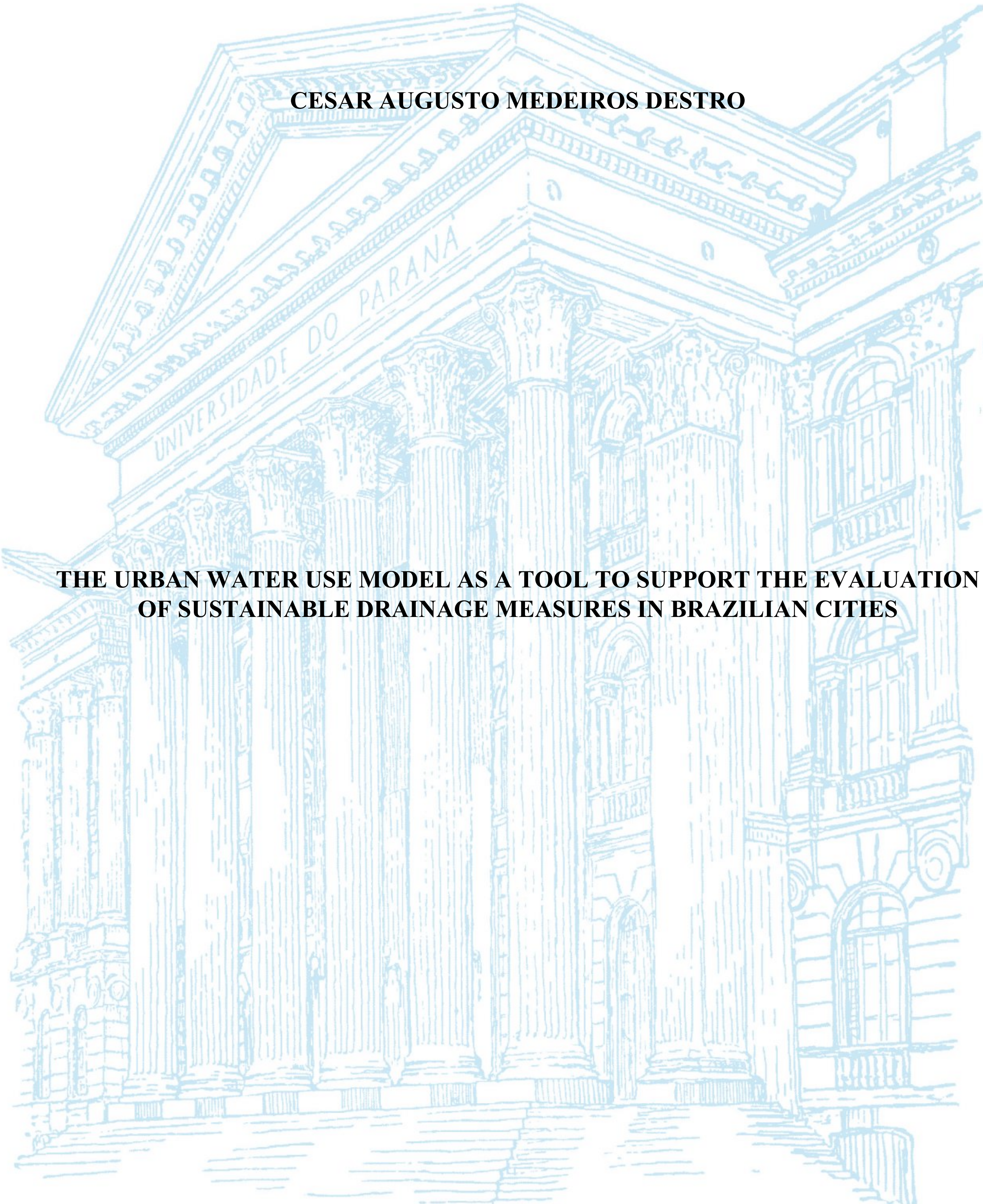
UNIVERSIDADE FEDERAL DO PARANÁ

CESAR AUGUSTO MEDEIROS DESTRO



THE URBAN WATER USE MODEL AS A TOOL TO SUPPORT THE EVALUATION OF SUSTAINABLE DRAINAGE MEASURES IN BRAZILIAN CITIES

CURITIBA

2016

CESAR AUGUSTO MEDEIROS DESTRO

THE URBAN WATER USE MODEL AS A TOOL TO SUPPORT THE EVALUATION OF SUSTAINABLE DRAINAGE MEASURES IN BRAZILIAN CITIES

Thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Water Resources and Environmental Engineering, Technology Sector, Federal University of Paraná.

Supervisor: Daniel Costa dos Santos, Ph.D.

Co-Supervisor: Berry Gersonius, Ph.D.

CURITIBA

2016

Destro, Cesar Augusto Medeiros
The urban water use model as a tool to support the evaluation of sustainable drainage measures in Brazilian cities / Cesar Augusto Medeiros Destro. – Curitiba, 2016.
154f. : il.; tabs.

Tese (doutorado) – Universidade Federal do Paraná, Setor de Tecnologia, Programa de Pós-Graduação em Engenharia de Recursos Hídricos e Ambiental.

