced back for several decades, early examples such as Graham (1976), Grimmond *et al.* (1986), and later ones like Wong *et al.* (2002). Niemczynowicz (1999) looked into the urban hydrological cycle holistically trying to reveal the future challenges in urban water management. As the urban water cycle is involving many elements and factors, more models were developed having different emphasis points. Icke *et al.* (1999) developed a mass balance model of water and phosphorus for evaluating the sustainability rate of the urban water cycle. Hellström *et al.* (2000) proposed a framework for analysis and comparison of urban water systems with respect to sustainability. Mitchell *et al.* (2001) developed the software called Aquacycle for modelling the daily hydrological cycle in cities considering water supply, wastewater disposal and storm water runoff all together. Mitchell and Diaper (2006) further extended and enhanced Aquacycle for simulating daily cycle of both water and contaminants flows in urban area by developing a new analysis tool called UVQ. With the tool of life cycle assessment, Lundin and Morrison (2002) developed an iterative procedure for the selection of environmental sustainability indicators for urban water systems. Van der Vleuten-Balkema (2003) developed a methodology for sustainability assessment of domestic water systems, including water supply, waster use, and wastewater treatment. Chanan and Woods (2006) introduced the total water cycle management in Sydney, which tried to approach to sustainable urban water management. Savic *et al.* (2008) developed the whole-life costing for the capital and operational management of water and wastewater networks.

So far there are no worldwide recognised and accepted conceptions or models for urban water systems, which can fulfil the requirements of sustainable development. Besides the difficulties from conceptual and technical sides, there are also risks and obstacles from many other aspects to innovate our urban water systems, such as economics, culture, tradition, religion, etc. All these inspire and encourage me to try out this research work.

1.2 Decision support systems (DSS)

1.2.1 General overview

Decision support systems (DSS) comprise a core subject area of the information systems (IS) discipline, being one of several major expansions that have occurred in the IS field (Springer 2008). DSS is defined by Sprague and Carlson (1982) as "*a class of information system that draws on transaction processing systems and interacts with the other parts of the overall information system to support the decision-making activities of managers and other knowledge workers in organizations*". Computerised DSS started practicing with the development of minicomputers, timeshare operating systems, and distributed competing since mid-1960s (Power 2008).

50 years of researches result in that many different scientific branches of DSS have been developed and crossed over. Arnott and Pervan (2005) traced the evolution of the DSS field from its radical beginnings to a complex disciplinary structure of partially connected subfields (Figure 2).

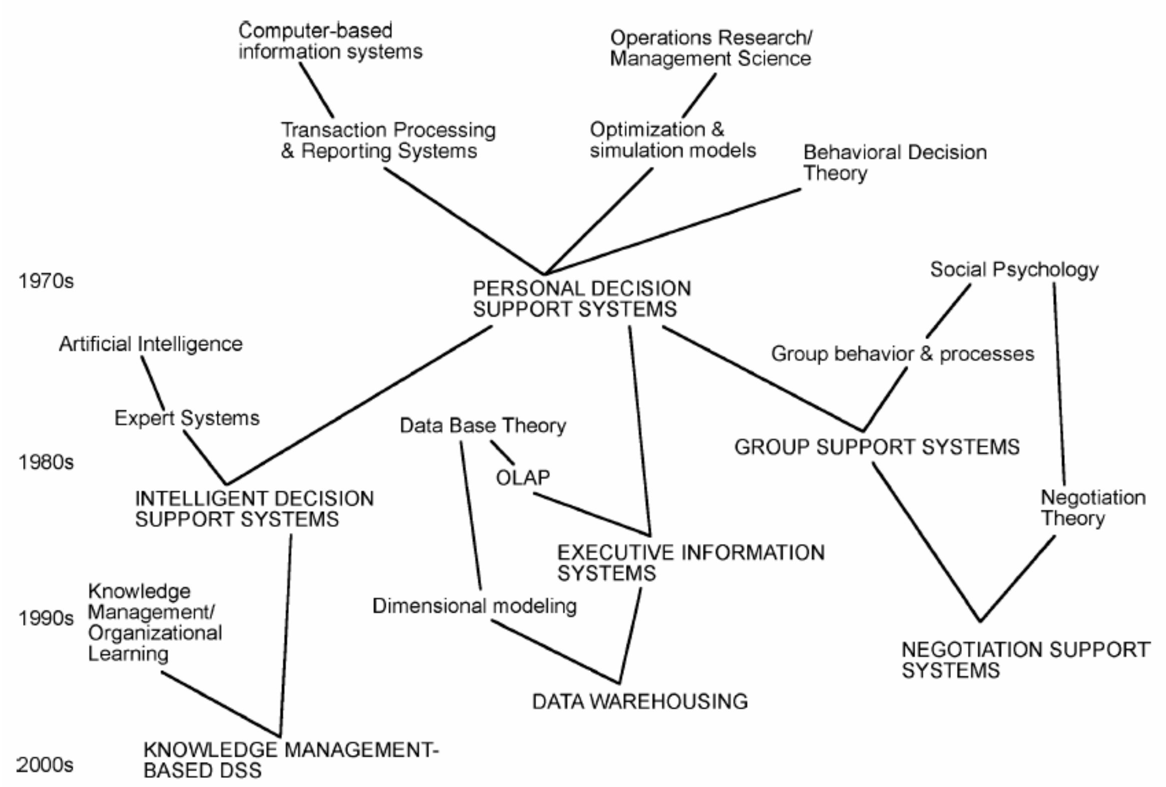

Figure 2: The evolution of the DSS field (Arnott and Pervan, 2005)

Power (2004) categorised DSS into five broad groups: communications-driven, data-driven, document-driven, knowledge-driven and model-driven decision support systems. Especially, model-driven DSS use limited data and parameters provided by decision makers to aid decision makers in analyzing a situation, but in general large data bases are not needed for model-driven DSS (Power 2002), so it is chosen for building up our model.

Regarding the generic architecture of DSS, Holsapple (2008) identified four essential components, i.e. *1*. language system, *2*. presentation system, *3*. knowledge system, and *4*. problem-processing system, which together structure the DSS. Subsequently, different types of DSS are derived (Figure 3).

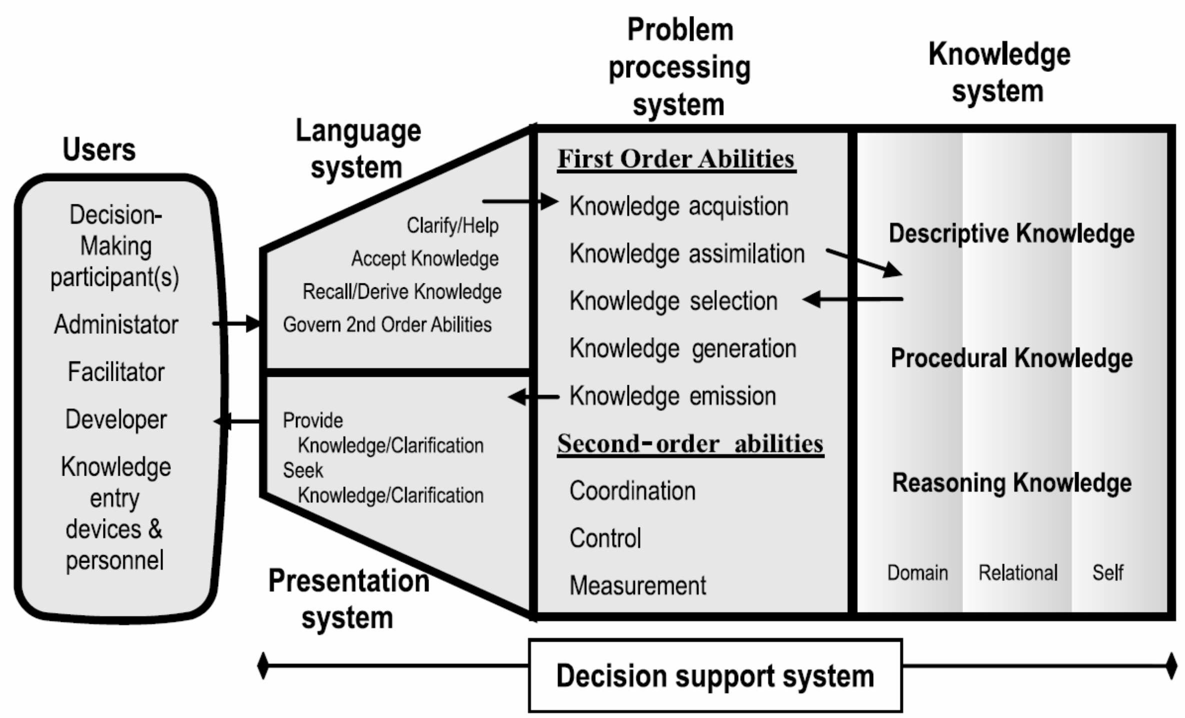

Figure 3: Basic architecture for decision support systems (Holsapple 2008)

1.2.2 Application to urban water systems

In the last two decades, DSS have been applied to the urban water systems more and more. Poch *et al.* (2003) reported that more than 600 references related to environmental DSS are found in scientific literature since the 1990s, where 25% is about water management, 11% is connected to risk assessment.

Initially, the focus lay on different branches, such as water demand prediction (e.g. An *et al.* 1996, Lertpalangsunti *et al.* 1999, Froukh 2001), water supply systems (e.g. Shepherd 1998, Davis 2000, Tillman *et al.* 2001), wastewater systems (e.g. Nemetz and Margolick 1984, Fenner and Sweeting 1999, Roda *et al.* 2000), and rainwater management (e.g. Kluck *et al.* 2005, Mbilinyi *et al.* 2005, Barraud *et al. 1999*). Later on, the water reuse was intensively in the focus, e.g. Ahmed *et al.* 2003, Dinesh and Dandy 2003, Sipala *et al.* 2003, Zhang 2004, and Joksimovic *et al.* 2006, etc.

Recently, the total urban water systems as a whole are paid attention to and the corresponding DSS are investigated and developed. Cheng *et al.* (2003) developed an expert system with the purpose of improving the urban water quality and enhancing urban environment management. Starkl and Brunner (2004) scrutinized the decision making procedures in urban water management considering both water supply and wastewater disposal systems. Focusing on the hazardous substances, Malmqvist and Palmquist (2005) created one decision support tool for urban water and wastewater systems. By comparison, the DSS for the total urban water systems are still rare, which further promotes this research work.

1.3 Scope of the research

1.3.1 Research objectives

This research work comprises three water systems, i.e. drinking water, wastewater and rainwater systems, into one integrated urban water system (IUWS) and subsequently, establishes a decision support model (DSM) that is specially for planning IUWS in the early project phase. Instead of generating concrete and absolute values, the model provides more orientation sense with appropriate comparison in selecting the sustainable and reasonable urban water systems. The model is designed for water consultants and city planers, as well as concerned authorities.

Cost is selected as the main criterion for evaluating the systems. Energy consumption is another independent and optional criterion for evaluating and comparing IUWS. Certainly, the energy consumption can be represented by the cost.

1.3.2 System Boundaries

Factually, the system boundaries equal to the boundaries of the object-city. If it is a megacity, like Hamburg, Shanghai and New York, it can be physically one independent district of the city. As the objective, water enters the system from the water intake and leaves the system after it is discharged into the natural water bodies. The natural processes, such as precipitation and evaporation, etc., are not included, as this work focuses on urban water usage and water infrastructure. Within the area of the object-city, water users, water sources, water infrastructure including water intake, treatment, transmission, distribution and collection facilities are considered.

1.3.3 Application fields

In urban area, two kinds of situation are usually confronted:

1. planning of a new water system,
2. expansion of an existing water system.

In the first situation, the new water system can be designed for the whole city, but more often, it is for the new spread urban districts that have no water infrastructure at all. The second situation can also include two different situations. The upgrade of the water system is either for the whole city or for certain district(s) only. Moreover, there can be the mixed conditions, i.e. the water systems needs to be planned for both the new spread districts and existing area simultaneously. All situations need to be properly dealt with.

Thereby, the new conception is conceived and created. The decision support model is subsequently developed, which is used to plan and design the IUWS in those different situations.

Chapter 2 New Conception

Based on the concept of water cycle, the urban water system is mapped by the hierarchy of four levels. The urban water end-users are defined as different types of the grouped users. Certain types of water end uses are categorised so that their required water quality can be identified. The desired water quality is therefore redefined. The treatment processes for both raw water and used water are classified into certain steps. Five subsystems are built up, i.e. water usage, water sources, desired water, used water and rainwater systems, which have individual structures, system otpions and planning processes. Eventually, all subsystems are constructed together as one IUWS.

2.1 Fundamentals of modern urban water systems

2.1.1 Water cycle in cities

Historically, the development of our urban water systems started from water transmission and distribution, followed by drinking water treatment, and then wastewater collection and discharge, followed by wastewater treatment, till wastewater reuse. It reveals that the faults and problems are recognised only when they already seriously impact on our daily life. More over, the problems are tried to resolve isolated. In a sustainable way, the urban water systems need to be looked at in a holistic view, whereby the water cycle needs to be properly completed relying on natural and artificial processes. Thereby, the water cycle is one of the headstones of this research.

Figure 4 shows the basic and possible components as well as the water pathways in modern urban water systems. Besides the traditional water systems, i.e. drinking water supply (left side in Figure 4), wastewater disposal (right side), and rainwater elimination (bottom area), more elements can be involved, such as on-site water advanced treatment, independent water sources, rainwater utilisation and wastewater reuse, etc. Obviously, the water cycle can occur in different locations with different system scales.

Considering this water cycle in modern cities, two sides can be formed, i.e. water usage side and water infrastructure side. The water usage side considers and organises the information of possible water demands, generated wastewater, available water sources, and the water qualities. The water demands and water sources are matched, whereby the water use is optimised. On the water infrastructure side, the urban infrastructure, including water intake, treatment facilities, transmission, distribution and collection, is planned and manage, so that the optimised water infrastructure system (WIS) is obtained, which fully satisfies the optimised water usage.

Especially, the term *Used Water* is used to substitute for *wastewater* in this report because the wastewater is not the waste anymore since it is used again. Meanwhile, *sewage* is used to indicate the conventional municipal wastewater.

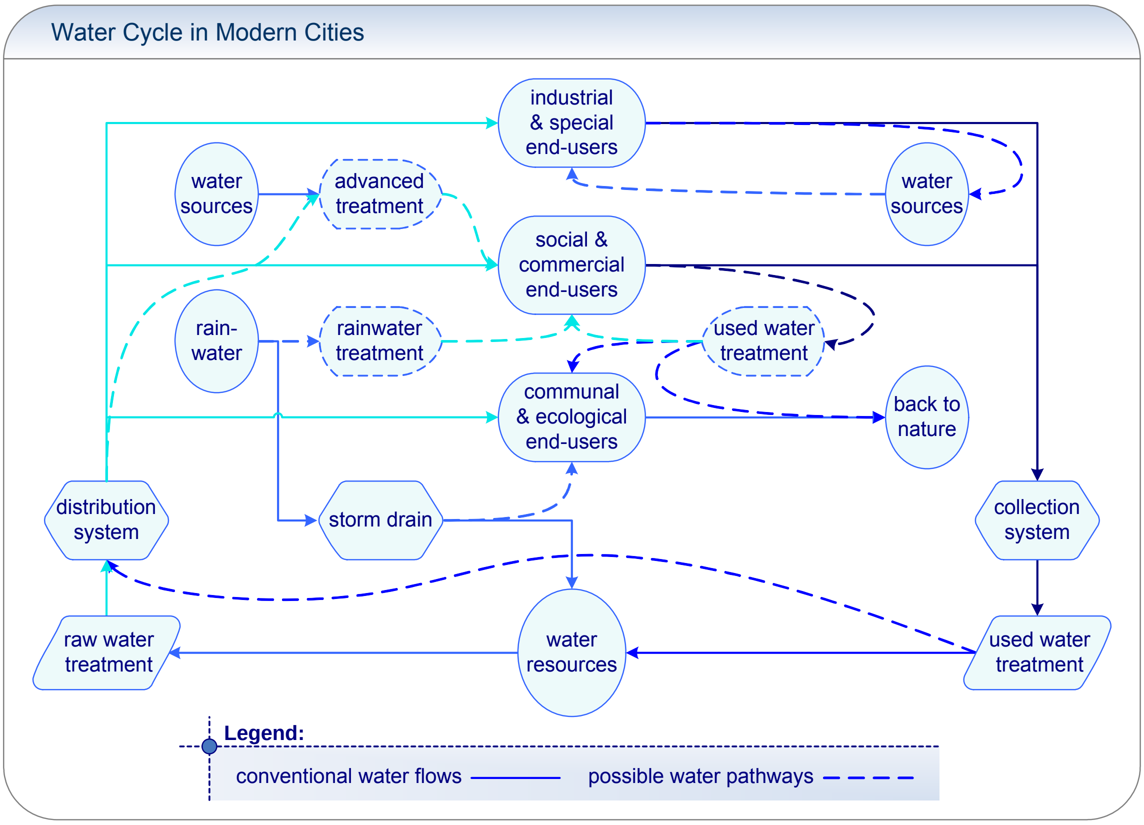

Figure 4: Water cycle in modern cities

2.1.2 Composition of water system

Consequently, several subsystems are constituted in the urban water system, i.e. water usage, water sources, desired water (see § 2.1.4.1 for definition), used water, and rainwater subsystems. Figure 5 depicts the interrelationships among the subsystems. The solid arrow lines represent the conventional water flow routine, where the dashed arrow lines show the possible water pathways in cities. The popular concepts of urban water systems are therewith involved, such as water reuse, and utilisation of rainwater. As independent but also related subsystems, each one can have their own system options and at the same time influences the related subsystems.

In order to introduce the new conception for the IUWS, in the following sections the structure of IUWS is established in the first, and then the essential components are defined. Afterwards, the subsystems are constructed. In the end, all elements are integrated together, whereby the IUWS is built up.

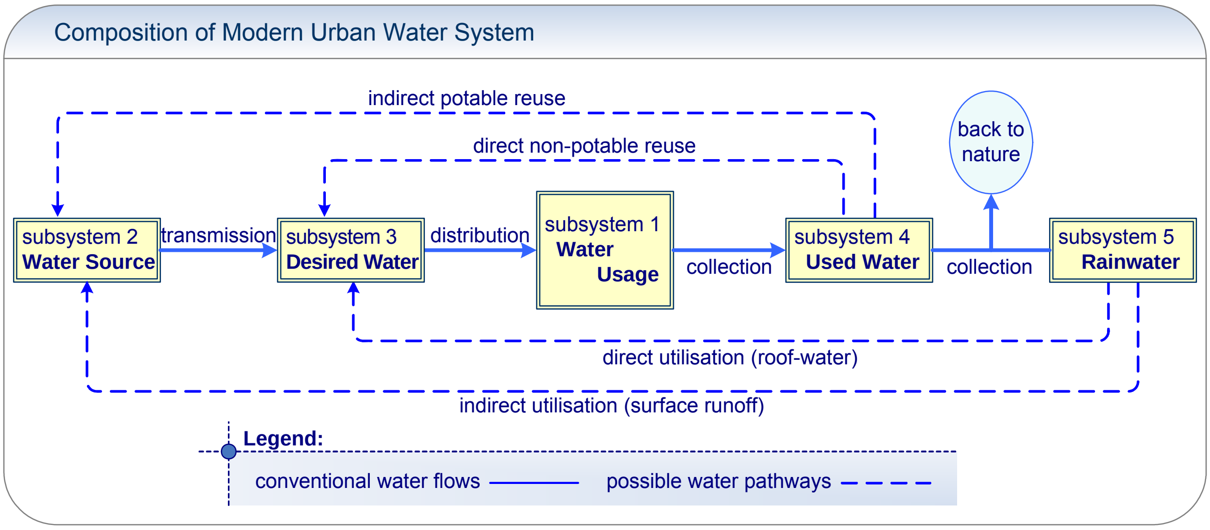

Figure 5: Composition of modern urban water system

2.1.3 Hierarchy of urban water system

In the last decades, there are extensive discussions about the forms of urban water systems. Typical argumentation is among centralised, de-centralised and semi-centralised water systems. Modern cities are the extremely complex aggregates, which usually cover big area with condensed large population, associated with multi-functions. Meantime, the water shortage caused by either the water sources or the capacity of water infrastructure is another ineluctable issue in cities. Therefore, the different design method is conceived.

The new conception structures the urban water system in the hierarchy. Based on the features and emphasises, the entire urban water system is divided into four levels consisting of two types of water entities, i.e. the *ZONE* type and the *GROUP* type (Figure 6). The water entity of ZONE type is planned and designed in the holistic perspective base on the area. It acts more as a container comprising other smaller but more detailed water entities. It stays in the upper levels of the hierarchy. The water entity of GROUP type holds the grouped water end-users that form the functional units of cities, such as hospitals, schools and shopping centres, as well as multifunctional skyscrapers, etc., whereby the grouped water end-users have specified and detailed water usage (more details in § 2.2.1.1). Regardless of the types, each water entity can be planned and managed as an independent unit in the hierarchy. The water entities in four levels are defined and explained as follows.

City Area (CA). It represents the whole urban water system or one absolute independent water system in urban area, which is going to be the final IUWS. It may not be equal to the total city area by its political meaning. This means it follows the natural status. In this level, its main tasks are to set up the whole water system, implement master planning, and generate directive information and strategic overview. Due to the large scale of CA, the plan of water systems is in a rough way, where many details and factors are skipt. In order to achieve a finer design, the second level in the hierarchy is constructed.

Urban District (UD). The city area is divided into certain small sections, whereby each section has its independent water entity that is defined as *Urban District*. It can coincide with administrative canton, but also can be the natural division. Potentially, it is quite appropriate for the municipal administration of water systems. UD is the container holding the water entities of GROUP type.

Water Utilisation Unit (WUU). It is the certain functional unit or group in cities and consequently, its water system can be managed and coordinated as one entity. For example, it can be one university or one hospital or two adjacent residential quarters. WUU covers certain area containing certain water end-users. The water uses with different requirements regarding quality and quantity are properly allocated and balanced within WUU.

Water Utilisation Cell (WUC). It has the same structure as WUU but on a small scale that mostly focuses on single large buildings or mono- water end-users. A typical example is a large building purely as a gastronomic centre, or a shopping mall. WUC is the subset and complement for WUU. For example, in one residential quarter (i.e. as a WUU), besides the household water demand as the main water consumption of WUU, there can be a shopping centre with significant water consumption, which is considered as the WUC. Another example is the university, which can contain several kinds of water end-users, like, cafeteria and sport centre, whose water usage can be calculated as individual WUCs.

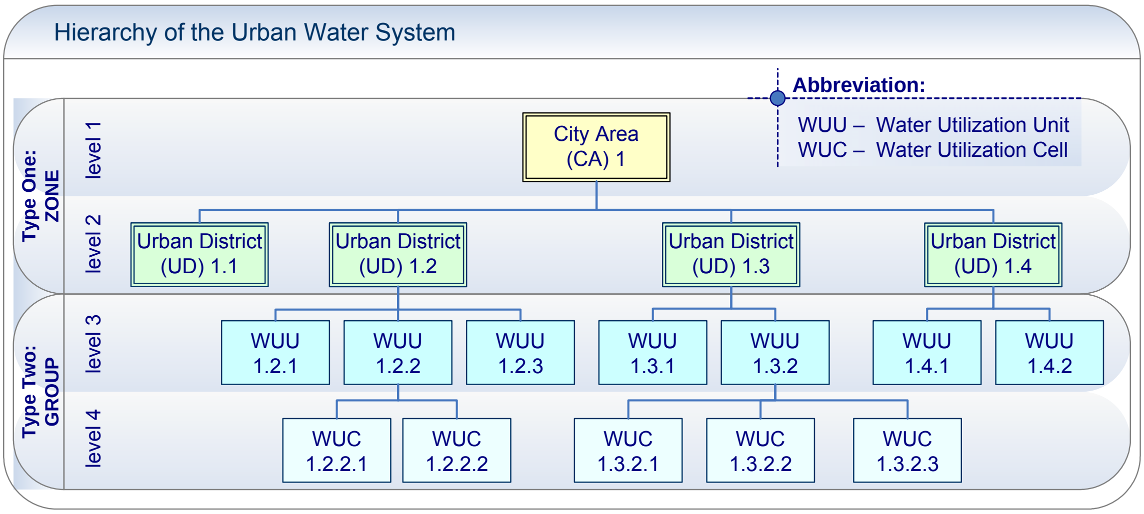

Figure 6: Hierarchy of the urban water system (demonstration)

Such a hierarchical structure is very flexible and versatile, which provides the chances to plan and manage urban water systems in different depths in various situations. As an integrated system consisting of many independent water entities, it allows to plan the water systems in blocks and steps, which can better cooperate with urban planning, and which is also closer to the actual development process of cities.

2.1.4 Essential components

Though urban water systems can be designed and managed in different ways, several essential components remain the same, i.e. water quality, water intake and treatment facilities, conveying system, and water fixtures. Working together they reach the targets of satisfying end-users and lowering fresh water and energy demands simultaneously. They are redefined based on the new conception of IUWS.

2.1.4.1 water quality

Due to the attributes and purposes, three sorts of water are classified, i.e. *Raw Water*, *Desired Water* and *Used Water*. Raw water refers to the water directly comes from the nature, such as surface water, groundwater and rainwater, etc. As mentioned above, *used water* is used to substitute for the conventional term “wastewater”, involving different types of urban sewage. Desired water has the quality that satisfies the requirements of the end uses. As an example, potable water is one type of desired water. Three sorts of water have certain types of quality that can be converted to each other through either treatments or uses. The relationships between water qualities are depicted in Figure 7.

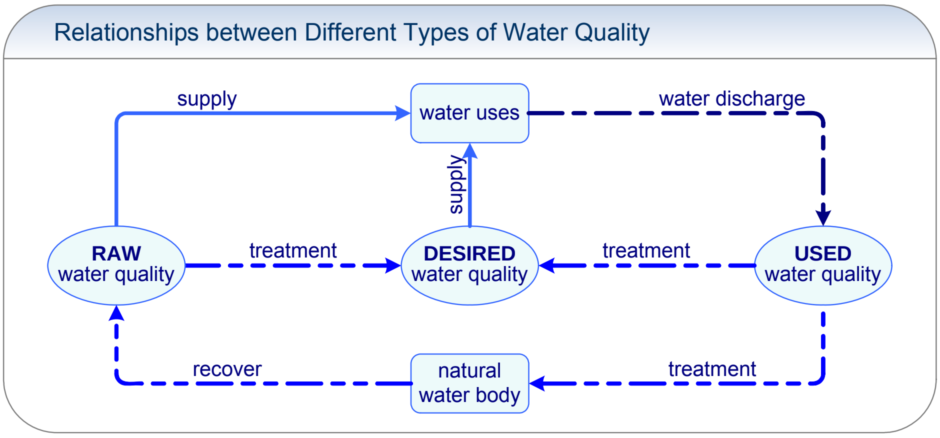

Figure 7: Relationship between different types of water quality

Raw water quality. It is for describing the fresh water, which helps to determine whether the source water is suitable for the urban use purposes, as well as to determine the proper treatment methods. Groundwater and surface water are the most common water sources, so their quality standards and regulations are well established in many countries and regions. In brief, the raw water quality is usually categorised into several levels based on certain critical parameters. The local standards and regulations have to be obeyed during the water source selection.

As another type of raw water, rainwater usually has very good quality before rain reaches the ground. The human beings’ activities cause the environmental pollution and subsequently, deteriorate the rainwater quality, e.g. acid rain. After rain falls onto ground, the substances or pollutants on the ground dissolve into the rainwater, which results in the pollution of rainwater. Different places contain different kinds of substances, so the rainwater quality is quite depending on its collection places. Normally two streams of rainwater are distinguished, i.e. *Surface Runoff* that is collected on the ground, and *Roof-water* that is gathered from building roofs. Some measurements of rainwater quality are given in Table 1 as the examples, which are based on the summation from Australian literature. For making the comparison, the effluent quality after secondary treatment is also listed on the right side in Table 1. Obviously, the rainfall in areas with limited air pollutants is very clean. Roof-water has also quite good quality but with the high content of coliforms, which is mostly because of birds’ excrement on roofs. Surface runoff is even worse because of various pollutants on the ground in cities.

Table 1: Rainwater quality in different streams (with secondary treated sewage for comparison)

parameter	unit	rainfall	roof-water	ground runoff	secondary sewage
suspended solids (SS)	mg/L	0 - 8,4	0,75 - 204	250 (13 – 1.620)	25
BOD_5	mg/L	NA	NA	15 (7 – 40)	15
Lead	mg/L	<0,01 – 0,15	<0,01 – 0,32	0,01 – 2,0	0,02
Zinc	mg/L	<0,01	0,2 – 1,1	0,01 – 5,0	0,1
Copper	mg/L	NA	0,002 – 0,32	0,4	0,03
Chromium	mg/L	NA	NA	0,02	0,01
Cadmium	mg/L	<0,002	<0,001 – 0,004	0,002 – 0,05	0,002
Fecal coliforms	CFU/ 100 ml	0	0 - 124	10^4 (10^3 – 10^5)	10^5
Total coliforms	CFU/ 100 ml	0	190 - 550	NA	NA
Ammonia	mg/L	0,05 - 0,4	0,2 - 0,56	0,7	0,002–0,16
total nitrogen	mg/L	NA	NA	3,5	0,39 – 4,9
Nitrate	mg/L	<0,05 – 0,2	0,1 – 0,87	NA	NA
Nitrite	mg/L	<0,02 – 2,4	0,36 – 3,3	NA	NA
Total Phosphorus	mg/L	NA	NA	0,6 (0,1 – 3)	8
Sulphate	mg/L	0,8 – 5,9	1,8 – 10,3	NA	NA

Adapted from: O'Loughlin, E.M. *et al*. (1992) and EA (2006).
NA: no value. Values in the parentheses are the range.

As a possible water source, seawater contains a high portion of mineral salts. The overall average salinity in oceans is around 35 ‰, where salinity of freshwater is less than 0,5 ‰. Distillation is the old method to desalinate seawater, which consumes tremendous energy. Membrane technology is the proper and promising method to treat the seawater, but it has also high energy demand and results in polluted brine. Thereby, the seawater is considered as the urban water source in special situations.

Desired water quality. Both national and international drinking water quality standards and guidelines are worldwide established. As the most spread standards, the guidelines for drinking-water quality from World Health Organization (WHO) are taken as the base or being directly used in many developing countries. Having the highest required quality (in the normal situation), traditionally the drinking water is supplied by the single water networks in urban area. Nevertheless, the water end uses in cities are quite diverse, where the water demand that requires drinking quality can be only a small portion in some urban districts. Meanwhile, the water scarcity forces us to use water in the more efficient ways. Hence, the water quality standards for other use purposes need to be established, as well. Many countries like

Australia [1], Canada [2], China [3] and USA [4], have established such water quality guidelines/standards, which are especially for utilising the reclaimed water.

According to the focus of this research, the desired water quality standards are categorised in three classes according to the end uses (Table 2). The first class represents the highest one, i.e. drinking water quality. The second class represents the water that is not potable but can be freely contacted by human beings. The third class indicates the water that is restricted to be contacted by human beings' body, which are mainly used for the environmental and irrigation purposes.

Moreover, as there are still big obstacles from the social, religious and psychological aspects for directly drinking or using the reclaimed water, the subscripts are used to distinguish the source water between raw water and used water (Table 2). In the following context, symbol **A**, **B** and **C** are used to represent the general situation that is not sensitive to the types of source water.

Table 2: Categorisation of desired water quality

source water	**Class 1:** Quality **A**	**Class 2:** Quality **B**	**Class 3:** Quality **C**
RAW water	**A**$_{(1)}$: potable water e.g.: cooking, drinking, bathing	**B**$_{(1)}$: non-potable, can be contacted by human e.g.: toilet flush, car wash, unrestricted area irrigation	**C**$_{(1)}$: restricted to be contacted by human e.g.: restricted area irrigation, golf course irrigation
USED water	**A**$_{(2)}$: non-direct potable e.g.: groundwater recharge	**B**$_{(2)}$: the same as above	**C**$_{(2)}$: the same as above

No certain parameters with limiting values are given in this work as it needs to be done on the national or regional base. Chugg (2007) and Feng *et al.* (2008) reviewed the water reuse standards and guidelines worldwide and suggested the parameters with values for different water reuse purposes, which can be refered to.

Used water quality. Several types of used water are identified, i.e. urban sewage, domestic sewage and industrial wastewater, which are discussed respectively as follows.

[1] Guidelines for Environmental Management – Use of Reclaimed Water (accessed 08.2008) http://epanote2.epa.vic.gov.au/EPA/Publications.NSF/PubDocsLU/464.2?OpenDocument

[2] Water Reuse Standards and Verification Protocol (accessed 08.2008) http://www.cmhc-schl.gc.ca/odpub/pdf/64802.pdf

[3] The Reuse of Urban Recycling Water – Water Quality Standards (National Standard, in Chinese) including six series for different kinds of water uses

[4] Guidelines for Water Reuse, USEPA (accessed 08.2008) http://www.epa.gov/nrmrl/pubs/625r04108/625r04108.pdf

As the mixed water stream, the urban sewage includes domestic sewage and industrial wastewater. Its water quality is influenced by many factors like local tradition, economic levels, and industrial scales, etc. Thus, it is localised. Some critical parameters with typical values and ranges are given in Table 3. As the prerequisite for used water treatment, the urban sewage quality has been well investigated, whereby it is not further discussed here. In order to protect the environment and meanwhile save the costs of water treatment, the treated water discharge standards are necessary. Similarly, the national or regional water discharge standards are well established worldwide, too.

Table 3: Quality comparison of greywater and urban sewage

no.	parameter	unit	greywater range	greywater mean	urban sewage
[1]1	E. coli / thermotolerant coliforms	CFU / 100 mL	$10^1 – 10^7$	no value	$10^6 – 10^8$
[2]2	Turbidity	NTU	22 – >200	100	NA
[1]3	Suspended Solids	mg/L	2 – 1500	99	100 – 500
[1]4	BOD	mg/L	6 – 620	430	100 – 500
[1]5	Nitrite	mg/L	<0,1 – 4,9	no value	1 – 10
[1]6	Ammonia	mg/L	0,06 – 25,4	2,4	10 – 30
[1]7	Total Kjeldahl Nitrogen	mg/L	0.06 – 50	12	20 – 80
[1]8	Total Phosphorus	mg/L	0,04 – 42	15	5 – 30
[2]9	Sulphate	mg/L	7,9 – 110	35	25 – 100
[1]10	pH		5,0 – 10,0	8,1	6,5 – 8,5
[2]11	Conductivity	mS/cm	325 –1140	600	300 – 800
[2]12	Hardness (Ca&Mg)	mg/L	15 – 55	45	200 – 700
[2]13	Sodium	mg/L	29 – 230	70	70 – 300

Adapt from: [1] Biotext (2006), [2] Department of Health WA (2005)

Source: A-Boal *et al.* (1995), Eriksson *et al.* (2002), Gardner and Millar (2003), Landloch (2005), Jeppersen and Solley (1994), Palmquist and Jönsson (2003)

Domestic sewage is one special stream of used water. Figure 8 is the characteristic analysis of domestic sewage. It distinctly shows that most nutrients of nitrogen (N) and phosphor (P) are contained in human beings excrement and urine. Being the solid organic material, faeces also contain most hygienically dangerous substances. So it is totally unwise to mix them with huge amount of water. Therefore, instead of dissolving and diluting our feaces and urine with plenty of water, they can be collected individually and thereafter, they can be handled in the more sustainable and efficient ways.

In the modern sanitation concepts, such as Resources Management Sanitation (Otterpohl *et al.* 1999), Decentralised Sanitation and Reuse (DESAR) (Lens *et al.* 2001) and Ecological Sanitation (EcoSan) (Langergraber and Muellegger 2005), it suggests that the different streams of domestic sewage should be collected separately, i.e. using the source separated collection system (SSCS), which is going to be one system option in IUWS, too. Subsequently, several definitions are introduced. *Blackwater* is the flushing water from toilets, where *Greywater* comes from household activities other than toilets. If urine and faeces is collected separately, the flushing water with faeces alone is defined as *Brownwater*. The measurements of greywater are given in Table 3.

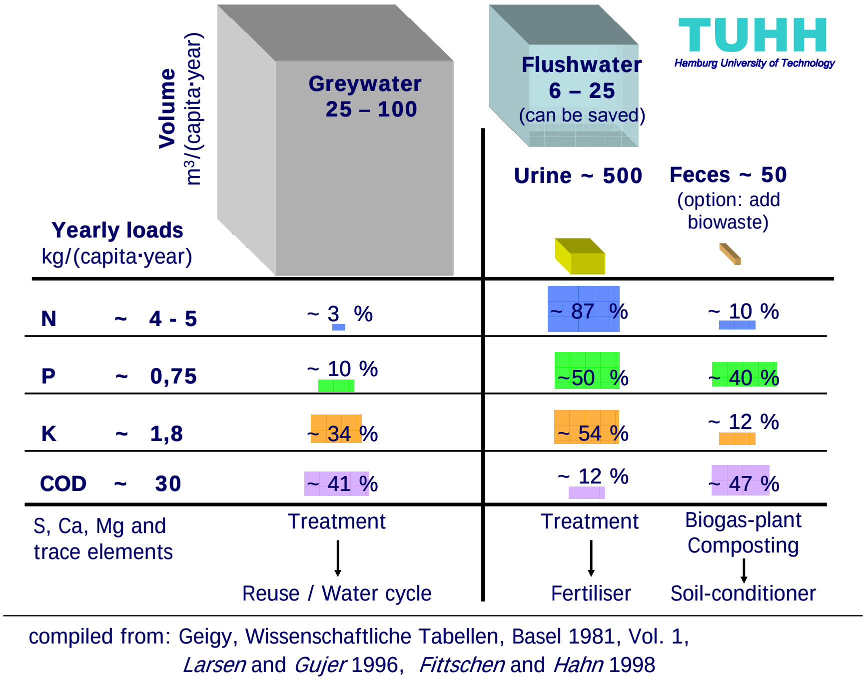

Figure 8: Characteristics of domestic wastewater with no dilution for faeces and urine (Otterpohl *at al.* 2004)

Regarding the industrial wastewater, it is very diverse. In many cases the industrial wastewater contains toxic substances that are harmful to the environment or the later treatment processes. Many countries and regions (e.g. China[1], Germany[2], and European Union (EU)[3]) issue the regulations with required pre-treatments according to the industry types and the water receptors. In order not to slump into the complexity of industries, only the quantity of industrial wastewater is taken into account, where its quality impact is skipped.

2.1.4.2 intake and treatment facilities

"*Intakes are structures built in a body of water for the purpose of drawing water for human use*" (AWWA & ASCE 1998). In many cases they are considered and constructed as the part of the whole water treatment plant and can be the significant part of the whole plant.

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[1] e.g. *Integrated wastewater discharge standard*. GB 8978-1996, Beijing, China, 1996. (in Chinese) (accessed 08.2008) http://www.zhb.gov.cn/tech/hjbz/bzwb/shjbh/swrwpfbz/

[2] *Ordinance on Requirements for the Discharge of Waste Water into Waters*. Federal Ministry for the Environment, Nature Conservation and Nuclear (BMU), Bonn, Germany. 2004

[3] *Urban Waste Water Treatment Directive*. Council Directive 91/271/EEC of 21-05-1991, as amended by Commission Directive 98/15/EEC of 27-02-1998.

Water treatments facilities involve two types of plants in conventional systems, which are waterworks treating raw water and WWTP purifying used water. Depending on the construction arts, treatment plants can be either on-site constructed plants that are custom designed or the package plants that are prefabricated by professional producers. The terms of waterworks and WWTP particularly indicate those on-site constructed plants.

According to the economies of scale, on-site construction is better for large sizes of treatment facilities where the package plants are mostly suitable for medium and small sizes. Some authors announced that package plants have maximal capacity of 11.000 m^3/d and it becomes more economical to design and construct a custom system generally in the range of 7.600 to 19.000 m^3/d (HDR 2001). Package plants have many advantages, such as flexible treatment capacity, high treatment efficiency, small floor space, simple operation, and competitive prices etc. Thus, package plants provide more possibilities to plan and structure urban water systems.

The treatment facilities constructed on-site are various having many different treatment trains and techniques, as well as many different combinations. As the conception for conceiving IUWS in the initial phases, too detailed treatment trains and techniques are unnecessary. Instead, the treatment processes can be classified in steps or in parts. There are certain similar classifications of the treatment processes, examples like Hammer & Hammer (2008), and Pettygrove & Asano (1985). Following the same idea, the detailed classification in this conception is graphed in Figure 9.

The water quality of inflow and outflow are one of the critical issues to determine the treatment process. The Chinese national standards categorise both surface water and groundwater into five classes, where the first three classes are suitable as the urban water sources (SEPA China 1994, SEPA China 2002). The EU Water Framework Directive defines the surface water quality into certain levels, i.e. high, good, moderate, and poor, instead of using numerical criteria (EC 2000). Such ideas are adapted and three types of raw water are included with the statements of high, good, and moderate (Figure 9 and Table 4). Two types of used water are involved. The first type represents the common case, and the second one represents the situation that special pollutant(s) occur(s), which require(s) the particular treatment trains. The explanation of inflow is given in Table 4. The outflow qualities after treatment steps are corresponding to the standards set up in Table 2.

The treatment processes are classified into four stages for raw water and five grades for used water (Figure 9). From the technical viewpoint, the treatment Stage 3 and 4 for raw water are the same as the treatment Grade 4 and 5 for used water respectively, as the same treatment trains and/or techniques are used. Hence, they are joined with the dashed lines and stripes in Figure 9. The explanation of each treatment stage/grade is given in Table 5. There are other indispensable parts in treatment plant, i.e. solids/sludge treatment and disinfection, which is shown in the middle of Figure 9. The related details are given in Table 6 and Table 7. Treatment Stage 3 and 4 and Grade 4 and 5 produce sludge that requires the special disposal methods, so it is not connected to the block of Solids/Sludge treatment. Instead, it is considered as the part of treatment steps. Moreover, if the SSCS is applied, the additional treatment process is needed for blackwater.

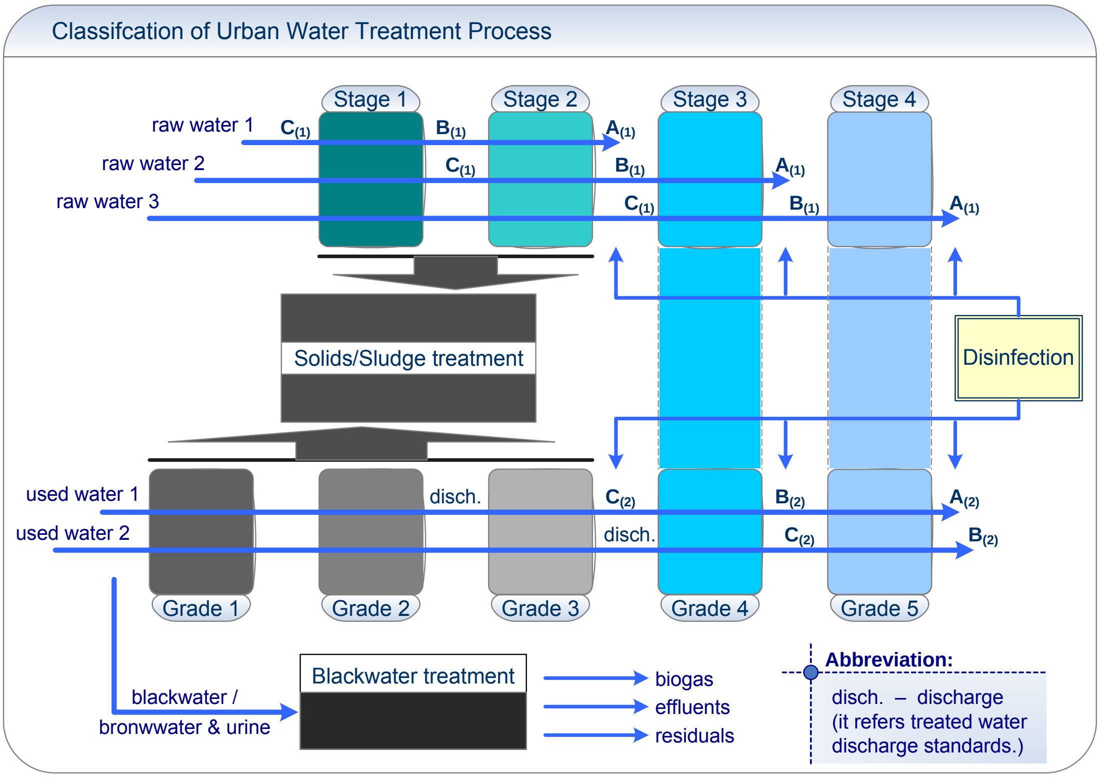


Figure 9: Classification of urban water treatment processes

Table 4: Classification of the inflow of water treatment facilities

type	status	specification
	raw water	
raw water 1	high	groundwater: -simple treatment and disinfection, e.g. aeration & rapid filtration surface water and roof-water: -simple physical treatment and disinfection, e.g. rapid filtration
raw water 2	good	groundwater: - additional treatment needed, i.e. softening, water stabilisation process surface water: -normal physical and chemical treatment and disinfection, e.g. coagulation, flocculation and sedimentation, filtration
raw water 3	moderate	groundwater: -certain substances occur, e.g. Nitrate, with ion exchange process surface water: -intensive physical and chemical treatment, plus advanced treatment e.g.: activated carbon, membrane filtration
	used water	
used water 1	common	can be domestic sewage and greywater: -after two or three treatment grades, the effluent quality can reach the water discharge standards. Advanced treatment is needed for reuse purpose.
used water 2	particularly polluted	can be domestic sewage mixed with industrial wastewater: -particular pollutants exist that require the specified treatment process. Advanced treatment is necessary for reuse purpose.