Supervisor: Daniel Costa dos Santos
Co-Supervisor: Berry Gersonius

1. Drenagem. 2. Planejamento estratégico. 3. . I. Santos, Daniel Costa dos. II. Gersonius, Berry. III. Título

CDD 628

TERMO DE APROVAÇÃO

CESAR AUGUSTO MEDEIROS DESTRO

THE URBAN WATER USE MODEL AS A TOOL TO SUPPORT THE EVALUATION OF SUSTAINABLE DRAINAGE MEASURES IN BRAZILIAN CITIES

Tese aprovada como requisito parcial à obtenção do grau de Doutor, pelo Programa de Pós-Graduação em Engenharia de Recursos Hídricos e Ambiental do Setor de Tecnologia da Universidade Federal do Paraná, pela comissão formada pelos professores:

PRESIDENTE:

Daniel Costa dos Santos
Universidade Federal do Paraná
Orientador

MEMBROS:

Marcelo Rodrigues Bessa
Universidade Federal do Paraná

Miguel Mansur Aisse
Universidade Federal do Paraná

Regina Tiemy Kishi
Universidade Federal do Paraná

Cristina de Araújo Lima
Universidade Federal do Paraná

Harry Alberto Bollmann
Pontifícia Universidade Católica do Paraná

Curitiba, 28 de março de 2016

This work is dedicated to my parents,
Celia Lima de Sá Medeiros and
José Francisco Destro (*in memoriam*).

ACKNOWLEDGEMENTS

The doctorate period is a personal journey which begins long before the four years in which it actually happens. It is a long dusty road which must be walked and overcome. But it was not necessary to walk alone. In the meantime, many people crossed my life, impacting it, changing it. Everyone in your own way leaves your mark. It was a learning painful and liberating experience. I have experienced unforgettable moments regardless of whether good or bad. And the most important lesson was that I can always get up and walk again. Now, I can say that I feel free and stronger than ever. I can walk by myself.

“*...finding out at last*
that freedom is
a state of mind...”.

Pain of Salvation

For everything, I would like to thank to:

- Daniel Costa dos Santos — for all support you gave me during the last four years. It was a pleasure working with a person who I respect, and who has a wide view of sustainability and environmental issues.
- Berry Gersonius — for all help, discussions and contributions you gave me in last two years. It was my pleasure to share an office with you and all other members of the Flooding Resilience Group (FRG) at UNESCO-IHE.
- Chris Zevenbergen — for accepting my project and to have opened the doors for me at UNESCO-IHE. It was certainly one of the most challenging and interesting moment of my life.
- Raquel dos Santos — for having made the initial contact with the UNESCO-IHE professors and helped in the realization of my sandwich doctorate.
- Richard Ashley — for all the jokes, tips, and advices you gave me in my period in Delft; for all good times in Kuching, Malaysia.
- Stephan Fuchs — for the initial discussion on my thesis project and for having made available the runoff pollutant concentrations database.
- Gilson Alberto Rosa Lima, Eliana Beatriz N. R. Lima, and João Batista Lima — you were the people who significantly contributed to my personal and professional growth and as an aspiring researcher.
- to all lectures and staff from PPGERHA-UFPR specially Celmar de Mattos, Cristovão Fernandes, Marcelo Bessa, Miguel Aisse, Regina Kishi, Tobias Bleninger, and Urivald Pawlowsky.

- Paulo Corgosinho — I will never forget all the conversation we had in my period in Delft. I really miss our philosophical conversations about evolution, Darwinism, science, pseudo-science, and all sorts of “nerd”, and ordinary, things we talked about. Certainly, you are a researcher who I will always respect. Proost!
- all the members of the FRG at UNESCO-IHE, especially Mohanasundar Radhakrishnan, Polpat Nilubon, and William Veerbeek — for all good times at the office, all the spicy food at Papenstraat and the good times in Kuching, Malaysia.
- all Brazilians I met at UNESCO-IHE, Chris Metzker, Eva Barros, Fernanda Braga, Luana Cruz, Marcelo Secron, Paulo Almeida, Thaine Assumpção, and Victor Paca — for all the good times we spent together in Delft and in the Netherlands.
- my colleagues from PPGERHA Anderson Frigo, Cínthia Lima, Fabiano Serpe, Gabriela Reichert, Jhonatas Antonelli, João Resende, Juliane Rizzi, Ricardo Morais, Steffany Baudisch, Tábata Miranda, and Thiago Formentini — you turn my return to Brazil really interesting; to share an office with you was my pleasure and, as you know, we had a lot of fun; I hope to keep you as friends for a long time.
- Alinne Mizukawa, and Guilherme Samways — for absolutely everything you have done for me in a complicated period of my life; it is just impossible to express the gratitude I feel for you.
- Eileen Acosta and Maciel Paulino — for all support, advices, conversations and fun we had together in Curitiba.
- my sister, Ana Paula Destro, my brother in law, Ronnie Barbosa, and my nephew, Felipe Barbosa — for all fun, all help, and all support you gave me during these last four years.
- my old friends Camilo Saes, Izabel Battistuzzi, Luciano Campbell and Valdir Brito — because you cannot imagine going through life without good friends. Thank you for being part of my life.
- Alberto Botelho, Leociley Menezes, Luana Chiarello, Karine Naidek, and Poliana Lima — for all fun we had, and all conversations at home. You were my family in Curitiba during the last year.
- IPPUC — for all help in selecting the study area and for providing the input data to the UWU Model application.
- HidroEX — for the sandwich doctorate scholarship at UNESCO-IHE Institute for Water Education, and the financial assistance for my participation in the 13^{th} International Conference on Urban Drainage.
- CAPES — for the postgraduate scholarship and all assistance during the doctorate period.

I thank you all!

“The Cosmos is all that is or was or ever will be. Our feeblest contemplations of the Cosmos stir us – there is a tingling in the spine, a catch in the voice, a faint sensation, as if a distant memory, of falling from a height. We know we are approaching the greatest of mysteries”.

Carl Sagan, Cosmos

ABSTRACT

It is well known that developed urban areas are characterized by alteration of the natural hydrologic cycle. Whereas evapotranspiration and infiltration decrease, there is an increase in the runoff volume. In Brazil, many urban areas have developed without any kind of planning. It has led to the implementation of drainage systems which primarily focus on collecting, transporting and disposing as quickly as possible the runoff into a receiving water body. These systems, called traditional systems, were not designed in agreement with the sustainability goals, and appears to be an inadequate solution to flood control since it has contributed to flooding downstream and to water body pollution. However, alternative solutions are still incipient in Brazil due to many issues that remain uncertain regarding the use of such technologies. Currently, some tools are being developed in order to assist the decision-making process and help planners to implement more sustainable approaches in cities, but the debate remains as the best approach. In this context, present work aimed at improving the Urban Water Use (UWU) Model and implement it as a decision-making support tool for sustainable urban drainage systems and contribute to the discussion and modernization of urban drainage infrastructure in Brazil. The methodology was divided into two main phases which were the drainage module development (Phase 1) and a case study application (Phase 2) in order to test the whole model. Seven indicators and five sustainable drainage measures were implemented. Notwithstanding, the scenarios formulation approach was adapted. Hereafter, the model was applied in a small study area (208.44 *hectares*) in the Curitiba Metropolitan Region (CMR), located within the Belém river basin. Four future scenarios were formulated considering a design period of 30 years and five different groups of measures (GM_m) were tested. The groups of measures combined the following structural measures: infiltration trenches, permeable pavements, rainwater harvesting, stormwater detention basins, and bioretention. The visions were established based on current and initial estimates and six simulations were performed in order to test the model outcomes. The results demonstrate the possibility of evaluating groups of drainage measures as to meet the indicators' visions in the formulated scenarios by using the UWU Model structure. Notwithstanding, the simulations showed that drainage measures can be evaluated in an integrated context linking the rainwater harvesting devices and the water usage per appliance in the buildings. Disregarding the control groups (GM_0 and GM_5), the results showed that a combination of detention basins, bioretentions and rainwater harvesting devices (GM_2) was the best group of measures to the study area considering the selected indicators. Therefore, the UWU Model could be useful in the decision-making process when planning the drainage measures for urban areas. In this sense, this work main contribution was to adapt the original model and provide an integrated environment for drainage measures evaluation. Further work could implement other indicators and measures and integrate the drainage measures with sewage system indicators.

Key-words: UWU Model; sustainable drainage system; integrated approach, strategic planning; decision-making.

RESUMO

O desenvolvimento das áreas urbanas e a consequente impermeabilização dos solos são responsáveis por grandes alterações no ciclo hidrológico natural. Enquanto ocorre a diminuição das taxas de evapotranspiração e infiltração, há um aumento no volume de escoamento superficial além da diminuição do tempo de concentração das bacias hidrográficas. No Brasil, grande parte das áreas urbanas se desenvolveram sem o devido planejamento o que, aliado a cultura de projeto, contribuiu para a implementação de sistemas tradicionais de drenagem, os quais visam o lançamento da água de escoamento superficial o mais rápido possível em um corpo hídrico receptor. Tal abordagem vai de encontro às metas de sustentabilidade e constam de soluções inadequadas para o controle de poluição e das inundações. No entanto, o uso de soluções alternativas está longe de se tornar realidade no Brasil. Apesar disso, há um crescente desenvolvimento de ferramentas de gestão que visam auxiliar o processo de tomada de decisão e a implementação de abordagens mais sustentáveis para as áreas urbanas. Por outro lado, não há consenso quanto a melhor abordagem a se utilizar. Neste contexto, o presente trabalho objetivou adaptar o *Urban Water Use* (UWU) *Model*, no intuito de tornar viável a avaliação de medidas de drenagem urbana sustentável (SuDS) e auxiliar o processo de tomada de decisão, além de contribuir para o debate e modernização da infraestrutura de drenagem urbana no Brasil. A metodologia foi dividida em duas etapas principais: o desenvolvimento do módulo de drenagem (Etapa 1), e a aplicação do modelo (Etapa 2). Foram implementados sete indicadores e cinco medidas de SuDS. Não obstante, o método de formulação dos cenários foi adaptado. A seguir, o modelo foi aplicado em uma pequena bacia urbana ($208,44$ *hectares*) na Região Metropolitana de Curitiba (RMC), no norte da bacia do Rio Belém. Quatro cenários foram formulados para um horizonte de projeto de 30 anos e cinco diferentes grupos de medidas (GM_m) foram propostos. As seguintes medidas foram utilizadas: trincheiras de infiltração, pavimentos permeáveis, utilização de águas pluviais nas edificações, bacias de detenção e bioretenções. As *visions* foram estabelecidas com base nas estimativas iniciais e seus atuais valores. Os resultados demonstraram a possibilidade de avaliação dos grupos de medidas de drenagem urbana sustentável considerando o atendimento ou não aos critérios estabelecidos por meio de indicadores e metas refletidas nas *visions*. Além disso, foi possível se estabelecer interfaces entre o sistema de drenagem urbana e o de abastecimento de água por meio do uso de água da chuva nas edificações e as tabelas de parametrização do consumo residencial. Excetuando-se os grupos de controle (GM_0 and GM_5), os resultados mostraram que a combinação de bacias de detenção, bioretenções e coleta de água de chuva (GM_2) forma o melhor grupo de medidas para a área de estudo considerando os critérios avaliados. Portanto, o *UWU Model* se mostrou útil no processo de tomada de decisão para o planejamento de medidas de drenagem urbana. Nesse sentido, a principal contribuição do presente trabalho foi a adaptação do modelo, fornecendo um ambiente integrado para avaliação das medidas. Trabalhos futuros devem ser desenvolvidos no sentido de testar o modelo em outras áreas buscando a adição de novos indicadores e medidas.

Palavras-chave: UWU Model; sistemas de drenagem sustentáveis; abordagem integrada, planejamento estratégico; tomada de decisão.