Table 5: Classification of water treatment steps

step	treatment train/technique included	primary constituents removed
	raw water	
Stage 1	groundwater: -aeration, chemical oxidation surface water: -screen -coag./floc./sedi.	-iron & manganese oxidation and removal - remove organic and inorganic particulate and soluble organic compounds that give colour
Stage 2	groundwater: -softening -rapid filtration surface water: -rapid filtration	-remove heavy metals, silica and fluoride, iron and manganese; reduce turbidity - remove turbidity, bacteria, algae, viruses, protozoa, colour, oxidized iron and manganese, chemicals added in pretreatment
Stage 3	for all types of water: -carbon adsorption, ion exchange, chemical clarification, air stripping -micro-filtration, ultra-filtration	-remove specific organic compounds -remove hardness, fluoride, arsenic, nitrates, colour and alkalinity -remove dissolved solids and micro-pollutants
Stage 4	for all types of water: -nano-filtration -reverse osmosis	-remove the dissolved salts, micro pollutants, and viruses
	used water	
Grade 1	i.e. preliminary and primary treatment -course screening, grit removal, -primary sedimentation, skimming -chemical addition (achieved)	-remove rags, sticks, floatages, grit and grease that may cause maintenance & operational problems -remove a portion of the suspended solids and organic matter
Grade 2	i.e. secondary treatment -biological treatment (e.g. activated sludge, MBR, TF, UASB, RBC, FAS) -secondary clarification	-remove biodegradable organic matter in solution or suspension, suspended solids
Grade 3	i.e. nutrients removal -N removal (nitrification-denitrification) -P removal (chemical or biological)	-remove nitrogen (N) and phosphorous (P)
Grade 4	i.e. advanced treatment -carbon adsorption, ion exchange, chemical clarification, air stripping -micro-filtration, ultra-filtration (*the same as Stage 3 above*)	-remove residual suspended solids after secondary treatment -remove certain dissolved solids and/or micro-pollutants
Grade 5	i.e. membrane filtration -nano-filtration -reverse osmosis (*the same as Stage 4 above*)	-remove the dissolved salts, micro pollutants, and viruses

Partly adapted and summarised from AWWA & ASCE (1998), Chugg (2007), Hammer & Hammer, (2008), Lin (2006), and Río González (2007)

Abbreviations: coag./floc./sedi. – coagulation, flocculation and sedimentation;
MBR – membrane bioreactor; TF – trickling filter;
BAF – biological aerated filter; UASB – upflow anaerobic sludge blanket;
RBC – rotating biological contactor; FAS – film activated sludge

Three most popular disinfection methods are enumerated in Table 6 with short specification. Other treatment methods and trains have the function of disinfection too, such as potassium permanganate, air stripping, activated carbon and membrane processes, etc. (Hazen and Sawyer 1992), which are not involved, as selecting disinfection methods is not the main task of planning IUWS in the early project phase, and also because other methods are not often used or considered as disinfection options.

Table 6: Summation of common disinfection methods

no.	methods	specification
1	chlorination	inactivation of pathogens and bacteria of concern for human health, control of biological growth in distribution system -advantages: applicable to large facilities, low energy intensive; can maintain a residual level in distribution system -disadvantages: not effective for Giardia and Crypto; formation of DBP; pH dependent
2	ozone	oxidation of organic and inorganic matter and disinfection -advantages: kills Giardia and Crypto; Applicable for large facilities; used as oxidant -disadvantages: needs skilful operation; possibility of producing DBP
3	UV light	for disinfections of small facilities -advantages: no produce halogenated organics or inorganic by-products -disadvantages: not effective for Giardia and Crypto; not lasted effects; not convenient for large facilities

Adapted from Río González (2007)

Abbreviation: DBP – disinfection by-products

Solids/sludge treatment is quite complicated, especially the sludge from WWTP. Due to the same reason, only the general treatments methods are involved and simplified into several steps (Table 7). The treatment processes of solids/sludge from waterworks and WWTP are listed parallel, so that a comparison can be easily made.

Concerning blackwater, so far the often considered treatment process in cities is the anaerobic digestion. Figure 10 is a schema of typical blackwater treatment process. In order to guarantee the treatment efficiency, the toilet flushing water entering the digesters has to be as little as possible. Therefore, the vacuum sewerage is compulsory. As one type of the collection systems, the vacuum toilets are discussed in the next section. Meanwhile, the kitchen refuse can be added into digesters in order to enhance the process and simultaneously generate more biogas, which also means that more energy is recovered.

As a relative new concept, the blackwater systems have not been practised in large scales in cities, although some pilot projects are taking place in Europe and Asia (Wendland 2008). In urban area, blackwater system can be quite expensive due to the complexity of the process control, the strict reaction conditions and very importantly, the safety reasons.

Table 7: Classification of solids/sludge treatment steps

treatment step	seq.	unit process included	per. [%]	seq.	unit process included	per. [%]
		from waterworks			***from WWTP***	
conditioning	1	-physical -chemical	[1]		(as the third step)	--
thickening	2	-natural -gravity	8 ~ 25	1	-settling, gravity, flotation -centrifuge, gravity belt, rotary drum	3 ~ 6
stabilisation		(not involved)	--	2	-lime, anaerobic digestion -aerobic digestion	[2]
conditioning		(as the first step)	--	3	-chemical -others	[1]
dewatering	3	-centrifuge -mechanic filter	35 ~ 60	4	-centrifuge, filter press -drying beds, reed bed	60 ~ 90
(Heat) drying	4	-natural -thermal	>35 ~ 60	5	-(in)direct dryer, -composting, long-term storage, pasteurisation	>60 ~ 90
thermal reduction		(not involved)	--	6	-incinerator	--

Summarised based on AWWA & ASCE (1998), Metcalf & Eddy (2003), and Río González (2007)

Abbreviations: seq. – sequence; per. – percent dry solids

[1] it improves the ability of thickening or dewatering.

[2] it has the function of mass reduction (i.e. with digestion).

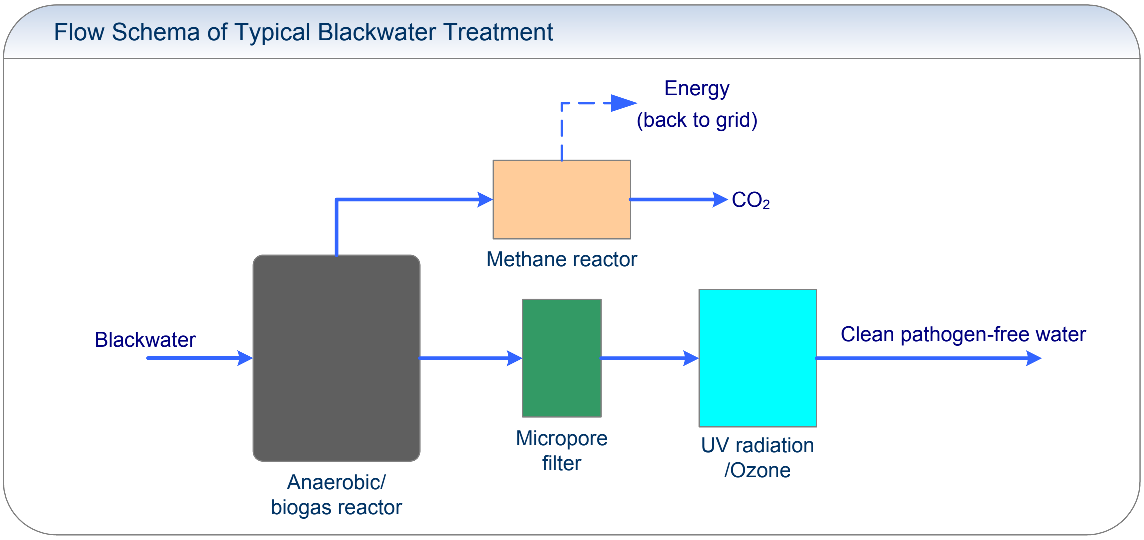


Figure 10: Flow schema of typical blackwater treatment (redrawn based on IAP[1])

[1] Indoor Agriculture Products (accessed 08.2008), http://www.verticalfarm.com/plans-2k3.htm

2.1.4.3 conveying system

Water conveying includes raw water transmission, finished water distribution, and used water and storm water collection. In the conventional idea, they are designed and managed independently. In IUWS they are considered and planned together in the same time as one conveying system. It further prompts to construct the distribution and collection systems simultaneously, which can result in less construction costs and better organisation of urban underground pipelines. The main components of conveying system are introduced as follows.

Conduits. Pipes and canals are the usual measures for conveying water, where pipes are mostly used in urban area. In pipe systems, the hydraulic conditions can be pressurization or gravity. Normally water distribution systems have the pressure pipes and the sewerage systems have the gravity systems. The canals can be used for the transmission of raw water and storm water if the space and surroundings are suitable.

As mentioned above, the vacuum system is another method to collect sewage. The record of vacuum sewerage can be traced back as early as 1868 (Elsevier 2004). As a very expensive system, the vacuum sewerage can still be cost competitive in the extreme situation that the area is very flat, the water consumers are scattered, and the ground conditions are difficult for deep excavation. In the context of our IUWS, vacuum system is only considered for collecting blackwater. Due to the high cost, earlier vacuum toilets were mainly applied to the particular situations like in airplanes and submarines. Today they are more and more applied in civil toilets and thereby, it is a good option to evolve our urban water systems.

Besides conduits, the ancillary works are necessary. In this work the main components are considered and involved, i.e. pumping stations, storages, and valves.

Pumping station. *Booster pump station* is used for upraising or pressurizing the raw water transmission or finished water distribution systems. The primary requirement of booster pump station is that the pumped water must remain the same water quality as before. *Lift station* is used in sewerage system for lifting urban sewage and storm water. Lift station has the comparably lower delivery head. Usually lift station has the severe operation conditions. Moreover, there is the vacuum pumping station, i.e. the collection station, which is attached to vacuum system for collecting sewage or blackwater.

Storage. Except very small systems, the storage is the essential part of the water distribution systems with the following purposes, e.g. providing constant water production and supply against variable demand in the networks, providing emergency supply, and maintaining the stable pressure (Trifunovic 2006).

In both roof-water utilisation and storm water management systems, the storage plays the critical role. The storage tank is the indispensable part of the roof-water utilisation systems, as it helps to supply water through a period, instead of only for one rainfall event. Moreover, it can even exert significant influence to the sewer downstream (Vaes and Berlamont 2001). The storage tanks can be divided into three classes: *1*. at-grade or aboveground, *2*. below-grade, and *3*. integral containers built into a building (Kinkade-Levario 2007).

In storm water systems, the storage has the functions of limiting flooding and reducing the amount of polluted storm flow discharged into a watercourse (Butler and Davies 2000). The storm water storage can be in many different forms, such as on-site storage, i.e. storm water is retained locally in buried tanks or surface ponds (Butler and Davies 2000), and larger scale urban watercourse storage (Hall *et al.* 1993).

Valves and gates. In water distribution systems, valves fulfil three main tasks: regulating flow and/or pressure, excluding the parts of the networks in the emergency or maintenance situations, and protecting reservoirs and pumps (Trifunovic 2006). In sewerage systems, the flow is controlled by different devices, such as orifice plate, penstock, vortex regulator, throttle pipe and flap valve. As the important and costly apparatuses, they are included.

In addition, the vehicles can also be the suitable transport method, especially for solid substances and liquid materials having small volume but with high substance contents, such as the solids and sludge after treatment, the digested blackwater and the pure urine.

2.1.4.4 water fixtures

Water fixtures are the terminals connecting water and end uses. Improving the efficiency of water fixtures is one of the most efficient and simple ways to save water. Typical example is the toilet flushing devices. The new models consume water about 4 to 6 litres per flushing, where the old type can reach 15 litres each flushing (NCDENR 1998). Meanwhile, the modern toilet flushing devices have two buttons as one is for urinating and another is for defecating, so that even less water is consumed for urinating. Thus, using water saving fixtures shall be always considered and performed in the first place. In this conception, water fixtures are not direct manifested, but the effects can be involved by managing the water usage of water end-users.

All above mentioned facilities and structures (except for water fixtures) are taken into account in IUWS, and their cost and energy consumption are calculated.

2.2 Subsystems

As discussed in § 2.1.2, the urban water systems consist of five subsystems that have their individual system options and planning processes. Figure 11 is the general view of structure and processes for determining each subsystem. The planning steps in Figure 11 have two tasks, i.e. information management, and infrastructure calculation. The information refers to the essential planning data that are used to determine and optimise the water usage and system scales. The task of infrastructure calculation is to determine the water system options and calculate the system cost and energy consumption. All processes for each subsystem work independently and are integrated together and applied to IUWS in the hierarchy later on.

The subsystem of used water consists of two streams, i.e. water and matter, where the stream of matter is particularly set up for the blackwater. As the solid substance, also as the hygienic dangerous material, the human beings excrement should be isolated from the water cycle. Hence, the blackwater system is designed as an independent system. The subsystem of rainwater involves also two streams as the surface runoff and roof-water behave totally different and can be the parallel systems, so they are managed and utilised in different ways.

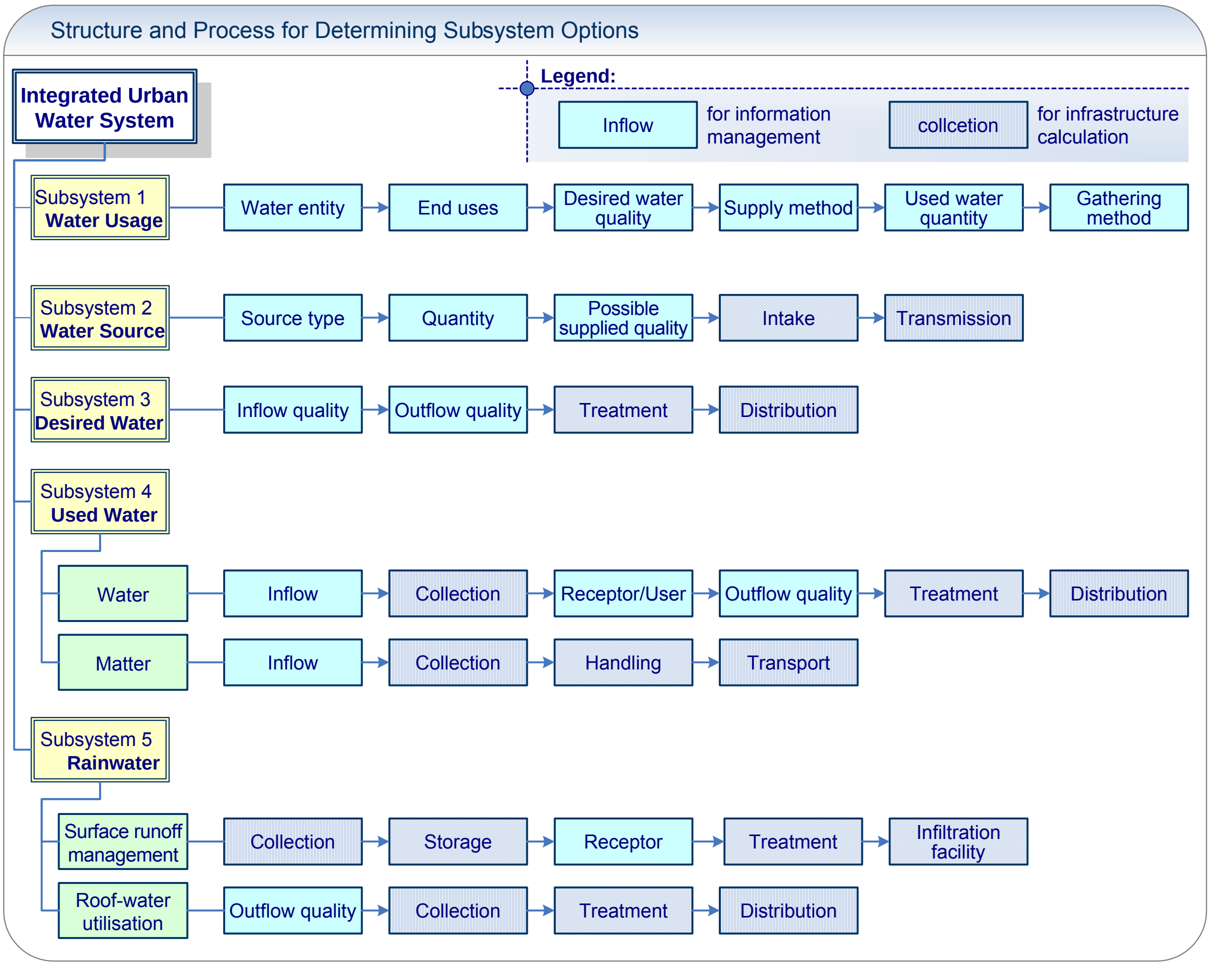


Figure 11: Structure and process for determining subsystem options

2.2.1 Water usage

Being of the water usage side, two aspects need to be satisfied, i.e. water quantity and quality. In order to fit the hierarchy of the IUWS, as well as fulfil the requirements of IUWS, the new system for water usage management is constructed based on the coordination between quantity and quality.

2.2.1.1 water end-user

In this conception, the water end-users are identified as grouped water consumers, which cover certain area and have different kinds of water end uses with different desired water qualities. These grouped end-users are the basic functional units in cities. Typical examples are university, hospital, school, shopping centre, etc. This categorisation provides chance to balance the water consumption inside groups and subsequently, promotes more system options in a small scale.

As one of the most important conception in IUWS, these kinds of grouped water end-users are specially corresponding to the WUU and WUC that are particularly constructed for the hierarchy of the IUWS (see § 2.1.3). In urban area, there are many different kinds of the grouped water end-users that are divided into three sorts, i.e. *1*. social and commercial, *2*. communal and ecological, and *3*. industrial and special end-users (Figure 12). There are more types than shown in Figure 12, so the corresponding database should be established for gathering and adding all possible grouped end-users.

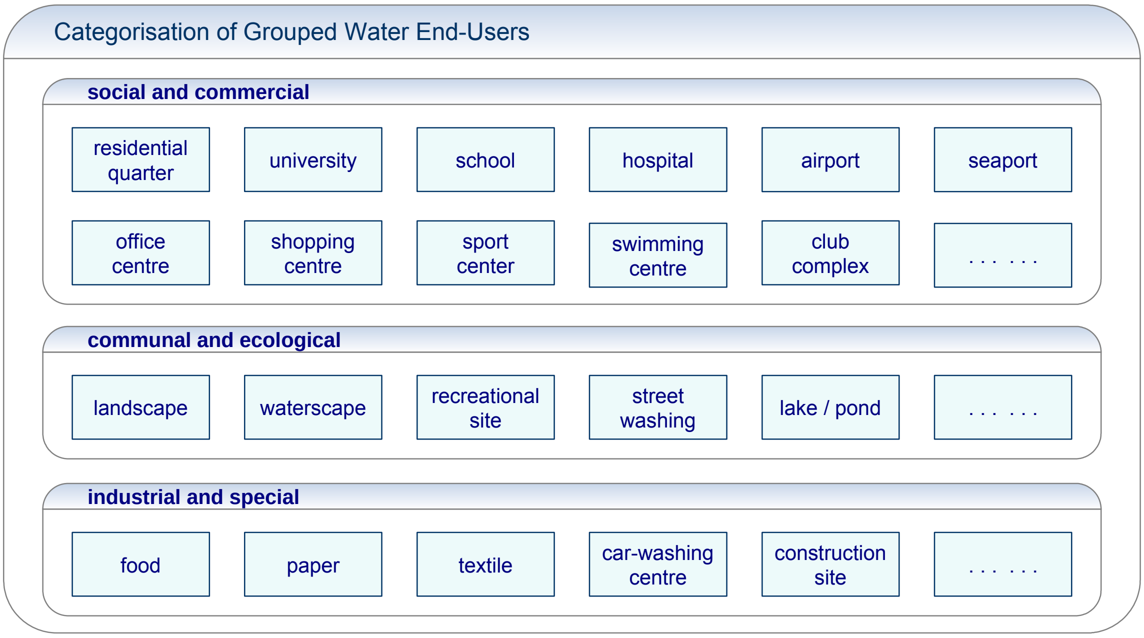


Figure 12: Categorisation of grouped water end-users

2.2.1.2 end-user's water usage profile (EUWUP)

Subsequently, the grouped water end-user's water usage profile (EUWUP) is defined as that each type of water end-user has specified and standardised information of water usage including water demand with required water qualities and used water amounts from different streams. Two measures are taken, i.e. detailed EUWUP and general EUWUP. The detailed EUWUP is applied when the adequate project information is available. Otherwise, the general EUWUP is adopted for rough evaluation.

Detailed EUWUP. It is constructed based on the quantity and quality requirements of end uses considering their occurring places and purposes of usage. Three sorts of end uses are defined: indoor, outdoor and specialised end uses, where each sort is further fractionised into concrete end uses (Figure 13). The indoor end uses are mainly the water consumption by human beings, the outdoor end uses are for ecological and environmental purposes, and the specialised end uses involve the specific and industrial water consumption. Their quality requirements are corresponding to the desired water standards set up in Table 2.

As depicted in Figure 13, besides categorising the water end uses with desired water quality, the information of used water is also shown simultaneously, where the normal water usage profiles take into account only the water demand just in the sense of quantity. The most important significance of the EUWUP is that it pictures the whole view of water usage and provokes the planners to consider and plan both desired water system (i.e. water supply system) and used water system (i.e. wastewater system) at the same time. The corresponding tables and the demonstration graphs for detailed EUWUP are provided in Appendix 1.5.

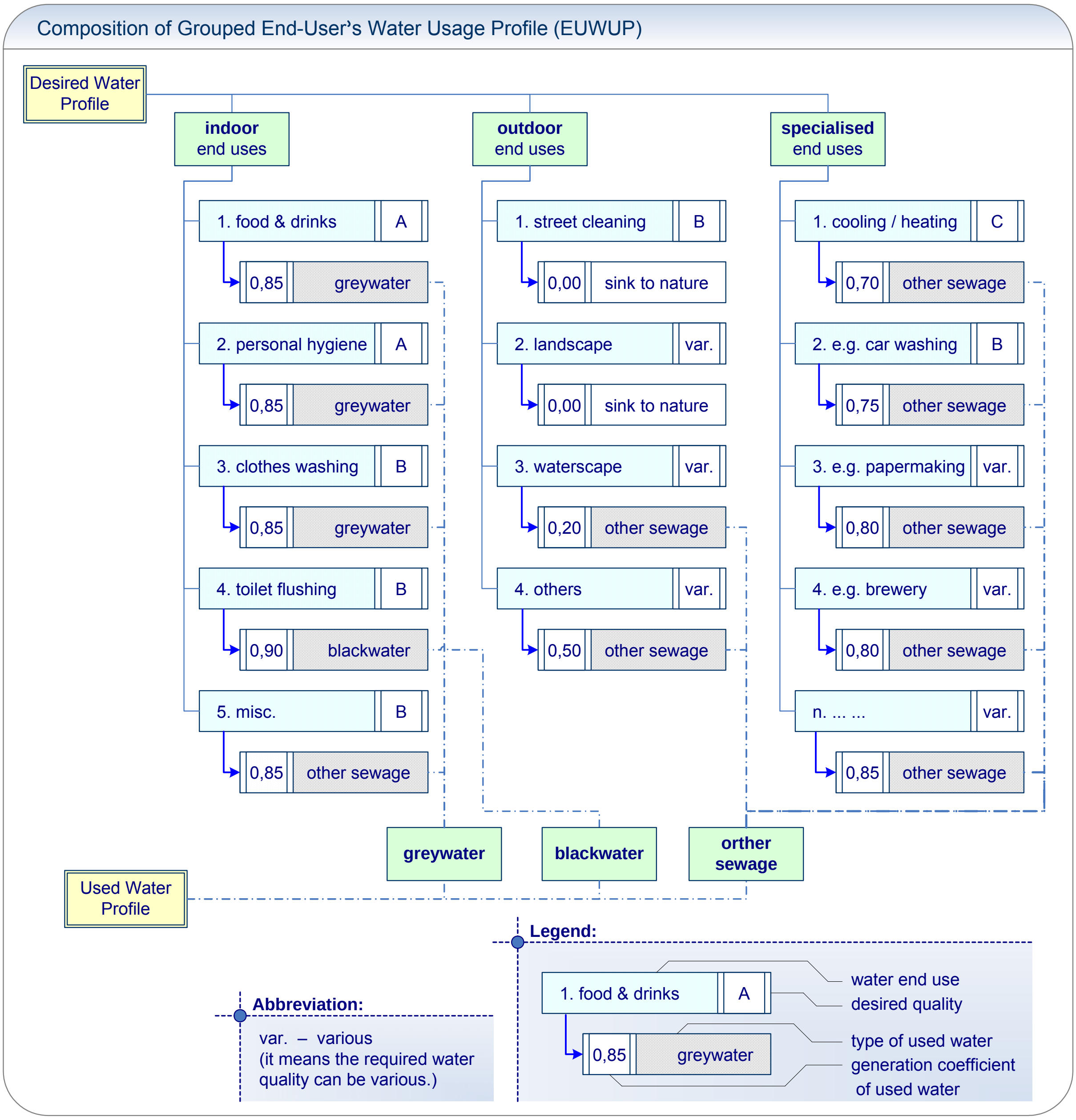


Figure 13: Composition of grouped end-user's water usage profile (EUWUP)

Each water end-user can have several EUWUPs simultaneously, which represent different water utilisation patterns. Water consumption depends on many factors, such as local traditions, water fixtures and economic levels. Through the demand side management, water end-users can have different water usage profiles. The demand side management is not directly included as it is not the focus of this research. Instead, its effects can be reflected by different EUWUPs, which are named as the *water usage scenarios* in IUWS.

General EUWUP. If the detailed EUWUP is not available, the general EUWUP can be used for roughly estimating water usage. General EUWUP is assessed by equivalent average water consumption. Two possible units of EUWUP are adapted. One is the capita equivalent water consumption, i.e. $m^3/(cap·d)$, and the other is the unit equivalent water consumption, i.e. $m^3/(unit·d)$. This unit can be area, volume, or number of products, etc., depending on the types of the end-user. For example, the EUWUP of shopping centre can be estimated either based on its costumer capacity (i.e. $m^3/(passenger·d)$) or construction area (i.e. $m^3/(m^2·d)$). Afterwards, the general water quality-quantity-ratio is used so that the water amount can be allocated to different types of desired water quality. The equivalent average water consumption and the quality-quantity-ratio are obtained from the statistical data and are localised.

2.2.1.3 estimation

In the hierarchy of the IUWS, the estimation of water usage starts from WUC and WUU. As UD consists of WUUs, the water usage of UD is the summation of its WUUs. Likewise, the water usage of CA is calculated by summing the water usage of all UDs.

As discussed above, EUWUP for each type of WUU and WUC should be established and stored in the database, so that the water usage is automatically calculated after inputing the planning information of WUU and WUC. Depending on the requirements, several water usage scenarios can be generated. One demonstration for the water usage of a WUU is given in Figure 14. First, the water end uses of the WUU (i.e. a school) are determined based on Figure 13. Then based on the scale of the WUU, the water usage is calculated. Two water usage scenarios are carried out, i.e. *Scenario 1*: the conventional situation, and *Scenario 2*: using the water saving fixtures Figure 14,.

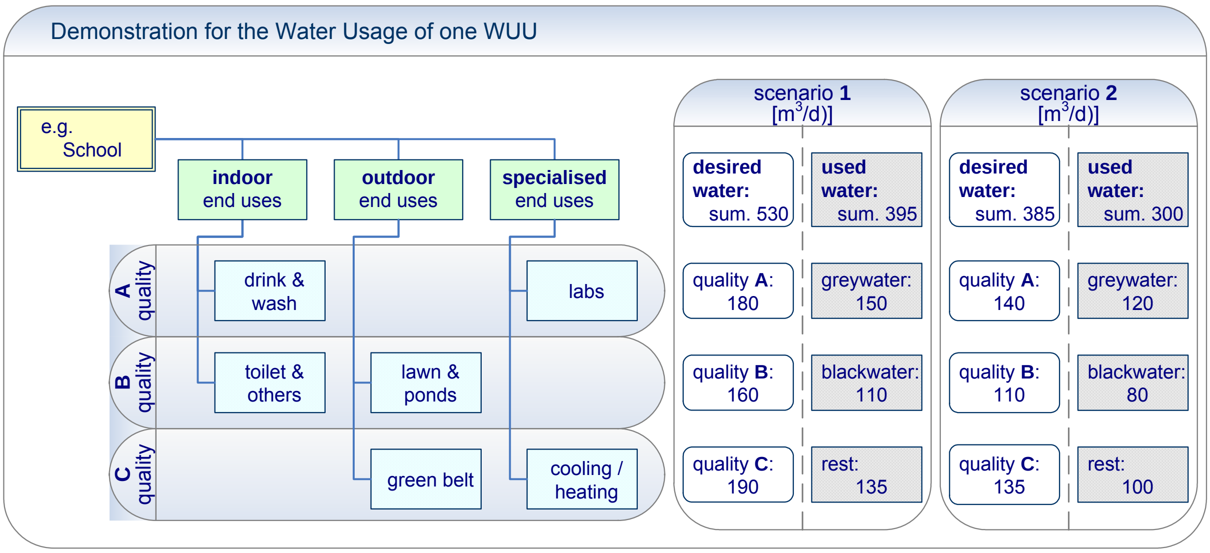


Figure 14: Demonstration for the water usage of one WUU

In the hierarchy, the water entity in higher levels comprises a number of water entities located in the inferior levels, and its water usage is determined by its affiliated water entities. The different water usage scenarios of different water entities can be combined unlimited. In order to simplify the calculation, the water usage scenarios of affiliated water entities retain the same as their superior water entity, e.g. the second water usage scenario of all affiliated water entities is summed as the second water usage scenario of their superior water entity. It only represents an extreme situation of reality, but all other combinations fall into the range between the extreme situations. As it is for the project design in the early stage, such simplifications are able to provide reasonable vision and adequate information for a first orientation.

Figure 15 shows the process of estimating water usage. Three steps are identified. In the first step the type of water entity is confirmed, and Step 2 and 3 determine the water demand and used water generation respectively. Consequently, the supply and gathering methods are determined. Here the gathering method especially refers to the gathering of domestic sewage, whereby it determines whether the SSCS is applied.

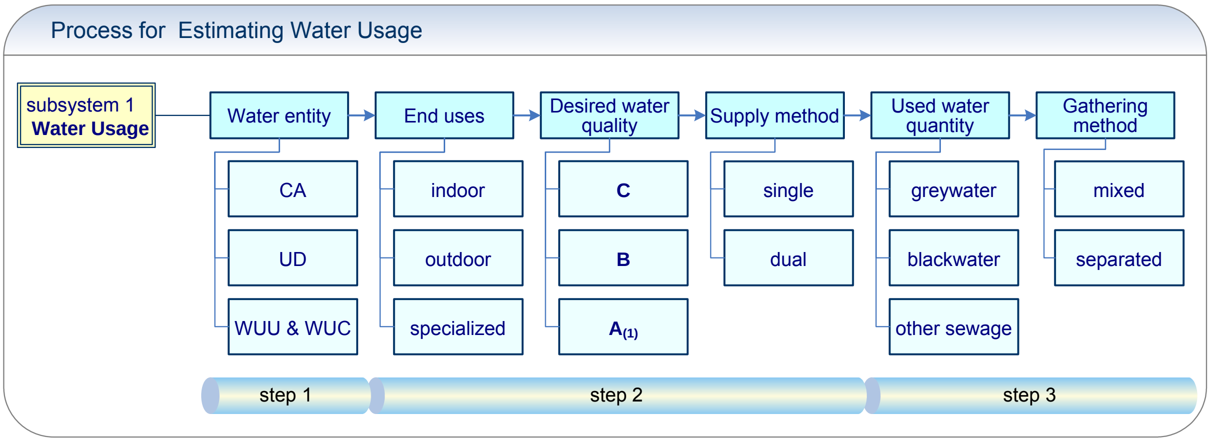


Figure 15: Process for estimating water usage

2.2.2 Water sources

Water resources should be managed in the scope of the whole (sub)catchment area, and usually the city is only one of the water consumers in the (sub)catchment area. Since the boundary of our system is the same as the city, the water resources management is not included in this system. Consequently, the information of the allocated water resources to the city should be obtained from other correlated water resources management projects. Such obtained information is further analysed in order to support the planning of IUWS. Therefore, water sources alone form one subsystem, where the attributes, i.e. water quantity, quality and priorities of water sources, are evaluated.

2.2.2.1 categorisation

The common water sources are groundwater and surface water. In some cases, long distance water diversion and seawater can be the sources, as well. Through certain treatment processes, rainwater and reclaimed water can also become urban water sources. In the hierarchy of the IUWS, since the water system is divided into water entities and all entities are managed as the independent units, the water sources are defined as two groups: (i) local source and (ii) external source (Figure 16).

(i) **Local source**. It refers to the water sources located within the domain of the designed water entity. Groundwater and surface water are the normal local water sources. Rainwater and reclaimed water can also be converted to local sources in certain circumstances.

The utilisation of rainwater is identified in two manners: surface runoff utilisation (i.e. indirect way) and roof-water utilisation (i.e. direct way). In the first case, huge amounts of storm water are gathered from ground and retained in the natural or artificial water bodies in the local area, whereby it is considered as local source. In the second case, rainwater collected from roofs are directly supplied to local end-users (details in § 2.2.5). Hence, both utilisations convert the rainwater to the local water source.

Reclaimed water is generated from the used water after certain treatment. Normally, the reclaimed water can be used in two ways, i.e. direct non-potable reuse and indirect potable reuse (details in § 2.2.4). The main difference between two ways is that the reclaimed water has the recovery phase in nature by indirect potable reuse, where another one does not have. Both ways supplement the local water sources. Therefore, reclaimed water reuse is considered as the local water source.

(ii) **External source**. It refers to the water sources that are situated outside the water entities. Obviously, the long distance diverted water and seawater are the external water sources. Based on the definition, the water from the networks of superior water entity is also treated as the external source. For example, the water from CA is the external source for UD. Thus, the main water sources of all WUU and WUC are external source that comes from their superior water entities. The only local sources at WUU and WUC are the roof-water and direct non-potable reused water. Such prescription provides the opportunity to design and manage all water entities absolutely independently.

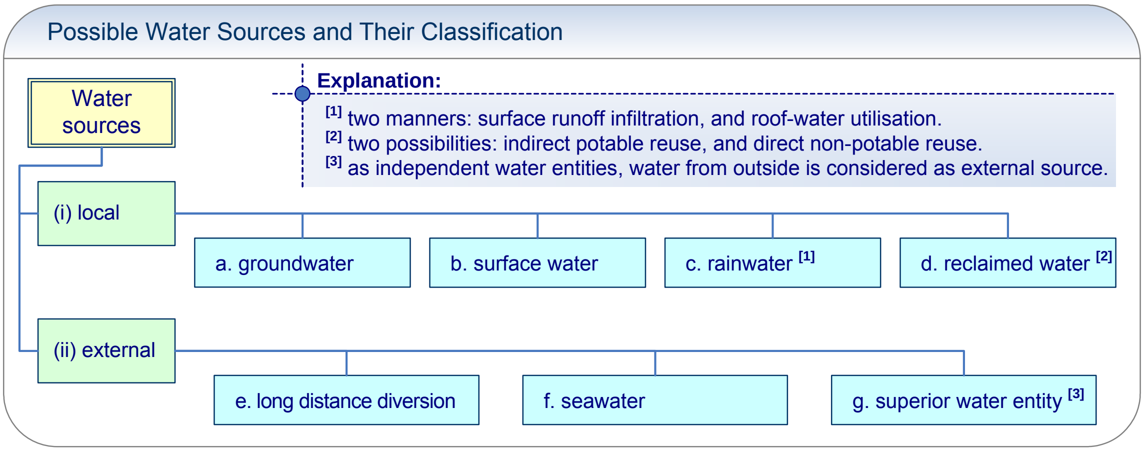


Figure 16: Possible urban water sources and their classification

The facilities for water abstraction from nature consist of two parts, i.e. intake facilities and water transmission lines. The estimation methods of their cost and energy consumption are introduced and discussed in § 3.4 together with other water infrastructure.

The general priority of water sources is given in Figure 17. Due to their different features, the water entities in different hierarchical levels have their own water source priorities, and the details are described in § 3.3.1. In reality, there are more boundary conditions that limit the availability and accessibility of water sources, which will change their priorities. Since it is for the early designing stage of urban water systems, this kind of general priority is adapted. During the project designing, the planners can adjust it based on their own actual situations.

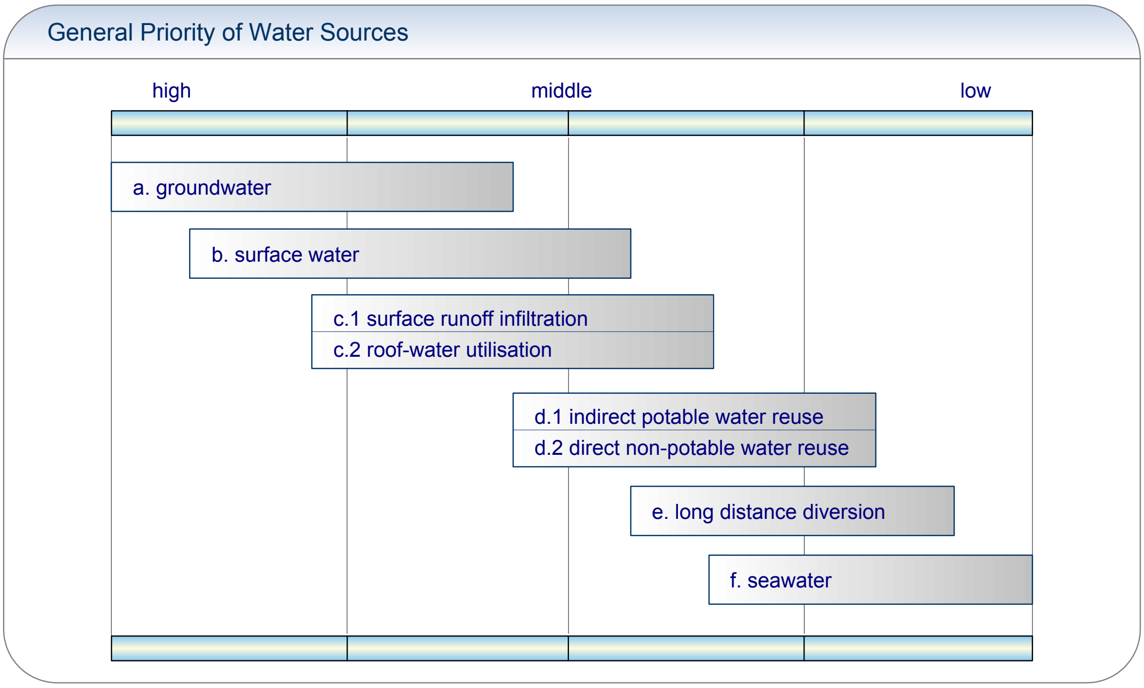


Figure 17: General priority of water sources

2.2.2.2 planning process

The general planning process is applicable to all types of water entities, which is divided into two steps (Figure 18). Firstly, the possible water sources are identified with consideration of their water quantity, quality and priorities. Based on the water usage of the water entity, the proper sources are selected. Afterwards, the corresponding facilities are calculated in the second step.

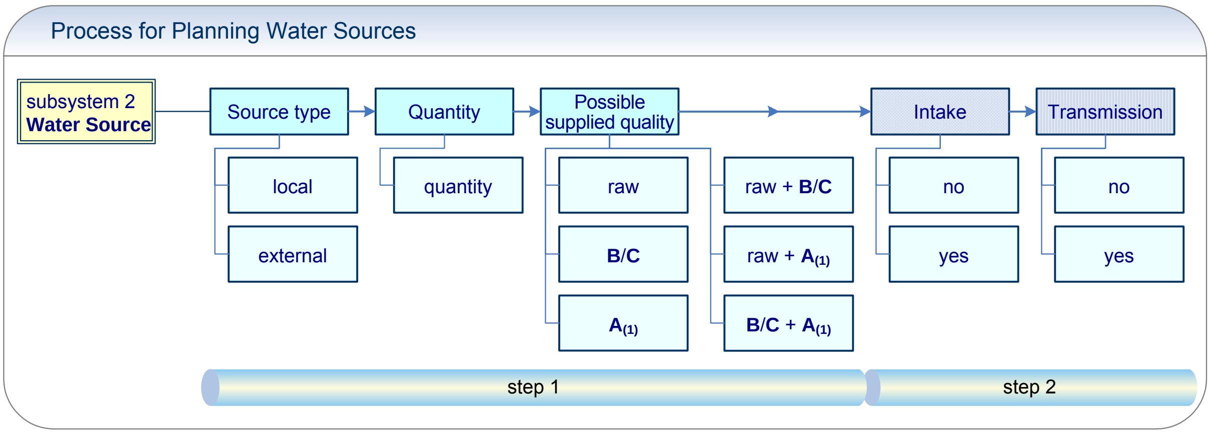


Figure 18: Process for planning water sources

The local sources only have the raw water quality as they are obtained from the nature. The raw water should be matched with the raw water categories given in Table 4, and meantime follow the local raw water quality standards. Regarding the external water sources, besides raw water quality, it can also be Quality $\mathbf{A_{(1)}}$, **B** and **C** when water comes from the superior water entities (see Table 2 for the categorisation of desired water quality). As reclaimed water cannot be for the direct potable use, $\mathbf{A_{(1)}}$ indicates that only raw water is used as the drinking water source. Since non-potable water use is not senible to the water sources, **B** and **C** are used representing that it can be either the treated raw water or the reclaimed water.

In such situation, the water can be supplied in either one or multiple types of quality. In reality, maximal two parallel pipe systems are applied. Hence, maximal two types of water quality can be supplied. Among Quality $\mathbf{A}_{(1)}$, **B** and **C**, Quality $\mathbf{A}_{(1)}$ is indispensable for IUWS. Therefore, always only one quality between **B** and **C** is supplied by the second pipe system. The symbol **B/C** is used in the following context that indicates either one of both is supplied.

The symbols of “raw + **B**/**C**” and “raw + $\mathbf{A}_{(1)}$” indicate that double water sources are used, i.e. “raw” represents the local source, and “**B**/**C**” or “$\mathbf{A}_{(1)}$” represents the external source coming form the superior water entity. The case of “**B**/**C** + $\mathbf{A}_{(1)}$” is that the superior water entity has the dual water supply system, which are possible as double external sources. All possible combinations of water quality as well as their applicability to different types of water entities are given in Table 8. The decision making mechanism and rules for determining the supplied water quality are introduced in § 3.3.2.

Table 8: Possible source water qualities and their applicability

no.	water source	possible quality	no.	possible supplied	CA	UD	WUU / WUC
(i)	Local	raw	1	raw	☑	☑	☐
			2	**B/C**	☐	☑	☑
(ii)	External	raw	3	$\mathbf{A}_{(1)}$	☐	☑	☑
		B/C	4	raw + **B/C**	☐	☑	☑
		$\mathbf{A}_{(1)}$	5	raw + $\mathbf{A}_{(1)}$	☐	☑	☑
			6	**B/C** + $\mathbf{A}_{(1)}$	☐	☑	☑

Legend: ☑ – applicable; ☐ – not applicable

2.2.3 Desired water supply

One goal has to be fully achieved by the desired water supply system, i.e. supplying sufficient quantity with satisfying quality to water costumers. It mainly deals with two objectives: the treatment facilities and the distribution systems.