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

IPCC	Intergovernmental Panel on Climate Change
GIS	Geographic Information Systems
WCED	World Commission on Environment and Development
IUWM	Integrated Urban Water Management
CMR	Curitiba Metropolitan Region
SPMR	São Paulo Metropolitan Region
GRP	Gross Regional Product
GDP	Gross Domestic Product
UWU	Urban Water Use
WSS	Water Supply Systems
SS	Sewage Systems
UDS	Urban Drainage Systems
PCS	Public Cleaning Services
WWTP	Wastewater Treatment Plant
ITB	Instituto Trata Brasil
SNIS	Sistema Nacional de Informações sobre Saneamento
BMP	Best Management Practices
LID	Low Impact Development
LIUDD	Low Impact Urban Design and Development
WSUD	Water Sensitive Urban Design
SuDS	Sustainable Drainage Systems
CT	Compensatory Techniques
AT	Alternative Techniques
GI	Green Infrastructure
USA	United States of America
IT	Infiltration Trenches
PP	Permeable Pavements
RWH	Rainwater harvesting

DB	Detention Basins
BR	Bioretention devices
CW	Constructed Wetlands
GR	Green Roofs
UHI	Urban Heat Island
EU	European Union
UWOT	Urban Water Optioneering Tool
VBA	Visual Basic for Applications
SUSTAIN	System for Urban Stormwater Treatment and Analysis Integration
USEPA	United States Environmental Protection Agency
DEM	Digital Elevation Model
KPI	Key Performance Indicators
UK	United Kingdom
UrbanBEATS	Urban Biophysical Environments And Technologies Simulator
WTP	Water Treatment Plant
MSW	Municipal Solid Waste
EI	Effectiveness Index
IAP	Instituto Ambiental do Paraná
SANEPAR	Paraná Sanitation Company
MHDI	Municipal Human Development Index
IPPUC	Instituto de Pesquisa e Planejamento Urbano de Curitiba
SC1	Scenario 1
SC2	Scenario 2
SC3	Scenario 3
SC4	Scenario 4
SC5	Scenario 5
IDF-Curve	Intensity-Duration-Frequency curve
FAA	Federal Aviation Administration
IBGE	Instituto Brasileiro de Geografia e Estatística
EMC	Event Mean Concentration

LIST OF SYMBOLS

λ	Population growth rate ($\%/year$)
T	Average annual temperature ($^\circ C$)
EP	Economic performance ($US\,\$/inh \cdot year$)
λ_m	Medium future population growth rate ($\%/year$ or $inh/year$)
T_m	Medium future temperature ($^\circ C$)
EP_m	Medium future economic performance ($US\,\$/inh \cdot year$)
EI_k	Effectiveness Index for the group of measures k
W_i	Weight of the indicator i
N_{ij}	Number of scenarios j in which the indicator i achieved the vision
λ_0	Current population growth rate ($\%/year$ or $inh/year$)
λ_1	Minimum future population growth rate ($\%/year$ or $inh/year$)
λ_2	Maximum future population growth rate ($\%/year$ or $inh/year$)
T_0	Current average annual temperature ($^\circ C$)
T_1	Minimum future average annual temperature ($^\circ C$)
T_2	Maximum future average annual temperature ($^\circ C$)
EP_0	Current per capita income ($R\$/inh \cdot year$)
EP_1	Minimum future per capita income ($R\$/inh \cdot year$)
EP_2	Maximum future per capita income ($R\$/inh \cdot year$)
I_0	Current design rainfall (mm/h)
I_1	Minimum future design rainfall (mm/h)
I_2	Maximum future design rainfall (mm/h)
P_s	Population saturation level (inh)
P_0	Current population (inh)
P_1	Minimum estimated future population (inh)
P_2	Maximum estimated future population (inh)
t_0	Current year
t_1	Future year
d	Duration of the precipitation (min)

R	Return period ($years$)
A	Land area of the study area (km^2)
$L_{0,\,l}$	Pollutant concentration ($mg\ L^{-1}$)
$L_{0,\,TSS}$	Total Suspended Solids average concentration ($mg\ L^{-1}$)
$L_{0,\,BOD}$	Biochemical Oxygen Demand average concentration ($mg\ L^{-1}$)
$L_{0,\,TP}$	Total Phosphorus average concentration ($mg\ L^{-1}$)
$L_{0,\,TKN}$	Total Kjeldahl Nitrogen average concentration ($mg\ L^{-1}$)
k	Soil Permeability Coefficient (m/s)
$Cwss_i$	Water Supply System Coverage (%)
$Qmax_j$	Maximum flowrate in the critical sewer (m^3/s)
$PAeq_j$	Equivalent permeable area (%)
$WE_{j,\,BOD}$	Biochemical Oxygen Demand specific loading rate ($kg\ km^{-2}$)
$WE_{j,\,TSS}$	Total Suspended Solids specific loading rate ($kg\ km^{-2}$)
$WE_{j,\,TP}$	Total Phosphorus specific loading rate ($kg\ km^{-2}$)
$WE_{j,\,TKN}$	Total Kjeldahl Nitrogen specific loading rate ($kg\ km^{-2}$)
Rv_j	Runoff coefficient
D_j	Population density (inh/ha)
IA_j	Impermeable area (%)
PA_j	Permeable area (%)
$W_{j,l}$	Pollutant loading rate (kg)
R_j	Precipitation (mm)
Rf	Fraction of the rainfall that produces runoff
L_l	Pollutant concentration ($mg\ L^{-1}$)
d	Duration of the precipitation ($hours$)
tc	Time of concentration ($hours$)
$WE_{j,\,l}$	Specific pollutant loading rate ($kg\ km^{-2}$)
Ac_m^{IT}	Average contributing area to the infiltration trenches (m^2)
L_m^{IT}	Length of the infiltration trench (m)
W_m^{IT}	Width of the infiltration trench (m)
D_m^{IT}	Depth of the infiltration trench (m)
A_m^{IT}	Area of the infiltration trench (m^2)

Qs_m^{IT}	Infiltration capacity of the trenches (m^3/s)
Qi_m^{IT}	Flowrate input of the trenches (m^3/s)
Qf_m^{IT}	Runoff overflow of the infiltration trench (m^3/s)
Ac_m^{PP}	Average contributing area to the permeable pavement (m^2)
L_m^{PP}	Length of the permeable pavement (m)
W_m^{PP}	Width of the permeable pavement (m)
A_m^{PP}	Area of the permeable pavement (m^2)
Qs_m^{PP}	Infiltration capacity of the permeable pavements (m^3/s)
Qi_m^{PP}	Flowrate input of the permeable pavement (m^3/s)
Qf_m^{PP}	Runoff overflow of the permeable pavements (m^3/s)
A_{AV}^{RWH}	Average harvesting area (m^2)
Rv_{AV}^{RWH}	Average roofs runoff coefficient
Da_m	Measure degree of acceptance (%)
P_{av}	Average people per building ($inh/building$)
A_{TOT}^{RWH}	Total harvesting area (m^2)
Q_s^{RWH}	Runoff flow subtraction of the rainwater harvesting (m^3/s)
V_m^{DB}	Detention storage volume (m^3)
Ac_m^{DB}	Contribution area of the stormwater detention basin (m^2)
Rv_m^{DB}	Average runoff coefficient to the contribution area of the stormwater detention basin (m^3/s)
tc_m^{DB}	Time of concentration for the inflow area of the detention basin (min)
$Qi_{j,m}^{DB}$	Stormwater detention basin inflow runoff (m^3/s)
Qf_m^{DB}	Runoff flow subtraction of the detention basin (m^3/s)
A_m^{BR}	Area of the bioretention device (m^2)
D_m^{BR}	Depth of the infiltration trench (m)
Qs_m^{BR}	Infiltration capacity of the bioretention (m^3/s)
Qi_m^{BR}	Flowrate input of the bioretention device (m^3/s)
Ac_m^{BR}	Contribution area of the bioretention device (m^2)
Qf_m^{BR}	Runoff overflow of the bioretention devices (m^3/s)

TABLE OF CONTENTS

1 INTRODUCTION

1.1 BACKGROUND

It is expected that between 2011 and 2050 the world population will increase from 7.0 to 9.3 billion. The population living in urban areas will grow of 2.6 billion people and, therefore, the prospects are that all expected population growth in the next four decades will occur in the urbanized areas, mainly in megacities and developing countries (UNITED NATIONS, 2011). In the meantime, the rural population will continue to decline. Data shows that in Latin America and Caribbean countries the rural population declined from approximately 50% to less than 25% from 1960 to 2000 (AIDE; GRAU, 2004).

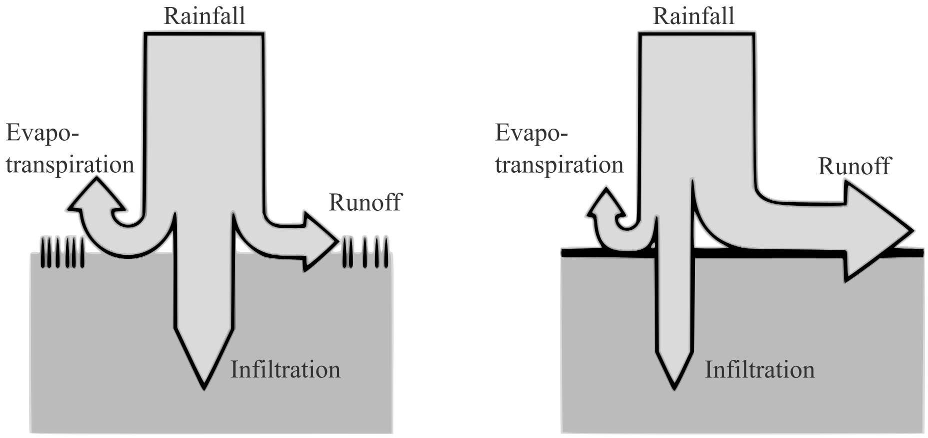
The Latin America's urbanization rate remains growing in poorer countries and, in some of them, almost 90% of the population live in urban areas (LEE, 2000). In Brazil, uncontrolled urban development and the hight rate of rural exodus — mainly between the 60's and 80's — led to a very fast process of city growing. Consequently, many urban areas have developed without any kind of planning. Nowadays, 84% of the Brazilian population lives in urban areas (IBGE, 2013).

Considering this scenario, it is expected that the current problems faced in urban areas of developing countries will be kept or worsened if technical and policy interventions are not implemented in a timely manner and considering the current context of climate change expected for the coming decades, which tends to increase water scarcity in the world and change rainfall regimes, as reported by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2007a).

Nowadays, there are about 700 million people in the world living with less water than the minimum recommended (UNITED NATIONS, 2013). Water shortages experienced in many parts of the world and the recurring shortages in highly urbanized areas have not changed the urbanization trend observed in various parts of the world which has a tendency to greatly change the environment. This situation has led to serious consequences and, in particular, to water resources and the biogeochemical cycles.

Notwithstanding, despite the difficulty of assessing water scarcity in the world, as discussed by Rijsberman (2006), it is currently accepted that more than two thirds of the world population will be affected by shortages in the coming decades. Considering the current population growth, regions suffering from lack of rain and that have high population levels tend to suffer more with water scarcity. The degree of some urban river pollution has contributed to increasing scarcity to the point of some rivers have been abandoned as a water source because of difficulties in their potabilization.