2.2.3.1 options

Traditionally central waterworks treat the raw water to the drinking water quality and finished water is supplied to costumers with a single water supply system. Nowadays, diverse water end uses in cities results in diverse requirements of water qualities unevenly distributed. The hierarchy of the IUWS offers the chance for water entities to have individual treatment and distribution systems so that the local water system can completely match the actual requirements. Thus, besides central waterworks and single water system, package plants and dual water system are also the alternatives.

Single water system. It is corresponding with the centralised water system, where single pipe system supplies single water quality. As the highest required water quality in common situation, drinking water quality is mostly adapted. Single water system has many advantages comparing to dual water system, like lower construction costs, easier to maintain, lower risks (i.e. no cross connection issues), etc. Up to now, most water supply systems worldwide are the single water system.

Dual water system. It is designed for supplying two types of water quality in the same time. The consideration of dual water system can be traced back as early as 1894 (Haney and Beatty, 1977). It is especially suitable for the situation that the source water is quantitatively adequate but qualitatively scarce. A dual water system is usually too expensive to be afforded because of its doubled pipe systems. However, it also depends on the system scales and project situations. Leconte *et al.* (1988) developed both static and dynamic models for evaluating dual water systems, and made two case studies in West Jordan City, USA. They proved that the dual water system is economically infeasible for the entire city but results in positive benefit when it is only for one district in the city area. Certainly, in the hierarchical system, the dual system can be flexibly applied in the proper places on the economical scales.

2.2.3.2 planning process

Figure 19 shows the process for planning the desired water system for all types of water entities. In general, there are two planning steps. First the information and data about quality, quantity and system options are managed and processed. Second the related water infrastructure is calculated concerning the cost and energy consumption.

The information of inflow quality is delivered from Subsystem 2 *water sources*, where the required outflow quality is based on the outcome from Subsystem 1 *water usage*. All possible inflow qualities are identical to the supplied water quality in Subsystem 2, and the possible outflow qualities are **$A_{(1)}$**, **B/C**, and **$A_{(1)}$** + **B/C** (Figure 19). The symbols remains the same sense, where the symbol of “**$A_{(1)}$** + **B/C**” indicates to use dual water system. Particularly, if the reclaimed water is directly reused, the dual water system automatically comes forth due to its non-potable water quality. This situation is explained more in the next section.

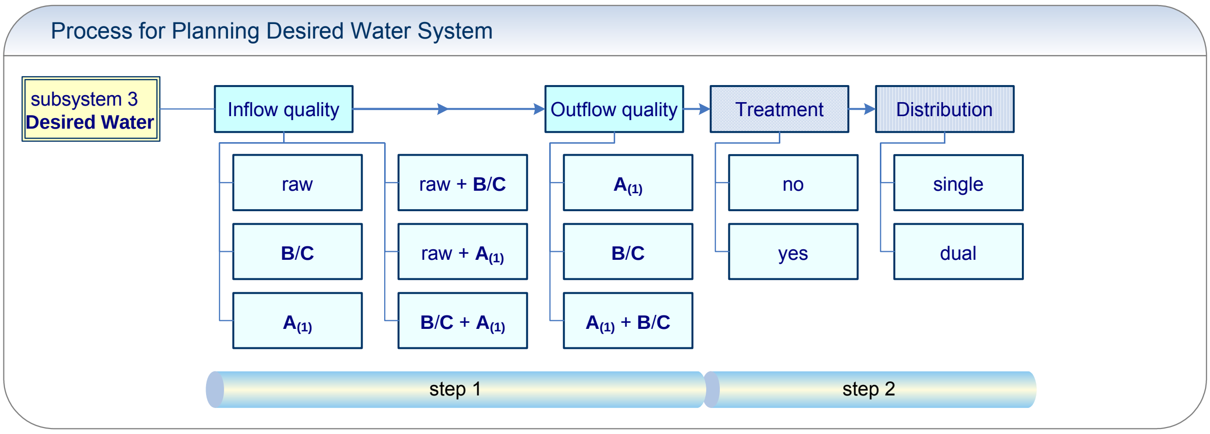


Figure 19: Process for planning desired water system

The possible system options are listed in Table 9. Six inflow possibilities multiplying three outflow possibilities and subtracting two unrealistic conditions generate eighteen system options in total. In reality, sixteen options are not possible at the same time because the boundary conditions screen out the improper options. Detailed system options in IUWS and selection rules are given in § 3.3.2.

Table 9: System options of desired water system

no.	inflow quality	treatment		no.	outflow quality	distribution
1	raw	√				
2	**B/C**	√		1	$\mathbf{A}_{(1)}$	single
3	$\mathbf{A}_{(1)}$	--		2	**B/C**	single
4	raw + **B/C**	√				
5	raw + $\mathbf{A}_{(1)}$	√		3	$\mathbf{A}_{(1)}$ + **B/C**	[1] dual
6	**B/C** + $\mathbf{A}_{(1)}$	--				

Legend: √ – needed; -- – no need

[1] dual supply system is not suggested for CA due to its extremely high cost.

2.2.4 Used water management

The term of *used water* substitutes for *wastewater* as the water does not turn to the waste after use. Besides the conventional dealing method, the used water can/shall be properly utilised.

2.2.4.1 options

Sewage disposal. Conventionally, all types of urban sewage are gathered together by sewer, treated in WWTP, and then both clarified water and generated sludge are often dumped back to the nature. Though this type of system is simple, but the potential of used water is not recognised and realised. As the centralised system, the large sewer system associated with lift stations is necessary. From today's point of view, it is not the sustainable solution, which is neither environment friendly, nor economically rational. The new concepts and alternatives consequently emerged.

As a quite broad concept, the water reuse in modern cities is being trialled for decades. The water reuse systems can be classified into many different manners. In this conception, two ways to reuse water are identified: direct non-potable reuse and indirect potable reuse.

Direct non-potable reuse. It is defined as pipe-to-pipe to reuse the reclaimed water for non-drinking purposes. There are two cases of direct non-potable water reuse. Firstly, the reclaimed water is supplied to the same end-user again. In the case of localised reuse, it needs distribution system on the small scale but more often requires sophisticated treatment process. For example, the treated domestic sewage is supplied to residents for non-drinking uses. Secondly, taking advantage of different end uses that require different water qualities, water is used more than one times. For example, the lightly treated greywater is used to irrigate the restricted green area in the neighbourhood. In some situations, the treatment is even unnecessary. On the contrary, the larger pipe system can be required. Importantly for both cases, if the reclaimed water may expose to human beings, it must be hygienic safe.

Indirect potable reuse. It is defined as after being buffered and recovered in nature for certain period, the reclaimed water is used for raw water supply. Unconsciously, water is already being reused in such manner. For example, the treated or even untreated sewage discharged upriver will be used as source water for water consumers downstream. By treating the used water into very high quality (Quality $\mathbf{A_{(1)}}$), the recovering period of used water is accelerated, whereby the local area gains more source water, and at the same time the risks can be better monitored and hereby reduced. Several methods are practised for indirect potable water reuse, typically groundwater recharge and river bank filtration. The additional treatment is added to the mixture of raw and reclaimed water before distribution as drinking water (Metcalf & Eddy 2007).

The reclaimed water can be also directly reused as drinking water without intervening storage. There are only a few cases of direct potable reuse implemented in situations of extreme water scarcity, e.g. in Windhoek, Namibia (Du Pisani 2006), However, it is still not universally accepted by our society and in fact the public often rejects water recycling activities (Dolnicar and Schäfer 2006). Thus, direct potable reuse is not involved in IUWS.

Source separated collection system (SSCS). For enhancing the efficiency of water reuse system, one method is to control the pollution sources. Particularly, the urban toilet system needs to be rethought, as it contains most hygienic dangerous substances. Hence, SSCS becomes an option for sewer systems.

Since different domestic sewage streams have different water characteristics (see § 2.1.4.1), they should be collected separately, so that they can be better handled with specified methods. SSCS has significant advantages. First of all, the reclamation and reuse of greywater become easier, as it contains less hygienically dangerous substances. If vacuum toilets are installed, plenty of water can be saved. Meantime, valuable nutrients can be regained such as N and P, and the renewable energy (i.e. biogas) can be generated, as well.

However, SSCS requires an additional and costly collection system as well as the additional treatment and storage systems for blackwater (or for brownwater + urine). As a result, the total system can be quite expensive. Therefore, the SSCS would be the proper option for water entities having medium or small sizes, whereby the large collection system can be avoided.

Separate or combined sewerage. Separate sewerage systems transport urban sewage and storm water in two independent systems, where combined sewerage systems gather them together in one system. Both types have advantages and disadvantages, and they are widely implemented. Furthermore, there are more possible types, e.g. the hybrid sewer system. Which kind of sewer system is better or more appropriate depends very much on the actual situations, such as city locations, geological conditions, system scales, local economy level and local regulations, etc. The general priorities and selecting rules are set up particularly for IUWS and shown in § 3.3.3.

2.2.4.2 planning process

The corresponding planning process is depicted in Figure 20. As discussed above, if the SSCS is applied, there will be two independent processing threads, i.e. one for used water and another for matter.

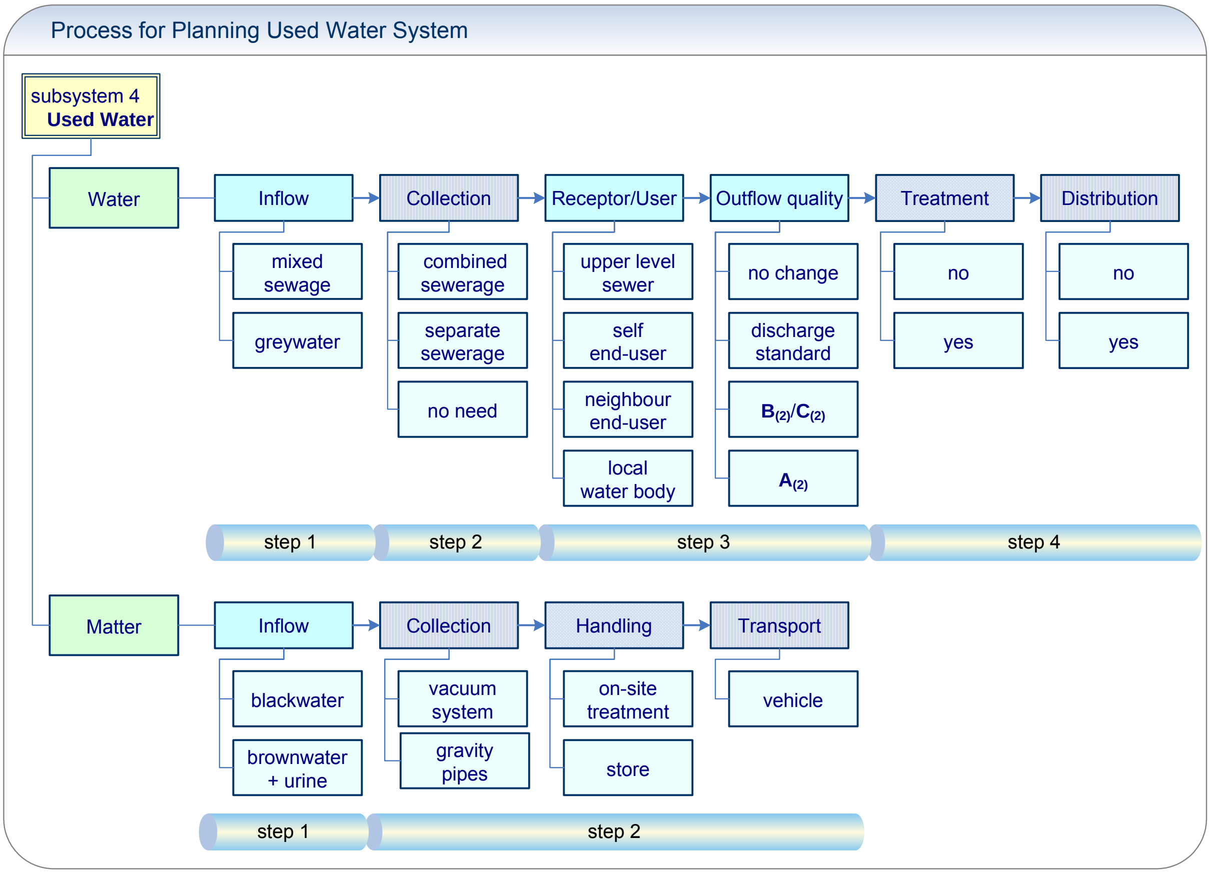


Figure 20: Process for planning used water system

The planning of the used water can be considered as 4 steps:

1. to determine the collection method, i.e. whether the SSCS is applied;
2. to determine the type of sewerage system, i.e. combined or separate, and the calculate the system scale, cost and energy consumption of sewerage system;
3. to determine the methods to deal with the used water, i.e. whether and how to reuse water, whereby the receptor or users and the required water quality are determined.
4. to calculate the system sizes, cost and energy consumption of the treatment and distribution systems.

Whether the SSCS is applied, it affects all other parts of the used water system. That is why it is assigned in the first step. The type of sewerage system is determined next, as it may join used water and rainwater systems together, whereby it influences both at the same time. Afterwards, the used water system is determined. The possible system options are given in Table 10. Depending on the types of water entities, the system options have different applicabilities (right side in Table 10). WUC is not considered, as it mostly has indoor water facilities on small scales. The selection mechanism for the options is given in § 3.3.3 and § 3.3.4.

Table 10: System options of used water – WATER

collection	transport	no.	receptor / user	outflow quality	treatment	distribu-tion	CA	UD	WUU
1. mixed sewage 2. grey-water	1. combine 2. separate 3. no need		***disposal***						
		1	upper level sewer	no change	--	--	☐	☑	☑
		2	local water body	discharge level	√	--	☑	☑	☐
			direct non-potable reuse						
		3	self end-user	**B**$_{(2)}$/**C**$_{(2)}$	√	√	☐	☑	☑
		4	neighbour end-user	**B**$_{(2)}$/**C**$_{(2)}$	√	√	☐	☐	☑
			indirect potable reuse						
		5	local water body	**A**$_{(2)}$	√	--	☑	☑	☐

Legend: √ – needed; -- – no need; ☑ – applicable; ☐ – not applicable

In order to effectively and efficiently treat the blackwater or brownwater, the vacuum system is necessary. One side, the treatment facilities need certain capacity for reaching the economical scale; on the other side, enlarging system results in increasing the cost of pipe system dramatically. Hence, blackwater systems are mainly implemented in WUU in the hierarchy. So far the blackwater system options are relative simple, i.e. mostly it is collected with vacuum system and treated through the anaerobic digestion process. The effluent from digester is transported to agriculture by vehicles. Regarding urine, a wide range of technical options is available to treat collected urine effectively, but except for “storage” (for hygienisation) and “evaporation” (for volume reduction), none of the processes have so far advanced beyond the laboratory stage (Maurer *et al.* 2006). Being the simple and cheap process, the storage is chosen as the common method to handle urine. The transport of urine is necessary, too. The possible options are listed in Table 11.

Table 11: System options of used water – MATTER

no.	inflow	collection	handling	transport	CA	UD	WUU	WUC
1	blackwater	vacuum system	on-site treatment	vehicle	☐	☑	☑	☐
2	blackwater	vacuum system	storage	vehicle	☐	☐	☑	☑
[1] +	urine	gravity pipes	storage	vehicle	☐	☐	☑	☑

Legend: ☑ – applicable; ☐ – not applicable

[1] it complements to brownwater, where brownwater has the same system options as blackwater.

2.2.5 Rainwater utilisation

Rainwater itself is very clean and already distributed over the area, but its temporal distribution is mostly very uneven. Also, due to the environmental pollution and the city complexities, many contaminants enter the rainwater in urban area. Therefore, despite being a very good water source, rainwater is barely extensively utilised in cities. To the contrary, due to its flooding risks, rainwater attempts to be eliminated from urban area as soon as possible, whereby the huge storm drains are often constructed. Today, the universal water scarcity together with the better understanding of the nature brings rainwater as water source back to our sight.

2.2.5.1 options

Storm water elimination. The rainfall strength in one event has the bell-shape. In order to avoid the flooding risks, the sizes of storm drain are designed based on the peak flow rate of one rainfall event with considering its recurrence possibilities. The design of storm drains is a well developed subject, and the national or local design standards and handbooks are generally available.

Urban storm water detention started in the 1960s when it became known that development tends to be followed by increasing the rainfall peak rate and aggravated flood damage (Ferguson 1998). Open ponds are probably the most common type of detention used in storm water management (Urbonas and Stahre 1993). Other methods to delay and reduce the peak flow are the increase of the permeable area and the construction of green area. Such measures do not only diminish the sizes of strom drains, but also potentially improve the urban environmental conditions.

Instead of being discharged out of the city with huge drains, the storm water can be retained inside and possibly converted to urban water resources, not only in water-scarce areas, but also in water-rich regions (Handia *et al.* 2003, Herrmann and Schmida 1999).

Surface runoff management. Impoundment is one good option for utilising surface runoff, which acts as the buffer storage during the rainfall events and as the irrigation water source for the vicinal green area during sunny days. Moreover, impoundments can improve the local ecological conditions and even be regarded as recreational sites. Constructed wetland can also be used to retain and utilise the rainwater, as well as to enhance the urban ecological system (e.g. Lawrence & Breen, 1998, Wong *et al.* 1999). For supplementing the local water source, the storm water is recharged into the groundwater usually by two measures: gravity filtration and direct injection. In this conception, groundwater recharge of rainwater is considered as the indirect rainwater utilisation.

As an example, an Australian program called *Water Sensitive Urban Design* is developed nationwide, which is particularly for designing and managing urban storm water in the sustainable way (e.g. Brisbane City 2005, Melbourne Water 2005). Other cities like Hamburg manage rainwater in the decentralised nature-closed system (HBSU 2006). All can be the good references for managing storm water in modern cities.

Roof-water utilisation. As barely touched area, roofs of buildings are the proper catchment area for collecting the clean rainwater that is called roof-water. After diverting the first flush of roof-water (mainly for removing sediments and debris on roofs), roof-water can easily reach very good water quality through simple treatment. Due to limited area, roof-water utilisation systems have generally small scales and only serve the local end-users. In the hierarchy of the IUWS, roof-water utilisation is considered for WUU and WUC. Since it provides a good water quality, it is mostly supplied to the indoor water uses.

2.2.5.2 planning process

First of all, the local rainfall patterns should be identified, which are the preconditions for determining the rainwater system. If the storm drain is compulsory or roof-water is adequate and suitable for utilisation, then the following planning processes come into action. As two independent and parallel rainwater systems, two general planning processes are developed (Figure 21). The corresponding options are listed in Table 12 and Table 13.

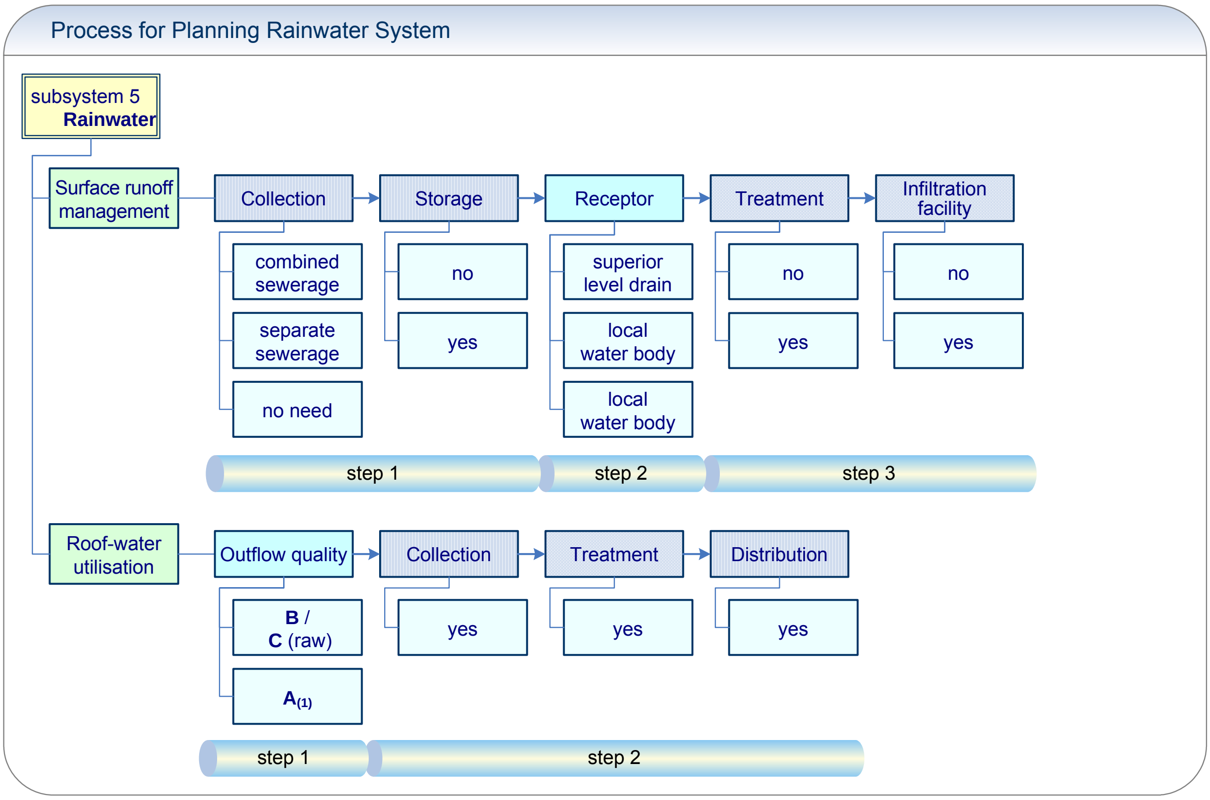


Figure 21: Process for planning rainwater system

For surface runoff management, firstly the type of the sewerage system is decided, i.e. combined or separate. According to the actual situation, the storage (e.g. impoundments) is determined afterwards. Then the dealing methods are selected, whereby water receptors and related facilities are decided. The applicability of system options based on the types of water entities is given on the right side of Table 12. Likewise, WUC is excluded from surface runoff management.

In the case of groundwater recharge, if combined sewerage is used or the water quality of surface runoff does not meet the relevant standards, certain treatment is obligatory for protecting the groundwater. The groundwater recharge is suggested applying to UD and then CA in consideration of the system sizes. If no additional treatment is needed, groundwater filtration can take place in WUU, as well. The corresponding decision making rules are introduced in § 3.3.3 and § 3.3.5.

Table 12: System options of rainwater water – Surface runoff management

no.	collection	storage	no.	receptor	treat-ment	CA	UD	WUU
				elimination				
1	combined	--	1	upper level drain	--	☐	☑	☑
2	separate	√	2	surface water body	--	☑	☑	☑
3	no need			***utilisation***				
			3	groundwater	--	☐	☑	☑
			4	groundwater	[1] √	☐	☑	☐

Legend: √ – needed; -- – no need; ☑ – applicable; ☐ – not applicable

[1] if the storm water quality does not meet the corresponding water standards, the additional treatment facilities are necessary.

As the small size system, the roof-water utilisation system is simple and applied only to WUU and WUC. Based on the supplied water quality, there are three options that are listed in Table 13.

Table 13: System options of rainwater water – Roof-water utilisation

no.	outflow quality	treatment	CA	UD	WUU	WUC
1	**C**$_{(1)}$	--	☐	☐	☑	☐
2	**B**$_{(1)}$	√	☐	☐	☑	☑
3	**A**$_{(1)}$	√	☐	☐	☑	☑

Legend: √ – needed; -- – no need; ☑ – applicable; ☐ – not applicable

All the subsystems of IUWS have been built up, and their system options have been discussed. As independent subsystems, all planning processes that are given above work individually. In the meantime as the IUWS, five subsystems must be properly constructed together. Consequently, the corresponding system options and planning processes need to be carried out, which are introduced and discussed in the next section.

2.3 *Integrated Urban Water System (IUWS)*

As an integrated system, all five subsystems are joined and considered at the same time. The system options for IUWS are developed. In the hierarchy, the planning process of IUWS is completely different, whereby a procedure is newly developed. A demonstration is presented in order to provide a comprehensive image of IUWS.

2.3.1 Options

If rainwater and/or water reuse systems are added in, the IUWS will be systematically changed. Both rainwater and reclaimed water can be used in either direct or indirect way. The key difference between direct and indirect utilisation/reuse is that the direct utilisation/reuse system changes the system structure and the infrastructure sizes, where the indirect utilisation/reuse only influences the arrangement of water sources. Correspondingly, four types of water system are identified (Table 14).

Table 14: System types of water entities in IUWS

no.	type	abbreviation	specification
1	***basic system*** only use conventional water sources	***Sys. Base***	i.e. conventional system
2	***adding rainwater utilisation systems*** 1. surface runoff utilisation AND 2. roof-water utilisation	***Sys. +Rainwater***	two options can occur at the same time
3	***adding water reuse system*** 1. indirct potable reuse OR 2. direct non-potable reuse	***Sys. +Reuse***	two options are mutual exclusive through all levels in the hierarchy
4	***adding both rainwater and reuse systems***	***Sys. +Both***	it follows the above roles

As an integrated system, all components of WIS need to be taken into account in the same time. In the WIS, seven parts are identified:

i. abstraction & transmission
ii. raw water treatment
iii. distribution (networks)
iv. collection (sewage sewer + storm drain)
v. used water treatment
vi. rainwater utilisation (surface runoff)
vii. rainwater utilisation (roof-water)

In Part **iv**, collection includes both sewage sewer and storm drain, as they can be either separate or combined. Part **vi** and **vii** are both for rainwater, as the utilisation of surface runoff and roof-water are two parallel independent systems. On the contrary, water indirect potable reuse and direct non-potable reuse are mutual exclusive through all levels in the hierarchy because in one system the water can be reused only once (in one time of water cycle). Water reuse system consists of treatment and distribution, which are included by Part **v** and Part **iii** respectively.

Since the system types vary the size and the structure of IUWS, they have to cooperate with the WIS. Therefore, a matrix is set up (Table 15). Corresponding to each type of water system given in Figure 13, the system size and seven parts of WIS have to be calculated individually. As the integrated system, the seven parts of WIS need to be added up to one lump sum. Hence, the summation is listed on the right side of the matrix. Since system cost and energy consumption are chosen as the evaluation criteria, the matrix in Table 15 is used to calculate those two parameters.

Table 15: General matrix for calculating cost and energy consumption of water entity

calculation of: 1. cost 2. energy		**system size [m^3/d]**	**abstraction & transmission**	**raw water treatment**	**distribution (networks)**	**collection (sewer + drain)**	**used water treatment**	**rainwater utilis. (surface runoff)**	**rainwater utilis. (roof-water)**	**summation**
no.	**water system type**	-	i.	ii.	iii.	iv.	v.	vi.	vii.	-
1	***Sys. Base*** water sources									
2	***Sys. +Rainwater*** 1. surface runoff 2. roof-water									
3	***Sys. +Reuse*** 1.indirct potable 2.direct non-potable									
4	***Sys. +Both*** rainwater & reuse									

Abbreviation: utilis. – utilisation

As discussed and depicted in § 2.2, all types of water systems are not universally applicable to all types of water entities. Therefore, a general Matrix (Table 15) needs to be further developed individually for CA, UD and WUU (where water facilities in WUC are excluded). For each type of water entity, options of all subsystems introduced in § 2.2 are integrated together, whereby three matrices are generated for CA, UD and WUU respectively and shown in Table 16, Table 17 and Table 18. In those matrices, the symbol "+" indicates that the subsystem option is added to the *basic system*. If several "+" occur in one cell, it means all indicated subsystem options are added at one time. The contents in the parentheses indicate that in which hierarchical level the system option takes place.

As the system types are detailed, the second column in those tables is changed to *system option*. Meanwhile, since not all seven parts of WIS are necessary to all types of water entities, the right side of those tables are various as well. In general, the main focus of CA lays on water sources and its system scales, as any variation of UD and WUU causes the changes of water usage that eventually change the scales of CA. UD is the most complicated type of water entity, while all kinds of subsystem options are applicable to it, as well as it connects CA and WUU. The system options of WUU are quite simple with only four varieties, as it has simple water sources.

Table 16: Matrix for calculating cost and energy consumption of CA

calculation of: 1. costs 2. energy no.	system option	system size [m³/d] -	abstraction & transmission i.	raw water treatment ii.	distribution (transmission) iii.	collection (sewer + drain) iv.	used water treatment v.	summation -
1	*Sys. Base*							
1.1	local source (CA)							
1.2	+ external source (CA)							
1.3	+ local source (UD)							
[1] 2	*Sys. +Rainwater*							
2.1	+ roof-water (WUU)							
[2] 2.2	+ local source (UD) + surface runoff (UD)							
2.3	+ local source (UD) + surface runoff (UD) + roof-water (WUU)							
3	*Sys. +Reuse*							
3.1	+ indirect potable (CA)							
3.2	+ indirect potable (UD)							
[3] 3.3	+ direct non-potable (UD or WUU)							
[4] 4	*Sys. +Both*							
4.1 (2.3+ 3.1/2)	+ local source (UD) + surface runoff (UD) + roof-water (WUU) + indirect potable (CA or UD)							
4.2 (2.3+ 3.3)	+ local source (UD) + surface runoff (UD) + roof-water (WUU) + direct non-potable (UD or WUU)							

[1] the implementation of rainwater utilisation is in the inferior levels, i.e. UD and WUU. Hence, its costs and energy consumption are evaluated in its corresponding levels.

[2] when surface runoff is considered as local water sources, the other types of local sources are automatically taken into account.

[3] direct non-potable reuse either in UD or in WUU are two different options. However, since they require the same amount of water from CA, they are considered as one case for CA.

[4] there are more possibilities of combination. However, if such complicated options are considered, it means that the water is very scarce, whereby only these two extreme options are involved.

Explanation: as the exemplar, the table is blank. During the calculation, two tables are generated for system cost and energy consumption each.

Table 17: Matrix for calculating cost and energy consumption of UD

calculation of: 1. costs 2. energy		system size [m³/d]	abstraction & transmission	raw water treatment	distribution (networks)	collection (sewer + drain)	used water treatment	rainwater (surface runoff)	summation
no.	**system option**	-	i.	ii.	iii.	iv.	v.	vi.	-
1	***Sys. Base***								
1.1	external source (CA)								
1.2	+ local source (UD)								
2	***Sys. +Rainwater***								
2.1	+ roof-water (WUU)								
[1] 2.2	+ local source (UD) + surface runoff (UD)								
2.3	+ local source (UD) + surface runoff (UD) + roof-water (WUU)								
3	***Sys. +Reuse***								
3.1	+ indirect potable (UD)								
3.2	+ direct non-potable (UD)								
3.3	+ direct non-potable (WUU)								
[2] 4	***Sys. +Both***								
4.1 (2.3+ 3.1)	+ local source (UD) + surface runoff (UD) + roof-water (WUU) + indirect potable (UD)								
4.2 (2.3+ 3.2)	+ local source (UD) + surface runoff (UD) + roof-water (WUU) + direct non-potable (UD)								
4.3 (2.3+ 3.3)	+ local source (UD) + surface runoff (UD) + roof-water (WUU) + direct non-potable (WUU)								

[1] when surface runoff is considered as local water sources, the other types of local sources are automatically taken into account.

[2] there are more possibilities of combination. However, if such complicated options are considered, it means that the water is very scarce, whereby only these three extreme options are involved.

Explanation: as the exemplar, the table is blank. During the calculation, two tables are generated for system cost and energy consumption each.

Table 18: Matrix for calculating cost and energy consumption of WUU

calculation of: 1. costs 2. energy		system size [m³/d]	advanced water treatment	distribution (networks)	collection (sewer + drain)	used water treatment	rainwater (surface runoff)	rainwater (roof-water)	summation
no.	**system option**	-	ii.	iii.	iv.	v.	vi.	vii.	-
1	***Sys. Base***								
1.1	external source (UD)								
2	***Sys. +Rainwater***								
2.1	+ roof-water (WUU)								
3	***Sys. +Reuse***								
3.1	+ direct non-potable (WUU)								
4	***Sys. +Both***								
4.1	+ roof-water (WUU) + direct non-potable (WUU)								

Explanation: as the exemplar, the table is blank. During the calculation, two tables are generated for system cost and energy consumption each.

2.3.2 Planning processes

As identified in the beginning, there are two sides of urban water system, i.e. the water usage side and the water infrastructure side. The water usage side deals with the water volume, including water demands, used water amounts, and capacity of water sources. The water infrastructure side includes all structures and facilities, which provide the complete service to the water end-users. The system planning is therefore implemented on the base of dealing with these two sides.

In the hierarchy of the IUWS, the water entities are embedded, which means they influence on each other. The influence of water usage is the bottom-up direction, i.e. the water usage of CA is decided by UD, and it of UD is decided by WUU, and the water usage of WUU is affected by WUC if it has WUC. Regarding the water infrastructure, the influence is reversed, as water facilities of WUU rely on UD, and they of UD depend on CA. There are interactions between water usage side and water infrastructure side, so the iteration is needed in order to reach the optimised the system options.

Therefore, the planning procedure for IUWS starts with the water usage calculation of WUC, sequentially followed by the water usage of WUU, UD and CA. The available and possible water sources of each water entity are simultaneously investigated and managed with the water usage. Because the main water sources (i.e. groundwater and surface water) enter the urban water systems through the water entities of CA and UD, the matching of water usage and water sources are performed first in CA, and then associated in UD.

After determining the water usage and water sources of CA, the water infrastructure is calculated in the sequence of CA, UD and WUU. As mentioned before, water facilities of WUC are not included. When the procedure ends at WUU, two sides are verified within each water entity. If they are not matched, the same procedure needs to be repeated. The procedure is sketched in Figure 22. The dashed arrow line indicates that the iteration can skip the calculation of WUC, as the water usage of WUC may have insignificant variations. The hollow arrows inside each water entity indicate the interrelation between water usage side and water infrastructure side.

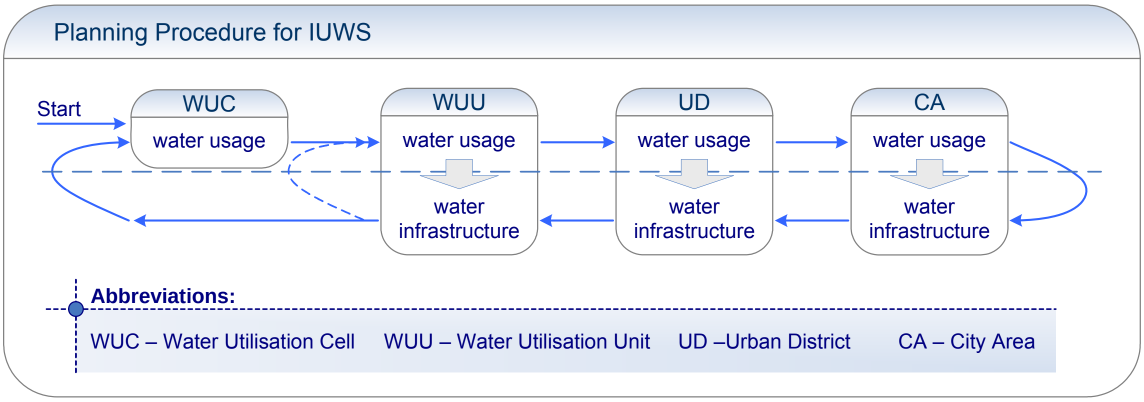


Figure 22: Planning procedure for IUWS

2.3.3 Demonstration

A proper planned IUWS should consider, design and organise all above mentioned components in the same time. For perceptually comprehending the IUWS, one demonstration as the diagram is made up (Figure 23), which displays all necessary elements synchronously, such as the hierarchy of the IUWS, water end-users, different water sources, water supply, used water and rainwater management. Different system options are also involved, like surface runoff and roof-water utilisation, direct non-potable water reuse and indirect potable water reuse. In the demonstration, only a few water entities are included with quite complicated system options for each entity. In reality, it is just contrary, where more water entities of WUC, WUU and UD are established, but each entity has simpler water system.

So far, the new conception of IUWSs is presented. It is the foundation of the decision support model for planning IUWSs, which is introduced in the next chapter.

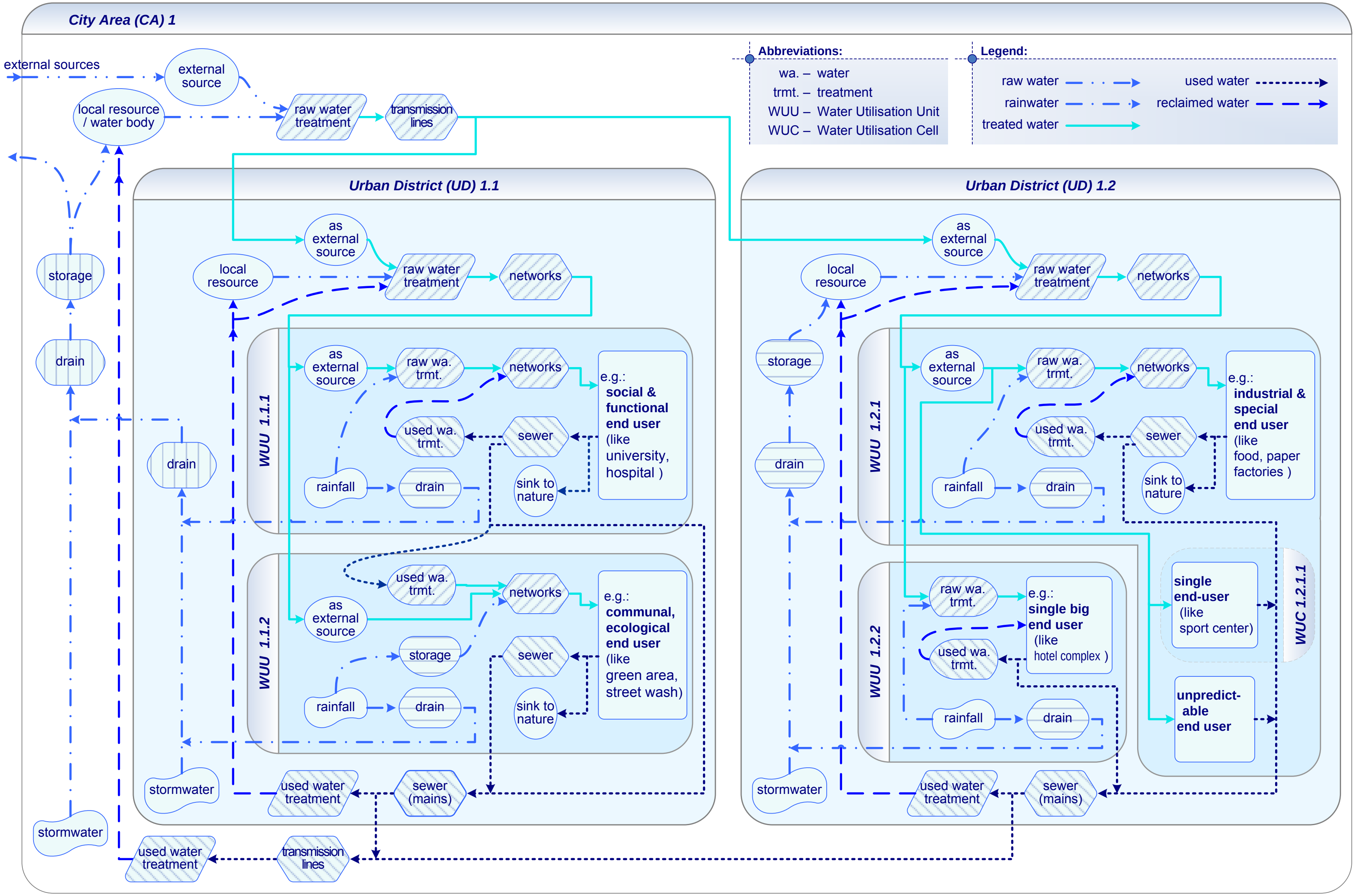


Figure 23: Demonstration of the integrated urban water system (IUWS)

Chapter 3 Decision Support Model (IUWS-DSM)

Based on the conception introduced in the last chapter, a decision support model for IUWS, namely IUWS-DSM, is conceived and constructed. The system structure and executable planning procedure are established, the decision making mechanisms and rules are developed, and the methods of calculation and comparison are introduced regarding system costs and energy consumption. Consequently, the concept to realise the IUWS-DSM in the software is proposed.

3.1 Architecture of IUWS-DSM

The basic idea is to build up a simple but functional DSM. The model should have a simple framework, as well as be easily realised in software. Moreover, the model should have the potential to be further developed in the future.

Figure 24 lays out the architecture of the decision support model (IUWS-DSM). The thick hollow arrows indicate the model procedure that is situated on the left side in Figure 24. The blocks on the right side represent the software components for managing the information and processing the data. Following the model procedure, first the project information is requested, which needs to be input by model users. Then the calculation is performed, which consists of two parts that are water usage management and WIS. The related information, such as EUWUP and water standards, etc., is acquired from the database that is set up independently. Then the system options are compared. For both calculation and comparison the necessary decision making policies are used. It can step back to calculation as the revision to water system may be needed after comparison. Finally, the optimised system options and suggestion are feedback to the model users. In the steps of calculation and comparison, the interaction between model users and the model can be necessary, which is indicated by dashed lines in Figure 24.

The components on the right side in Figure 24 are for constructing the software. The database is used to store the information and data. Three types of data containers are identified, i.e. for project information, for general information, and for knowledge base. Project information is the private information belonging to each project, where general information is the sharable public information, e.g. EUWUP and water standards, etc. By definition, Knowledge base is the database containing the knowledge with which the inference engine draws conclusions (Giarratano and Riley 2005). Those conclusions are the expertise that the model users query. In the IUWS-DSM, it is used to manage the information of evaluation tools and decision making policies. All these components can be intervened in by model users.

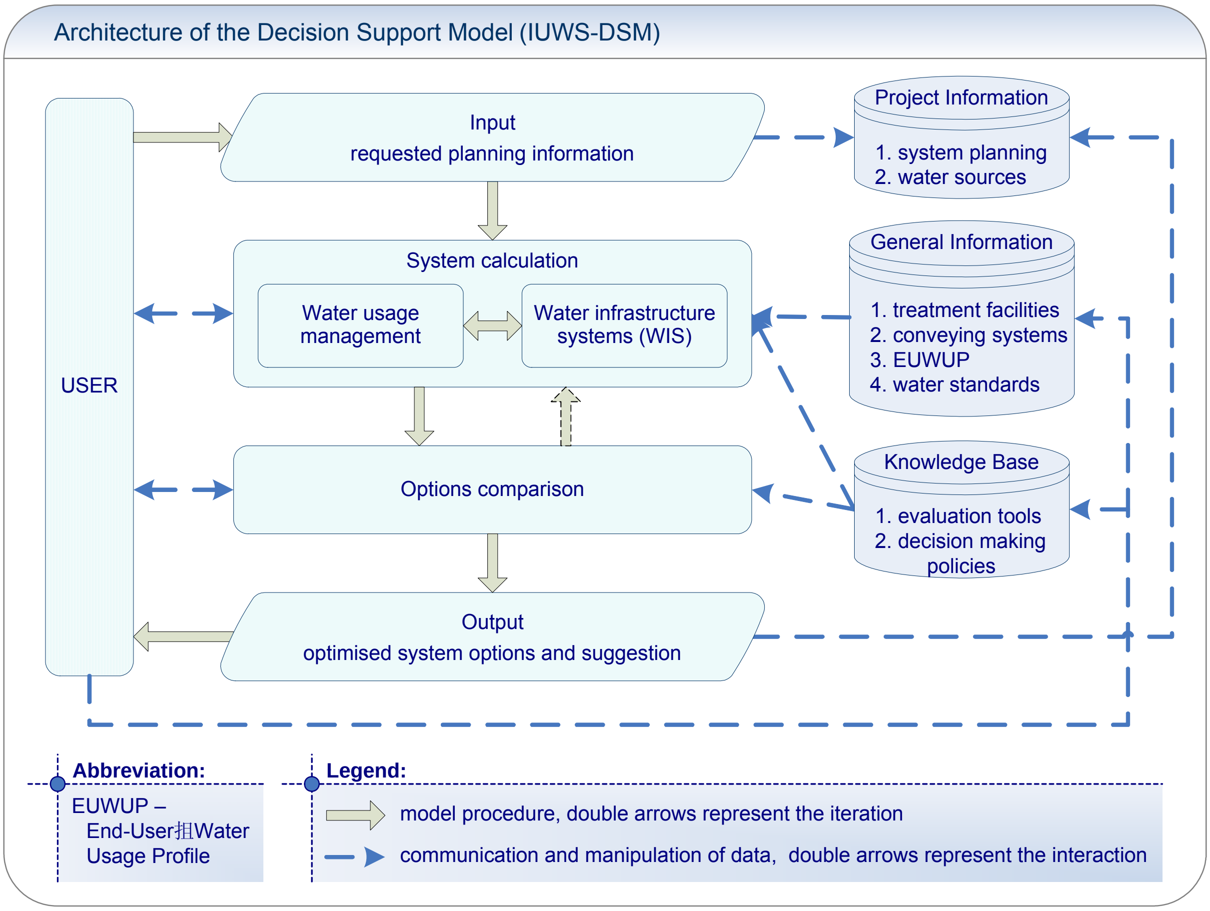


Figure 24: Architecture of the decision support model (IUWS-DSM)

Based on the above concepts, the planning procedure, the decision making policies, and the methods for system calculation and comparison are developed.