One of the main issues about increasing urbanization and population growth in urban areas is the soil impermeabilization which is responsible by reducing both infiltration — with consequences to groundwater recharge or cycle — and evapotranspiration. It increases the surface runoff volume, the peak runoff, the nutrient transport and the amount of sediments transported by runoff from urban areas (NIRUPAMA; SIMONOVIC, 2007; SAGHAFIAN et al., 2007; SURIYA; MUDGAL, 2012). In other words, there is major changes in the local hydrological cycle compared to that observed in the pre-urbanized situation, as depicted schematically in Figure 1.1.



(a) Pre-urbanization (b) Post-urbanization

Source: Butler and Davies (2004)

FIGURE 1.1: Effect of urbanization on the local hydrological cycle. (a) natural situation in which the infiltration and evapotranspiration is greater than the runoff and, (b) post-urbanization situation in which the opposite occurs

The intensification of peak flows due to changes in the use and occupation of land has been extensively studied in recent decades. Case studies using Geographic Information Systems (GIS) and hydrological models have shown that the growth of the urban area and the land cover changes significantly increased peak flows as well as shorten the concentration time of the studied basins (PORTMANN, 1997; MILLER et al., 2002; LIU; SMEDT, 2005; NIRUPAMA; SIMONOVIC, 2007; SURIYA; MUDGAL, 2012).

In this sense, the urbanization process has made the environment highly domesticated. As Kareiva et al. (2007) argue, there are few locations without human influence in the world and, in urban areas, every element of the environment has been consciously or unconsciously selected. The scientific challenge, therefore is not to decide which of the wild ecosystems to protect, but mainly to “determine to what extent we can change a negative tradeoff to a positive one by altering the details of our domestication process”.

The urban drainage systems are necessary because of the interaction between human activities and the natural water cycle. The drainage of stormwater runoff from urban areas is a key measure to protect the population against flood risk and waterborne diseases (BUTLER; DAVIES, 2004; FLETCHER; ANDRIEU; HAMEL, 2013). The traditional solution was to drain rainwater runoff as quickly as possible from urban areas. However, this solution proved to be unsustainable and it has contributed in flooding downstream. In addition, it did not cope with the main cause of increasing runoff peaks — the urban land impermeabilization.

Authors like Mitchell (2006) and Mostert (2006) criticize the traditional systems, as they focus on managing large infrastructure and centralized solutions. The authors emphasize that it is important to take into account an integrated infrastructure approach and social, economic, environmental and policy aspects, including a long-range perspective to cope with rainwater runoff issues.

Therefore, the traditional approach until now employed has been proven partly ineffective and failed to satisfactorily mitigate the impermeabilization and pollution problems. Considering cities as highly domesticated environments, the challenge is to change our traditional way of thinking about planning cities and the urban water infrastructure, reconsidering the traditional water and sewer systems to a more sustainable and ecological approach.

In this sense, there is a growing acceptance that a paradigm shift is necessary in order to incorporate urban structures that are aligned with the concept of sustainability and seeking to reintegrate the water and biogeochemical cycles in urban areas (DICKIE et al., 2010) providing amenity and aesthetic awareness and reconnecting people to the environment.

A paradigm shift from traditional systems to decentralized alternatives is essential for a sustainable water management (MEENE; BROWN; FARRELLY, 2011) but, as pointed out by Elliott and Trowsdale (2007) and Barbosa, Fernandes and David (2012) the transition between these approaches tends to be quite slow. Notwithstanding, despite the development of more sustainable approaches over the past decades there remains debate about the most appropriate approach, demonstrating the complexities surrounding the management of stormwater in urban areas (FLETCHER; ANDRIEU; HAMEL, 2013).

1.2 A WAY FORWARD: A SUSTAINABLE APPROACH TO URBAN WATER MANAGEMENT

The sustainable approach to urban water management seeks to integrate the sustainable development concept with the city's sanitary infrastructure. The Brundtland Report[1], published by the World Commission on Environment and Development (WCED), defines sustainable development as that which

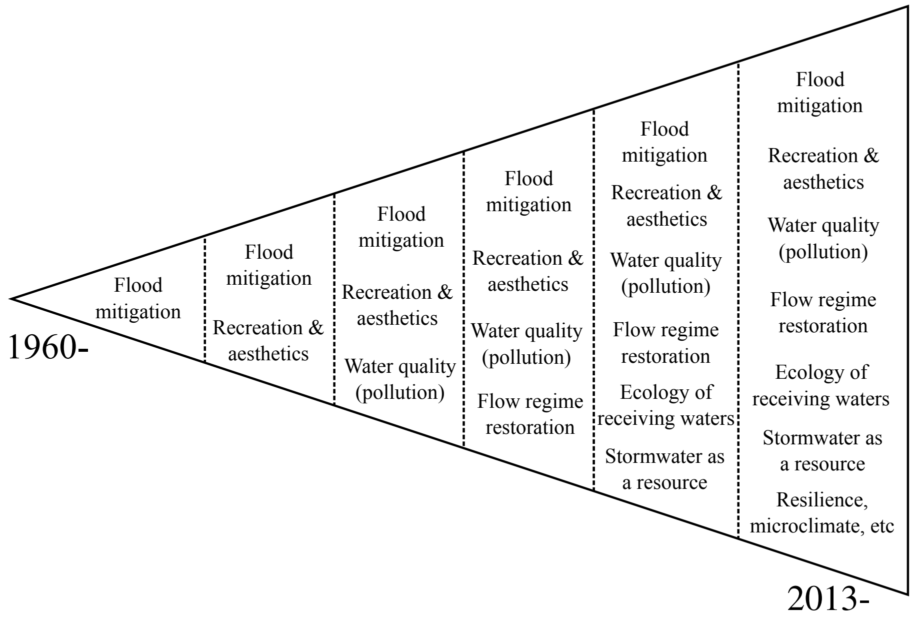
> meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts (i) the concept of needs, in particular the essential needs of the world's poor, to which overriding priority should be given; and (ii) the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs (UNITED NATIONS, 1987).