3.2 *Planning procedure for water entities*

In principle, the water system is planned based on the annually average daily water consumption, as the flow rate m^3/d. Because the model is for planning IUWS in the early project phase, the monthly, daily and hourly fluctuations of water demand are not taken into account at present. In the same way, water sources are calculated as daily water amount based on the annually available water volume, where the seasonal or monthly fluctuations of both quantity and quality are skipped. Such fluctuations can be involved in the future development of the model.

Being the independent water entities, the CA, UD, WUU and WUC, are planned individually. Meanwhile, since the water entities are hierarchically embedded, the interrelations must be properly described and managed. Based on these concepts, the general planning procedure is developed, and then the particular procedures or steps are set up according to each type of water entities.

3.2.1 General procedure

Following the conception given in § 2.3.2, the planning procedure falls into two stages with eight designing steps (Figure 25). This general procedure is the base for planning all four types of water entities.

General Planning Procedure for Water Entities

step	main work and aims
	Stage One: water usage management
1	request basic planning information
2	ascertain possible EUWUP, assess the water usage scenarios
3	evaluate available and possible water sources
4	determine the planning principles of water system
	Stage Two: design of WIS
5	appraise the system sizes
6	estimate systems costs
7	evaluate system energy consumption
8	compare the different system options, generate the advisable system options

Figure 25: General planning procedure for water entities

Stage One. Water demand, sewage generation and water sources are determined and matched. The optimised water usage is thereby found out, which acts as the footstone of the next stage. Corresponding to Figure 25, each step is explained as follows.

Step 1. First of all, basic information of water entity is requested, such as the area sizes, the planned or existent population. If it is WUU or WUC, its type needs to be confirmed so that its EUWUP can be determined (see Figure 12). Other information, like green area, road area, water bodies (rivers or ponds) should also be given but not compulsory. The suggested data-acquiring forms (i.e. tables) are built up and shown in Appendix 1.1.

Step 2. Afterwards, the water usage of water entity is measured. As discussed in previous chapter, the EUWUP is set up for grouped end-users, which is pre-defined and stored in database. Therefore, the water usage of WUC and WUU is simply obtained based on their types and sizes and the corresponding EUWUP, where the water usage of UD and CA are calculated based on their affiliated water entities. Each water entity can use several EUWUP, which represent different scenarios.

Step 3. Subsequently, the water sources of the planned water entity are inspected and matched to the water demands. The water quantity and quality of each possible water source are measured. If several water sources are available, the priorities of water sources need to be determined. The general priorities of water sources are discussed in § 3.3.1. The data-acquiring table is set up in Appendix 1.2.

Step 4. Based on water usage and water sources, the planning principles are set up, e.g., with single or dual water supply system, with combined or separate sewerage system, with or without rainwater utilisation, with or without water reuse, in which manners to reuse water, etc. The principles guide the calculation and comparison of WIS in the next stage.

Regarding the water sources, besides the actual data, there are four additional calculations, i.e. surface runoff utilisation, roof-water utilisation, indirect potable reuse, and direct non-potable reuse. The calculation methods are introduced as follows.

Calculation: surface runoff utilisation. The amount of surface runoff that is converted to the local water source can be calculated with the simple method:

$$Q_{srfc.runoff} = \left(c_{srfc.runoff} \cdot P_{ann.} \cdot A_{srfc.} \cdot \mu\right) / 365 \qquad (1)$$

where: $Q_{srfc.runoff}$ – daily usable rainwater, m^3/d

$c_{srfc.runoff}$ – average coefficient of surface runoff collection, -

$P_{ann.}$ – annual precipitation, m

$A_{srfc.}$ – ground catchment area, m^2

μ – percentage of surface runoff used for groundwater recharge, -

Calculation: roof-water utilisation. Eq. (2) is the general method to calculate the daily availability of roof-water. The rainfall may distribute unevenly over months, so the storage tanks are essential to compensate it. As the good reference, German standard of DIN 1989 (2002) provides the detailed methods to calculate and install the appropriate rainwater tanks.

$$Q_{rf.wa.} = \left(c_{rf.wa.} \cdot P_{ann.} \cdot A_{roof} \cdot \eta\right) / 365 \qquad \text{(Fraunhofer 2004)} \qquad (2)$$

where: $Q_{rf.wa.}$ – daily usable rainwater, m^3/d

$c_{rf.wa.}$ – coefficient of roof-water collection, -

$P_{ann.}$ – annual precipitation, m

A_{roof} – projected usable roof area, m^2

η – effectiveness of filter, 0,9 ~ 0,95

Calculation: indirect potable reuse. All collected used water can be treated to the suitable quality and supplement to local water sources. It can be simply calculated as:

$$Q_{indrct.reu.} = c_{used.wa.} \cdot Q_{used.wa.} \qquad (3)$$

where: $Q_{indrct.reu.}$ – water amount of indirect potable reuse, m^3/d

$c_{used.wa.}$ – coefficient of used water reclamation, -

$Q_{used.wa.}$ – collected used water amount, m^3/d

Calculation: direct non-potable reuse. It needs to be proved whether the reclaimed water amount is bigger than the real needed amount. Maximal only the real needed amount is supplied.

$$Q_{drct.reu.} = Min\left(c_{used.wa.} \cdot Q_{used.wa.}\ ;\ Q_{demand.B/C}\right) \tag{4}$$

where: $Q_{drct.reu.}$ – water amount of direct non-potable reuse, m^3/d

$c_{used.wa.}$ – coefficient of used water reclamation, -

$Q_{used.wa.}$ – collected used water or greywater, m^3/d

$Q_{demand.B/C}$ – water demand with Quality **B** or **C**, m^3/d

Stage Two. In this stage, the costs and energy consumption of WIS are evaluated followed by the comparison betweendifferent system options.

Step 5. The sizes of water intake and treatment facilities, and conveying system are determined based on the information obtained from Stage One. The determination methods are given in § 3.4.1.

Step 6. and *Step 7*. The costs and energy consumption of water system are hereby calculated. The corresponding evaluation methods are described and discussed in § 3.4.2 and § 3.4.3.

Step 8. Based on the costs and energy consumption, the system options are compared, and then the optimal or appropriate options are advised to system planners and decision makers.

This is the general planning procedure. Since different types of water entities have their particular attributes, the individual planning procedure varies, whereby it is further developed and discussed.

3.2.2 Planning of water entity of GROUP type

As discussed in § 2.2.1, the water usage of WUU and WUC is obtained based on EUWUP, where two types of EUWUP can be used. If local data are not available at all, the information of adjacent area or similar projects can be used as references.

The main water sources of WUU and WUC are the external source, i.e. from their superior water entities. The possible local sources are roof-water utilisation and direct non-potable water reuse, which can be calculated by Eq. (2) and Eq. (4).

Concerning the water infrastructure, it is not considered in WUC, as WUC has mostly indoor water facilities. Therefore, only Stage One in Figure 25 is executed for WUC. Whether the water infrastructure of WUU is involved in IUWS is not fixed, as it can either belong to the local municipality or be the private properties. If the water infrastructure of WUU is included, Stage TWO in Figure 25 is performed. Having small dimensions, all treatment facilities in WUU are considered only as package plants. The information of their cost and energy consumption can be obtained from the manufacturers. The information of pipe systems can be directly obtained from either the statistical data, or modified data from the similar WUU, or actual design.

If WUU is designed as the single project, then it can exactly follow the procedure in Figure 25. If WUU is designed within UD, after managing its water usage, it needs to go to superior level for requesting the necessary information firstly (as shown in Figure 22). Thereby, the procedure is further developed.

3.2.3 Planning of water entity of ZONE type

In the hierarchy, the planning procedure for water entities of ZONE type is the combination of the two procedures in Figure 22 and in Figure 25. The entire planning procedure of CA is shown in Figure 26. As the inferior water entities of CA, the planning procedure of UD is already embedded in. If the procedure is used only for UD, the steps of **a.i**, **a.ii** and **a.iii** in Figure 26 are skipped. As there are interactions between water entities in different levels, the iteration is needed in order to achieve the appropriate and optimised solutions.

Planning procedure for water entities of type CA and UD

Step				main work and aims
a	b	c	d	
			in WUC	
			d.i	***Stage One***: water usage management
			d.ii	if there are more WUC, repeat step **d.i**
		in WUU		
		c.i		***Stage One***: water usage management
		c.ii		if there are more WUU, repeat step **c.i**
	in UD			
	b.i			***Stage One***: water usage management
	b.ii			if there are more UD, repeat step **b.i**
in CA				
a.i				***Stage One***: water usage management
a.ii				***Stage Two***: design of WIS for CA
	b.iii			***Stage Two***: design of WIS for UD
		c.3		***Stage Two***: design of WIS for WUU
	b.iv			adaptability inspection of UD for its WUU if not proper or can be optimised, go to step **b.iii**
a.iii				adaptability inspection of CA for its UD if not proper or can be optimised, go to step **a.ii**
output of the optimised IUWS				

Figure 26: Planning procedure for water entities of type CA and UD

The water demand of UD is the summation of the demands of its WUU. Since one UD contains a number of WUU and each WUU can have several possible water demands, the water demand of UD can be many possibilities due to the combination. As explicated in 2.2.1.3, the simplication is taken in order to reduce the variations, whereby only the same water usage scenarios are summed, e.g. *scenario 1* of all WUUs in the same UD are summed as *scenario 1* of water usage for the UD. The water usage of CA is carried out in the same ways but with the summation of its UD. Such kind of summation represents the extreme situations covering the range where other possibilities fall into. As the planning tool for the early phase of projects, such simplification is appropriate as it generates suitable solutions but dramatically reduce the calculation work.

UD can have individual water sources, but with the second priority. It means in normal situation the water supplied from CA is considered for UD in the first. Only when the source water from CA has either quantity shortage or quality issues, the local water sources in UD will be taken into account. In CA, local water sources are always considered firstly, where external sources have lower priorities. More detailed decision making mechanism and rules for water source selection are given in § 3.3.1.

Though having redundant water sources result in a more secure supply system, it causes also a more complicated and expensive system. Initially it is not in the concern of this model, and it keeps open for planners to consider redundant water sources in their systems.

The methods for determining the sizes of WIS are described in § 3.4.1. The methods for estimating system costs and evaluating energy consumption are introduced and discussed in § 3.4.2 and § 3.4.3. The comparison methods are explicated in § 3.5.

3.3 Decision making policies

If there is more than one option, the decision has to be made. Following the design procedure and based on the subsystem options, a flowchart is developed, whereby the positions for making decisions are clearly revealed (Figure 27). Three blocks are built up from top to bottom in Figure 27. The first block *water usage & sources* just represents *Stage One* of the planning procedure shown in Figure 25. The third bock *subsystem options & applicability* summarises the information from Table 8, Table 9, Table 10, Table 11, Table 12 and Table 13, which determines the WIS that is calculated in *Stage Two*. The second block *decision making positions* that connects two parts is just the critical place where the proper dicisions have to be made, which are identified as follows:

1. selection of water sources,
2. supply methods of desired water,
3. collection and transport methods of used water and rainwater,
4. utilisation methods of used water,
5. utilisation methods of rainwater.

The corresponding decision making policies are thereby developed.

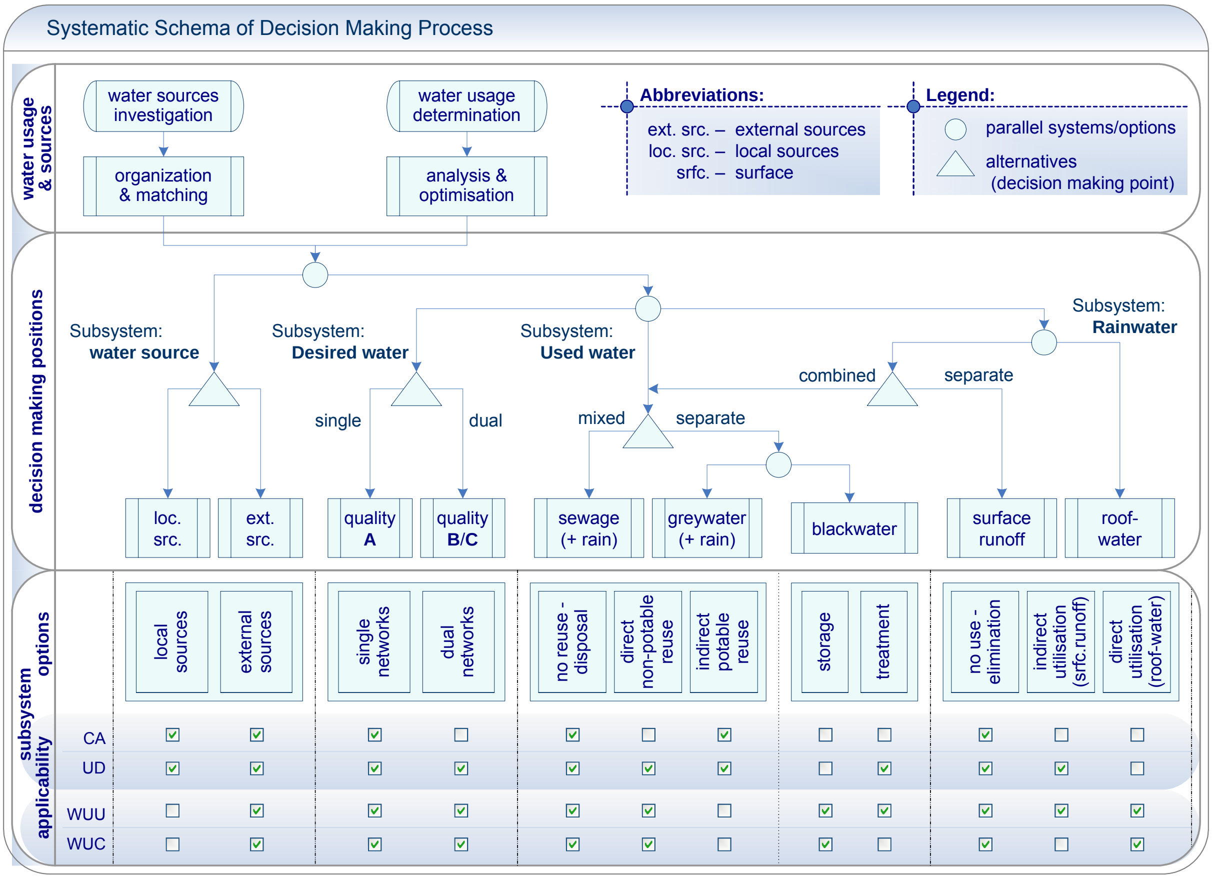


Figure 27: Systematic schemma of decision making process

3.3.1 Water sources

As categorised in § 2.2.2, there are two sorts of water sources with seven types. The external source of *superior water entity* is the man-made type in the purpose of planning water entities independently. One water entity can have several water sources and it is possible that either one of them is able to satisfy the water demand. So the general priorities of water sources regarding the types of water entities are set up in Table 19.

Primarily, the local natural sources, i.e. groundwater and surface water are considered as the main water sources, which have various subtypes and different accessibilit. The selection of natural water sources is well developed and practised, whereby no further discussion is made for them. Based on the conception and hierarchy of IUWS, other water sources are investigated and thereafter, general priority and determination mechanism are developed.

Rainwater is considered as the additional source. Two utilisation methods have different applicability. The groundwater augmentation is a long-term process that is implemented in UD and WUU. If additional treatment is necessary, it is suggested implementing only in UD due to the economies of scales. Since it turns to the groundwater, it is not dealed with apart from groundwater afterwards. Having only small scales, roof-water utilisation is applied to WUU and WUC. As the groundwater augmentation is a more environmental friendly and natural-like process, and has less facilities and maintenance requirement (but not always), it has higher priority than roof-water utilisation in principle.

If rainwater is not appropriate or still not sufficient, the option of water reuse is taken into account. Rainwater is much more clean but with uncertainty, where reclaimed water requires sophisticated treatment facilities but with the stable water quantity. In considering of treatment costs, ecological conditions and the social acceptance, rainwater utilisation has higher priority than reclaimed water. Regarding two water reuse methods, usually the indirect potable reuse is firstly considered than the direct non-potable reuse, because the first option requires no additional distribution system, and it has the recovery phase in the nature that makes the reclaimed water more natural and safer.

If all above local sources are not adequate, the external sources are comprised. The *long distance water diversion* is mainly considered and the coastal city can have *seawater* as the source with desalination process. Being still the very expensive process, the desalination of seawater has the lowest priority.

In reality, the conditions are various, so the priority of water sources given in Table 19 is in general that is used in the early project stage. The model users need to make the final decisions based on the actual conditions.

Table 19: Priority of water sources based on the type of water entity

no.	water source	priority				critical considerations
		general	**CA**	**UD**	**WUU/ WUC**	
a	groundwater	1	1	2	--	accessibility, natural pollutants, groundwater level
b	surface water	2	2	3	--	seasonal variation, pollution risks, intake feasibility
c	rainwater					distribution of annual precipitation, rainfall pattern, soil type, groundwater level, roof material, storage capacity
	[1] – surface runoff	3.1	3	4	--	
	– roof-water	3.2	--	--	2	
d	reclaimed water					collection methods, natural water body, recovery time, risks of pipe cross connection
	– indirect potable	4.1	4	5	--	
	– direct non-potable	4.2	--	6	3	
e	long distance diversion	5	5	--	--	geographical conditions, transmission method
f	seawater	6	6	--	--	place of abstraction, impacts of humans' activities
g	superior water entity	7	--	1	1	water quality

[1] it is used as the groundwater source in CA and UD, but the infiltration processes take place in UD and WUU.

Based on the priorities, a decision making tree is set up in Figure 28. The water demand is the base that is firstly matched by the local natural sources in CA, supplemented by local natural sources in UD. If all of them are not adequate, then rainwater followed by reclaimed water can be utilised, which is treated as the *alternative 1*, or looking for the external sources as the *alternative 2*. In alternative 1, the utilisation of surface runoff is considered first, followed by the roof-water utilisation. If the demand is still not satisfied, the options of water reuse are considered. In alternative 2, long-distance water diversion and seawater desalination are the options. In general, alternative 1 has higher priority that alternative 2.

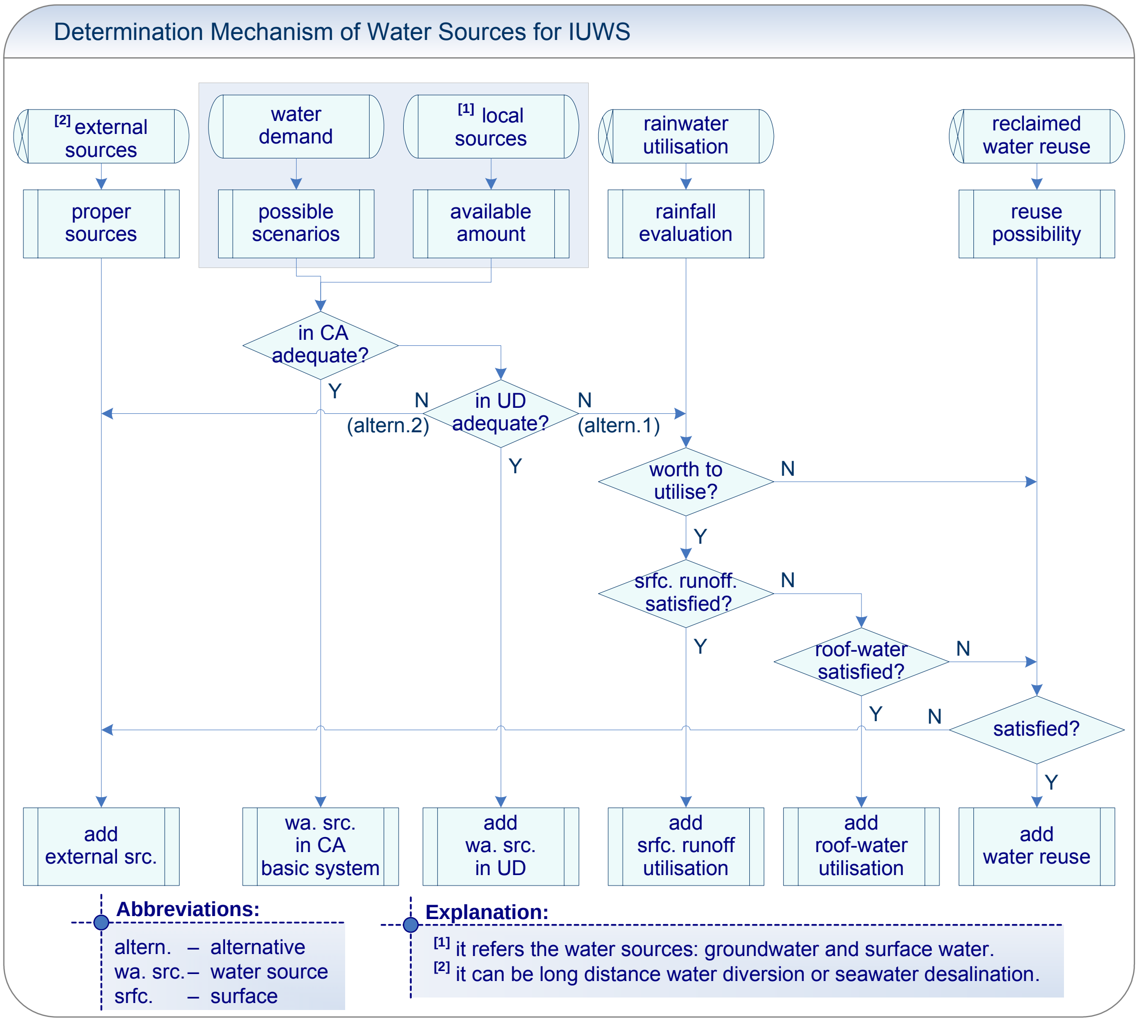


Figure 28: Determination mechanism of water sources for IUWS

3.3.2 Water supply

Based on the end uses, either single or dual water supply system can be adopted. The decisive factor is the combination of water quality and quantity. First of all, Quality **A** is considered. If its amount is less than 30% of total water amount, it is suggested with dual system, i.e. Quality **A** has one distribution system where the Quality **B** and **C** together have the second one. On the opposite side, if Quality **A** is dominant (set up as 70%), the single system is deployed. Being at the middle stage, the water amount of Quality **B** can be merged with either Quality **A** or **C** depending on its portion. The amount of Quality **C** can be supplied either with **A** and **B** if it has the small portion, or only with **B** if the portion of **B** plus **C** is the dominant, or have an independent distribution system if the portion of **A** plus **B** is the minority. Particularly, reclaimed water cannot be distributed together with drinking water networks, so whenever there is a direct non-potable reuse system, it is must be the dual system.

For easier manipulating the rules, one matrix is built up in Figure 29. In the matrix, horizontal axe represents the water quantity, where three types of water quality are situated in vertical direction. The up or/and down arrows in the matrix indicate that its water amount can be merged with the other portion (following the arrow direction). The horizontal double arrows indicate that it is possible to be handled in the same methods as both sides. Meanwhile, the percentages as critical conditions set up in the matrix are 20%, 30%, 50% and 60%. Such numbers can be either directly adopted or varied according to the local conditions. Based on the matrix, the rules are established and listed in Table 20.

Matrix for Determining the Type of Distribution Systems

Quality	**Quantity (%)**	**Suggested networks**	**Quantity (%)**	**Suggested networks**	**Quantity (%)**	**Suggested networks**	**Quantity (%)**
A	0	———	30	———	60	———	100
		dual		↔ both possible		single	
B	0	———	20	———	50	———	100
		↑ merged with **A**		↕ merged with **A** or **C**		↓ dual (with **C**)	
C	0	———	20	———	50	———	100
		↑ merged with **B**		↔ both possible		dual	

Figure 29: Matrix for determining the type of distribution systems

Table 20: Rules for determining the type of distribution systems

No.	**IF** (quantity of Quality **X**)	**THEN**	**explanation and consideration**
1	**A** < 30%	Dual	drinking water pipes have small sizes; dual system can be compensated by reduced treatment cost
2	**A + B** < 30%	Dual	the same as the above case
3	**A** > 70%	Single	due to the economies of scale, the parts of Quality **B** and **C** should supplied together with **A**
4	**A** > 30% and **A + B** > 70%	Single	as reduced treatment cost probably cannot cover the second pipe system
5	direct non-potable reuse	Dual	it is forbidden to cross connect potable water and reclaimed water, so dual system is prerequisite
6	rest situations	both possible	except above situations, the types of distribution system have to be figured out case-to-case

Down to each type of water entity, its water supply system has the particular conditions and consequently, it need to be regulated individually. Based on the system options given in Table 8 and Table 9 and considering the determination roles, the possibilities of water supply systems for CA, UD and WUU are detailed and depicted in Table 20, Table 21, Table 22 Table 23, Table 24, and Table 25. Those tables have the unified form. The water sources are listed in the first, followed by the supplied quality, where the treatment stages are also given simultaneously. Symbol "↗" indicates the water quality is upgraded, and symbol "→" means that the water quality remains the same. On the right side the essential explanation is given.

The general procedure to plan the water supply systems is as follows. At first, the options of possible water sources are determined based on the decision making mechanism in Figure 28. Then, the supply manners are further narrowed by using the rules given in Table 20. Afterwards, based on the sources options and supply methods, the possible water supply systems are determined through the tables below.

Because the pipe distribution systems do not follow the law of the economies of scale, CA has only the situation of single supply system due to its large system size. The options are shown in Table 21.

Table 21: Water supply options for CA – with SINGLE system

no.	water source	supplied quality (+ trmt. stage)	explanation and consideration
1	loc.src.	loc.src. ↗ $\mathbf{A}_{(1)}$	loc.src. are adequate, easily to treat to Qual. **A**, or the demand of Qual. **A** (or **A**+**B**) is dominant
2	loc.src.	loc.src. ↗ **B**/**C**	loc.src. are adequate, very costly to treat loc.src. to Qual. **A**, or the demand of Qual. **A** (or **A**+**B**) is minor
3	ext.src.	ext.src. ↗ $\mathbf{A}_{(1)}$	loc.src. are improper water sources, and the demand of Qual. **A** (or **A**+**B**) is dominant, and it is easer to treat ext.src. into Qual. **A**
4	ext.src.	ext.src. ↗ **B**/**C**	loc.src. are improper water sources, very costly to treat ext.src. into Qual. **A**, or the demand of Qual. **A** (or **A**+**B**) is minor
5	loc.src. + ext.src.	loc.src. ↗ $\mathbf{A}_{(1)}$ ext.src. ↗ $\mathbf{A}_{(1)}$	loc.src. are insufficient, easily to treat loc.src. and ext.src. into Qual. **A**, or the demand of Qual. **A** (or **A**+**B**) is dominant
6	loc.src. + ext.src.	loc.src. ↗ **B**/**C** ext.src. ↗ **B**/**C**	loc.src. are insufficient, very costly to treat loc.src. and/or ext.src. into **A**, or the demand of Qual. **A** (or **A**+**B**) is minor

Abbreviations: loc.src. – local sources; ext.src. – external sources; trmt. – treatment; Qual. – Quality
Explanation: both local and external water sources have the raw water quality.

UD can have either single or dual water distribution systems. UD can also have the local water sources, so it is the most complicated water entity. If local sources of UD are involved, they can be local natural sources like groundwater and surface water, or surface runoff utilisation, or indirect potable water reuse. All three sources are lumped together as the local water source. Being two different situations, the water supply options for UD with single and dual systems are described in Table 22 and Table 23, separately.

Table 22: Water supply options for UD – with SINGLE system

no.	**water source** (with quality)	**supplied quality** (+ trmt. stage)	**application conditions**
1	sp.nk. (**A**$_{(1)}$)	**A**$_{(1)}$ → **A**$_{(1)}$	CA supplies sufficiently,
2	sp.nk. (**B/C**)	**B/C** ↗ **A**$_{(1)}$	CA supplies sufficiently, the demand of Qual. **A** (or **A**+**B**) is dominant
3	sp.nk. (**B/C**)	**B/C** → **B/C**	CA supplies sufficiently the demand of Qual. **A** (or **A**+**B**) is minor
4	sp.nk. (**A**$_{(1)}$) + loc.src.	**A**$_{(1)}$ → **A**$_{(1)}$ loc.src. ↗ **A**$_{(1)}$	CA supplies insufficiently, loc.src. are the good complementary sources the demand of Qual. **A** (or **A**+**B**) is dominant
5	sp.nk. (**B/C**) + loc.src.	**B/C** ↗ **A**$_{(1)}$ loc.src. ↗ **A**$_{(1)}$	CA supplies insufficiently, and loc.src. are the good complementary sources, and the demand of Qual. **A** (or **A**+**B**) is dominant
6	sp.nk. (**B/C**) + loc.src.	**B/C** → **B/C** loc.src. ↗ **B/C**	CA supplies insufficiently, loc.src. are the good complementary sources and the demand of Qual. **A** (or **A**+**B**) is minor

Abbreviations: loc.src. – local sources; trmt. – treatment; Qual. – Quality; sp.nk. – superior networks, indicates water from networks of superior water entity

Explanation: local water sources have the raw water quality.

Table 23: Water supply options for UD – with DUAL system

no.	**water source** (with quality)	**networks X** (+ trmt. stage)	**networks Y** (+ trmt. stage)	**application conditions**
	Sys. Base			
1	sp.nk. (**A**$_{(1)}$)	**A**$_{(1)}$ → **A**$_{(1)}$	--	no need of dual system
2	sp.nk. (**B/C**)	**B/C** ↗ **A**$_{(1)}$	**B/C** → **B/C**	CA supplies sufficiently, dual system is more economical
3	sp.nk. (**A**$_{(1)}$) + loc.src.	**A**$_{(1)}$ → **A**$_{(1)}$	loc.src. ↗ **B/C**	CA supplies insufficiently, loc.src. are treated into **B/C**, as loc.src. are not easily treated into Qual. **A**, and the demand of Qual. **A** (or **A**+**B**) is minor
4	sp.nk. (**B/C**) + loc.src.	loc.src. ↗ **A**$_{(1)}$	**B/C** → **B/C**	CA supplies insufficiently, loc.src. are treated into Qual. **A**, as loc.src. have good raw Qual., and the demand of Qual. **A** (or **A**+**B**) is minor
5	sp.nk. (**B/C**) + loc.src.	**B/C** ↗ **A**$_{(1)}$	loc.src. ↗ **B/C**	CA supplies insufficiently, harder to treat loc.src. into Qual. **A** than sp.nk., and the demand of Qual. **A** (or **A**+**B**) is minor

Table 23: Water supply options for UD – with DUAL system (*continued*)

no.	water source (with quality)	networks X (+ trmt. stage)	networks Y (+ trmt. stage)	application conditions
	+direct reuse	reclaimed water is directly supplied in networks Y		
6	sp.nk. (**A**$_{(1)}$)	**A**$_{(1)}$ → **A**$_{(1)}$	used wa. ↗ **B/C**	CA supplies insufficiently
7	sp.nk. (**B/C**)	**B/C** ↗ **A**$_{(1)}$	used wa. ↗ **B/C** [1] (**B/C** → **B/C**)	CA supplies insufficiently, if reclaimed water is inadequate, sp.nk. complements it
8	sp.nk. (**A**$_{(1)}$) + loc.src.	**A**$_{(1)}$ → **A**$_{(1)}$ loc.src. ↗ **A**$_{(1)}$	used wa. ↗ **B/C**	CA supplies insufficiently even only for Qual. **A**, and loc.src. are the good addition
9	sp.nk. (**A**$_{(1)}$) + loc.src.	**A**$_{(1)}$ → **A**$_{(1)}$	used wa. ↗ **B/C** loc.src. ↗ **B/C**	CA supplies insufficiently, reclaimed water is inadequate, loc.src. can supplement, but hard to treat into Qual. **A**
10	sp.nk. (**B/C**) + loc.src.	loc.src. ↗ **A**$_{(1)}$	used wa. ↗ **B/C** [1] (**B/C** → **B/C**)	CA supplies insufficiently, loc.src. are easier treated into Qual. **A**, if reclaimed water is inadequate, sp.nk. complements
11	sp.nk. (**B/C**) + loc.src.	**B/C** ↗ **A**$_{(1)}$	used wa. ↗ **B/C** [1] (**B/C** → **B/C**, loc.src. ↗ **B/C**)	Qual. **A** is very small portion, harder to treat loc.src. into Qual. **A** than sp.nk. sp.nk. sumplements reclaimed water in the first, and then loc.src.

Abbreviations: loc.src. – local sources; trmt. – treatment; Qual. – Quality; sp.nk. – superior networks, indicates water from networks of superior water entity

[1] the water sources in the parentheses are considered as the additional source for the emergency situations.

Explanation: local water sources have the raw water quality.

It is possible for WUU to have either single or dual water system, as well. Its main water source is the water from the networks of its superior water entity. The local water source can be the roof-water, and the direct non-potable water reuse is also the suitable option for WUU. Likewise, the water supply options for WUU with single and dual systems are given in Table 24 and Table 25, respectively.

There can be more possibilities of water supply systems for CA, UD and WUU. However, those skipped ones are neither reasonable nor realisable. The options given in the tables cover the most situations. In reality, each project has certain boundary conditions that screen out the improper options, whereby the system options for each project are quite limited.

Table 24: Water supply options for WUU – with SINGLE system

no.	water source (with quality)	supplied quality (+ trmt. stage)	application conditions
	Sys. Base		
1	sp.nk. (**A$_{(1)}$**)	**A$_{(1)}$** → **A$_{(1)}$**	UD supplies sufficiently
2	sp.nk. (**B/C**)	**B/C** ↗ **A$_{(1)}$**	UD supplies sufficiently, single system is the better option
3	sp.nk. (**B/C**)	**B/C** → **B/C**	UD supplies sufficiently, no demand of Qual. **A**
4	[1] sp.nk. (**A$_{(1)}$**) + sp.nk. (**B/C**)	**A$_{(1)}$** → **A$_{(1)}$**	UD has dual system, single system is the better option
5	[1] sp.nk. (**A$_{(1)}$**) + sp.nk. (**B/C**)	**B/C** → **B/C**	UD has dual system, no demand of Qual. **A**
	+roof-water	roof-water is supplied together with sp.nk. after treatment	
6	sp.nk. (**A$_{(1)}$**)	**A$_{(1)}$** → **A$_{(1)}$** rf.wa. ↗ **A$_{(1)}$**	UD supplies insufficiently, the demand of Qual. **A** (or **A**+**B**) is dominant or roof-water is a very good and sufficient source
7	sp.nk. (**B/C**)	**B/C** ↗ **A$_{(1)}$** rf.wa. ↗ **A$_{(1)}$**	UD supplies insufficiently, the demand of Qual. **A** (or **A**+**B**) is dominant, or roof-water is a very good and sufficient source
8	sp.nk. (**B/C**)	**B/C** → **B/C** rf.wa. ↗ **B/C**	UD supplies insufficiently, no demand of Qual. **A**, roof-water is a very good and sufficient source
9	[1] sp.nk. (**A$_{(1)}$**) + sp.nk. (**B/C**)	**A$_{(1)}$** → **A$_{(1)}$** rf.wa. ↗ **A$_{(1)}$**	UD supplies insufficient water of Qual. **A**, the demand of Qual. **A** (or **A**+**B**) is dominant or roof-water is a very good and sufficient source
10	[1] sp.nk. (**A$_{(1)}$**) + sp.nk. (**B/C**)	**B/C** → **B/C** rf.wa. ↗ **B/C**	UD supplies insufficiently (of both qualities), no demand of Qual. **A** or roof-water is a very good and sufficient source

Abbreviations: rf.wa. – roof-water; trmt. – treatment; Qual. – Quality;
sp.nk. – superior networks, indicates water from networks of superior water entity

[1] it indicates that the superior water entity has the dual system.

Table 25: Water supply options for WUU – with DUAL system

no.	water source (with quality)	networks X (+ trmt. stage)	networks Y (+ trmt. stage)	application conditions
	Sys. Base			
1	sp.nk. (**A$_{(1)}$**)			no need for dual system
2	sp.nk. (**B/C**)	**B/C** ↗ **A$_{(1)}$**	**B/C** → **B/C**	dual system is the better option
3	[1] sp.nk. (**A$_{(1)}$**) + sp.nk. (**B/C**)	**A$_{(1)}$** → **A$_{(1)}$**	**B/C** → **B/C**	dual system is the better option

Table 25: Water supply options for WUU – with DUAL system (*continued*)

no.	**water source** (with quality)	**networks X** (+ trmt. stage)	**networks Y** (+ trmt. stage)	**application conditions**
	+roof-water	roof-water is treated into Qual. $\mathbf{A}_{(1)}$ or **B**/**C**		
4	sp.nk. ($\mathbf{A}_{(1)}$)	$\mathbf{A}_{(1)} \rightarrow \mathbf{A}_{(1)}$	rf.wa. ↗ **B**/**C**	roof-water is sufficient for the demand of Qual. **B**/**C**
5	sp.nk. (**B**/**C**)	rf.wa. ↗ $\mathbf{A}_{(1)}$	**B**/**C** → **B**/**C**	roof-water is sufficient for the demand of Qual. **A**
6	sp.nk. (**B**/**C**)	**B**/**C** ↗ $\mathbf{A}_{(1)}$	rf.wa. ↗ **B**/**C** [2] (**B**/**C** → **B**/**C**)	easier to treat sp.nk. into Qual. **A** than roof-water
7	[1] sp.nk. ($\mathbf{A}_{(1)}$) + sp.nk. (**B**/**C**)	$\mathbf{A}_{(1)} \rightarrow \mathbf{A}_{(1)}$	rf.wa. ↗ **B**/**C** [2] (**B**/**C** → **B**/**C**)	UD has dual system, the demand of Qual. **A** (or **A**+**B**) is minor
	+direct reuse	reclaimed water is directly supplied in networks Y		
8	sp.nk. ($\mathbf{A}_{(1)}$)	$\mathbf{A}_{(1)} \rightarrow \mathbf{A}_{(1)}$	used wa. ↗ **B**/**C**	UD supplies insufficiently
9	sp.nk. (**B**/**C**)	**B**/**C** ↗ $\mathbf{A}_{(1)}$	used wa. ↗ **B**/**C** [2] (**B**/**C** → **B**/**C**)	UD supplies insufficiently, if reclaimed water is inadequate sp.nk. complements it
10	[1] sp.nk. ($\mathbf{A}_{(1)}$) + sp.nk. (**B**/**C**)	$\mathbf{A}_{(1)} \rightarrow \mathbf{A}_{(1)}$	used wa. ↗ **B**/**C** [2] (**B**/**C** → **B**/**C**)	UD supplies insufficiently
	+both	both roof-water utilisation and direct water reuse are applied		
11	sp.nk. ($\mathbf{A}_{(1)}$)	$\mathbf{A}_{(1)} \rightarrow \mathbf{A}_{(1)}$ rf.wa. ↗ $\mathbf{A}_{(1)}$	used wa. ↗ **B**/**C**	UD supplies scarce, the demand of Qual. **A** (or **A**+**B**) is dominant
12	sp.nk. ($\mathbf{A}_{(1)}$)	$\mathbf{A}_{(1)} \rightarrow \mathbf{A}_{(1)}$	rf.wa. ↗ **B**/**C** used wa. ↗ **B**/**C**	UD supplies scarce, the demand of Qual. **A** (or **A**+**B**) is minor
13	sp.nk. (**B**/**C**)	rf.wa. ↗ $\mathbf{A}_{(1)}$	used wa. ↗ **B**/**C** [2] (**B**/**C** → **B**/**C**)	UD supplies scarce, roof-water is sufficient for the demand of Qual. **A** (or **A**+**B**)
14	sp.nk. (**B**/**C**)	**B**/**C** ↗ $\mathbf{A}_{(1)}$ rf.wa. ↗ $\mathbf{A}_{(1)}$	used wa. ↗ **B**/**C** [2] (**B**/**C** → **B**/**C**)	UD supplies scarce, the demand of Qual. **A** (or **A**+**B**) is dominant, roof-water alone is inadequate for the demand of Qual. **A** (or **A**+**B**)
15	sp.nk. (**B**/**C**)	**B**/**C** ↗ $\mathbf{A}_{(1)}$	rf.wa. ↗ **B**/**C** used wa. ↗ **B**/**C** [2] (**B**/**C** → **B**/**C**)	UD supplies scarce, the demand of Qual. **A** (or **A**+**B**) is minor easier to treat sp.nk. into Qual. **A** than roof-water

Abbreviations: rf.wa. – roof-water; trmt. – treatment; Qual. – Quality;
sp.nk. – superior networks, indicates water from networks of superior water entity

[1] it indicates that the superior water entity has the dual system.

[2] the water source in the parentheses is considered as the additional source for the emergency situations.

3.3.3 Used water and rainwater collection

Basically the following questions need to be properly answered regarding the collection systems:

1. whether the storm drain is necessary?
2. whether the centralised sewage sewer is necessary?
3. using combined or independent sewerage system?
4. whether SSCS for used water should be applied?

The decision making mechanism is therefore developed and laid out in Figure 30.

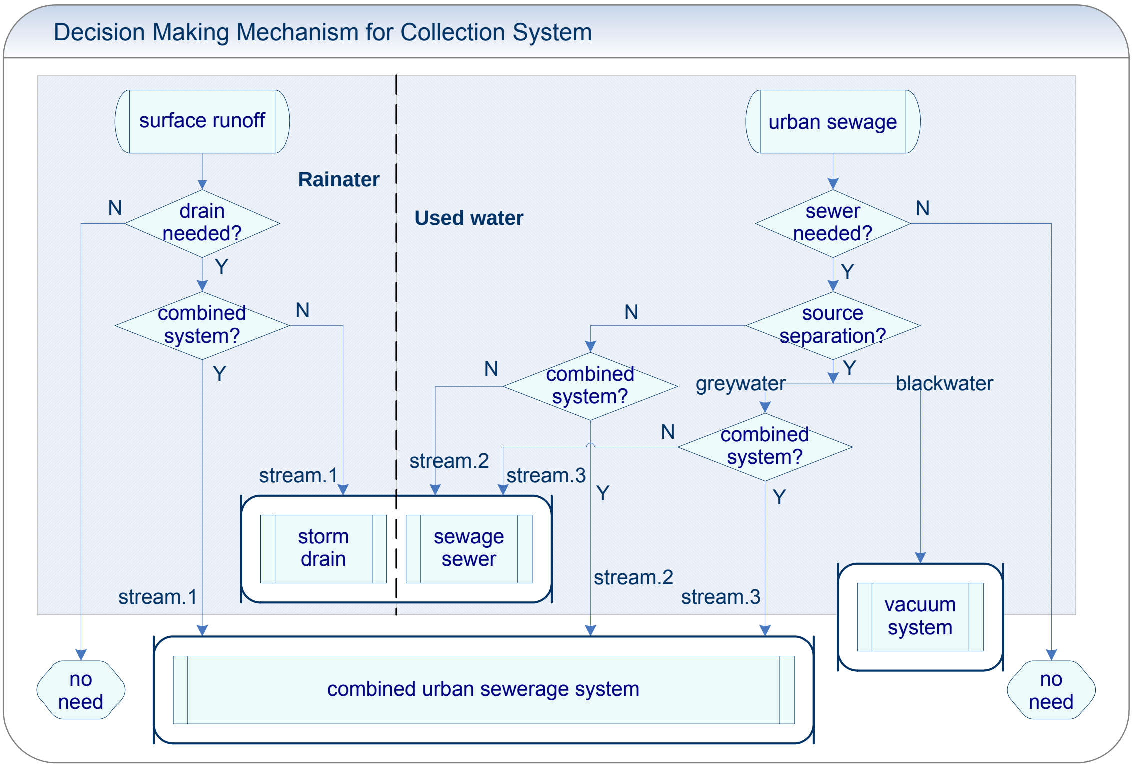


Figure 30: Decision making mechanism for collection system

Following the process in Figure 30, first of all the necessity of collection system for both urban sewage and storm water is determined. It can be the case that the storm drain or centralised sewage sewer is not needed, e.g. the precipitation is very low, or the used water is entirely disposed or reused in inferior water entities. Afterwards, the type of sewerage system is decided, i.e. combined or separate (hybrid system is not considered, as it is not a reasonable option that usually happens only in existing systems). In Figure 30, the vacuum system is the addition for handling blackwater.

Regarding the types of collection system, although it believes that the separate sewerage system is more environmental friendly, the separate system does not have the inevitable higher priority than combined one. In reality, it is impossible to completely separate two streams. Also, in many cases there is no enough place to bury two pipelines under a narrow street. Besides, the combined sewerage system has advantage of being able to treat the initial surface runoff that can contain a large amount of pollutants that are flushed out from the ground.

There are totally eight options of collection systems, which are listed and explained in Table 26. The recommended general priorities of collection systems are set up mainly by considering the economic, environmental and sanitary aspects. The general decision making criteria for selecting the proper system types are developed and depicted in Table 27. Certainly, the criteria in Table 27 are very rough, which are used to orientate the model users in the early project phase. The detailed design can be achieved by following the professional manuals and books in the coming project stages.

Table 26: Possible collection systems and their general priorities

no.	collection system	priority	conditions and considerations
	with two streams		
1	COMBINED: surface runoff & greywater + vacuum system	1	Combined system is more economic. SSCS is applied for better water reuse and resources recovery. Greywater has better hygienic conditions than urban sewage so it suggests using combined system. Blackwater system can recover nutrients & energy. It is most recommended option.
2	SEPARATE: a. storm drain b. sewage sewer	2	It believes that it is more environmental friendly. Doubled conduit systems make it more expensive. It requires more underground spaces which can be critical in urban area.
3	COMBINED: surface runoff & urban sewage	3	Most existing systems are combined systems. It is more economical but less environmental friendly. It has higher environmental risks with the overflow problems.
4	SEPARATE: a. storm drain b. greywater sewer + vacuum system	4	It is most expensive option, besides doubled conduit systems, vacuum system is also involved. It can be the system with higher security and more environmental friendly. It has lower priority due to its very high cost.
	with one stream		
5	greywater sewer + vacuum system (no storm drain)	[1] --	Storm drain is unnecessary based on the actual conditions (criteria in Table 27). SSCS is applied for better water reuse and resources recovery.
6	urban sewage sewer (no storm drain)	[1] --	It is the conventional sewerage system, where storm drain is unnecessary.
7	only storm drain (no sewage sewer)	[1] --	Sewage sewer is no need, as the sewage or greywater and blackwater has/have been already disposed or reused in inferior water entities.
8	non of storm drain and sewage sewer	[1] --	Both storm drain and sewage sewer are unnecessary in the conditions that are described above.

[1] no priority, as they are the special situations.

Table 27: General rules for determining collection system

no.	IF	THEN	conditions or examples
	without storm drain		
[1] 1	precipitation < 400 mm/a	no storm drain	The ground slope has also the effect that cannot be skipped.
[2] 2	impervious area < 30% or infiltration rate > 60%	no storm drain	e.g. urban green space, urban agriculture quarter
	without sewage sewer		
3	sewage is totally disposed or reused in inferior water entities	no sewage sewer	e.g. all WUU in UD have their own water reuse systems
4	no or very little sewage is generated	no sewage sewer	e.g. urban large green area
	combined system		
[2] 5	400 mm/a < precipitation < 800 mm/a	use COMBINED system	There are lower risks and less impact from storm water to environment due to the low precipitation.
6	SSCS is applied	use COMBINED system	i.e. surface runoff + greywater has the highest priority
7	no place to construct two pipelines parallel	use COMBINED system	e.g. many municipal pipelines under the narrow streets
8	cost of pipe laid down is extremely high	use COMBINED system	e.g. in the rock area
	sewage sewer: source separated collection		
[2] 9	household water consumption > 50%	consider SSCS	The main water consumption is from household.
[3] 10	reclaimed water from greywater can be fully reused by local users	consider SSCS	It reaches the local water balance.
[3], [4] 11	capita equivalent of water entity > 5000	consider SSCS and construct blackwater treatment system	It mainly considers economies of scale and energy balance.

[1] from MOHURD (2006)

[2] it set up based on experience, which can be adjusted based on the local conditions.

[3] the treatment facilities of greywater and blackwater are two independent systems, so they are determined separately.

[4] personal contact with Mrs. Wendland (Sanitation Policy Advisor, Women in Europe for a Common Future (WECF), E-mail: claudia.wendland@wecf.eu)

Explanation: in the rest situations that are not mentioned in the table, the types of collection systems need to be determined according to the actual conditions.

3.3.4 Used water

After determining the collection system (in Table 26), based on the application conditions (in Table 27) and following the planning process (in Figure 20), the system options of used water in Table 10 are further detailed by given their priorities (Table 28). The priorities in Table 28 should be read in vertical direction. The column of *receptor/user* in Table 28 indicates the system options where the contents in parentheses represent the desired quality after treatment. Only options *1* to *6* of the collection system (in Table 26) are taken into account since option *7* and *8* have not sewer system.

In CA, the options for used water are simple, i.e. either discharge or indirect potable reuse, whereby the water quality is upgraded to either discharge level or Quality **A**$_{(2)}$. If local water source is adequate, indirect potable reuse is not taken into account because it is more expensive after all. If the indirect potable reuse is the proper option, the greywater has higher priority to be considered than urban sewage without respect to sewerage types. Having the simple variation, the option priorities for CA are not shown in Table 28.

Table 28: System options and general priorities of used water

no.	**receptor / user**	**applicability**	**Priority**					
			1 combine srfc.runoff + gry.wa.	**2 separate** **a.** srfc.runoff **b.** gry.wa.	**3 combine** srfc.runoff + sewage	**4 separate** **a.** srfc.runoff **b.** sewage	**5 only** gry.wa. sewer	**6 only** sewage sewer
	UD							
1	upper level sewer (quality: no change)	☑	4	4	1	2	4	2
2	local water body (quality: disch. level)	☑	1	1	2	1	1	1
3	self end-user (quality: **B**$_{(2)}$/**C**$_{(2)}$)	☑	3	3	4	4	3	4
4	neighbour end-user (quality: **B**$_{(2)}$/**C**$_{(2)}$)	☐	-	-	-	-	-	-
5	local water body (quality: **A**$_{(2)}$)	☑	2	2	3	3	2	3
	WUU / WUC							
1	upper level sewer (quality: no change)	☑	3	3	1	1	3	1
3	self end-user (quality: **B**$_{(2)}$/**C**$_{(2)}$)	☑	1	1	3	3	1	3
4	neighbour end-user (quality: **B**$_{(2)}$/**C**$_{(2)}$)	☑	2	2	2	2	2	2

Abbreviations: srfc. – surface; gry.wa. – greywater; disch. – discharge

Legend: ☑ – applicable; ☐ – not applicable; - – not applied;

Explanation: in the column of *Priority*, the sub-columns are corresponding to the options in Table 26.

If used water is collected in UD, it is not suggested transferring used water further to CA in order to avoid large sewer and lift stations. The treatment plant is necessary if used water is disposed in UD. Due to its severe conditions, the used water treatment plant can have strong impact on its surroundings. On the other hand, it can be the advantage because it forces the city planners to plan the urban area in a more volumetric and natural way.

Regarding four system options in UD, there are three kinds of priority sequences based on the types of collection system. If the SSCS is applied, local discharge is considered in the first, and then two types of water reuse in UD, and at last diversion of used water to CA. This is because greywater can have better hygienic conditions than urban sewage. In the second kind of sequence, the SSCS is not used, whereby the bad quality of urban sewage results in that both water reuse options have lower priorities than diversion of used water to CA. The third kind of sequence is for the combined sewerage system without SSCS. As the conventional system, transporting used water to CA is considered first, then local discharge in UD, followed by two water reuse options. In principle, indirect potable reuse has higher priority than direct non-potable reuse because of the dual water system.

WUU has three system options of used water. There are two kinds of priority sequence depending on whether the SSCS is applied and regardless of the types of the collection system. If greywater is gathered, self direct non-potable reuse is mostly considered in the first, and then direct reuse to neighbours. Diverting greywater to UD is the last option. If urban sewage is collected, the priority order is just reversed. Either combined or separate sewerage system plays no important role in determining the system options of used water in WUU.

Blackwater is the additional and independent system that is attached to the greywater system. If the SSCS is applied, the blackwater system is automatically involved. Usually, two system options are suggested, i.e. either store or anaerobic digestion. The item 11 in Table 27 is the recommended condition to build up blackwater treatment plants.

All priorities are set up for general conditions. Eventually, the system options are determined based on the actual situation of projects.

3.3.5 Rainwater

In principle, rainwater should be retained in its initial place and supplemented to groundwater afterwards. Following the characteristics of rainwater, the utilisation systems should be also scattered. Rainwater should be assimilated into the nature mostly in WUU. The groundwater recharge of treated rainwater or the groundwater injection is suggested in UD due to economic scales of treatment and injection facilities. Disposing rainwater in CA should be avoided by all means in order to avert the huge storm drain and lift stations.

In the same way, by integrating Table 26, Table 27, Figure 21 and Table 12, the priorities of system options for rainwater management are set up in Table 29. Since CA has only one option to deal with rainwater, i.e. discharge to local surface water body, it is not listed in Table 29. Though it is not recommended option, it can be the suitable solution in some particular situations, e.g. city is located on the hillside.

In UD, if it is the separate sewerage system, groundwater recharge without treatment is always considered in the first. If treatment is needed for groundwater recharge, then discharging rainwater to surface water body is considered at first. If none of them is appropriate, rainwater is transported to CA for disposal. In combined sewerage system, if the SSCS is used, discharging mixed surface runoff and greywater to local surface water body is in the first place, followed by groundwater recharge with additional treatment, and transporting to the CA is the last option. If it is the combined sewerage without SSCS, discharging locally still has the highest priority, followed by transporting to CA, and finally groundwater recharge. These sequences are mainly based on considering water qualities.

Basically, WUU has the same principle as UD to manage rainwater except that the additional treatment is not taken into account by concerning the economies of scales. In the separate sewerage system, the priorities of groundwater, local surface water body and upper level drain have the descending order. In combined system, groundwater as receptor is excluded due to the necessity of treatment. If the SSCS is applied, surface water body has higher priority than upper level drain as receptor; if not, the priority is then reversed.

Table 29: System options and general priorities of surface runoff management

no.	receptor	applicability	Priority				
			1 combine srfc.runoff + gry.wa.	**2 separate** **a.** srfc.runoff **b.** gry.wa.	**3 combine** srfc.runoff + sewage	**4 separate** **a.** srfc.runoff **b.** sewage	**7 only** storm drain
	UD						
1	upper level drain	☑	3	4	2	4	4
2	local surface water body	☑	1	2	1	2	2
3	groundwater (no treatment)	☑	-	1	-	1	1
4	groundwater (with treatment)	☑	2	3	3	3	3
	WUU						
1	upper level drain	☑	2	3	1	3	3
2	local surface water body	☑	1	2	2	2	2
3	groundwater (no treatment)	☑	-	1	-	1	1
4	groundwater (with treatment)	☐	-	-	-	-	-

Abbreviations: srfc. – surface; gry.wa. – greywater;

Legend: ☑ – applicable; ☐ – not applicable; - – not applied;

Explanation: in the column of *Priority*, the sub-columns are corresponding to the options in Table 26.

As the simple application, roof-water utilisation is applied to WUUs and WUCs having the system options given in Table 13. Being an efficient and easy way to access the clean water source, roof-water utilisation is always recommended if local rainfall is suitable. As two parallel applications, surface run off utilisation and roof-water utilisation are determined and applied independently.

3.4 System evaluation

The cost and energy consumption are chosen as the criteria to evaluate system options, where the cost estimation is the essential criterion. The general methods to determine them are proposed. The model users choose the suitable criteria and methods according to their actual situation.

3.4.1 System sizes

As introduced in 2.1.2, the water infrastructure consists of intake and treatment facilities, and conveying system. Their sizes need be determined in the first.

The sizes of intake and treatment facilities are directly corresponding to the water demand. The common metrical units are water volume (e.g. China, Australia) and capita equivalent (e.g. Germany). Usually the large treatment plants are on-site constructed, whose structures and facilities are concentrated. The package plants have even simpler situation as they are manufactured and generally have small sizes.

Unlike intake and treatment facilities, the conveying system is spread over the whole service area. Hence, the determination of its scales is complex. In classical methods, it is calculated case by case based on the real data. In the early project phase, besides the difficulty of gathering the adequate actual data, the requirement of calculation accuracy is also relative low. Hence, the scales of conveying system, especially water networks and sewerage system, can be estimated based on statistical data, whereby certain relations between population and pipe system scales are established. One typical pattern is demonstrated in Table 30.

Such statistical information in some nations is available, which can be used directly or as references. As the examples, in USA this information of water networks and sewer system can be obtained from USEPA (2002) and Dames and Moore (1978), respectively. Burnside (2005) provides the statistical information of both water mains and sewer for Canada.

Table 30: Evaluation of pipe assets based on statistical data (as pattern)

no.	[1] **population range**	**average length based on pipe diameters [km]**					**average length [m/capita]**
		< 150 [2]	150 – 250	250 – 600	> 600 [3]	total	
1	3.000 – 10.000						
2	10.000 – 50.000						
3	50.000 – 100.000						
4	100.000 – 500.000						
5	> 500.000						
6	average						

[1] the planners should define the population ranges based on their own situation.
[2] the clusters of pipes should be categorised based on the statistical data and local conditions.
[3] the unit of pipe diameter is *mm*.

3.4.2 Cost estimation

Cost estimation is the most critical criterion in decision making. Depending on the specificity of design, the economic assessment can be distinguished in several levels with certain accuracies (Humphreys 1991):

a. order-of-magnitude +50% to -30 %
b. budget +30% to -15%
c. definitive assessment +15% to -5%

Because the IUWS-DSM is the tool for planning IUWS in the early project phase, the first level *order-of-magnitude assessment* can meet the requirement. The methods of cost estimation are thereby suggested.

3.4.2.1 general methods

In economic assessment, two sorts of cost are involved that are investment cost and annual costs, where the revenue represents the profits. In order to compare different system options, investment cost, annual costs and annual revenue are together expressed as either present value (P_0) (i.e. the value at the beginning of the project or the calculation period), or future value (F_n) (i.e. the value at the end of the calculation period), or annuity amount (A) (i.e. the value in each year during the calculation period) (Kleinfeld, 1993). In urban water projects, investment cost refers to the construction cost, where annual cost is the costs of operation and maintenance (O&M). As the municipal projects, the profits are usually not considered. Likewise, the IUWS-DSM includes only construction cost and O&M costs, too.

Cost estimation of package plants is simple, as all cost information must be provided by manufacturers. It needs to update the information from manufacturers in due course.

If the structures and facilities are constructed on-site, the cost estimation can be achieved by the classic economic calculation, which has higher accuracy but requires detailed project information and professional knowledge of economics. If the required accuracy is not high, the simpler methods can be used, whereby the empirical cost functions are suggested in the IUWS-DSM. The empirical cost functions are generated base on the statistical data of the existing projects, where the costs of facilities or structures are the functions of the critical parameters. It is a simple method but providing appropriate cost estimation, especially for the projects in their early phase. In the viewpoint of economics, three sorts of cost functions can be generated:

1. construction cost and O&M costs have individual cost functions;
2. construction cost has the cost function, and O&M costs are represented as the percentage of construction cost;
3. construction cost and O&M costs are lumped together represented by single cost function.

On-site constructed plants consists many components with the variations of treatment trains. Hence, in the viewpoint of treatment facilities, the cost functions of both construction and O&M fall into three cases:

1. the water treatment processes are classified into steps and each step has the cost function;
2. cost functions are generated for each treatment train or each structure;
3. cost functions are generated for the major components, where the costs of ancillary works or minor facilities are represented as percentage of the major parts.

The first case is corresponding to the classification of treatment processes (Figure 9) in the IUWS-DSM, so it is highly recommended. In the second case, the cost functions have the highest accuracy but require tremendous work. The third case requires less statistical data, which can cut down the work significantly. Depending on the availability of cost functions and actual requirements of projects, the model users choose the proper types of cost functions.

The empirical cost functions require a large amount of raw data in order to represent the universality. Therefore, gathering the data and publishing the cost functions are generally implemented by public authorities, official institutes or concerned agencies. According to the English literature review, most available cost functions of municipal water projects come from USA, which has been extensively developed since 1970s.

As to conveying system, its cost estimation is similar to on-site constructed plants, except that the cost functions can also be generated for each construction step (e.g. Clark *et al.*, 2002), whereby the higher accuracy can be reached. Moreover, as the costs of pipes are directly related to the diameters, which may not be properly expressed by the continuous functions, certain cost sheet can be built up (an example in Table 32).

Mostly the cost functions calculate the values of the year that the functions are generated. There are variations and fluctuations of costs along time and places. Cost indices can compensate those variations by using Eq. (5). Generally, construction cost index (CCI) is used for adjusting the costs of construction, where producer price index (PPI) can be used for O&M costs. These cost indices are usually available in local or national authorities.

$$Cost_{Current\ Year} = Cost_{Base\ Year} \cdot \frac{Index_{Current\ Year}}{Index_{Base\ Year}} \qquad \text{(Sethi \& Clark, 1998)} \qquad (5)$$

where: $Cost_{CurrentYear}$ – cost of current year, local currency

$Cost_{BaseYear}$ – cost calculated by the cost function, local currency

$Index_{CurrentYear}$ – Index of current year, -

$Index_{CurrentYear}$ – index of the year that the cost function is generated, -

In general, cost estimation methods for urban water infrastructure are summarised and structured in Figure 31, which provides the holistic view of cost estimation, as well as the procedure of determining the proper methods.

The cost functions can be in different mathematical forms. Eq. (6) is the common form involving multi-variables, and each variable represents one influential parameter.

$$Cost = a \cdot X_1^{\,b} \cdot X_2^{\,c} \cdot \ldots \cdot X_n^{\,r} \qquad \text{(Clark \& Dorsey 1982)} \qquad (6)$$

where: Cost – average cost, local currency

$X_1, X_2, \ldots X_n$ – variables influencing costs, unit is various

a, b, c,…,r – coefficient, - (estimated using regression techniques)

If only one influential parameter is considered, the Eq. (7) or Eq. (8) is commonly used.

$$Cost = a \cdot X^{b} \tag{7}$$

or $$Cost = a \cdot X^{2} + b \cdot X + c \tag{8}$$

where: Cost – average cost, local currency

X – variable influencing costs, e.g. flowrate or diameter, etc.

a, b, c, – coefficient, - (estimated using regression techniques)

All function forms are widely used. Different regression techniques are used in order to estimate the coefficients, and the common methods are non-linear analysis (Ong 1988) or fuzzy analysis (Wen and Lee, 1999), etc.

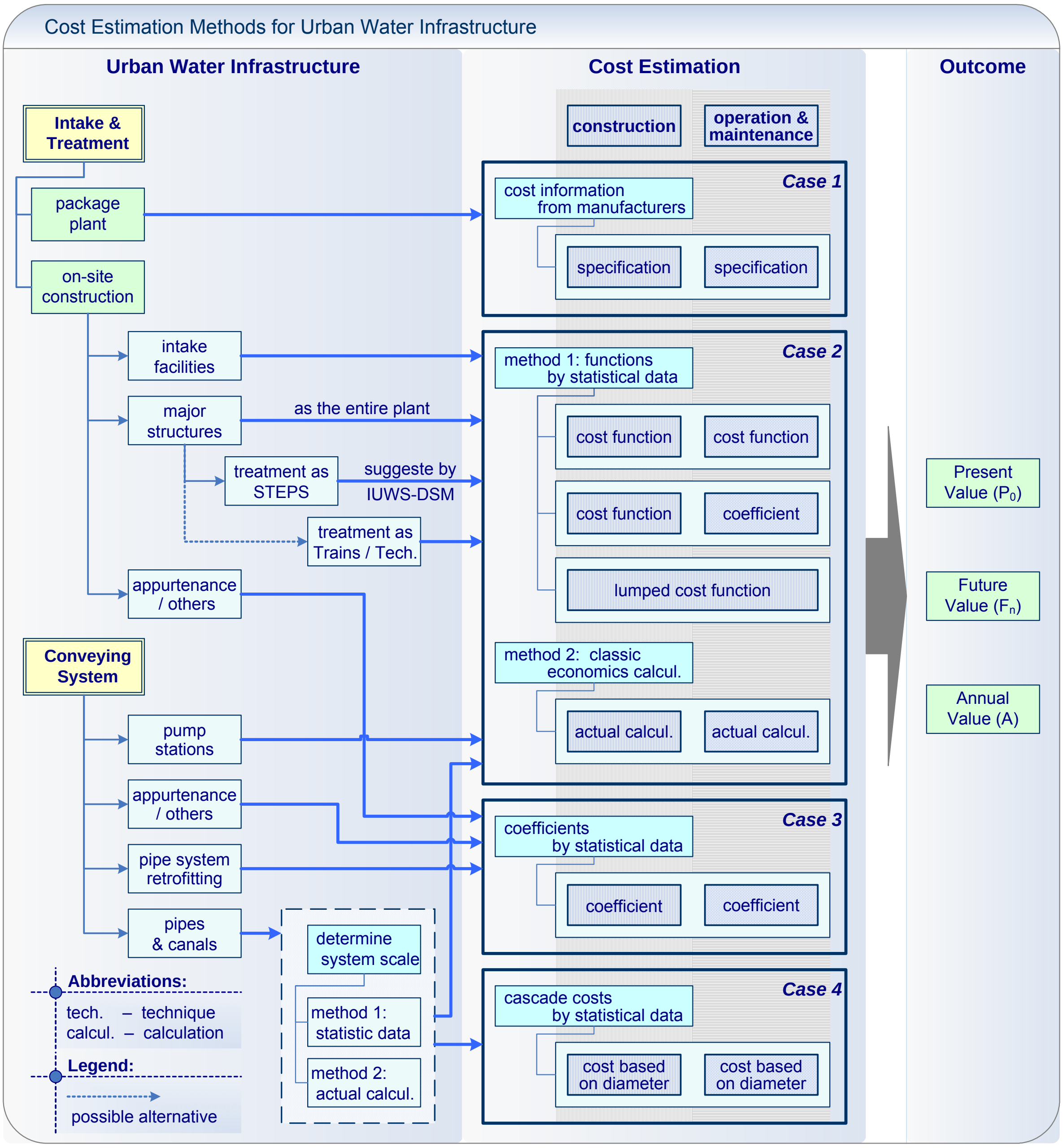


Figure 31: Cost estimation methods for urban water infrastructure

Above all, all cost functions and sheets are country or region based. Unless two countries have very similar conditions, including economic, social and government aspects, the individual cost functions and sheets should be generated based on the local statistics.

3.4.2.2 intake and treatment facilities

Concerning the IUWS-DSM, as discussed in § 2.1.4.2, the treatment facilities of both raw water and sewage in are categorised into certain steps. The cost functions can therefore set up for each step. A blank sheet is set up in Table 31 as the pattern. If the cost functions are unavailable and the project data are inadequate, it is suggested to use the *Stage2* of raw water treatment and *Grade2* of used water as the base, where the costs of other steps are obtained by multiplying the coefficients with the base. Thereby, the relative costs can be obtained and compared.

In order to more precisely represent the reality, certain ranges of system sizes are often established and each range has its specialised cost functions. Consulting USEPA (1979a) and USEPA (1979b), two levels are suggested and taken for the IUWS-DSM (Table 31).

Table 31: Table of cost functions (or coefficients) for different treatment steps (as pattern)

level	**range [m³/d]**		**Stage1**	**Stage2**	**Stage3**	**Stage4**
1	< 4.000					
2	> 4.000					
level	**range [m³/d]**	**Grade1**	**Grade2**	**Grade3**	**Grade4**	**Grade5**
1	< 4.000					
2	> 4.000					

The construction cost of intake facilities is various that depends every much on the actual conditions. It can be also rough estimated as the portion of the total waterworks cost. Reliable intake systems may represent as much as 20% of the total investment of the water treatment plant (AWWA & ASCE 1998).

As introduced above, several methods are available to estimated O&M costs. The individual cost functions can be generated. The O&M costs can also be lumped together with the construction cost, or estimated as the portion of construction cost.

3.4.2.3 conveying system

In urban area, the underground pipes are mostly used. Hence, two critical parameters are usually taken into account for cost calculation, i.e. the pipe diameter and the excavation depth, whereby the cost function of Eq. (9) is often used. If only pipe diameter is considered, Eq. (7) is used. Ong (1988) summarised the empirical cost functions of sewer, which all are the nonlinear functions of pipe diameters and the excavation depth is not always considered.

Using Eq. (9), Clark *et al.* (2002) generate the cost functions for each step of pipe construction, such as trenching and excavation, backfill and compaction, etc. The IUWS-DSM suggests using the single function representing all construction cost of pipes. In the case of pipes retrofitting, besides using Eq. (7) or Eq. (9), the coefficients can be applied to the costs between replacement and new construction. For example, Burnside 2005 applied the factor of 0,75 to the replacement cost curves for new construction situations.

$$Cost = a + b \cdot D^c + d \cdot H^e + f \cdot (D \cdot H) \qquad \text{(Clark } et\ al.\text{, 2002)} \qquad (9)$$

where:
- Cost – average cost, local currency
- D – diameter of pipe, mm
- H – depth of excavation, m
- a, b, c, d, e, f – coefficient, - (estimated using regression techniques)

Besides mathematical functions, the certain cost tables can also be used. Pipes have numerous different diameters. In such situation, the single cost function may not contently represent all conditions, so the cost tables are adopted. Table 32 gives a blank sheet of average pipe costs as a pattern. The frost line has the notable impacts on the exaction depth, especially to the small-diameter pipes. Thus, the condition of frost may be included.

Table 32: Sheet of average pipe costs based on pipe diameters (as pattern)

no.	pipe diameter [mm]	costs [m.u./m] (new)				costs [m.u./m] (retrofit)
		frost		non-frost		
		distribution	transm.	distribution	transm.	
1	< 150					
2	150 – 250					
3	250 – 400					
4	400 – 500					
5	500 – 600					
6	600 – 800					
...	...					
	2500 – 3000					

Abbreviations: m.u. – monetary unit; transm. – transmission

Pipe material is another key factor influencing the pipe costs. As comparing and selecting pipe materials are not the focusing point of the IUWS-DSM, the most common pipe materials are used, and they keep the same in all system alternatives.

If the geological conditions need to be involved, the additional cost can be added or specific coefficient can be used. For example, Burnside (2005) adds the additional allowance for rock conditions.

As to population densities, intuitively it directly affects the sizes of pipe systems. Nevertheless, after surveying 3895 medium and large sizes of water systems, USEPA (2006) found that population density has no significant improvement to the simpler cost model based only on pipe diameter and length. Thereby, the IUWS-DSM excludes the factor of population density, too.

Pump stations are the essential parts of the conveying system, so the empirical cost functions are developed in general. Other ancillary works such as storages, valves and hydrants, etc., are often estimated approximately as the percentage of the pipe costs. Certainly, the costs of those ancillary works can be estimated by empirical cost function, as well (e.g. USEPA 1999 and Burnside 2005).

The same methods are used to estimating O&M costs of conveying system, i.e. with cost functions or as percentage of construction cost. Oron (1996) states that annually O&M costs of distribution system are usually up to 3,0% of the overall capital investment over the lifetime of the asset, and Tang *et al.* (2006) calculated O&M costs of the water reuse system in Hong Kong to be 1,03% of the capital cost. The general O&M cost is thereby suggested as 2,0% of the capital cost (Chugg 2007).

3.4.3 Energy assessment

Nowadays the energy gains more and more attention worldwide. As an objective criterion, the assessment of energy consumption can help to compare not only different equipments and techniques, but also operational and management levels of water facilities between regions/countries. However, the research and information about the energy consumption in urban WIS are universally inadequate. So there are no existing simple tools to estimate the energy consumption in WIS. Against this background, a sketchy method for assess energy consumption is proposed.

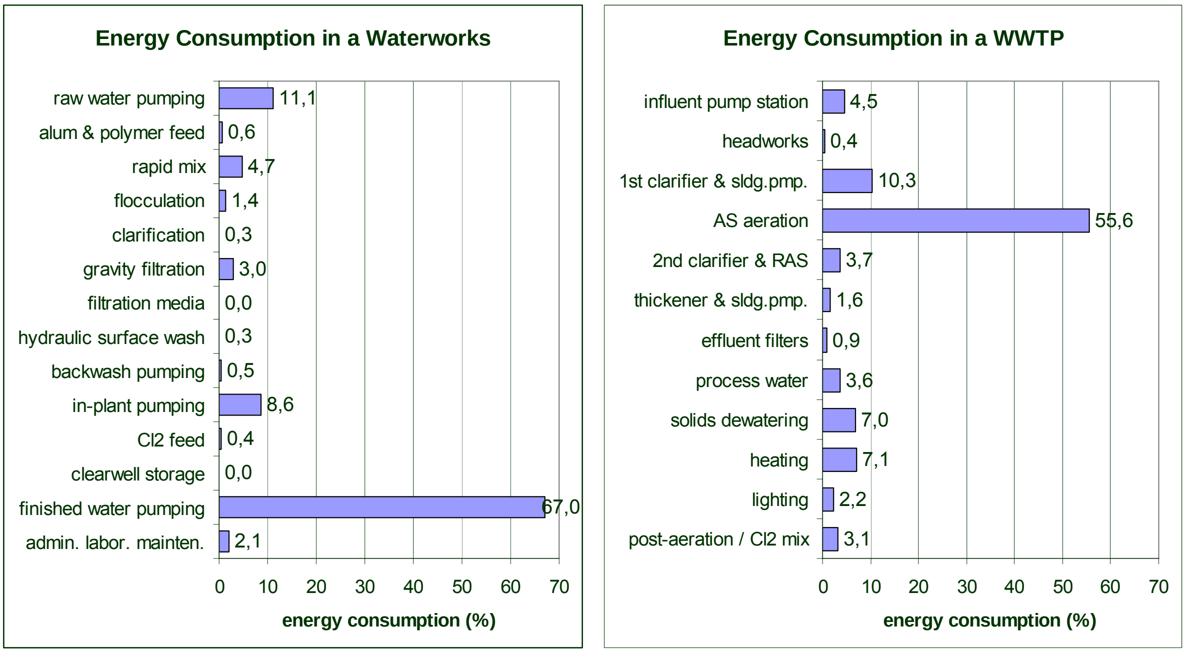


Figure 32: Distribution of energy consumption in a waterworks (HDR 2001) and a WWTP (Metcalf & Eddy 2003)

In WIS, energy is mainly used to drive motors, and it occurs mostly in two places, i.e. treatment plant and pump station. Figure 32 depict the distribution of energy consumption in a typical waterworks and a typical WWTP. It shows clearly that more than half of energy is consumed by finished water pumping and activated sludge aeration, respectively. Each of other parts has small portion. Meanwhile, the different treatment trains for the same treatment purposes may have different energy consumption. In the conveying system, pump stations consume the most energy.

In the IUWS-DSM, the proposed procedure to assess the energy consumption for urban water infrastructure is depicted in Figure 33. In the same way, treatment facilities involve two types of facilities, i.e. package plant and on-site constructed. As discussed above, the information of package plants are obtained from the manufacturers. Regarding on-site constructed plants, there are five parts of energy consumption. First part is the intake facilities. Second part is the treatment steps, which are corresponding to the classification of urban water treatment processes in Figure 9. If the energy information of each treatment train or treatment technique is available, the energy assessment can be also performed in more detailed way.

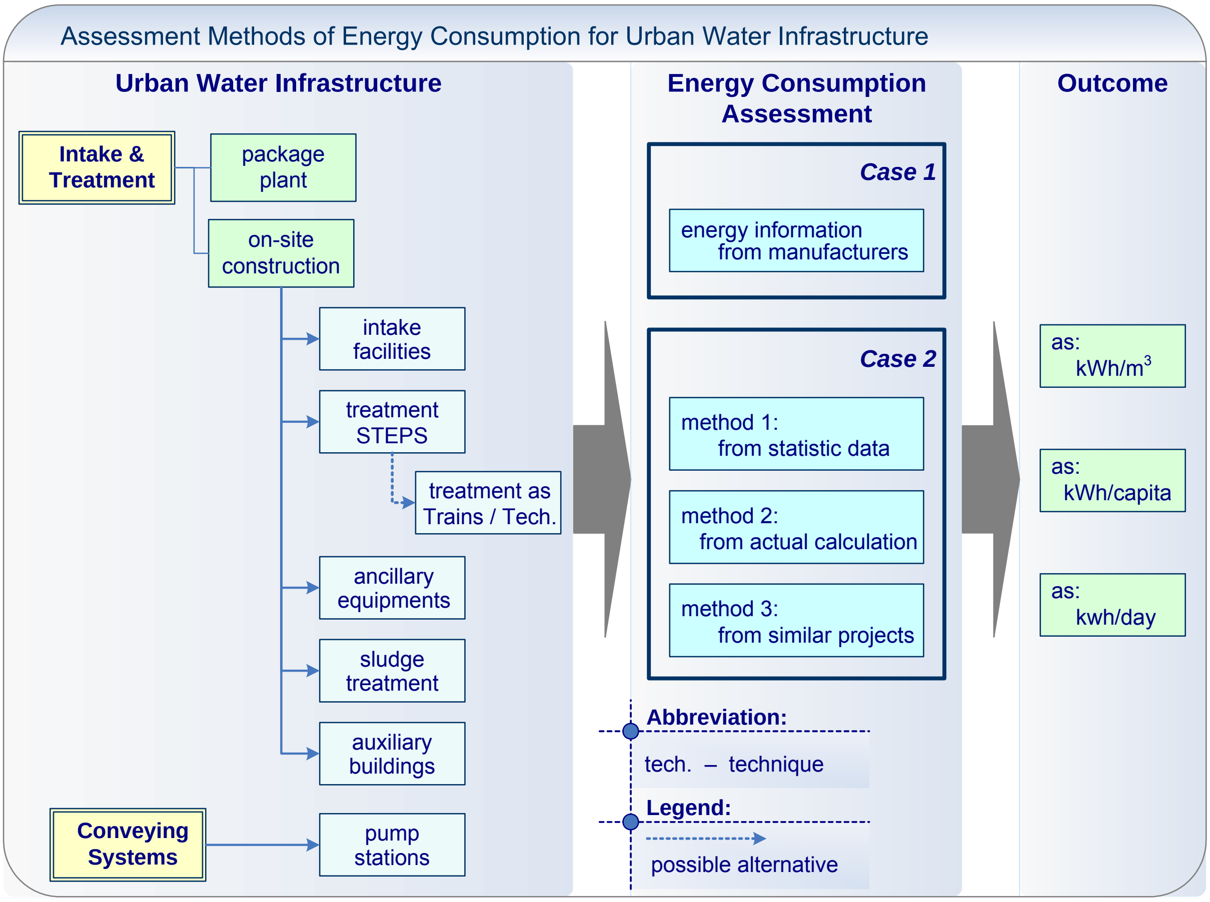


Figure 33: Assessment methods of energy consumption for urban water infrastructure

The ancillary equipments form the third part, which are indispensable components for any kind of treatment plant. Certainly, the energy consumption between different types of equipments is different too. Nonetheless, the detailed comparison for ancillary equipments is unnecessary in the early project phase. Hence, in generally this part energy consumption keeps the same between waterworks or between WWTPs.

The fourth part is sludge treatment, which can consume significant energy in treatment plants. Meantime, certain treatment processes can recover the energy, e.g. by anaerobic sludge digestion. Also, in some regions the sludge treatment is not the essential part in treatment plants. Thereby, sludge treatment is set up as an independent part.

The fifth part is the auxiliary buildings. It stands as an individual part because of the building heating, which is related to the local climates. Heating system consumes significantly higher energy in cold area than in tropic area. It even can become the major energy consumption in treatment plants. In conveying system, pump stations are taken into account including booster pump station and lift satation.

Assessment methods of energy consumption fall into two cases (Figure 33). *Case 1* is especially for package plants, as all energy information is acquired from manufacturers. *Case 2* is for rest of facilities. There are three methods to assess the energy consumption, i.e. *1*. based on the statistical data, *2*. through the actual calculation, and *3*. comparing to similar projects. In the IUWS-DSM, the unit measuring energy can be KWh/m^3, KWh/capita, or KWh/day, whereby the model users choose the proper unit for their situation.

Energy is related to the cost. In many cases, energy consumption is considered as one portion of O&M costs. By showing the distribution of O&M costs in a typical waterworks and WWTP, Figure 34 reveals the relations between energy consumption and O&M costs. In typical, 34% in waterworks and 28% in WWTP of O&M costs are covered by energy consuming (Carns 2005).

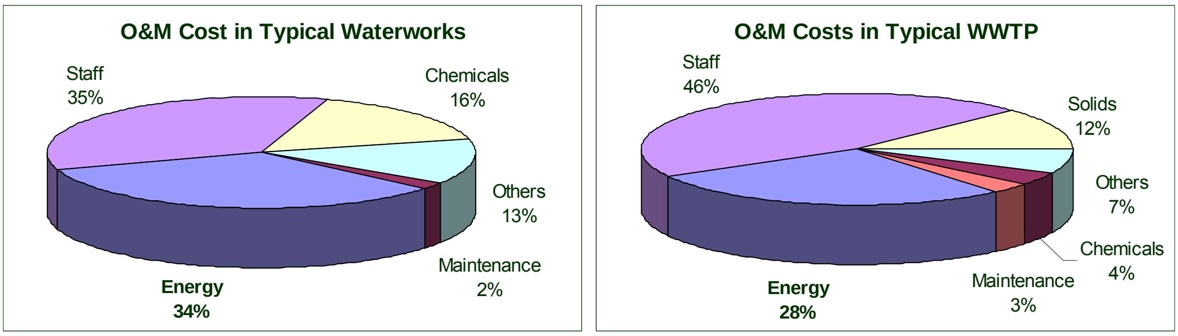


Figure 34: Distribution of O&M costs in a typical waterworks and WWTP (Carns 2005)

3.5 Option comparison

Each water entity has an independent water system and there can be a large number of water entities in the hierarchical system. Meanwhile, as shown in Figure 27 (p. 56), the water subsystems have coinstantaneous system options, whereby the options of the integrated system that consists of those subsystems can be numerous. Hence, the methods of comparing the system options are introduced. In the same way, it is considered in two aspects, i.e. water usage and water infrastructure.

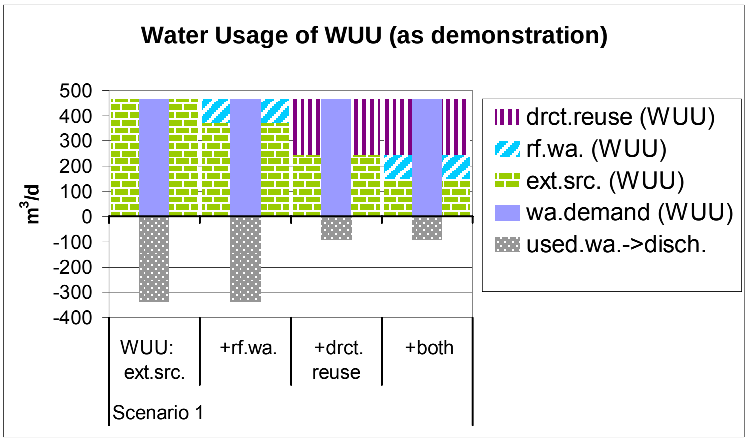
3.5.1 Water usage

The management of water usage is always considered in the first place as it eventually affects the sizes of WIS. In the hierarchy, the variation of water amount in inferior water entities will affect the superior water entities. As demonstrated in Figure 22, the management of water usage starts from WUC, followed by WUU, UD, and finally CA. As discussed in § 2.2.1, one water end-user can have several water usage scenarios, which represent different conditions. In order to demonstrate the way to manage the water usage, a fictitious example with one of its water usage scenarios is implemented. Since WUC has the same structure and functions as WUU, it is skipped in the example. Thereby, it starts from WUU.

In WUU, the water usage is determined based on EUWUP, whereby the possible water sources for sufficing the water demand are determined. There can be four options of water source in WUU (see Table 18 in § 2.3.1):

1. only external source, i.e. from UD; as *WUU: ext.src.*
2. add roof-water utilisation system; as *WUU: +rf.wa.*
3. add direct non-potable water reuse system; as *WUU: +drct.reuse*
4. add both roof-water and direct reuse systems. as *WUU: +both*

As the example, Figure 35 demonstrates how the water usage of WUU looks like. In order to simplify the demonstration, only one water usage scenario is shown here since others have the same form. In the graph, the contents in the parentheses indicate that in which water entity the option takes place. All abbrevations and their meaning remain the same in Figure 35, Figure 36 and Figure 37.



Abbreviations:
wa. – water
drct. – direct
indrct. – indirect
loc.src. – local sources
ext.src. – external sources
rf.wa. – roof-water
dish. – discharge

Explanation:
used.wa.->dish. indicates the amount of used water that needs to be discharged either into super sewer or into the nature.

Figure 35: Water usage of WUU (demonstration)

Based on the water usage of its affiliated WUUs, the water usage of UD is calculated. There can be four different water demands of UD, becasue the required external source in WUU (as *ext.src. (WUU)* in Figure 35), is just the water demand of UD. The water sources of UD can be four options:

1. only external source, i.e. from the CA; as *UD: ext.src.*
2. add local sources; as *UD: ext.src. (+ loc.src.)*
3. add indirect potable water reuse system; as *UD: +indrct.reuse*
4. add direct non-potable water reuse system. as *UD: +drct.reuse*

Likewise, Figure 36 is an example showing the water usage of UD. Since the first option is almost the same as second one, it is skipped for simplifying the graph. The local sources (as *loc.src.(UD)*) are added into the third options because the reclaimed water anyway turns to the local water source through the indirect potable reuse. On the contrary, it is skipped in the fourth option of direct non-potable reuse in order to reduce the system complexity. As water reuse system can only be involved once, three options, i.e. directly reuse in WUU, indirect reuse in UD and direct reuse in UD, are mutually exclusive. In this example, the suface runoff utilisation is not considered in UD as it is utilised in CA.

The graph already clearly shows different parts of water usage including demands, water source composition and discharged used water, as well as the relations in between. Thereby, the graph helps to make decision in the way of considering both water supply and used water management simultaneously.

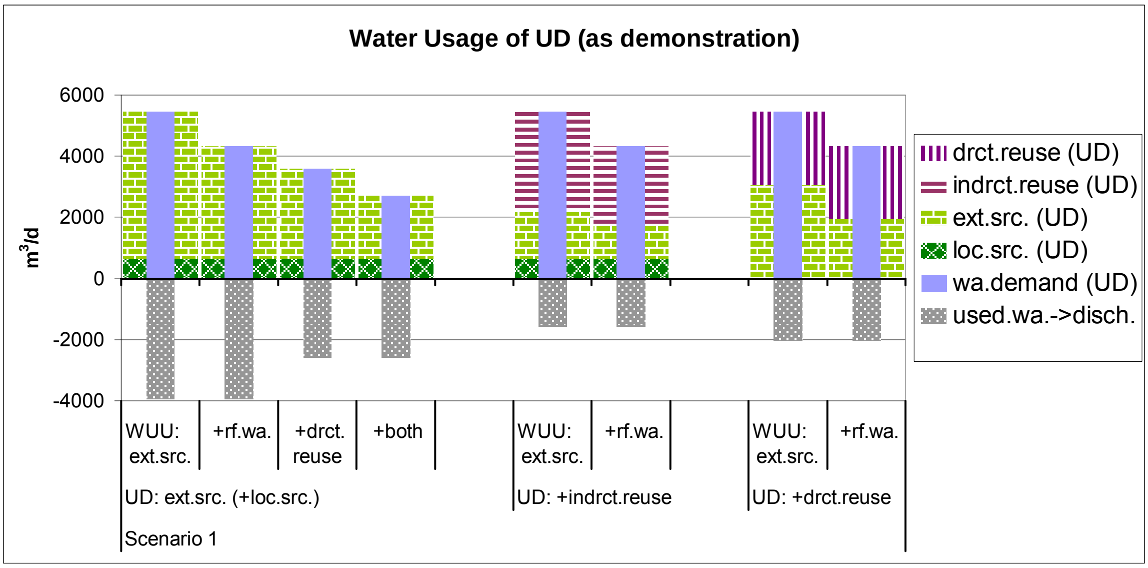


Figure 36: Water usage of UD (demonstration)

Up to CA, its water usage is the superimposition of its affiliated UDs and WUUs. In the same way, the required external source in UD is the water demand of CA (as *wa.dmnd.(CA)* in Figure 37. Meanwhile, for better revealing the relation between water demand and water sources, the water amounts of local sources of CA (as *loc.src.(CA)*) and surface runoff utilisation (as *srfc.runoff(CA)*) are presented in Figure 37. For representing the complicated situation, the local source of UD (as *loc.src(UD)*) is also involved and its covered water demand is correspondingly subtracted from CA. In actual projects, the situation is normally simpler than it in Figure 37.