Aligned for this purpose, the integrated urban water management (IUWM) aims "to provide socially acceptable, economically viable and environmentally sustainable water supply, wastewater and stormwater services in urban areas by considering the interdependencies between water/wastewater/stormwater, energy, urban design and the surrounding environment" (BURN; MAHEEPALA; SHARMA, 2012).

Concerning this, the sustainable urban drainage aims to manage the urban water cycle — which changed depending on the urbanization process — to produce more benefits than the traditional approaches (MARLOW et al., 2013) by turning the water cycle as close as possible to the pre-urbanized situation in order to prevent flooding, pollution, to increase urban amenity,

[1] Document published in 1987, called Our Common Future, which constitutes one of the first initiatives in order to develop and implement the concept of sustainability.

among other objectives. Therefore, within a sustainable perspective, the urban drainage systems are not related to flood control issues only, but they also seek to provide a range of other benefits as depicted in Figure 1.2.



Source: Fletcher et al. (2014)

FIGURE 1.2: Increasing integration and sophistication of urban drainage management over time

As highlighted by Willems (2004), coping with water pollution due to urban runoff remains a major challenge because of its large spatiotemporal variability and the large uncertainty in its evaluation. To deal with both quantitative and qualitative issues, sustainable drainage systems try to reduce runoff by promoting infiltration, detention, retention and treatment as close as possible to the generating source, in other words, it seeks to promote source control and/or treatment using decentralized structures (HOYER et al., 2011).

It is important to note that the system decentralization is a recurrent issue in the sustainable drainage approach, but as argued by Sitzenfrei, Möderl and Rauch (2013) the transition towards it leads to a variety of technical and socioeconomic issues and, until now, there is not a comprehensive impact assessment of the transition because the lack of case studies.

Although widely known that urban runoff can impact the water quality of receiving water bodies, the implementation of measures that aim at mitigating the impacts is still incipient in many countries. As aforementioned, once the sustainable drainage systems do not try to deal with the runoff quantity merely, they could be used to try to deal with runoff pollution issues as well.

1.3 THE BRAZILIAN ISSUES SURROUNDING URBAN WATER MANAGEMENT

The lack of planning and the widespread adoption of traditional drainage infrastructure have deepened the problems of pollution and flooding downstream in Brazilian cities. The development of integrated urban water management plans that consider the use of alternative structures and sustainable approaches is important to change the current trend.

Some efforts have been made towards a more sustainable and integrated approach among sanitation infrastructure, as the law number 11,445 (BRASIL, 2007) which establishes national guidelines for sanitation. The law considers the water supply, sewer and urban drainage systems and public cleaning services as part of an integrated sanitation program, but there is not available tools and methodologies to make it feasible.

Despite current criticism, the traditional urban drainage systems are widely used in many Brazilian cities. In fact, the use of alternative systems is far from reality and the development of sanitation infrastructure has followed the opposite direction, with rare exceptions, to approaches such as sustainable drainage systems (WOODS-BALLARD et al., 2015), water sensitive urban design (WONG, 2006) or the green infrastructures (BENEDICT; MCMAHON, 2006). These approaches are briefly discussed in section 3.2.

The usage of sustainable drainage systems in Brazil is still incipient for many different reasons. Cruz, Souza and Tucci (2007) mention that it is due to poor public outreach and a natural resistance to new structures and approaches. Moreover, large quantities of solid and liquid waste reach the drainage system — and they could accumulate in reservoirs or detention ponds — disturbing the public well-being.

With regards to the solid waste, the public cleaning services are the most important issue once the solid waste on the streets can easily reach the drainage system. Despite of that, there is little information about this component, but it is known that daily sweeping can reduce it by 98% (NEVES; TUCCI, 2008). Furthermore, studies cited by the authors have shown that a large amount of used plastic packages are found within the drainage system.

There are other reasons for the difficulties in sustainable drainage adoption in Brazil. For example, the greater environmental complexity of the concept in terms of design, which involves multidisciplinary knowledge (POLETO, 2011). Even so, the author remarks that some Brazilian cities have developed urban drainage master plans with environmental principles. Among these cities, the author mention: Caxias do Sul and Porto Alegre both in the Rio Grande do Sul state, Santo André in São Paulo state, Belo Horizonte in Minas Gerais state, Curitiba in Paraná state, and in the Iguaçu-Sarapuí Basin in Rio de Janeiro state.

The author highlights that although these plans take into account environmental principles they are far from fit into an ideal model for urban drainage, as proposed by sustainable drainage systems approach, for instance. In addition, further studies are needed as the application of any sustainable drainage measures in Brazil, given that most studies and applications have been performed in developed countries and with temperate climate.

About the urban drainage master plan from the city of Porto Alegre, Goldenfum et al. (2007) mention that planning measures in developing countries are limited by problems such as the lack of appropriate data and the uncontrolled urban expansion with informal occupation that does not follow the land occupation rules. A similar aspect was highlighted for the Curitiba Metropolitan Region (CMR) in a technical report (TUCCI, 2004). The author pointed that the land-use is closely related to urban drainage and it is necessary a strong integration between them. Moreover, public cleaning services should be considered in an integrated approach to urban water management plans.