There are generally two situations in CA:

1. combination of local source and indirect potable reuse; as *CA: loc.src. + indrct.reuse*
2. combination of local source and external source. as *CA: loc.src. + ext.src.*

Following the same rule, if water is indirect potable reused in CA, the reuse options in UD and WUU do not take place, whereby only two cases are in the first situation. If external sources (as *ext.src.(CA)*) is considered, all other options in UD and WUU can be involved

Figure 37 provides the chance to compare the the water usage from different angles. Indirect potable reuse in CA consumes the most water but discharge the least used water. Indirect potable reuse in UD stays in the medium condition considering both water withdrawal and used water discharge. Using the options of roof-water and direct non-potable reuse in WUU and local sources in UD together has the lowest water withdrawal with the medium level of used water discharge. And whatever in which situation, roof-water utilisation reduces the water withdrawal. Such kind of analyses and comparison can be further performed based on the graph. If it is helpful, it can go back to UD and WUU in order to find out the optimal water usage. Moreover, the same comparison can be carried out between different water usage scenarios, which are not verbosely described here.

There can be some options that are appropriate, and which are the better ones may not be directly identified based on the water usage. Therefore, further comparison for WIS needs to be achieved based on system costs and energy consumption.

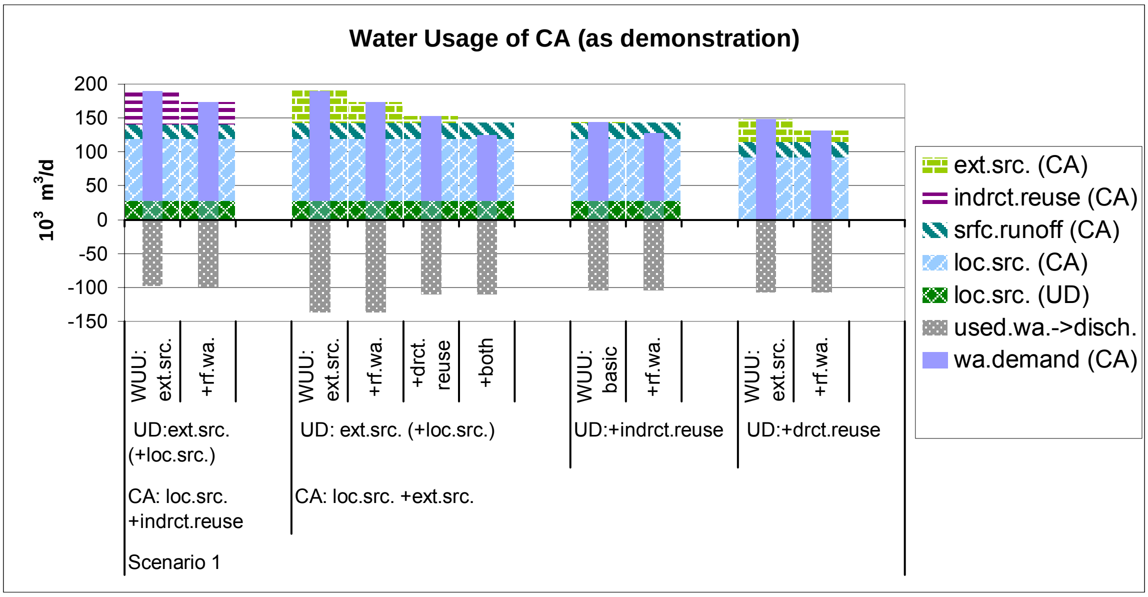


Figure 37: Water usage of CA (demonstration)

In a holistic view, the relations between total water demands and water sources need to be revealed. As defined in § 1.3.3, the model copes with two situations: *1*. planning of new area and *2*. expansion of existing area. Both situations are presented together in Figure 38. All possible sources are given for satisfying the maximum possible water demand. The maximal amount of reused water is adapted in order to represent the extreme situation. All water sources depicted from bottom to top in the figure are in the same sequence as their general priorities given in Table 19. The total water demands in IUWS can be various in different scenarios based on different EUWUPs. Figure 38 clearly shows the relations between water demands and sources, which help model users to determine the suitable water scenarios and properly organise the water sources.

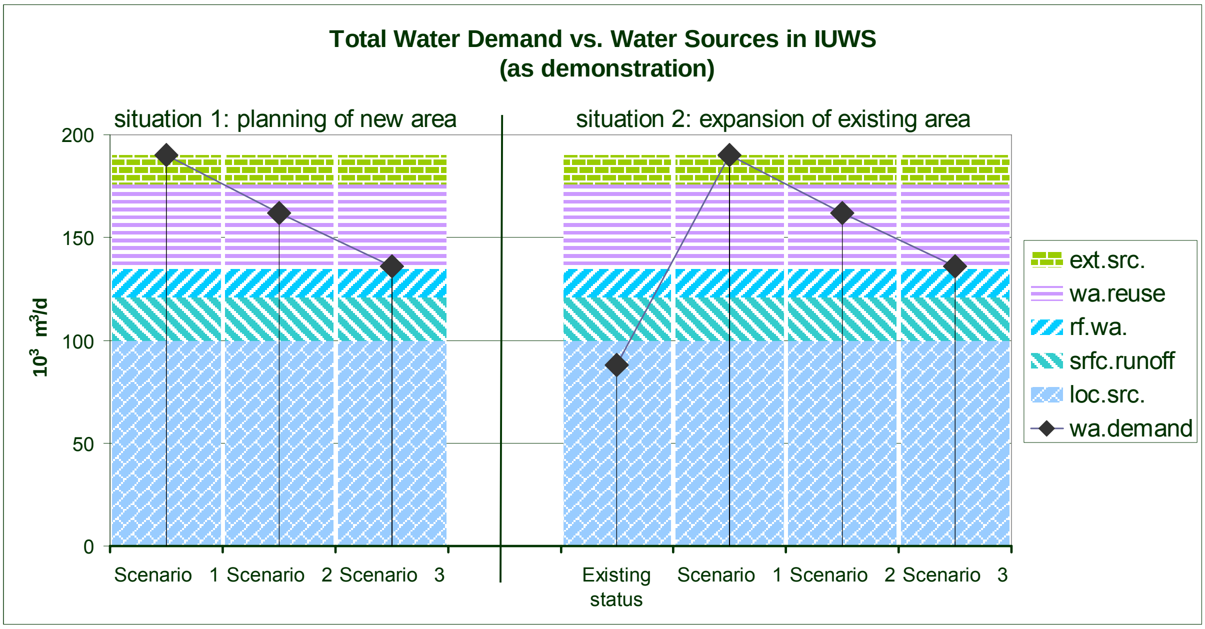


Figure 38: Strategic view of total water demand vs. water sources in IUWS (demonstration)

3.5.2 Water infrastructure

In the hierarchy of the IUWS, the system options of WIS are diverse, whereby the general comparison methods are developed. It can be further progressed by model users according to their situation and special requirements.

After deciding the system sizes based on the water usage, the comparison can be categorised into three cases:

1. different system options of WIS with the same type of water usage, i.e. comparison within water usage scenario;
2. the same system options of WIS with different types of water usage, i.e. comparison between water usage scenarios;
3. different system options of WIS with different types of water usage, i.e. comparison in the mixed situation.

In general, there are certain system alternatives that are interested mostly, so they shall be involved in any case. Such alternatives are the conventional system, the system with the lowest water demand, with the lowest costs, and with lowest energy consumption, etc.

As shown in Table 15, one complete set of WIS in one water entity includes seven parts and the comparison focuses on two aspects that are costs and energy consumption. Different system options may only effect changes of some parts in WIS, which are exactly the portion that needs to be compared. The comparison thereby falls into two classes:

1. within the water entity;
2. crossing levels among water entities.

So the most general comparison between system options with the specified system parts are given in Table 33 and Table 34. Besides, two classes of comparison may need to be combined. One typical example is the comparison of water reuse: direct non-potable reuse in

WUU or in UD, or indirect potable reuse in UD or in CA. Following such idea, the model users can implement more comparison based on their particular needs.

In the same way as the water usage, the calculated cost or energy of each part in WIS can be converted to the graphs, so that the comparison becomes more understandable. Therefore, the specific software needs to be developed in order to properly manuplated the IUWS-DSM and visualise the calculation, comparison and conclusions. The realisation method for the IUWS-DSM in Software is subsequently proposed.

Table 33: Option comparison – within water entities

calculation of: 1. cost 2. energy		**abstraction & transmission**	**raw/ advanced water treatment**	**distribution (networks)**	**collection (sewer + drain)**	**used water treatment**	**rainwater utilis. (surface runoff)**	**rainwater utilis. (roof-water)**
no.	**comparison**	i.	ii.	iii.	iv.	v.	vi.	vii.
1	***In CA***							
1.1	source 1 ***vs***. source 2 ***vs***. ... source *n*	√	√					
1.2	indirect reuse –**CA** ***vs***. long distance ***vs***. seawater	√	√					
2	***in UD***							
2.1	source –**UD** ***vs***. direct reuse	√	√	√	√	√		
2.2	indirect reuse ***vs***. direct reuse			√	√	√		
2.3	Qual. **A** ***vs***. Qual. **A** + **B/C**		√	√				
3	***in WUU***							
3.1	direct reuse ***vs***. roof-water			√		√		√
3.2	Qual. **A** ***vs***. Qual. **A** + **B/C**		√	√				
3.3	SSCS ***vs***. mixed collection				√	√	√	
4	***sewer & drain***							
4.1	separate ***vs***. combined				√	√	√	

Abbreviations: utilis. – utilisation; Qual. – Quality; vs. – versus

Legend: √ – applied

Table 34: Option comparison – crossing levels

calculation of: 1. cost 2. energy		in **CA**					in **UD**						in **WUU**					
		abstraction & transmission	**raw water treatment**	**distribution (networks)**	**collection (sewer + drain)**	**used water treatment**	**abstraction & transmission**	**raw water treatment**	**distribution (networks)**	**collection (sewer + drain)**	**used water treatment**	**rainwater utilis. (surface runoff)**	**advanced water treatment**	**distribution (networks)**	**collection (sewer + drain)**	**used water treatment**	**rainwater utilis. (surface runoff)**	**rainwater (roof-water)**
no.	**comparison**	i.	ii.	iii.	iv.	v.	i.	ii.	iii.	iv.	v.	vi.	i.	ii.	iii.	iv.	v.	vii.
1	***sources***																	
1.1	source –**CA** ***vs.*** sources –**UD**	√	√	√			√	√	√									
2	***reuse***																	
2.1	indrct. –**CA** ***vs.*** –**UD**			√	√	√				√	√							
2.2	drct. –**UD** ***vs.*** –**WUU**								√	√	√			√	√	√		
3	***Qual. A or B/C***																	
3.1	**CA *vs.* UD**		√					√										
3.2	**CA *vs.* WUU**		√										√					
3.3	**UD *vs.* WUU**							√					√					
4	***single or dual sys.***																	
3.1	**CA *vs.* UD**		√					√	√									
3.2	**CA *vs.* WUU**		√										√	√				
3.3	**UD *vs.* WUU**							√	√				√	√				

Abbreviations: utilis. – utilisation; drct. – direct; indrct. – indirect ; Qual. – Quality ; sys. – system; vs. – versus

Legend: √ – applied

3.6 Realisation Method in Software

The functions of the IUWS-DSM can be built up and realised in the Microsoft® EXCEL in a simple way. In order to make the model more accessible, it is suggested realising the model as the specific software. The proposed concept and methods are hereby given.

3.6.1 Concepts

The supposed architecture of the software for IUWS-DSM is depicted in Figure 39, which consists of several modules. The core is the *Model Engine* that holds the major functions of data processing, calculation and comparison, as well as data transfer internally and externally. It is also in charge of communicating between all modules.

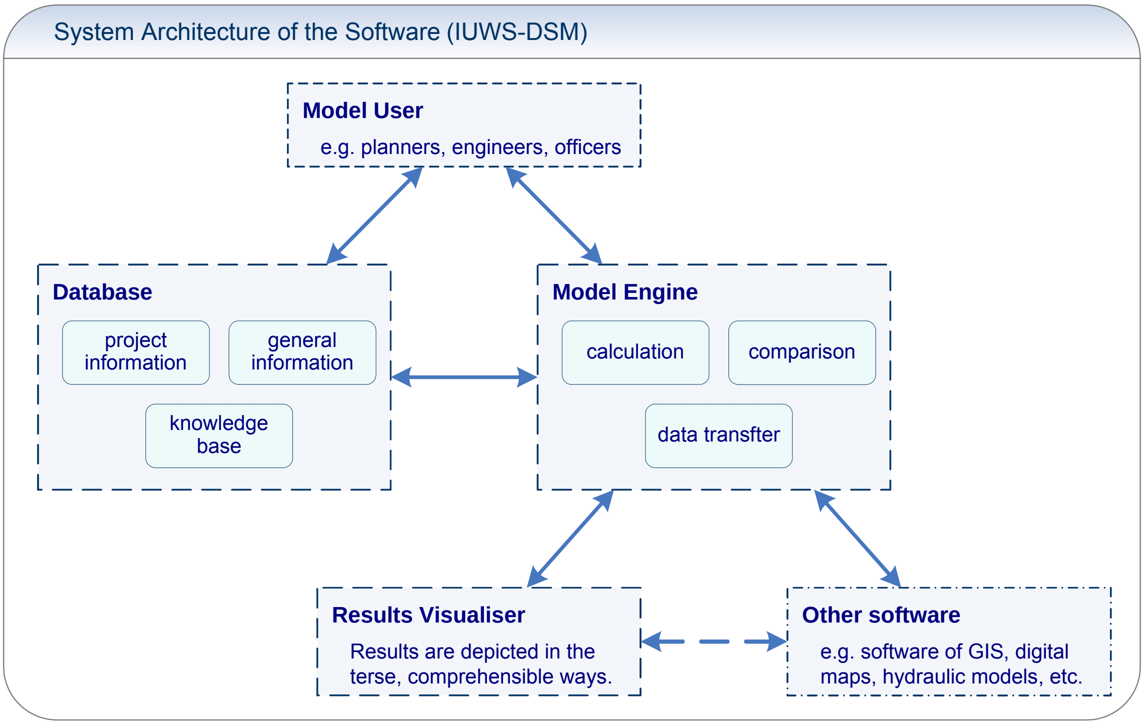


Figure 39: System architecture of the software (IUWS-DSM)

The Database is used for storing all kinds of information and data. The module of *Database* contains three storages that are for Project Information, General Information and Knowledge Base. Project information refers to the factual information and data of designed projects. The outcome calculated by the software is also the project information. Opposite to it, general information is the sharable common information. Knowledge base includes functions and information of cost estimation, energy assessment, and decision making roles.

One module is set up especially for visualising the results, i.e. *Results Visualiser*. As the software of the DSM, it is very important to present the results in a terse, comprehensible, and perceivable way, because the results are presented to the decision makers who are often not the water specialists or technical experts. Meanwhile, the software should be compatible with other water-related software, so that the data can be shared.

Very importantly, the user friendly Graphical User Interface (GUI) must be developed, so that the software can be easily controlled by water engineers and city planners. Moreover, the function of guidance, prompts, and instant help should be embedded, too. For example, the compulsory and optional items of input can be labelled with different backgrounds and likewise, the user input values and default values can be displayed in different colours.

As two main modules, *Model Engine* and *Database* are explained a bit more as follows.

3.6.2 Model engine

Most functions and tasks are achieved by the model engine. Based on the planning procedure established in § 3.2, the calculation and comparison that are introduce in § 3.4 and § 3.5 are realised by the model engine. Though the decision making polices developed in § 3.3 are stored in the database, the model engine has the right to control and call them to infer the solutions. The model engine is in charge of the communication between model users and the IUWS-DSM, other software and the IUWS-DSM, as well as between modules inside the IUWS-DSM.

3.6.3 Database

Based on the structure of the IUWS-DSM, eight subsets are built up in the database, i.e. *1*. System Planning, *2*. Water Sources, *3*. Treatment Facilities, *4*. Conveying Systems, *5*. Water Usage Profiles, *6*. Quality Standards, *7*. Evaluation Tools, *8*. Expert Knowledge (Figure 40). As categorised above, the subsets *1* and *2* contain the project information, and the subsets *3* to *6* contain the general information, where the subsets *7* and *8* are the knowledge base. The corresponding tables in database are established as the examples and displayed in Appendix 1.

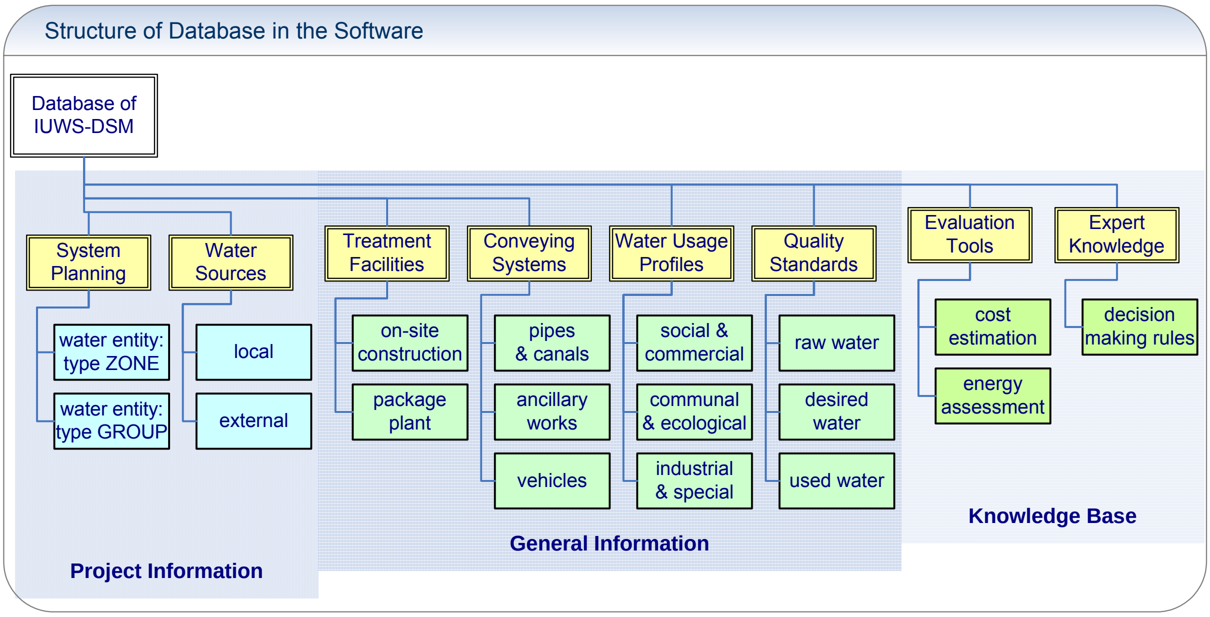


Figure 40: Structure of Database in the Software

The subset of *System Planning* is for requesting and organising the basic planning information of the project, which is corresponding with the hierarchy of the IUWS. The pattern tables are given in Appendix 1.1. Likewise, the information of available and possible water sources are requested and stored in the subset of *Water Sources*, where the pattern tables are given in Appendix 1.2. The subset 3 stores the information of treatment facilities including all possible treatment trains with their application conditions, treatment purposes, advantage and disadvantages. This information provides fully support when model users present the planning results to decision makers or the public. The subset 4 stores technical information of pipes, ancillary works and vehicle transport system, and the corresponding pattern tables are in Appendix 1.4. Similarly, the pattern tables for EUWUP and water standards are built up in Appendix 1.5 and Appendix 1.6. Therewith, an example of the water usage profile is demonstrated. It needs to be pointed out that EUWUP and water standards have the attribute of country/region, as different countries or regions have different situations.

Especially it is suggested establishing one general data set as the default values including EUWUPs, water standards and cost functions, so that even if the local information is not adequate, the software can still calculate the water system in the most normal/possible situation.

Knowledge base contains all information introduced in § 3.3, § 3.4 and § 3.5. During the application of the software, the relevant information, i.e. the general information and the knowledge base, need to be supplemented constantly.

Chapter 4 Discussion and Conclusion

Through this new conception, the urban water systems are rethought as one integrated system, where desired water, used water and rainwater systems are considered and planned at the same time. The decision support model, namely IUWS-DSM, was developed, wherewith engineers can carry out different system options for the IUWS, make the proper comparison, and then reach the appropriate decisions. As the precursory research, the conception and model provide introductory compendium and remarks with primary functions. Based on it, the further research work can be implemented whereby, the potential developments of IUWS are suggested.

4.1 New conception

In general, the conventional urban water systems are simpler and readily systems in the sense of design and management. However, the conventional systems exert huge burdens directly to the environment by withdrawing too much high quality water from nature and damping too many pollutants into water bodies afterwards, whereby the nature cannot sustain it further with today's industrialisation and urbanisation.

Demand management should always be considered in the first. Opposite to the general thinking, in reality demand is more difficult to be constrained than supplies, because many factors influences it, such as human needs and behaviour, and the variations over time and space (Brooks *et al.* 1997). In this new conception, since the urban water systems are constructed as many independent water entities, the demand management of each water entity becomes simpler with less indeterminacy. Meantime, the hierarchical system provides the chances to reuse water and utilised rainwater in a very flexible way. Thus, instead of enlarging the water supply system to fulfil the increase of water demand, the management of water usage inside the system should be executed first of all based on the new conception.

The end-user's water usage profile of, i.e. EUWUP, is another very important conception. First of all, it is the water usage profile of the grouped users, which are locally standardised. Meanwhile, the water demand and used water amount are depicted simultaneously with the labels of their qualities in the usage profile. Putting desired water and used water profiles together does not only conceptually connect water and used water systems, but also substantially plan the urban water system as one integrated system from the beginning. Meanwhile, the normalisation of EUWUP reduces the planning work, and potentially it can be further developed to the benchmark to estimate and optimise the water usage.

Water reuse and rainwater utilisation are two key elements in IUWS. Water reuse can take place in different locations on different scales. As the cycle, it is actually the use of water in multiple times. If the different quality requirements between different water end-users are properly exploited, less water with less treatment is needed for satisfying the same water demands as of conventional systems.

With regards to the natural hydrological cycle, rainfall should be dealt with in an environmental friendly way, i.e. initially retained in soil and then infiltrated into groundwater. Thereby, the surface runoff is reduced and consequently, the flood risks are lowered. In the meantime, the groundwater obtains the augmentation. In order to reach such goals, the city has to be constructed in the more natural ways, which can also improve the urban ecological conditions. Rainwater can be easily used on-site by collecting roof-water. Its options are relative simple as it is usually a small scale system with simple treatment units.

The water treatment is classified into steps with, which is especially for on-site constructed treatment plants. The selection of the treatment processes depends on the qualities of inflow and outflow. Package plants are used for water entities having medium or small size. Using package plants to treat both raw water and used water on-site is a tendency.

In summary, the highlights of the new conception are as follows:

- urban water system is reconstructed into the four-level hierarchy.
- urban water system consists of the independent and nested water entities in the hierarchy.
- corresponding to the water using unit, the water end-users are considered as grouped users that are identified as certain types, e.g. university, shopping centre.
- each type of grouped end-user has the specified water usage profile, i.e. EUWUP. One grouped end-user can have several EUWUPs at the same time.
- both water demand and used water amount are considered simultaneously in the WUWUPs.
- the water withdrawal from the nature is remained as low as possible, and all accessible water sources is therewith organised and then utilised.
- water reuse is the essential component of IUWS, which completes one type of water cycle.
- rainwater should be retained inside urban area in proper ways and at the same time roof-water can be supplied directly to water end-users.

Since the beginning of 21st century, more and more projects or frameworks concerning IUWS are coming up. Although many of them have such names like *integrated urban water system / management*, the water and wastewater are still considered as two independent systems. Several projects that are quite advanced and close to this research are selected as references and shown in Table 35.

The first project is the large project proposed by the international specialists group. Its core aims are very close to this work, i.e. reveal and systemise the mutual interactions of urban water systems and the software based tools are the expected results. Besides, it involves more components, such as climate change, solid waste, integrated catchment management comprising urban centres. The duration of the project is proposed for 5 years, and the financial implications are not fixed yet.

The SWITCH is a huge international cooperated project, which has 33 partners from 15 countries around the world. Six sub-topics are included: *1*. Urban water paradigm shift, *2*. Storm water management, *3*. Efficient water supply and use, *4*. Waste water, *5*. Urban water planning, and *6*. Governance and institutions. It focuses more on the practice with the goal of sustainable urban water management.

The third and fourth projects have rather the same framework and aims as the first one, which are implemented just nationwide. Both projects are ongoing projects and announce that eventually the decision making tools for planning IUWSs will be provided. It would be worthwhile to share our research with other projects.

Table 35: Example projects of IUWSs

no.	example projects
1	**Project**: *Integrated Urban Water System Interactions* **Organisation**: UNESCO - IHP Division of Water Sciences, France **Objective**: an expanded knowledge base related to the interactions of man-made systems in the urban environment and development applicable tools and approaches. **Webpage**: http://www.aquatic.unesco.lodz.pl/index.php?p=integrated_urban_water_system
2	**Project**: *SWITCH, Sustainable Water Management Improves Tomorrow's Cities' Health* **Organisation**: research groups and partners, implemented and co-funded by the EU **Objective**: catalyses of change towards more sustainable urban water management in the "City of the Future". **Webpage**: http://www.switchurbanwater.eu
3	**Project**: *Urban Water: Integrated Water Systems* **Organisation**: Commonwealth Scientific and Industrial Research Organisation, Australia **Objective**: an approach for planning and management of urban water systems to plan and manage water supply, wastewater and storm water systems in a coordinated manner. **Webpage**: http://www.csiro.au/science/ps3k3.html
4	**Project**: *Integrated Urban Water Management* **Organisation**: Delft Cluster, the Netherland **Objective**: an integrated set of tools that can be used to forecast and optimise development and management of water systems in urban areas. **Webpage**: http://www.delftcluster.nl/website/en/page72.asp

4.2 Decision support model (IUWS-DSM)

Based on the new conception, the DSM is established, i.e. IUWS-DSM. Certain procedures with nested structure are established for planning water entities especially in the hierarchy. The iteration is needed in order to attain the optimised solutions. Being a flexible approach, the procedure can be used to plan water entities on different system scales.

As the cardinal element, decision making polices are constructed. It is divided into five sections, i.e. water sources, water supply, collection system, used water and rainwater. The decision making mechanisms are developed, which can be easily followed by model users. The decisions making rules are set up that are relatively rough, as this research intends to build up the framework rather than gather the detailed existing information. Thereby, to detail and consummate the decision making rules can be the emphasis in the next step.

Cost and energy consumption are chosen as the criteria for system evaluation. For cost estimation, the empirical cost functions are introduced and adapted by the IUWS-DSM as the default method. Though it is the simple method, the large statistical data are required for generating the cost functions. Meanwhile, the functions are location related, which means different countries and regions have different functions. Thus, since one of main goals of this work is to build up a general DSM, none specified functions are included. Cost estimation is the essential criterion for estimating IUWSs.

Energy consumption is involved, as it was less focused in the past, and as it is one of the critical issues today. The same as cost estimation, a procedure of energy assessment is developed, instead of providing the concrete values of energy consumption. Currently, the information of energy use in urban WIS is still deficient. There are ongoing projects of energy optimisation for water supply (e.g. TUHH[1]) and wastewater systems (e.g. DWA[2]), which follow the definition of conventional water systems. The results of those projects may be used to enhance the IUWS-DSM. In the meantime, based on the concept of IUWS, such kinds of projects shall be joined together, so that a holistic view of energy consumption in urban water system can be obtained.

The comparison of system options focuses on two aspects that are water usage and WIS. Likewise, the comparison methods are particularly developed for the hierarchy of the IUWS. The comparison of WIS is rather complicated, not only because of the integration of desired water, used water and rainwater systems, but also due to the hierarchical structure. This research develops the general method to perform the proper comparison for WIS, the model users can make their desired the comparison based on the same methods.

4.3 Uncertainty of urban water systems

As the complicated aggregate, vicissitude of a city is uncertain, which results in an uncertainty of water demand, whereat the urban water system has to cope with. In the new conception, the urban water system is broken down to four hierarchical levels and thereby, water systems are planned based on independent and interrelated water entities, which provide the chance to look individually into the variation of water demand. Thus, the uncertainty of water demand is reduced. Some facts causing uncertainty are summarised in Table 36 followed by their affects and variation tendency of water demand.

The IUWS-DSM can properly deal with the uncertainty caused by the city development, which can help to carry out proper system options. Climate change is the less known issue but having a tremendous impact on the whole system. Therewith, the evident and latent interrelations between climate change and urban water systems are not revealed. Consequently, the further investigation and research can be accomplished.

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[1] Energieeffizienz / Energieeinsparung in der Wasserversorgung (Energy efficiency / energy saving in water supply systems), http://www.tu-harburg.de/wwv/energie/index.html (in German)

[2] Forschungsvorhaben zur Energieoptimierung auf Kläranlagen (Reserach project of energy optimisation in WWTP), http://www.dwa.de/ (in German)

Regarding the social movements, its mutual influence with water usage is more obscure, which is difficult to be described numerically. A multi-disciplinary working group needs to be set up including engineers, sociologists and politicians. As it is the complicated and valuable topic, an independent research project is recommended.

Table 36: Uncertainty of water usage along with city vicissitudes

no.	causes	affects
	city development	
1	*new developing area*: development does not follow master plan	If it is located at the remote end of the water networks, and water demand is amplified significantly, networks may not content all end-users in certain conditions.
2	*existing area*: change of area use	Water demand can be thereby dramatically increased or decreased.
3	*existing area*: re-construction or re-function	Variation of water end-users (in the sense of both types and sizes) can significantly change the water usage profiles.
4	rise-up of living standards	Higher living standards usually imply higher water consumption, but it is not inevitable.
5	innovation of water fixtures in households	Application of water saving fixtures can remarkably reduce water consumption, which is the tendency.
6	innovated techniques in industries	It can reduce the consumption of processing water notably. Water cycle can performed inside factories, as well.
	climate change	
7	variation of rainfall patterns	E.g. oftener enlarged storm events fail drain systems. E.g. less rainfall or more uneven rainfall distribution reduces the availability of roof-water.
8	season changes	E.g. longer drought summer can cause more water consumption.
9	temperature change	E.g. higher daily temperature can increase water consumption.
	social movements	
10	awareness of environ-mental protection	Better personal habits can reduce water consumption significantly.
11	use of price lever	Water price and water demand have the non-linear relation, e.g. Thompson (1999), p.146.
12	shift of religion	E.g. giving possibility of using reclaimed water results in the reduction of total water withdrawal.

4.4 Improvement of the IUWS-DSM

Urban water systems have the huge scopes covering different topics and issues. The IUWS-DSM provides the initial functions for planning the IUWS. The following aspects can be considered in order to further develop the IUWS-DSM.

GIS is another very powerful tool to plan, design, operate and control urban water systems (Shamsi 2005). It is therefore suggested connecting the IUWS-DSM to GIS.

Nonetheless, GIS software is usually very expensive. Instead, other free internet maps, e.g. *Google Earth*[1], can be integrated in the IUWS-DSM. Moreover, the IUWS-DSM should be able to be used or communicated by/with other software of water systems, so that the results can be shared and directly used.

Water treatment methods are very diverse containing a large number of treatment trains and techniques. Because the IUWS-DSM is the tool for designing urban water systems in the early stage, the treatment processes are simplified into certain steps. In future, more concrete treatment trains and units can be added in based on the treatment steps. Then the model is able to reach more detailed design, which makes the model better capable for the next planning stage.

Visualisation of water quality is a worthy enhancement for the model as well, especially when digital maps are available. In each water entity, the water quality should be traced and labelled along the conveying system, whereby the possible pollution points are automatically highlighted. For better monitoring the variation of urban water quality, certain pollutants can be chosen and traced. It helps to picture the complete view of urban water systems and consequently, the better administrative strategy can be figured out.

Visualisation of energy consumption on the map is another potential direction development. In the context of the IUWS, energy flow provides the overall view of how energy use distributes, and how different the energy consumption is between different system options. Such overall pictures are also valuable for the public utilities of the electricity department.

4.5 Prospect of further research for IUWSs

Today, it has been realised that managing urban water as an integrated system is the inevitable direction. Nevertheless, there is still a lack of mature conception, models and experience of how to consider and deal with all urban water subsystems within one integrated system. In general, some further research work is advised as follows:

- EUWUP can be further developed into the benchmark to assess and optimise water suage.
- the governance of urban water facilities is another hot topic which is also widely discussed and trailed. Therefore, it can and should be involved in the management of IUWS.
- the effects of water price to water usage can be involved.
- the influence of climate change on IUWS should be investigated and determined.
- the seasonal or monthly water flocculation can be included considering both water demand and water resources.
- the emission of green-house gas from urban water systems can be involved.

The scientific research of IUWSs starts to be executed worldwide. This research conceives new thoughts and methodologies, which could act as the footstone for further investigations, and which could inspire other researchers to explore further. A prototype of DSM for IUWS is correspondingly established, which can be the initial tool for designing IUWS, and which could promote other researchers to progress further.

[1] http://earth.google.com/

Chapter 5 Summary

Conventionally, three water systems in urban area, i.e. drinking water supply, wastewater disposal and rainwater elimination, are planned, designed, and managed individually. Very often water supply and wastewater disposal systems are centralized systems, where rainwater is eliminated from cities as soon as possible. It has been realised that such kind of urban water systems is neither sustainable nor optimised. Today, the water scarcity is becoming the global problem due to many man-made reasons, such as population explosion, water pollution, industrialisation and urbanisation. Hence, the better solutions of our urban water systems are desiderated.

The cycle makes the world endless. The appropriate cycle makes the nature balanced. Thus, the water cycle in urban area needs to be properly closed, too. As two sides of urban water systems, water usage and water infrastructure need to be properly matched. Based on these ideas, the new conception for integrated urban water system (IUWS) is conceived. The conception is further developed into the decision support model IUWS-DSM that is a tool for planning IUWSs in the early project phase. For having the clear overview of the dissertation, the systematic structure of the dissertation is sketched in Figure 41. Following the arrows, the ideas and systems can be easily discerned.

First of all, the urban water system is structured in the hierarchy, where the entire water system is divided into four levels including two types of water entities, i.e. *ZONE* type and *GROUP* type. The water entities of ZONE type cover the first two levels in the hierarchy, and the water entities of GROUP type form the third and the fourth levels. From top to bottom, four levels are: **a**. City Area (CA), **b**. Urban District (UD), **c**. Water Utilisation Unit (WUU) and **d**. Water Utilisation Cell (WUC). CA represents the whole water system or one absolute independent water system in urban area, which is going to be the IUWS. UD is the divided urban area that is contained by CA. It can either coincide with administrative canton or be the natural division. WUU is the certain functional unit or group in cities and subsequently, its water system can be managed and coordinated as one entity, e.g. a university or a hospital or two adjacent residential quarters. WUC has the same structure as WUU but on the small scale that mostly focuses on the single large buildings or mono- water end-users. The hierarchy is the base of the IUWS. (§ 2.1.3, p. 11)

For constructing the IUWSs, the essential components in urban water systems are re-identified. First, the new terms are defined: *Desired water* has the quality that satisfies the requirements of end uses. *Used water* is substituted for the conventional term “wastewater” and includes different types of urban sewage. Desired water quality is further categorised. Besides drinking water quality (represented by Quality **A**), other two categories (represented by Quality **B** and Quality **C**) are set up in order to adapt to the variety of required water quality in cities. Based on the characteristics of used water, the source separated collection system (SSCS) is introduce and adopted, which means that different streams of used water coming from domestic activities should be collected separately. (§ 2.1.4.1, p. 13)

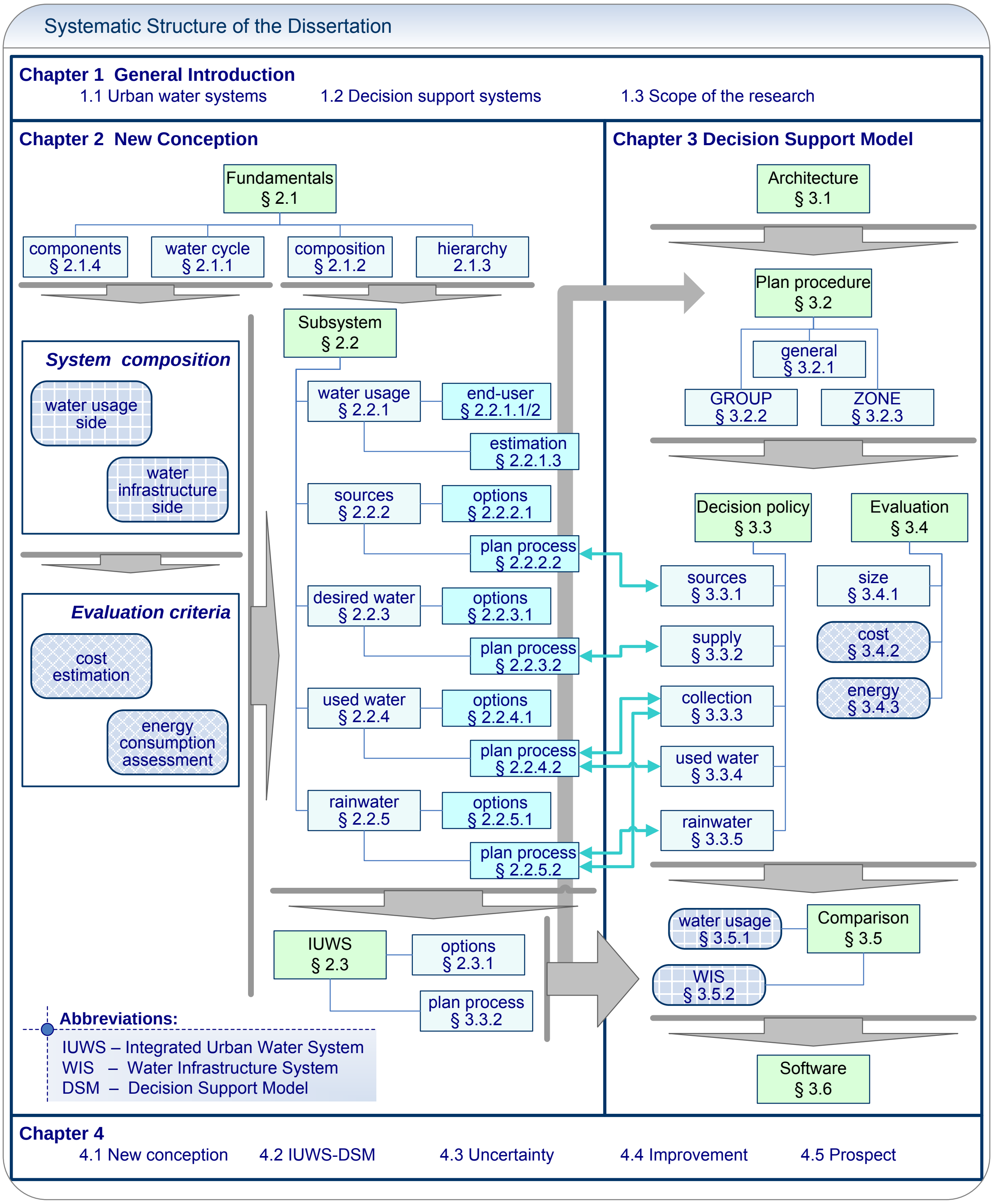

Figure 41: Systematic structure of the Dissertation

The water infrastructure system (WIS) is redefined that consists of two parts: the intake and treatment facilities, and the conveying system. The treatment processes of raw water and used water are classified into certain steps. Meantime, the construction methods of treatment facilities are emphasised, i.e. on-site constructed or package plant, where the later one plays important role in IUWS. The conveying system includes water transmission, distribution and collection, as well as their ancillary works. Vacuum toilet is involved because it is essential for SSCS. (§ 2.1.4.2, p. 17 and § 2.1.4.3, p. 23)

Before eventually reaching the IUWS, five subsystems are built up in the first, i.e. *1*. water usage, *2*. water sources, *3*. desired water, *4*. used water, and *5*. rainwater, which have individual structures, system options and planning processes. Five subsystems are joined together through certain interrelations. (§ 2.1.2, p. 10 and § 2.2, p. 24)

Subsystem of water usage deals with water end-users that are defined as the grouped water consumers. In IUWSs, the grouped water end-users are specially corresponding to WUU and WUC. Consequently, the grouped water end-user's water usage profile (EUWUP) is defined. Two types of EUWUP are introduced, i.e. *detailed EUWUP* and *general EUWUP*. The EUWUPs are specified and standardised, and will be pre-stored in database. EUWUPs are important and particular, because they consider and display the water demand and used water amount together with their water qualities at the same time. It fully shows the idea of integration. Based on the EUWUPs, the general method is given for estimating the water usage. (§ 2.2.1, p. 25)

Subsystem of water sources categorises the water sources into two groups, i.e. local sources and external sources. In order to plan each water entity independently in the hierarchy, a special external source is made up that is the water coming from the superior water entities. Regarding the water quality, besides the raw water quality it can also be Quality **A**, **B** or **C** that comes from superior water entities. The general priority of water sources is given, too. The process for planning water sources is then depicted. (§ 2.2.2, p. 29)

Subsystems of desired water supply (§ 2.2.3, p. 32), used water management (§ 2.2.4, p. 34) and rainwater utilisation (§ 2.2.5, p. 38) look into the WIS. The system options including dual water supply system, water reuse (direct or indirect) and rainwater utilisation (surface runoff and roof-water) are intensively discussed. The system options and planning processes for each subsystem are developed and depicted respectively.

Based on the above conception and components, the IUWS is accomplished. Four water system types are identified, i.e. *1*. basic system that uses conventional water sources, *2*. adding rainwater utilisation systems, *3*. adding water reuse system, and *4*. adding both rainwater and reuse systems. The system options of IUWS are therefore carried out based on the types of water entities, i.e. for CA, UD and WUU, respectively. The general process for planning IUWS is then developed. A demonstration is presented for easier comprehending the IUWS in the hierarchy. (§ 2.3, p. 41)

Above all, the architecture of the decision support model IUWS-DSM is established, whereby the procedure and components of the model and the elements in the proposed software are introduced. (§ 3.1, p. 49)

In the IUWS-DSM, the general planning procedure is sketched firstly, which can be directly applied to the water entities of GROUP type (i.e. WUU and WUC). In the hierarchy of the IUWS, since water entities in different levels have different attributes and water entities are embedded, the specified planning procedure needs to be set up for water entities in higher levels. A planning procedure is developed for the water entities of ZONE type (i.e. CA and UD), where the nested structure is built up. As the IUWS has two sides, i.e. water usage and WIS, the planning procedure consists of two sections, too. The water usage is planned in the bottom-up direction, i.e. from WUC to WUU, then UD and finally CA, where the WIS is planned in the top-down direction, i.e. from CA to UD and then WUU. The water facilities in WUC are not included as they are mainly indoor facilities on small scales and usually the private properties. The interaction between two sections in each water entity is also taken into account. (§ 3.2, p. 50)

If there is more than one option, the decision has to be made. Decision making policies are developed, which are divided into five sections for dealing with five issues: *1*. selection of water sources, *2*. supply methods of desired water, *3*. collection and transport methods of used water and rainwater, *4*. utilisation methods of used water, and *5*. utilisation methods of rainwater. The decision making mechanisms are developed for each issue and the decision making rules are set up respectively, as well. (§ 3.3, p. 55)

The cost and energy consumption are chosen as the criteria to evaluate the alternatives of IUWSs, where the cost estimation is the essential criterion. The estimation method is built up, and the empirical cost functions are suggested. The information about energy consumption in urban WIS is universally lacking, so a general procedure for assessing energy consumption is proposed. (§ 3.4, p. 71)

Afterwards, the methods for comparing system options of IUWSs are introduced. In the same manner, two parts need be compared, i.e. water usage and WIS. The water usage is compared within each water entity with consideration of the interrelations between water entities. In the hierarchy of the IUWS, since water entities are embedded, there are two kinds of comparison for the WIS, i.e. within water entities and crossing levels. The demonstration graphs are given for the water usage, and the comparison matrices are established for the WIS. (§ 3.5, p. 79)

In the holistic view, the relations between total water demands and water sources need to be revealed. As defined in § 1.3.3, the model copes with two situations: *1*. planning of new area and *2*. expansion of existing area. Such relations of both situations are presented together in Figure 38 (p. 83) as a demonstration. It can help the model users easily determine the suitable scenarios of water usage and properly organise the water sources.

In order to easily and widely use the IUWS-DSM, it needs to be realised in the software. The realisation method is therefore proposed. The architecture of the software is sketched. Especially, the structure of database in the software is described in details. (§ 3.6, p. 86)

In Chapter 4, the new conception and IUWS-DSM are summarised. Several similar projects related to IUWSs are shortly described. As the IUWS is a quite new progress direction, other projects are either ongoing or new proposed, so no concrete comparison can be done. The uncertainty of IUWS is discussed. The potential improvement of the IUWS-DSM is suggested. Last but not least, the prospect of further research for IUWSs is expected. (§ Chapter 4, p. 89)

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Appendices

Appendix 1 Tables built up in database

All following tables are initially established for the database that is built up in the software of the IUWS-DSM. The tables can be set up in Microsoft® Excel for pure calculating, too.

Appendix 1.1 Water entities

Appendix.Table 1: Information of urban planning – for water entity of ZONE type (CA and UD)

no.	entity name	planned year	total area [km^2]	popullation	geen area [km^2]	road area [km^2]	lakes / ponds [m^3]	rivers / creeks (Y/N)	groundwater infiltration (P/N)
1									
2									
…									

Abbreviations: Y – yes; N – no; P – possible

Appendix.Table 2: Information of urban planning – for water entity of GROUP type (WUU and WUC)

no.	entity name	type [1]	total area [ha]	measure 1 [2]	measure 2 [2]	green area [%]	roof area [m^2]	ponds [m^3]	creeks (Y/N)
1									
2									
…									

Abbreviations: Y – yes; N – no; P – possible

[1] it refers to the type of the grouped end-user that is categorised and shown in Figure 12.

[2] Two methods to determine the size of water entity, which are the population equivalent (as *measure 1*) and the unit equivalent (as *measure 2*), with the measurement units m^3/(capita·d) and m^3/(unit·d), respectively.

Appendix 1.2 Water sources

Appendix.Table 3: Information of water resources

no.	project name	city / area	urban district	source name	source type	quality	quantity [m^3/d]	to WW. [km] [1]
1								
2								
...								

[1] it is the distance from the water intake facilities to the waterworks (WW.).

Appendix 1.3 Treatment facilities

Two tables are established for on-site constructed and package plants respectively.

Appendix.Table 4: Information of treatment trains

no.	name	treatment step [1]	treatment purpose	application conditions	cost function (construction)	cost function (O&M)	energy consumption	advantage	disadvantage
1									
2									
…									

[1] it is corresponding to Figure 9.

Explanation: there is no specification of inflow and outflow qualities as it is specified in Figure 9. *Advantage* and *disadvantage* provide the supplementary information that helps planners to understand the treatment trains, as well as to better present the results to decision makers.

Appendix.Table 5: Information of package plants

no.	name	capacity [m^3/d] [1]	inflow quality	outflow quality	application conditions	price	O&M cost	energy consumption	producer information
1									
2									
…									

[1] it can be a range.

Appendix 1.4 Conveying system

Two tables are established for pipes and ancillary works. In the column of *cost function*, it can be either the function or the coefficient. If it is coefficient, its related cost function has to be specified.

Appendix.Table 6: Information of pipes

no.	Land / region	geological factor [1]	frost-line [2]	pipe material	working condition [3]	cost function (construction)	cost function (O&M)	energy consumption	specification
1									
2									
…									

[1] it indicates that the additional cost in the special geological conditions, e.g. the rock condition. It can be either the cost function, or a coefficient, or the value directly added on top.

[2] it indicates that whether the the frost-line is considered. It can be involved in the same way as *geological factor*.

[3] the condition can be either *pressure* or *gravity*.

Appendix.Table 7: Information of ancillary works

no.	name	type [1]	capacity [m³/d] [2]	application condition	cost function (construction)	cost function (O&M)	energy consumption	specification
1								
2								
…								

[1] e.g. booster pump station, lift station, valve

[2] it can be a range.

Appendix 1.5 EUWUP

Based on Figure 13, the detail information of water usage for water end-users is investigated and recorded in Appendix.Table 8. Then the information from Appendix.Table 8 is summarised and stored in Appendix.Table 9. The graphs are suggested for the better view of the EUWUPs. Appendix.Figure 1 and Appendix.Figure 2 are made up as the demonstration.

Appendix.Table 8: Information of the detailed EUWUP

indoor end uses (domestic) [m^3/(capita·d)]

no.	category	required quality [2]	scenario 1	scenario 2	scenario 3	used wa. coef. [1]
id.1	food & drinks	**A**				
id.2	personal hygiene	**A**				
id.3	clothes washing	**A**				
id.4	toilet flushing	**B**				
id.5	misc.	**B**				

outdoor end uses (ecological and environmental) [m^3/(m^2·d)]

no.	category	required quality	scenario 1	scenario 2	scenario 3	used wa. coef. [1]
od.1	landscape 1	var. [3]				
od.2	landscape 2	var.				
od.3	waterscape 1	var.				
od.4	waterscape 2	var.				
od.5	street washing	**B**				
od.6	others	var.				

specialised end uses (industrial and special) [m^3/(unit·d)]

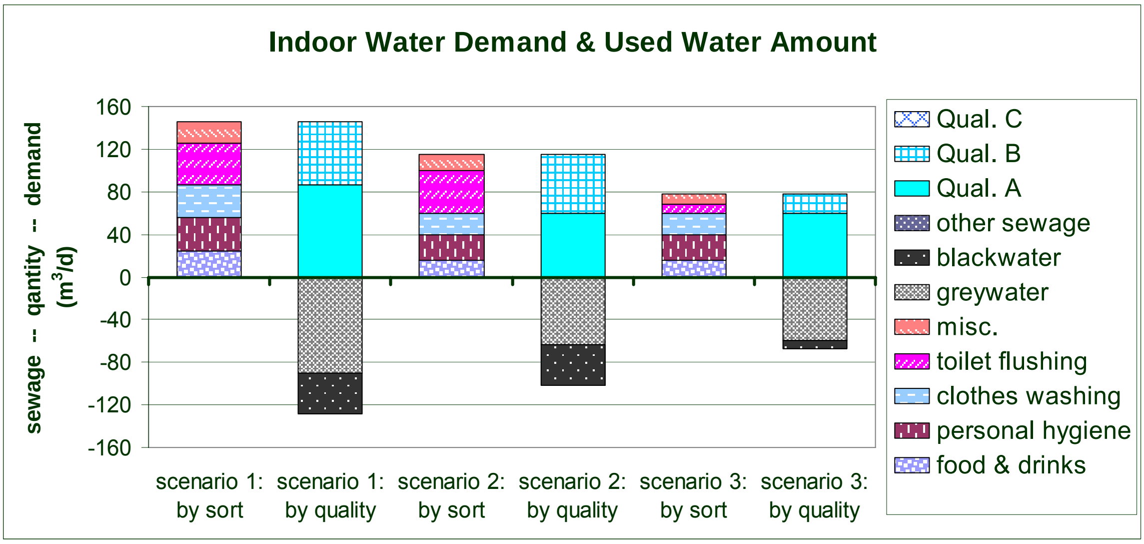
no.	category	required quality	level 1	max. size of lvl. 1 [4]	level 2	max. size of lvl. 2 [4]	used wa. coef. [1]
is.1	industrial 1						
is.2	industrial 2						
is.3	special 1						
is.4	special 2						
	…						

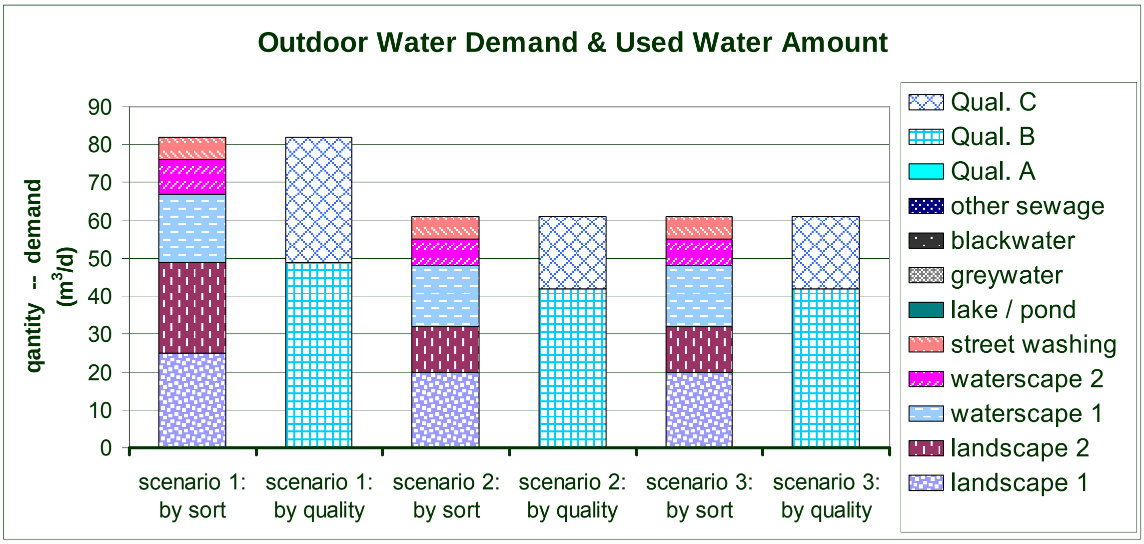
[1] used wa. coef. – generation coefficient of used water, which indicates how much used water generated after use.

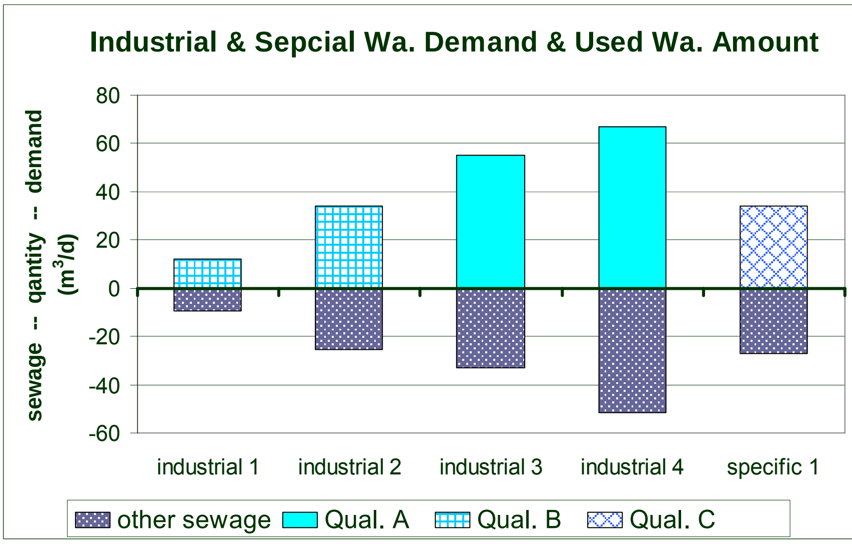
[2] it is corresponding to the quality standards that are set up in Table 2.

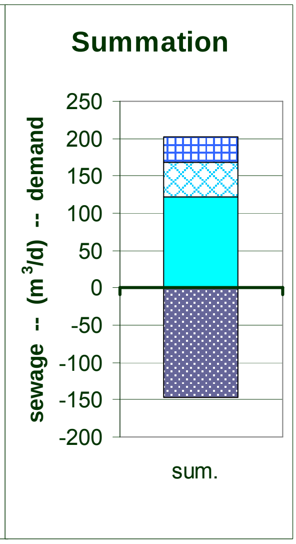
[3] var. – various, which indicates the required water quality is various depending on the actual conditions. After determining the end uses, the required water quality is fixed simultaneously.

[4] max. size of lvl. – maximum size of level, it is classified into two levels based on the system sizes in order to better estimate the water usage.







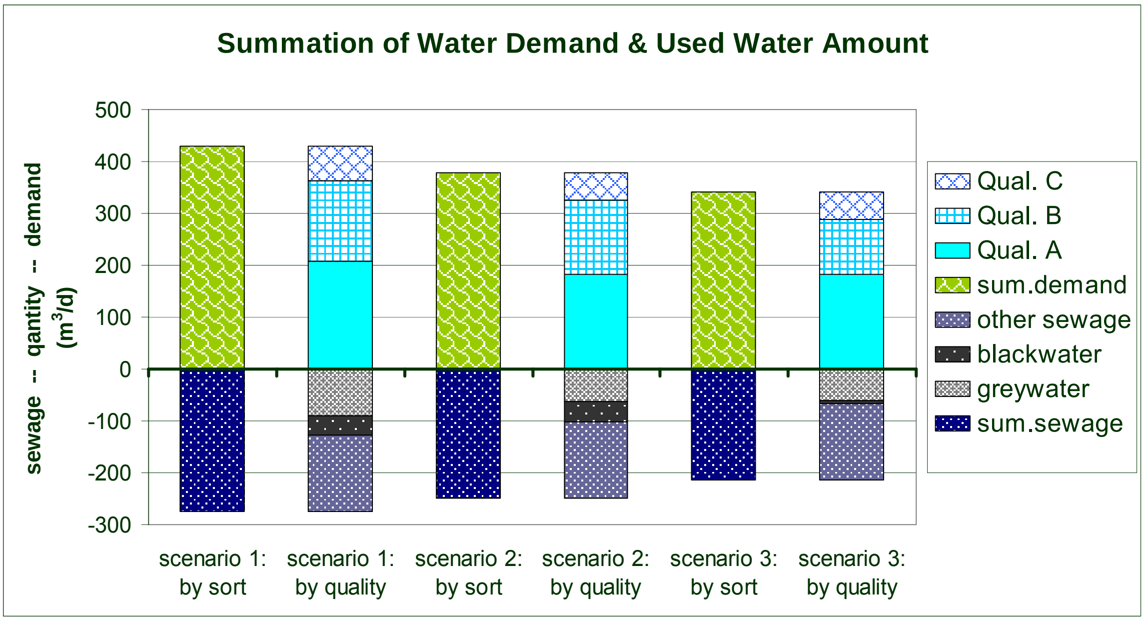


Appendix.Figure 1: The detailed EUWUP (demonstration)

Appendix.Table 9: Summation of the detailed EUWUP

no.	Category	scenario 1	scenario 2	scenario 3
sum.1	demand: summation			
sum.2	demand: Quality **A**			
sum.3	demand: Quality **B**			
sum.4	demand: Quality **C**			
sum.5	used water: summation			
sum.6	used water: greywater			
sum.7	used water: blackwater			
sum.8	used water: mixed			

Explanation: more scenarios can be added based on the requirements of projects.



Appendix.Figure 2: Summation of the EUWUP (demonstration)

Appendix 1.6 Water standards

It is used to gather and sort the water standards from different countries and regions.

Appendix.Table 10: General information of water standards

no.	Land / region	water type	name of standard	serial number	issue year
1					
2					
…					

Explanation: this table records the general information of standards, and it is associated with the Appendix.Table 11 that stores the controlled parameters and values of the standards.

Appendix.Table 11: Controlled parameters and values of water standards

no.	Name of standard	parameter	unit	value (lvl. 1)	value (lvl. 2)	value (lvl. 3)	value (lvl. 4)	value (lvl. 5)
1								
2								
…								

Abbreviation: lvl. – level

Explanation: each parameter can have several limited values in different levels. Maximum 5 levels are pre-configured, which are adequate for most situations.

Appendix 2 Case study

For demonstrating how to use the IUWS-DSM, a case study is performed. It is based on one Chinese city. The unavailable and inaccessible information that is essential for calculation is made up in order to execute the model. Therefore, the calculated values may deviate from the actuality.

Appendix 2.1 Basic information

Appendix 2.1.1 introduction to the city

Taizhou is a fast-developing city located in the southern part of the Yangtze River Delta on the east coast of China. Taizhou City consists of three large independent urban areas i.e. Jiaojiang, Huangyan and Luqiao, which were two independent cities and one town in earlier time. Being transferred from a town, Luqiao has the large requirements of development and grows quickly now. Meantime, its water infrastructure is insufficient. Hence, Luqiao area is selected for this case study.

Luqiao has a large administrative area with 274 km^2, where mostly are farms and small villages. The total current population is 0,33 million. The land is flat in general. There are hills on the north-west and south-west sides of the area. The networks of natural waterways cover the whole area very well. So far the central urbanised area is around 9,5 km^2 with the population of 100 thousand.

Luqiao has the typical subtropical monsoon climate with evident four seasons. The precipitation is abundant, with the average value of 1.530 mm/a. But it is uneven distributed, where 60% occurs in three rain seasons within a year.

According to the statistical data, local water sources are insufficient at the level of 634 m^3/capita. 85% of total water sources are the surface water. Most surface water is heavily polluted that cannot be as the source of drinking water. Abstraction of groundwater is strictly limited due to the risk of seawater intrusion. Therefore, Reservoir Changtan is the water source for the total Taizhou City. Reservoir Changtan is located 30 km in the west of the city.

Currently, Luqiao has a waterworks with the maximum capacity of 40x10^3 m^3/d. The source water is diverted from a pump station located in Huangyan. Luqiao has a wastewater treatment plant with the maximum capacity of 40x10^3 m^3/d, which is located in the south-east corner of Luqiao next to the urbanised area.

Appendix 2.1.2 study area

There is a long-range city master planning for the whole Luqioa area (Appendix.Figure 6). Due to the master planning, the urban population will reach 0,32 million and daily average water demand will hit 287x10^3 m^3/d over the whole planned area. A new transmission pipeline is planned, which directly diverts the raw water from Reservoir Changtan to Luqiao.

In this case study, only the kernel area of Luqiao is chosen as the study area. First of all, neither detailed information nor detailed plans of suburbs and new area is available. Second of all, this case study focuses on demonstrating the way to use the model, so the narrowed area can highlight the system structure but simplify the calculation. Moreover, since the urban water system is managed as certain independent water entities structured in the hierarchy, the chosen area can be the water entities in the whole Luqiao area later on.

Being the water entity of the City Area (CA), the chosen area is named *LuQi*. Three water entities as the Urban District (UD) are formed, namely *LuQi.01*, *LuQi.02* and *LuQi.03*. The basic information of CA and UDs are given in Appendix.Table 12.

The water entities as the Water Utilisation Unit (WUU) are defined in each UD (Appendix.Figure 7). A three-dimensional (3-D) map is provided in order to better understand the area (Appendix.Figure 8). The 3-D map is the combination of the status quo and the urban planning. It means that besides the existing facilities, the planned and confirmed ones are also depicted in the map. The website (http://map.3dtz.cn/) providing the 3-D map supplies also the detailed information of the buildings, structures and streets, which contains the basic information to determine the water usage of water entities. Subsequently, the water entities as the Water Utilisation Cell (WUC) in WUUs are determined. The basic information of WUUs and WUCs are described in Appendix.Table 13.

There is deviation of data in both Appendix.Table 12 and Appendix.Table 13. Meantime, the missing but indispensable data are made up in order to complete the case.

Appendix 2.2 System planning

The plan of the IUWS is implemented following the procedure given in Figure 26:

1. basic information of the planned area is collected.
2. the water entities of CA, UD, WUU and WUC are defined, and their basic information is determined, which is listed in (Appendix.Table 12 and Appendix.Table 13).
3. water usage of WUUs and WUCs is determined. Due to the lack of data, the general EUWUPs are used. The water demands (Appendix.Table 14 for WUCs and Appendix.Table 15 for WUUs), and the used water amounts (Appendix.Table 16 for WUUs) are calculated. Three scenarios are considered.
   Scenario 1: base on the conventional water consumption,
   Scenario 2: use water saving fixtures,
   Scenario 3: use Source Separated Collection System (SSCS) with vacuum toilets.
4. as the possible water sources for WUU, roof-water utilisation and direct potable water reuse are measured for each WUU. The composition of water sources is determined for each WUU (Appendix.Table 15).
5. the water system for each WUU is then determined: water supply method is based on § 3.3.2 and collection system is based on § 3.3.3. The decisions are listed in Appendix.Table 17 for Scenario 1.
   In the first round, the water quality supplied from UD is not clear, so the determination of supply and collection methods are suspended till the feedback comes from UDs.
6. the water usage of UDs is calculated by summing the water usage of their WUUs (the water demands in Appendix.Table 18 and the used water amounts in Appendix.Table 19).
7. the water sources for UD are managed. In this case study, local surface water is not usable as they are completely polluted, and groundwater is baned from using. Thus, UDs have neither surface water nor groundwater sources. Initially, the process of storm water to groundwater infiltration and indirect potable water reuse are not considered in UDs due to

the pollution and the high condensation of the urban area. The direct non-potable reuse is taken into account in UDs. The system options are depicted in Appendix.Figure 3.

8. the water system for each UD is determined, which follow the same decision making mechanisms that are used for WUU.
9. the water usage of CA is calculated based on UDs (Appendix.Table 18 and Appendix.Table 19). It is shown in Appendix.Figure 4.
10. the determination of water sources follows the decision making mechanism given in § 3.3.1. Based on the current situation, there is no proper local water source. Hence, only external sources are considered. Two options are available:
    a. water diversion from Reservoir Changtan with 30 km transmission pipeline,
    b. seawater desalination with transmission pipeline. The linear distance between urban area and seashore is 16 km.
    The indirect potable reuse is considered for CA as a potential option in future.
11. the water system for CA is determined. In principle, if only external sources are used, the single water supply system is applied. The separate sewerage system is adopted due to the well distributed natural waterways.
12. the information is fed back to UDs and then from UDs to WUUs. Each water entity is adjusted based on the feedback.

The determination of WUUs and WUCs are based on the available information. There must be the omitted water end-users due to two reasons. Firstly not all data are accessible; secondly the detailed urban planning is not accomplished for all city blocks, yet. Hence, in the actual projects if it is certain that some WUUs or WUCs are missing, the amplification coefficient may be used.

The general EUWUPs (Appendix.Table 20) are composed based on the reachable information. The calculation of the used water amounts of WUCs are not presented here for reducing the length of the dissertation. Similarly, only Scenario 1 is presented for the determined water systems of WUUs (Appendix.Table 17). The calculation of roof-water amount is based on the Eq. (2). In Appendix.Table 17, if the roof-water amount is zero, it means that the roof-water utilisation system is not involved in the WUU. Eq. (4) is used for calculating the water amount for direct non-potable reuse.

Currently, the indirect potable reuse is not a proper option for CA due to the pollution of surface water. However, it could be an alternative in future, as improving the local environmental conditions is one of the main goals for the local government. The calculation of indirect potable reuse in CA is base on the Eq. (3), where the reuse percentage is considered as 0,55. Likewise, the utilisation of surface runoff can be also the option in future. Eq. (1) is used to calculate the amount of surface runoff, and it is supposed that 30% of surface runoff is converted to the groundwater.

So far the planning of water usage is performed. Due to the deficiency of essential information, the calculation of system costs and energy consumption is not implemented in the case study. Comparing to the planning of water usage, the calculation of cost is much easier to comprehend and manipulate, which more follows the conventional methods. As discussed in the § 3.4.3, the information of energy consumption for urban water systems is universally few that needs to be further investigated. Therefore, the calculation of costs and energy is skipped from the case study.

Appendix 2.3 System analyses and discussion

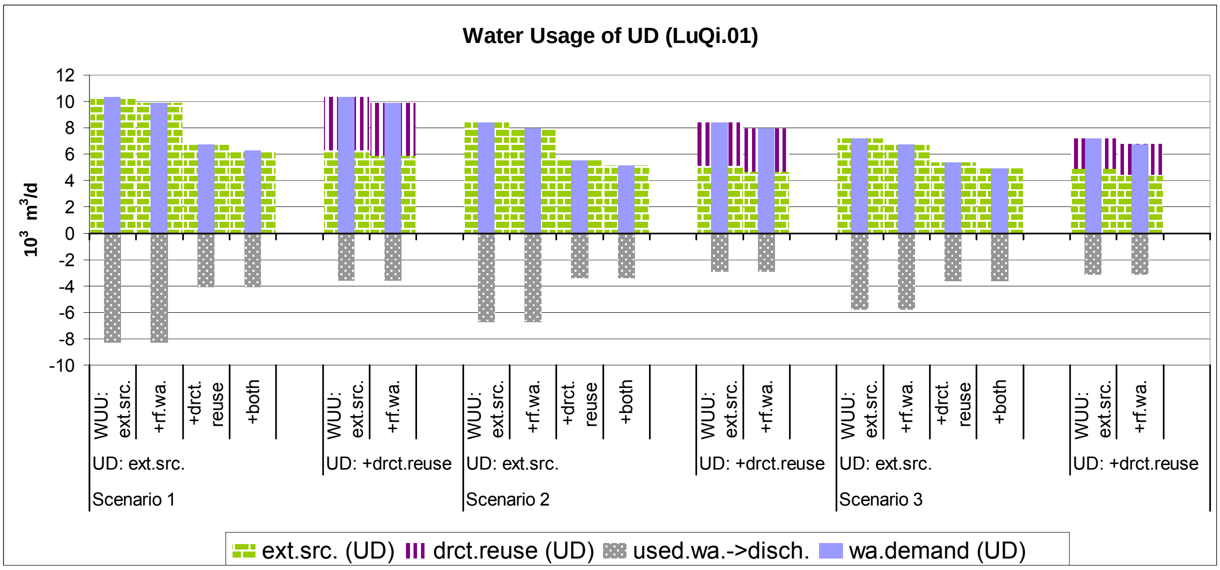
The water systems of CA and UDs are the main focus. As the independent water entities, the water usage of each UD is presented resprectively (Appendix.Figure 3). In each UD, the water usage of three scenarios is depicted simultaneously. As an example, UD of *LuQi.01* is chosen for performing the analyses. Comparing to Scenario 1, Scenario 2 has significantly lower water consumption where 18% of total water demand can be saved. Scenario 3 has the lowest water demand in general. However, it requires the SSCS and blackwater system, which can be very expensive. Hence, Scenario 2 is certainly a better situation, where the priority of Scenario 3 depends on its costs.

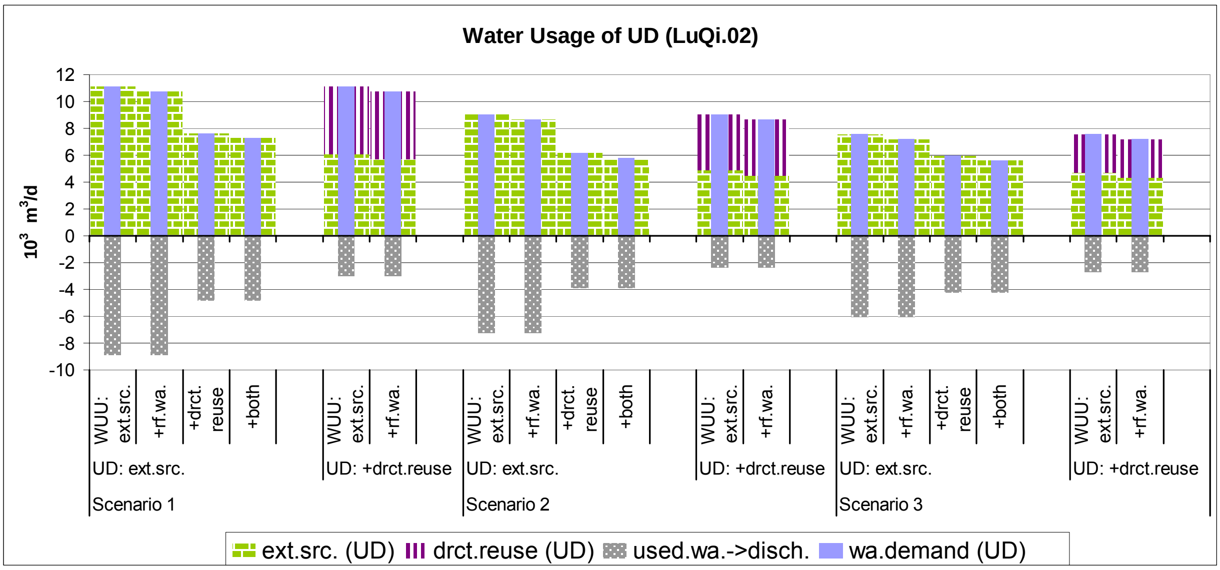
Within each scenario, roof-water utilisation has little influence on the total system due to its small volume. Hence, whether using roof-water system is the individual decision for each WUU, but not for the whole system. Direct non-potable water reuse can be applied either in WUUs or UD, which save the similar amount of water. Direct reuse in UD generates even less used water that needs to be discharged into the nature. Thus, the costs of two types of water reuse need to be calculated, and then compared based the method given in Table 34 in § 3.5.2. If it is desired, the water reuse systems between scenarios can also be performed.

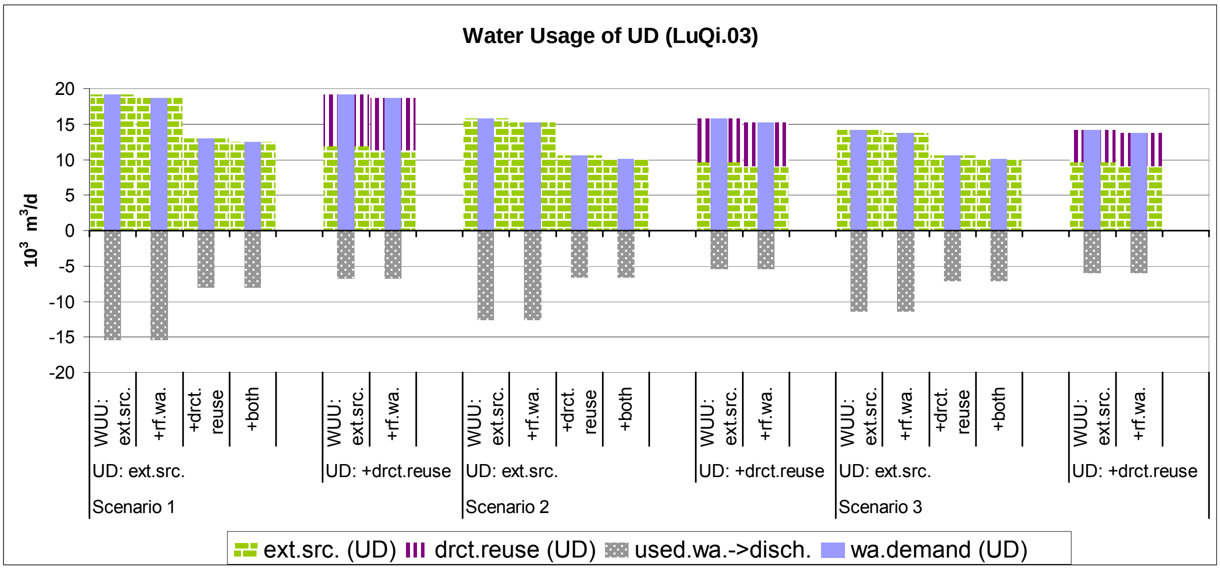
Regarding CA, the similar figure of water usage is generated (Appendix.Figure 4). The difference of water consumption between different system options and scenarios are clearly revealed. The amounts of used water can be also easily compared. Roof-water utilisation does not have the significant change to the total water system, either. Indirect potable reuse may be applied in CA. The cost comparison of the Indirect potable reuse systems can be done between scenarios. In each scenario, the comparison of water reuse can be performed between indirect potable reuse in CA, direct non-potable reuse in UD, and direct non-potable reuse in WUU. Since there are two types of external sources, i.e. long-distance water diversion and seawater desalination, the comparison of cost needs to be achieved. Step further, since local water sources have the quality problem, the dual water system may be taken into account, which can be another system option that needs to be compared. All comparison follows the methods given in Table 33 and Table 34 in § 3.5.2.

For the strategic management of the IUWS, the water balance between water usage and sources is mapped in Appendix.Figure 5**.** Besides the external water sources, there are other potentials, whereby threes cases are proposed: *Case 1*: no usable local water sources; *Case 2*: with surface runoff utilisation; and *Case 3*: with usable local water sources. It shows that the volume of rainwater is huge, whereas only 30% of rainwater can already fulfil the water demand of certain scenario. If local water sources are usable, they can satisfy the most portion of water demand. If surface runoff and local sources are both utilisable, the water reuse system is not necessary anymore. Since the local environment is polluted, the additional treatment can be necessary for both groundwater recharge of surface runoff and surface water utilisation. Subsequently, the costs comparison can be implemented between different types of water sources.

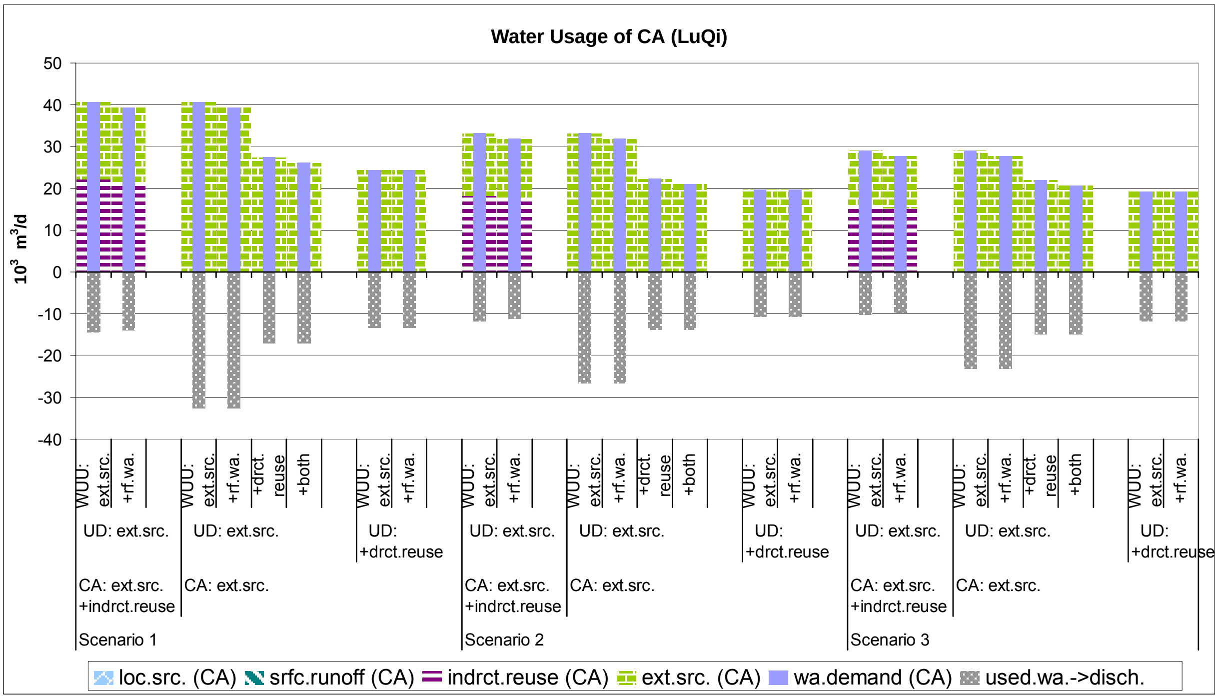
This case study is a terse demonstration of using the IUWS-DSM. It focuses on how to follow the planning procedure and how to generate the system options and then analyse them. The calculation of system costs and energy consumption are skipped because of the deficiency of the essential information.



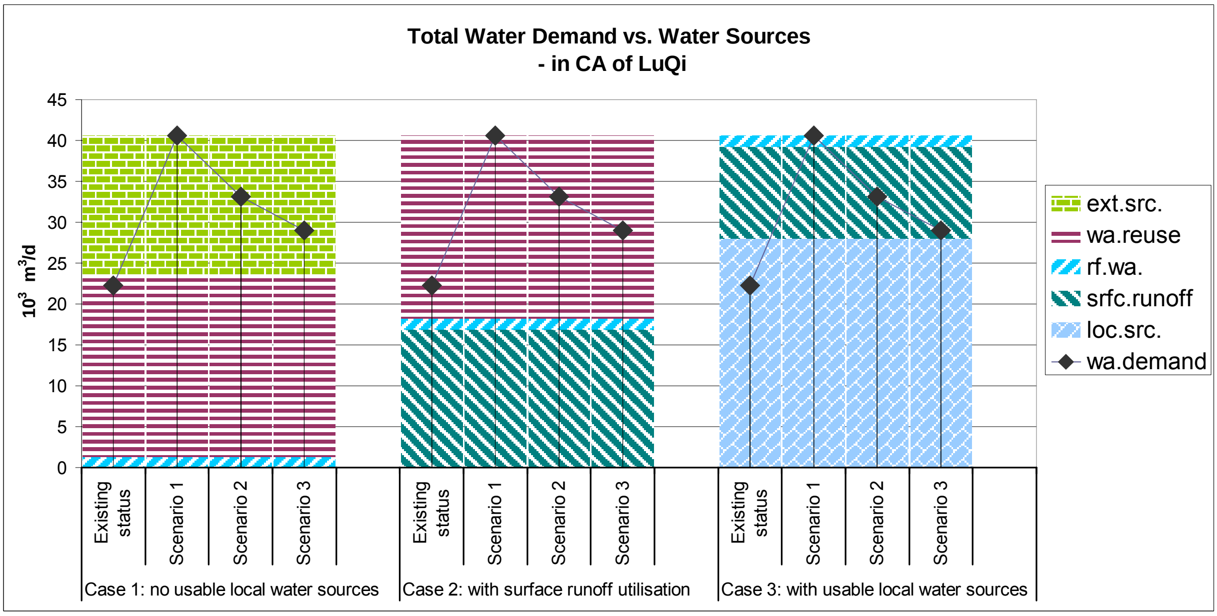




Appendix.Figure 3: Water usage of UDs



Appendix.Figure 4: Water usage of CA



Appendix.Figure 5: Water balance between demands and sources

The basic information of Taizhou City and LuQiao District is obtained from the following sources (all accessed in 08.2008):

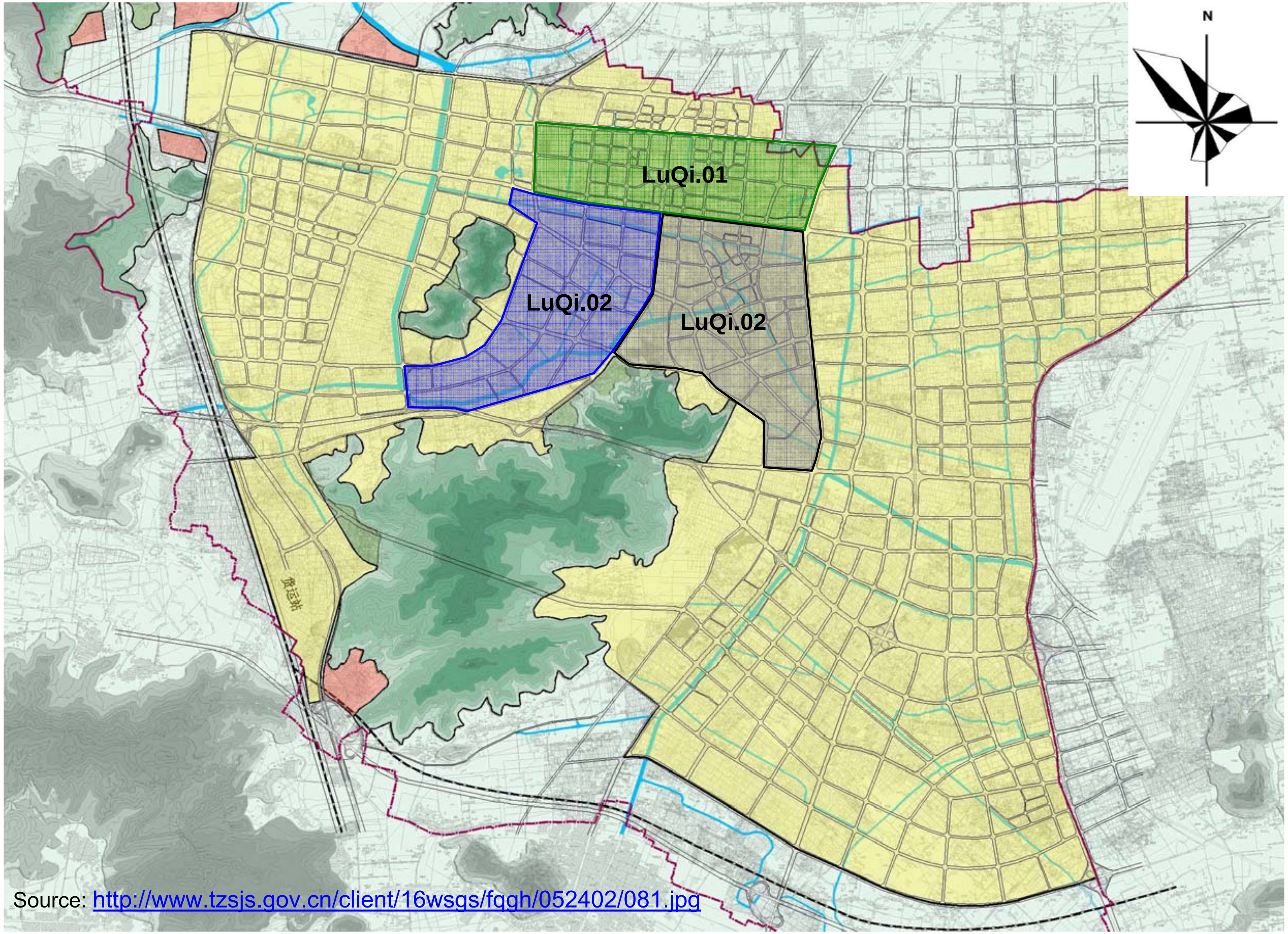
Urban Maste Planning of LuQiao District, Taizhou City, http://www.tzsjs.gov.cn/client/16wsgs/detail.jsp?id=235&category=3

Planning and Construction Bureau of Taizhou City: http://www.tzsjs.gov.cn/

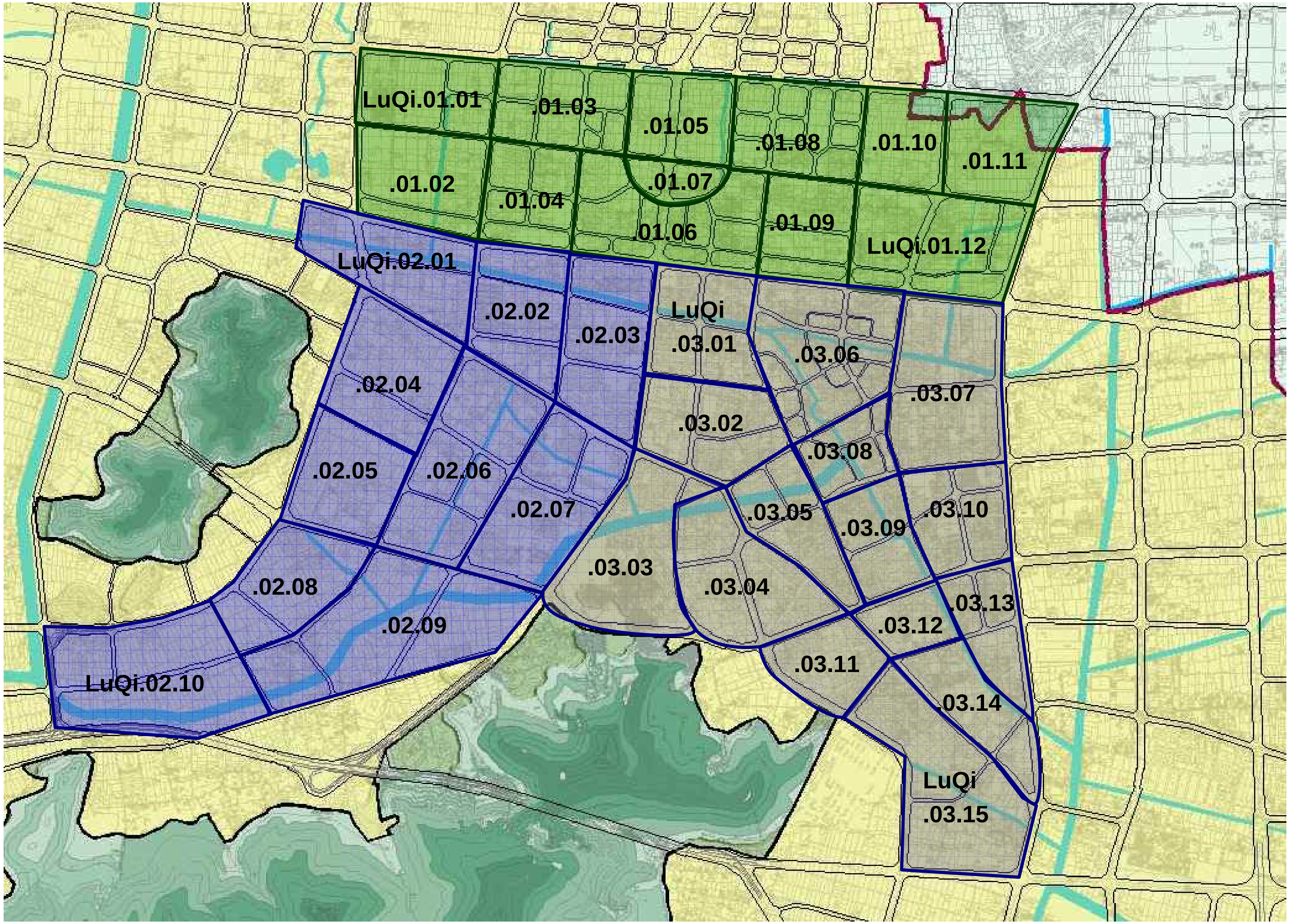
People's Government of Luqiao District, Taizhou City: http://www.luqiao.cn/En/

3-D city map (Hangzhou Aladdin Inormation & Technology Co. Ltd): http://map.3dtz.cn/

Appendix 2.4 Planning maps and calculation tables



Appendix.Figure 6: Total planned Luqiao area in Taizhou city (lang-range plan)



Appendix.Figure 7: Case study area in Luqiao with the division of WUUs

Source: http://map.3dtz.cn/

Appendix.Figure 8: 3-D map of the case study area

Appendix.Table 12: Basic information of CA and UDs

CA	UD	planned year	area [km^2]	population [capita]	green area [%]	road area [km^2]	lakes / ponds [10^3 m^3]	rivers / creeks (Y/N)	grd.wa. infiltration (P/N)
LuQi		2020	23,68	150.000	17				
	LuQi.01	2020	6,50	44.100	21			Y	P
	LuQi.02	2020	9,08	51.600	17			Y	P
	LuQi.03	2020	8,11	54.300	14			Y	P

Abbreviations: Y – yes; N – no; P – possible; grd.wa. – groundwater

Appendix.Table 13: Basic information of WUUs and WUCs

WUU	WUC	type	area [ha]	popul. [capita]	scale [1] [x10^3]	unit [1]	green area [%]	roof area [10^3 m^2]	ponds [m^3]	creeks (Y/N)
UD: LuQi.01										
LuQi.01.01			44,1							
	WUU	residential		7.000			18	2,5	0	N
LuQi.01.02			48,3							
	WUU	residential		6.000			15	2,8	250	Y
LuQi.01.03			45,0							
	WUU	residential		4.400			20		0	Y
	LuQi.01.03.01	school	3,4		1,5	student		2,5		
LuQi.01.04			34,8							
	WUU	shopping centre			55,0	m^2	8		0	N
	LuQi.01.04.01	market: goods	12,0		40,0	m^2		30,0		
	LuQi.01.04.02	market: food	3,5		6,0	m^2		9,0		

WUU	WUC	type	area [ha]	popul. [capita]	scale [1] [x10^3]	unit [1]	green area [%]	roof area [10^3 m^2]	ponds [m^3]	creeks (Y/N)
	LuQi.01.04.03	residential		1.200						
	LuQi.01.04.04	hotel			0,8	bed				
LuQi.01.05			36,3							
	WUU	conference centre			86,0	m^2	17	28,0	450	Y
LuQi.01.06			47,5							
	WUU	residential		3.500			13		0	Y
	LuQi.01.06.01	shopping centre			4,0	m^2				
	LuQi.01.06.02	hotel			1,2	bed				
	LuQi.01.06.03	restaurant			2,0	seat				
LuQi.01.07			16,1							
	WUU	residential		4.200			7		0	N
	LuQi.01.07.01	office centre			25,0	m^2				
LuQi.01.08			47,0							
	WUU	residential		8.000			15		0	Y
LuQi.01.09			45,3							
	WUU	residential		3.400			11		0	N
	LuQi.01.09.01	hotel			0,6	bed				
	LuQi.01.09.02	swimming centre			0,6	guest				
	LuQi.01.09.03	office centre			7,5	m^2		3,0		
	LuQi.01.09.04	industry: 1			0,8	p.u.				
	LuQi.01.09.05	industry: 2			2,0	p.u.		3,5		
LuQi.01.10		residential	38,2							
	WUU	residential		4.200			15		0	Y
LuQi.01.11			28,4							
	WUU	industry: 3			1,2	p.u.	7		0	Y
	LuQi.01.11.01	market: goods			12,0	m^2		10,0		

WUU	WUC	type	area [ha]	popul. [capita]	scale [1] [x10^3]	unit [1]	green area [%]	roof area [10^3 m^2]	ponds [m^3]	creeks (Y/N)
LuQi.01.12			61,1							
	WUU	residential		2.200			14		0	Y
	LuQi.01.12.01	school			1,0	student		1,0		
	LuQi.01.12.02	shopping centre			22,0	m^2		8,0		
	LuQi.01.12.03	hotel			0,4	bed				
	LuQi.01.12.04	restaurant			0,5	seat				
	LuQi.01.12.05	market: food			1,8	m^2		1,8		
	LuQi.01.12.06	market: goods	1,0		6,0	m^2		6,0		
UD: LuQi.02										
LuQi.02.01			54,1							
	WUU	residential		4.200			11		0	Y
	LuQi.02.01.01	school	2,1		1,4	student				
	LuQi.02.01.02	market: food			0,9	m^2		0,9		
	LuQi.02.01.03	market: food			1,4	m^2		1,4		
	LuQi.02.01.04	office centre			4,0	m^2				
	LuQi.02.01.05	shopping centre			9,0	m^2				
	LuQi.02.01.06	hotel			0,5	bed				
	LuQi.02.01.07	restaurant			0,6	seat				
	LuQi.02.01.08	industry: 4			0,8	p.u.		50,0		
LuQi.02.02			44,4							
	WUU	office centre			20,0	m^2	25		300	Y
	LuQi.02.02.01	residential		3.400						
	LuQi.02.02.02	bus station	3,5		4,0	passen.		4,0		
	LuQi.02.02.03	recreational site	2,9		0,9	m^2		14,0		
LuQi.02.03			54,1							
	WUU	residential		9.000			14		0	Y

WUU	WUC	type	area [ha]	popul. [capita]	scale [1] [$x10^3$]	unit [1]	green area [%]	roof area [10^3 m^2]	ponds [m^3]	creeks (Y/N)
	LuQi.02.03.01	school	5,6		3,0	student		2,5		
	LuQi.02.03.02	hotel			0,5	seat				
	LuQi.02.03.03	market: goods			40,0	m^2		18,0		
LuQi.02.04			92,4							
	WUU	residential		6.000			18		400	Y
	LuQi.02.04.01	shopping centre			3,0	m^2				
	LuQi.02.04.02	restaurant			0,6	seat				
LuQi.02.05			15,1							
	WUU	school			3,3	student	20		0	Y
LuQi.02.06			76,0							
	WUU	residential		8.000			15		0	Y
	LuQi.02.06.01	shopping centre			3,3	m^2				
	LuQi.02.06.02	restaurant			1,1	seat				
LuQi.02.07			65,1							
	WUU	residential		10.000			11		0	Y
LuQi.02.08			92,1	3.000						
	WUU	residential		6.000			25		500	Y
LuQi.02.09			94,5							
	WUU	residential		2.000			25			Y
	LuQi.02.09.01	shopping centre			3,0	m^2				
	LuQi.02.09.02	hotel			0,4	bed				
	LuQi.02.09.03	restaurant			0,8	seat				
LuQi.02.10			100,0							
	WUU	Industry: 5			0,5	p.u.	17		0	Y
UD: LuQi.03										
LuQi.03.01			41,0							

WUU	WUC	type	area [ha]	popul. [capita]	scale [1] [x10³]	unit [1]	green area [%]	roof area [10³ m²]	ponds [m³]	creeks (Y/N)
	WUU	residential		4.200			7		0	Y
	LuQi.03.01.01	school	0,4		1,1	student		1,0		
	LuQi.03.01.02	hotel			0,9	bed				
	LuQi.03.01.03	restaurant			1,2	seat				
	LuQi.03.01.04	market: food	4,2		9,0	m^2		8,0		
	LuQi.03.01.05	market: goods	3,7		12,0	m^2		11,0		
	LuQi.03.01.06	industry: 6			0,4	p.u.		15,0		
LuQi.03.02			40,1		0,0	ha				
	WUU	shopping centre			80,0	m^2	7			N
	LuQi.03.02.01	residential		1.600						
	LuQi.03.02.02	hotel			0,3	bed				
	LuQi.03.02.03	hotel			0,6	bed				
	LuQi.03.02.04	restaurant			3,0	seat				
	LuQi.03.02.05	market: goods	18,0		12,0	m^2		8,0		
LuQi.03.03			38,5							
	WUU	residential		6.500			19			Y
LuQi.03.04			50,7							
	WUU	residential		4.500			18		400	Y
	LuQi.03.04.01	school	1,9		1,4	student		2,0		
	LuQi.03.04.02	shopping centre			2,5	m^2				
	LuQi.03.04.03	restaurant			0,7	seat				
	LuQi.03.04.04	industry 7			2,5	p.u.		8,0		
	LuQi.03.04.05	industry: 2			3,0	p.u.		6,0		
LuQi.03.05			34,2							
	WUU	residential		11.000			12		0	Y
	LuQi.03.05.01	shopping centre			2,5	m^2				

WUU	WUC	type	area [ha]	popul. [capita]	scale [1] [$x10^3$]	unit [1]	green area [%]	roof area [10^3 m^2]	ponds [m^3]	creeks (Y/N)
	LuQi.03.05.02	swimming centre			1,2	m^2				
	LuQi.03.05.03	market: goods			6,0	m^2				
LuQi.03.06			77,9							
	WUU	shopping centre			120,0	m^2	7	20,0	0	Y
	LuQi.03.06.01	residential		2.500						
	LuQi.03.06.02	hotel			2,0	bed				
	LuQi.03.06.04	hotel			0,5	m^2				
	LuQi.03.06.03	restaurant			3,0	seat				
	LuQi.03.06.05	market: goods			7,0	m^2		6,5		
	LuQi.03.06.06	industry: 3			0,6	p.u.				
LuQi.03.07			63,7							
	WUU	residential		2.800			21		0	Y
	LuQi.03.07.01	school			2,8	student		1,9		
	LuQi.03.07.02	school			1,4	student		1,4		
	LuQi.03.07.03	hostipal			3,0	bed				
	LuQi.03.07.04	shopping centre			6,0	m^2		3,0		
	LuQi.03.07.05	industry: 6			0,5	p.u.				
LuQi.03.08			22,0							
	WUU	residential		3.500			9		0	Y
	LuQi.03.08.01	hostipal			0,8	bed				
	LuQi.03.08.02	nursery school			0,5	child				
LuQi.03.09			30,0							
	WUU	residential		2.200			10		0	Y
	LuQi.03.09.01	shopping centre			2,2	m^2				
	LuQi.03.09.02	nursery school			0,7	child		1,6		
	LuQi.03.09.03	markets: goods	3,0		4,5	m^2		4,5		

WUU	WUC	type	area [ha]	popul. [capita]	scale [1] [x10^3]	unit [1]	green area [%]	roof area [10^3 m^2]	ponds [m^3]	creeks (Y/N)
LuQi.03.10			46,5							
	WUU	residential		7.000			11		0	Y
	LuQi.03.10.01	market: goods	6,2		20,0	m^2		16,0		
LuQi.03.11			22							
	WUU	residential		2.500			22		0	Y
	LuQi.03.11.01	school	2,0		1,3	student		1,2		
	LuQi.03.11.02	school			2,2	student		2,1		
	LuQi.03.11.03	school			1,8	student		1,6		
	LuQi.03.11.04	hotel			0,8	bed				
LuQi.03.12			13,7							
	WUU	hostipal			4,5	bed	25		0	Y
LuQi.03.13			26							
	WUU	residential		6.000			17		0	Y
LuQi.03.14			32,4							
	WUU	market: goods			42,0	m^2	12		0	Y
	LuQi.03.14.01	bus station			2,5	passen.				
LuQi.03.15			75,5							
	WUU	industry:8			5,0	p.u.	14		0	Y

Abbreviations: popul. – population; passen. – passenger; p.u. – product unit

[1] the scale of the water entity, which is used to estimate the water usage. The units are corresponding to the units in Appendix.Table 20.

Explanation: the row next to each WUU holds the basic information of the WUU.

Appendix.Table 14: Water demands and water sources of WUCs

unit: m^3/d		Scenario 1					Scenario 2					Scenario 3				
	demand : current	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both
UD: LuQi.01																
LuQi.01.01	0															
WUU		980	980	970	647	637	770	770	760	508	498	595	595	585	488	478
LuQi.01.02	0															
WUU		840	840	828	554	543	660	660	648	436	424	510	510	498	418	407
LuQi.01.03	400															
WUU		616	616	616	407	407	484	484	484	319	319	374	374	374	307	307
LuQi.01.03.01		83	83	72	50	39	72	72	62	43	33	0	0	-10	0	-10
LuQi.01.04	1.350															
WUU		990	990	990	545	545	770	770	770	424	424	825	825	825	454	454
LuQi.01.04.01		240	240	117	120	-3	240	240	117	120	-3	240	240	117	120	-3
LuQi.01.04.02		240	240	203	180	143	210	210	173	158	121	210	210	173	158	121
LuQi.01.04.03		168	168	168	87	87	132	132	132	87	87	102	102	102	84	84
LuQi.01.04.04		113	113	113	74	74	86	86	86	57	57	71	71	71	53	53
LuQi.01.05	500															
WUU		602	602	487	397	282	430	430	315	284	169	430	430	315	353	238
LuQi.01.06	500															
WUU		490	490	490	323	323	385	385	385	254	254	298	298	298	244	244
LuQi.01.06.01		72	72	72	40	40	56	56	56	31	31	60	60	60	33	33
LuQi.01.06.02		180	180	180	119	119	138	138	138	91	91	114	114	114	86	86
LuQi.01.06.03		94	94	94	66	66	84	84	84	59	59	44	44	44	31	31

unit: m^3/d	demand : current	Scenario 1					Scenario 2					Scenario 3				
		demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both
LuQi.01.07	600															
WUU		588	588	588	388	388	462	462	462	305	305	357	357	357	293	293
LuQi.01.07.01		875	875	875	525	525	750	750	750	450	450	600	600	600	360	360
LuQi.01.08	0															
WUU		1.120	1.120	1.120	739	739	880	880	880	581	581	680	680	680	558	558
LuQi.01.09	1.000															
WUU		476	476	476	314	314	374	374	374	247	247	289	289	289	237	237
LuQi.01.09.01		90	90	90	59	59	69	69	69	46	46	57	57	57	43	43
LuQi.01.09.02		18	18	18	14	14	16	16	16	12	12	16	16	16	12	12
LuQi.01.09.03		263	263	250	158	145	225	225	213	135	123	180	180	168	108	96
LuQi.01.09.04		263	263	263	263	263	263	263	263	263	263	263	263	263	263	263
LuQi.01.09.05		170	170	156	170	156	170	170	156	170	156	170	170	156	170	156
LuQi.01.10	250															
WUU		588	588	588	388	388	462	462	462	305	305	357	357	357	293	293
LuQi.01.11	0															
WUU		264	264	264	264	264	264	264	264	264	264	264	264	264	264	264
LuQi.01.11.01		72	72	31	36	-5	72	72	31	36	-5	72	72	31	36	-5
LuQi.01.12	350															
WUU		308	308	308	203	203	242	242	242	160	160	187	187	187	153	153
LuQi.01.12.01		53	53	49	32	28	46	46	42	28	24	39	39	35	30	25
LuQi.01.12.02		396	396	363	218	185	308	308	275	169	137	330	330	297	182	149
LuQi.01.12.03		60	60	60	40	40	46	46	46	30	30	38	38	38	29	29

unit: m^3/d	demand : current	Scenario 1					Scenario 2					Scenario 3				
		demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both
LuQi.01.12.04		24	24	24	16	16	21	21	21	15	15	11	11	11	8	8
LuQi.01.12.05		72	72	65	54	47	63	63	56	47	40	63	63	56	47	40
LuQi.01.12.06		36	36	11	18	-7	36	36	11	18	-7	36	36	11	18	-7
UD: LuQi.02																
LuQi.02.01	110															
WUU		588	588	588	388	388	462	462	462	305	305	357	357	357	293	293
LuQi.02.01.01		74	74	74	45	45	65	65	65	39	39	55	55	55	42	42
LuQi.02.01.02		36	36	32	27	23	32	32	28	24	20	32	32	28	24	20
LuQi.02.01.03		56	56	50	42	36	49	49	43	37	31	49	49	43	37	31
LuQi.02.01.04		140	140	140	84	84	120	120	120	72	72	96	96	96	58	58
LuQi.02.01.05		162	162	162	89	89	126	126	126	69	69	135	135	135	74	74
LuQi.02.01.06		75	75	75	50	50	58	58	58	38	38	48	48	48	36	36
LuQi.02.01.07		28	28	28	20	20	0	0	0	9	9	13	13	13	0	0
LuQi.02.01.08		640	640	435	640	435	560	560	355	560	355	560	560	355	560	355
LuQi.02.02	1.500															
WUU		700	700	700	420	420	600	600	600	360	360	480	480	480	288	288
LuQi.02.02.01		476	476	476	314	314	374	374	374	247	247	289	289	289	237	237
LuQi.02.02.02		160	160	144	96	80	144	144	128	86	70	144	144	128	86	70
LuQi.02.02.03		315	315	257	142	84	315	315	257	142	84	315	315	257	142	84
LuQi.02.03	1.400															
WUU		1.260	1.260	1.260	832	832	990	990	990	653	653	765	765	765	627	627
LuQi.02.03.01		165	165	155	99	89	144	144	134	86	76	123	123	113	92	82

unit: m³/d	demand : current	Scenario 1					Scenario 2					Scenario 3				
		demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both
LuQi.02.03.02		75	75	75	50	50	58	58	58	38	38	48	48	48	36	36
LuQi.02.03.03		240	240	166	120	46	240	240	166	120	46	240	240	166	120	46
LuQi.02.04	100															
WUU		840	840	840	554	554	660	660	660	436	436	510	510	510	418	418
LuQi.02.04.01		54	54	54	30	30	42	42	42	23	23	45	45	45	25	25
LuQi.02.04.02		26	26	26	18	18	23	23	23	8	8	12	12	12	16	16
LuQi.02.05	160															
WUU		182	182	182	109	109	158	158	158	95	95	135	135	135	101	101
LuQi.02.06	600															
WUU		1.120	1.120	1.120	739	739	880	880	880	581	581	680	680	680	558	558
LuQi.02.06.01		59	59	59	33	33	46	46	46	25	25	50	50	50	27	27
LuQi.02.06.02		52	52	52	36	36	46	46	46	17	17	24	24	24	32	32
LuQi.02.07	0															
WUU		1.400	1.400	1.400	924	924	1.100	1.100	1.100	726	726	850	850	850	697	697
LuQi.02.08	0															
WUU		840	840	840	554	554	660	660	660	436	436	510	510	510	418	418
LuQi.02.09	300															
WUU		280	280	280	185	185	220	220	220	145	145	170	170	170	139	139
LuQi.02.09.01		54	54	54	30	30	42	42	42	23	23	45	45	45	25	25
LuQi.02.09.02		60	60	60	40	40	46	46	46	30	30	38	38	38	29	29
LuQi.02.09.03		38	38	38	26	26	34	34	34	12	12	18	18	18	24	24
LuQi.02.10	400															

unit: m^3/d	demand : current	Scenario 1					Scenario 2					Scenario 3				
		demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both
WUU		900	900	900	900	900	720	720	720	720	720	720	720	720	720	720
UD: LuQi.03																
LuQi.03.01	1.300															
WUU		588	588	588	388	388	462	462	462	305	305	357	357	357	293	293
LuQi.03.01.01		59	59	55	36	32	52	52	48	31	27	44	44	40	33	29
LuQi.03.01.02		128	128	128	84	84	98	98	98	65	65	81	81	81	61	61
LuQi.03.01.03		56	56	56	39	39	50	50	50	18	18	26	26	26	35	35
LuQi.03.01.04		360	360	327	270	237	315	315	282	236	203	315	315	282	236	203
LuQi.03.01.05		72	72	27	36	-9	72	72	27	36	-9	72	72	27	36	-9
LuQi.03.01.06		240	240	178	240	178	220	220	158	220	158	220	220	158	220	158
LuQi.03.02	1.460															
WUU		1.440	1.440	1.440	792	792	1.120	1.120	1.120	616	616	1.200	1.200	1.200	660	660
LuQi.03.02.01		224	224	224	148	148	176	176	176	116	116	136	136	136	112	112
LuQi.03.02.02		39	39	39	25	25	30	30	30	20	20	24	24	24	18	18
LuQi.03.02.03		90	90	90	59	59	69	69	69	46	46	57	57	57	43	43
LuQi.03.02.04		141	141	141	99	99	126	126	126	46	46	66	66	66	88	88
LuQi.03.02.05		72	72	39	36	3	72	72	39	36	3	72	72	39	36	3
LuQi.03.03	200															
WUU		910	910	910	601	601	715	715	715	472	472	553	553	553	453	453
LuQi.03.04	200															
WUU		630	630	630	416	416	495	495	495	327	327	383	383	383	314	314
LuQi.03.04.01		74	74	66	45	36	65	65	57	39	31	55	55	47	42	33

unit: m³/d	demand : current	Scenario 1					Scenario 2					Scenario 3				
		demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both
LuQi.03.04.02		45	45	45	25	25	35	35	35	19	19	38	38	38	21	21
LuQi.03.04.03		31	31	31	21	21	27	27	27	10	10	14	14	14	10	10
LuQi.03.04.04		125	125	92	125	92	125	125	92	125	92	125	125	92	125	92
LuQi.03.04.05		255	255	230	255	230	255	255	230	255	230	255	255	230	255	230
LuQi.03.05	1.350															
WUU		1.540	1.540	1.540	1.016	1.016	1.210	1.210	1.210	799	799	935	935	935	767	767
LuQi.03.05.01		45	45	45	25	25	35	35	35	19	19	38	38	38	21	21
LuQi.03.05.02		36	36	36	27	27	31	31	31	23	23	31	31	31	23	23
LuQi.03.05.03		36	36	36	18	18	36	36	36	18	18	36	36	36	18	18
LuQi.03.06	2.600															
WUU		2.160	2.160	2.078	1.188	1.106	1.680	1.680	1.598	924	842	1.800	1.800	1.718	990	908
LuQi.03.06.01		350	350	350	231	231	275	275	275	182	182	213	213	213	174	174
LuQi.03.06.02		300	300	300	198	198	230	230	230	152	152	190	190	190	143	143
LuQi.03.06.04		75	75	75	50	50	58	58	58	38	38	48	48	48	36	36
LuQi.03.06.03		141	141	141	99	99	126	126	126	46	46	66	66	66	46	46
LuQi.03.06.05		42	42	15	21	-6	42	42	15	21	-6	42	42	15	21	-6
LuQi.03.06.06		121	121	121	121	121	121	121	121	121	121	121	121	121	121	121
LuQi.03.07	1.600															
WUU		392	392	392	259	259	308	308	308	203	203	238	238	238	195	195
LuQi.03.07.01		154	154	146	92	85	134	134	127	81	73	115	115	107	86	78
LuQi.03.07.02		79	79	73	48	42	69	69	63	41	36	59	59	53	44	39
LuQi.03.07.03		1.080	1.080	1.080	810	810	930	930	930	698	698	930	930	930	698	698

unit: m^3/d	demand : current	Scenario 1					Scenario 2					Scenario 3				
		demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both
LuQi.03.07.04		108	108	96	59	47	84	84	72	46	34	90	90	78	50	37
LuQi.03.07.05		270	270	270	270	270	248	248	248	248	248	248	248	248	248	248
LuQi.03.08	660															
WUU		490	490	490	323	323	385	385	385	254	254	298	298	298	244	244
LuQi.03.08.01		288	288	288	216	216	248	248	248	186	186	248	248	248	186	186
LuQi.03.08.02		20	20	20	12	12	18	18	18	11	11	15	15	15	9	9
LuQi.03.09	400															
WUU		308	308	308	203	203	242	242	242	160	160	187	187	187	153	153
LuQi.03.09.01		40	40	40	22	22	31	31	31	17	17	33	33	33	18	18
LuQi.03.09.02		32	32	26	19	13	29	29	22	17	11	24	24	17	14	8
LuQi.03.09.03		180	180	162	90	72	158	158	139	79	60	158	158	139	79	60
LuQi.03.10	750															
WUU		980	980	980	647	647	770	770	770	508	508	595	595	595	488	488
LuQi.03.10.01		120	120	54	60	-6	120	120	54	60	-6	120	120	54	60	-6
LuQi.03.11	200															
WUU		350	350	350	231	231	275	275	275	182	182	213	213	213	174	174
LuQi.03.11.01		69	69	64	42	37	60	60	56	36	31	52	52	47	39	34
LuQi.03.11.02		121	121	112	73	64	106	106	97	63	55	90	90	82	68	59
LuQi.03.11.03		99	99	92	59	53	86	86	80	52	45	74	74	67	55	49
LuQi.03.11.04		120	120	120	79	79	92	92	92	61	61	76	76	76	57	57
LuQi.03.12	1.100															
WUU		1.620	1.620	1.620	1.215	1.215	1.395	1.395	1.395	1.046	1.046	1.395	1.395	1.395	1.046	1.046

unit: m^3/d	demand : current	Scenario 1					Scenario 2					Scenario 3				
		demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both
LuQi.03.13	200															
WUU		840	840	840	554	554	660	660	660	436	436	510	510	510	418	418
LuQi.03.14	200															
WUU		252	252	252	126	126	252	252	252	126	126	252	252	252	126	126
LuQi.03.12.01		100	100	100	60	60	90	90	90	54	54	90	90	90	54	54
LuQi.03.15	500															
WUU		750	750	750	750	750	600	600	600	600	600	600	600	600	600	600

Abbreviations: ext. src. – external sources; drct. – direct

Explanation: The row next to each WUU holds the calculation for the WUU, which is the main water demand of the WUU.

There are minus amount of source water in some WUCs. It indicates that the amount of source water is more than the demand in the WUC. It may happen when both roof-water and reclaimed water are involved as the water sources. Because the water usage is managed within WUU, the superfluous amount of water can be used by other water end-users.

Appendix.Table 15: Water demands and water sources of WUUs

unit: m^3/d	demand : current	Scenario 1					Scenario 2					Scenario 3				
		demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both
UD: LuQi.01																
LuQi.01.01	0	980	980	970	647	637	770	770	760	508	498	595	595	585	488	478
LuQi.01.02	0	840	840	828	554	543	660	660	648	436	424	510	510	498	418	407
LuQi.01.03	400	699	699	688	456	446	556	556	546	363	352	374	374	364	307	296
LuQi.01.04	1.350	1.751	1.751	1.590	1.006	846	1.438	1.438	1.278	845	685	1.448	1.448	1.288	868	708
LuQi.01.05	500	602	602	487	397	282	430	430	315	284	169	430	430	315	353	238
LuQi.01.06	500	836	836	836	548	548	663	663	663	435	435	516	516	516	393	393
LuQi.01.07	600	1.463	1.463	1.463	913	913	1.212	1.212	1.212	755	755	957	957	957	653	653
LuQi.01.08	0	1.120	1.120	1.120	739	739	880	880	880	581	581	680	680	680	558	558
LuQi.01.09	1.000	1.279	1.279	1.252	977	950	1.116	1.116	1.089	872	845	974	974	947	832	805
LuQi.01.10	250	588	588	588	388	388	462	462	462	305	305	357	357	357	293	293
LuQi.01.11	0	336	336	295	300	259	336	336	295	300	259	336	336	295	300	259
LuQi.01.12	350	948	948	879	581	512	762	762	693	467	398	704	704	635	466	397
UD: LuQi.02																
LuQi.02.01	110	1.799	1.799	1.585	1.384	1.169	1.471	1.471	1.256	1.153	938	1.345	1.345	1.130	1.122	907
LuQi.02.02	1.500	1.651	1.651	1.577	972	898	1.433	1.433	1.359	835	761	1.228	1.228	1.154	753	679
LuQi.02.03	1.400	1.740	1.740	1.656	1.100	1.016	1.432	1.432	1.347	898	814	1.176	1.176	1.091	875	791
LuQi.02.04	100	920	920	920	602	602	725	725	725	467	467	567	567	567	459	459
LuQi.02.05	160	182	182	182	109	109	158	158	158	95	95	135	135	135	101	101
LuQi.02.06	600	1.231	1.231	1.231	808	808	972	972	972	623	623	754	754	754	617	617
LuQi.02.07	0	1.400	1.400	1.400	924	924	1.100	1.100	1.100	726	726	850	850	850	697	697

unit: m^3/d		Scenario 1					Scenario 2					Scenario 3				
	demand : current	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	demand: planned	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both
LuQi.02.08	0	840	840	840	554	554	660	660	660	436	436	510	510	510	418	418
LuQi.02.09	300	432	432	432	280	280	342	342	342	211	211	271	271	271	216	216
LuQi.02.10	400	900	900	900	900	900	720	720	720	720	720	720	720	720	720	720
UD: LuQi.03																
LuQi.03.01	1.300	1.503	1.503	1.359	1.093	950	1.269	1.269	1.125	911	767	1115	1115	972	914	770
LuQi.03.02	1.460	2.006	2.006	1.973	1.159	1.127	1.593	1.593	1.560	879	847	1.555	1.555	1.523	957	924
LuQi.03.03	200	910	910	910	601	601	715	715	715	472	472	553	553	553	453	453
LuQi.03.04	200	1.160	1.160	1.094	886	821	1.002	1.002	936	775	709	870	870	804	766	700
LuQi.03.05	1.350	1.657	1.657	1.657	1.086	1.086	1.312	1.312	1.312	859	859	1.040	1.040	1040	829	829
LuQi.03.06	2.600	3.189	3.189	3.080	1.907	1.798	2.532	2.532	2.423	1.483	1.375	2.479	2.479	2.370	1.531	1.422
LuQi.03.07	1.600	2.083	2.083	2.057	1.538	1.512	1.773	1.773	1.747	1.317	1.291	1.679	1.679	1.653	1.320	1.294
LuQi.03.08	660	798	798	798	552	552	651	651	651	451	451	560	560	560	439	439
LuQi.03.09	400	560	560	535	335	309	459	459	434	273	248	401	401	376	264	239
LuQi.03.10	750	1.100	1.100	1.034	707	641	890	890	824	568	502	715	715	649	548	482
LuQi.03.11	200	759	759	739	484	464	619	619	599	394	374	504	504	484	393	373
LuQi.03.12	1.100	1.620	1.620	1.620	1.215	1.215	1.395	1.395	1.395	1.046	1.046	1.395	1.395	1.395	1.046	1.046
LuQi.03.13	200	840	840	840	554	554	660	660	660	436	436	510	510	510	418	418
LuQi.03.14	200	252	252	252	126	126	252	252	252	126	126	252	252	252	126	126
LuQi.03.15	500	750	750	750	750	750	600	600	600	600	600	600	600	600	600	600

Abbreviations: ext. src. – external sources; drct. – direct

Appendix.Table 16: Used water amounts of WUUs

unit: m3/d	Scenario 1				Scenario 2				Scenario 3			
	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both
UD: LuQi.01												
LuQi.01.01	784	784	392	392	616	616	308	308	476	476	350	350
LuQi.01.02	672	672	336	336	528	528	264	264	408	408	300	300
LuQi.01.03	559	559	274	274	445	445	217	217	299	299	220	220
LuQi.01.04	1.370	1.370	494	494	1.151	1.151	453	453	1.159	1.159	476	476
LuQi.01.05	482	482	241	241	344	344	172	172	344	344	253	253
LuQi.01.06	683	683	343	343	530	530	262	262	412	412	269	269
LuQi.01.07	1.170	1.170	523	523	970	970	432	432	766	766	408	408
LuQi.01.08	896	896	448	448	704	704	352	352	544	544	400	400
LuQi.01.09	1.023	1.023	668	668	893	893	605	605	779	779	612	612
LuQi.01.10	470	470	235	235	370	370	185	185	286	286	210	210
LuQi.01.11	269	269	226	226	269	269	226	226	269	269	226	226
LuQi.01.12	759	759	326	326	610	610	263	263	563	563	283	283
UD: LuQi.02												
LuQi.02.01	1.440	1.440	951	951	1.177	1.177	802	802	1.076	1.076	814	814
LuQi.02.02	1.321	1.321	522	522	1.146	1.146	443	443	982	982	424	424
LuQi.02.03	1.392	1.392	639	639	1.145	1.145	517	517	940	940	587	587
LuQi.02.04	736	736	362	362	580	580	277	277	454	454	327	327
LuQi.02.05	145	145	60	60	127	127	52	52	108	108	68	68
LuQi.02.06	985	985	487	487	778	778	367	367	603	603	442	442
LuQi.02.07	1.120	1.120	560	560	880	880	440	440	680	680	500	500
LuQi.02.08	672	672	336	336	528	528	264	264	408	408	300	300

unit: m3/d	Scenario 1				Scenario 2				Scenario 3			
	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both
LuQi.02.09	345	345	167	167	273	273	120	120	216	216	152	152
LuQi.02.10	720	720	720	720	576	576	576	576	576	576	576	576
UD: LuQi.03												
LuQi.03.01	1.203	1.203	720	720	1.015	1.015	594	594	892	892	655	655
LuQi.03.02	1.604	1.604	609	609	1.274	1.274	435	435	1.244	1.244	540	540
LuQi.03.03	728	728	364	364	572	572	286	286	442	442	325	325
LuQi.03.04	928	928	606	606	802	802	534	534	696	696	574	574
LuQi.03.05	1.326	1.326	654	654	1.050	1.050	517	517	832	832	584	584
LuQi.03.06	2.551	2.551	1.043	1.043	2.025	2.025	792	792	1.983	1.983	867	867
LuQi.03.07	1.667	1.667	1.025	1.025	1.418	1.418	881	881	1.343	1.343	921	921
LuQi.03.08	639	639	348	348	521	521	285	285	448	448	305	305
LuQi.03.09	448	448	183	183	367	367	148	148	321	321	160	160
LuQi.03.10	880	880	417	417	712	712	333	333	572	572	375	375
LuQi.03.11	607	607	283	283	496	496	230	230	403	403	273	273
LuQi.03.12	1.296	1.296	820	820	1.116	1.116	706	706	1.116	1.116	706	706
LuQi.03.13	672	672	336	336	528	528	264	264	408	408	300	300
LuQi.03.14	202	202	53	53	202	202	53	53	202	202	53	53
LuQi.03.15	600	600	600	600	480	480	480	480	480	480	480	480

Abbreviations: ext. src. – external sources; drct. – direct

Appendix.Table 17: Determination of the water system for WUUs (Scenario 1)

WUU	water amount [m³/d]			scale of package plant [m³/d]				type of conveying system		
	total demand	drink.wa.percent.	used water	drinking water	roof-water	used water	black-water	networks	SSCS	sewerage system
UD: LuQi.01										
LuQi.01.01	980	0,66	784	0	10	392	0	single	N	sepa,
LuQi.01.02	840	0,66	672	0	12	336	0	single	N	sepa,
LuQi.01.03	699	0,65	559	0	10	285	0	single	N	sepa,
LuQi.01.04	1.751	0,57	1.370	0	160	876	0	single	N	sepa,
LuQi.01.05	602	0,66	482	0	115	241	0	single	N	sepa,
LuQi.01.06	836	0,66	683	0	0	339	0	single	N	sepa,
LuQi.01.07	1.463	0,62	1.170	0	0	647	0	single	N	sepa,
LuQi.01.08	1.120	0,66	896	0	0	448	0	single	N	sepa,
LuQi.01.09	1.279	0,63	1.023	0	27	355	0	single	N	sepa,
LuQi.01.10	588	0,66	470	0	0	235	0	single	N	sepa,
LuQi.01.11	336	0,11	269	0	41	42	0	single	N	sepa,
LuQi.01.12	948	0,61	759	0	69	432	0	single	N	sepa,
UD: LuQi.02										
LuQi.02.01	1.799	0,41	1.440	0	215	489	0	single	N	sepa,
LuQi.02.02	1.651	0,59	1.321	0	74	799	0	single	N	sepa,
LuQi.02.03	1.740	0,63	1.392	0	84	753	0	single	N	sepa,
LuQi.02.04	920	0,65	736	0	0	374	0	single	N	sepa,
LuQi.02.05	182	0,60	145	0	0	85	0	single	N	sepa,
LuQi.02.06	1.231	0,66	985	0	0	498	0	single	N	sepa,
LuQi.02.07	1.400	0,66	1.120	0	0	560	0	single	N	sepa,
LuQi.02.08	840	0,66	672	0	0	336	0	single	N	sepa,
LuQi.02.09	432	0,65	345	0	0	178	0	single	N	sepa,
LuQi.02.10	900	0,00	720	0	0	0	0	single	N	sepa,

WUU	water amount [m³/d]			scale of package plant [m³/d]				type of conveying system		
	total demand	drink.wa.percent.	used water	drinking water	roof-water	used water	black-water	networks	SSCS	sewerage system
UD: LuQi.03										
LuQi.03.01	1.503	0,73	1.203	0	144	482	0	single	N	sepa,
LuQi.03.02	2.006	0,58	1.604	0	33	995	0	single	N	sepa,
LuQi.03.03	910	0,66	728	0	0	364	0	single	N	sepa,
LuQi.03.04	1.160	0,54	928	0	66	322	0	single	N	sepa,
LuQi.03.05	1.657	0,66	1.326	0	0	672	0	single	N	sepa,
LuQi.03.06	3.189	0,56	2.551	0	109	1.508	0	single	N	sepa,
LuQi.03.07	2.083	0,74	1.667	0	26	641	0	single	N	sepa,
LuQi.03.08	798	0,69	639	0	0	290	0	single	N	sepa,
LuQi.03.09	560	0,60	448	0	25	265	0	single	N	sepa,
LuQi.03.10	1.100	0,64	880	0	66	463	0	single	N	sepa,
LuQi.03.11	759	0,64	607	0	20	324	0	single	N	sepa,
LuQi.03.12	1.620	0,75	1.296	0	0	476	0	single	N	sepa,
LuQi.03.13	840	0,66	672	0	0	336	0	single	N	sepa,
LuQi.03.14	252	0,50	202	0	0	148	0	single	N	sepa,
LuQi.03.15	750	0,00	600	0	0	0	0	single	N	sepa,

Abbreviations: drink. wa. percent. – drinking water percentage; SSCS – Source Separated Collection System;
Y – yes; N – no; comb. – combined; sepa. – separate

Explanation: “drinking water percentage” indicates the percentage of drinking water amount in the total water demand.

Appendix.Table 18: Water demands and water sources of CA and UDs

unit: 10^3 m^3/d	demand : current	Scenario 1						Scenario 2					Scenario 3				
		demand: planned	In WUUs: ext. src.	In WUUs: +roof-water	In WUUs: +drct. reuse	In WUUs: +both	demand: planned	In WUUs: ext. src.	In WUUs: +roof-water	In WUUs: +drct. reuse	In WUUs: +both	demand: planned	In WUUs: ext. src.	In WUUs: +roof-water	In WUUs: +drct. reuse	In WUUs: +both
CA: LuQi	22,2	40,6	40,6	39,3	27,4	26,1	33,1	33,1	31,8	22,3	21,0	29,0	29,0	27,7	22,0	20,6
UD: LuQi.01	5,0	10,3	10,3	9,9	6,8	6,3	8,4	8,4	8,0	5,6	5,1	7,2	7,2	6,8	5,4	4,9
UD: LuQi.02	4,6	11,1	11,1	10,7	7,6	7,3	9,0	9,0	8,6	6,2	5,8	7,6	7,6	7,2	6,0	5,6
UD: LuQi.03	12,7	19,2	19,2	18,7	13,0	12,5	15,7	15,7	15,2	10,6	10,1	14,2	14,2	13,7	10,6	10,1

Appendix.Table 19: Used water amounts of CA and UDs

unit: 10^3 m^3/d	Scenario 1				Scenario 2				Scenario 3			
	In WUUs: ext. src.	In WUUs: +roof-water	In WUUs: +drct. reuse	In WUUs: +both	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both	sources: ext. src.	sources: +roof-water	sources: +drct. reuse	sources: +both
CA: LuQi	32,5	32,5	16,9	16,9	26,5	26,5	13,8	13,8	23,2	23,2	14,9	14,9
UD: LuQi.01	8,2	8,2	4,1	4,1	6,7	6,7	3,4	3,4	5,8	5,8	3,6	3,6
UD: LuQi.02	8,9	8,9	4,8	4,8	7,2	7,2	3,9	3,9	6,0	6,0	4,2	4,2
UD: LuQi.03	15,3	15,3	8,1	8,1	12,6	12,6	6,5	6,5	11,4	11,4	7,1	7,1

Appendix.Table 20: General end-user's water usage profiles (general EUWUPs)

no.	type of end-user	general EUWUP Scen. 1	Scen. 2	Scen. 3	unit	drinking water percentage [1] Scen. 1	Scen. 2	Scen. 3	used wa. coef. [2]
1	residential	0,140	0,110	0,085	m^3/(capita·day)	0,66	0,66	0,82	0,8
2	school	0,055	0,048	0,041	m^3/(student·day)	0,6	0,6	0,75	0,8
3	shopping centre	0,018	0,014	0,015	$m^3/(m^2 \cdot day)$	0,55	0,55	0,55	0,8
4	office centre	0,035	0,030	0,024	$m^3/(m^2 \cdot day)$	0,6	0,6	0,6	0,8
5	hotel	0,150	0,115	0,095	m^3/(bed·day)	0,66	0,66	0,75	0,85
6	restaurant	0,047	0,042	0,022	m^3/(seat·day)	0,7	0,7	0,7	0,85
7	swimming centre	0,030	0,026	0,026	$m^3/(m^3 \cdot day)$	0,75	0,75	0,75	0,8
8	market: food	0,040	0,035	0,035	$m^3/(m^2 \cdot day)$	0,75	0,75	0,75	0,75
9	market: goods	0,006	0,006	0,006	$m^3/(m^2 \cdot day)$	0,5	0,5	0,5	0,7
10	conference centre	0,007	0,005	0,005	$m^3/(m^2 \cdot day)$	0,6	0,6	0,6	0,8
11	recreational site	0,350	0,350	0,350	$m^3/(m^2 \cdot day)$	0,45	0,45	0,45	0,6
12	bus station	0,040	0,036	0,036	m^3/(passen-ger·day)	0,6	0,6	0,6	0,8
13	hospital	0,360	0,310	0,310	m^3/(bed·day)	0,75	0,75	0,75	0,8
14	nursery school	0,045	0,040	0,033	m^3/(child·day)	0,6	0,6	0,6	0,8
15	industry: 1	0,350	0,350	0,350	m^3/(unit·day)	1	1	1	0,7
16	industry: 2	0,085	0,085	0,085	m^3/(unit·day)	0	0	0	0,7
17	industry: 3	0,220	0,220	0,220	m^3/(unit·day)	0	0	0	0,8
18	industry: 4	0,800	0,700	0,700	m^3/(unit·day)	0	0	0	0,85
19	industry: 5	2,000	1,600	1,600	m^3/(unit·day)	0	0	0	0,6
20	industry: 6	0,600	0,550	0,550	m^3/(unit·day)	1	1	1	0,5
21	industry: 7	0,050	0,050	0,050	m^3/(unit·day)	1	1	1	0,5
22	industry: 8	0,15	0,12	0,12	m^3/(unit·day)	0	0	0	0,7

Abbreviations: scen. – scenario; wa. – water; coef. – coefficient

[1] the percentage of drinking water in the total water demand.

[2] generation coefficient of used water, which indicates how much used water generated after use.

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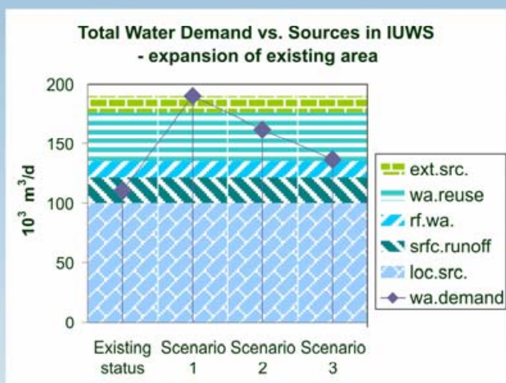
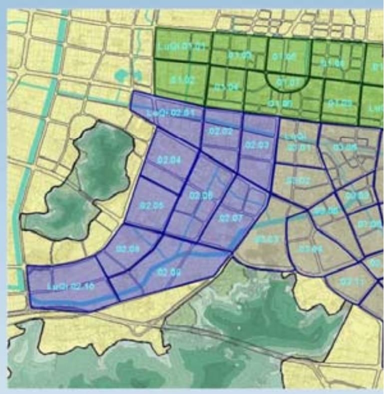
Traditionally, water supply, wastewater disposal, and rainwater elimination systems are three separate systems in cities. It has been realised that urban water systems must be planned, designed, and managed as one integrated urban water system (IUWS). This research conceives a new conception and methods for IUWSs. The urban water system is structured into a four-level hierarchy. The decision support model IUWS-DSM is developed as a planning tool for IUWSs in the early project phase.





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