In a case study performed in the São Paulo Metropolitan Region (SPMR), Haddad and Teixeira (2015) discuss the economic impacts of flooding by analyzing the affected businesses in the flooded areas. The results showed that the flooding occurrence in 2008 have decreased the

São Paulo gross regional product (GRP) by 0.0263% and the national gross domestic product (GDP) by 0.0071%.

The authors remark that flooding occurrence has contributed to reduce city growth and resident's welfare. Furthermore, they highlight the importance in planning measures to ensure land use control and to improve the urban drainage infrastructure in order to "prevent the emergence of new risk areas".

The flooding issues and economic losses comprise a major driving force to urban drainage modernization. On the other hand, as discussed by Silveira (2002) the challenge in the structural modernization in Brazil is to create mechanisms to stimulate an awareness that change the current urban development to a more integrated and multidisciplinary approach in which the urban drainage is integrated with urban planning instead of being simply an engineering issue.

In order to bring an integrated way of thinking in planning the measures for the urban water infrastructure, the Urban Water Use (UWU) Model (SANTOS; STEEN, 2011) was initially built as an educational tool based on the SWITCH's (STEEN et al., 2010) structure. The tool was built based on Roleplay Game principles and it incorporates a scenarios building phase, a visioning and a measures definition phases, and an evaluation system.

The UWU Model could be understood as a decision-support tool which intends to evaluate and rank groups of measures for urban areas considering the water supply systems (WSS), the sewage systems (SS), the urban drainage systems (UDS) and the buildings. In summary, it is necessary to formulate the future scenarios based on external factors — e.g. population growth rate and average annual temperature — , select the indicators by means of which the measures will be evaluated — e.g. flood flowrate in critical sewer — establish the vision and the weight of each indicator, select the measures and group them. Finally, the evaluation is carried out through the effectiveness index. The tool is best described in section 3.7.

2 OBJECTIVES OF THE STUDY

2.1 OVERALL AIM

This work aims at improving the Urban Water Use Model (SANTOS; STEEN, 2011) and implement it as a decision-making support tool for sustainable urban drainage systems and contribute to the discussion and modernization of urban drainage infrastructure in Brazil.

2.2 SPECIFIC OBJECTIVES

1. To establish drainage system measures interfaces with the water supply system and link them within UWU Model;
2. To insert sustainable urban drainage measures and specific indicators to urban drainage;
3. To assess additional benefits from sustainable drainage measures implementation by using the improved UWU Model;
4. To perform an UWU Model application to test the tool and give directions on the decision-making process.

3 LITERATURE REVIEW

This chapter presents the literature review about some issues in dealing with urban drainage systems nowadays. The section 3.1 presents the traditional urban water systems approach, focusing on the separated systems — i.e. the separated sanitation and drainage systems. The section 3.2 describes some of the new approaches used in the urban drainage management over the world. The section 3.3 briefly presents some structural measures which could be used in order to seek the new approaches objectives. Then, in the section 3.4 it is presented some benefits reported by using new strategies and approaches in urban drainage, focusing on the Sustainable Drainage System benefits. The section 3.5 presents tools which aim to support decision-making in urban drainage infrastructure. In section 3.6 is mentioned the urban drainage interfaces, which is an important aspect to be considered in an integrated drainage management context and, finally, in the section 3.7 it is presented the Urban Water Use Model. The last section, section 3.8, summarizes the identified knowledge gaps throughout the literature review.

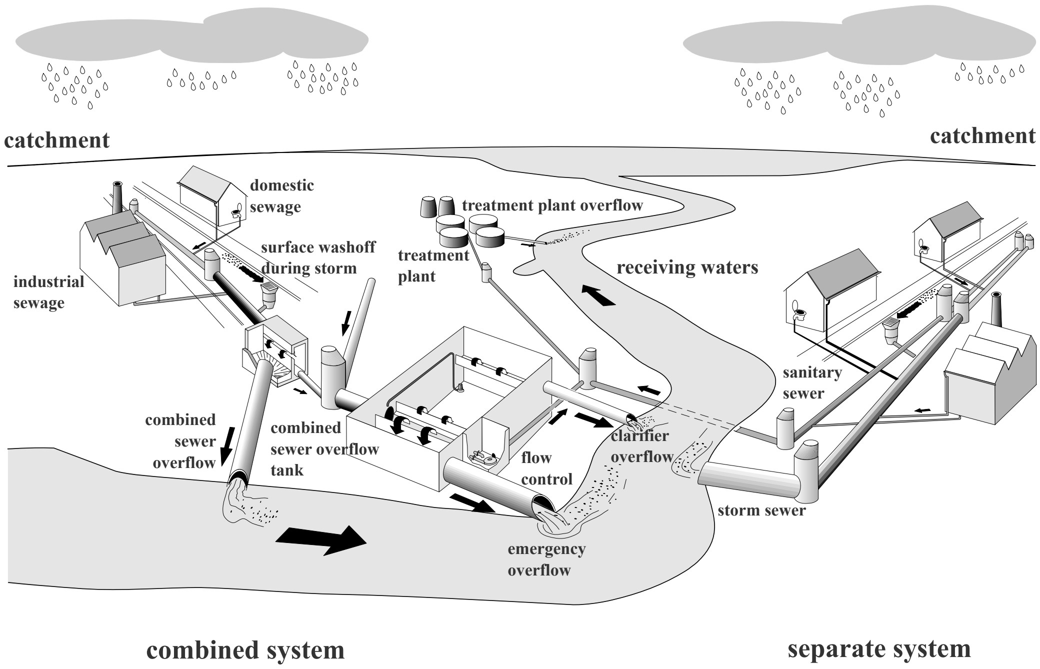
3.1 TRADITIONAL URBAN WATER SYSTEMS

The urbanization process has imposed major changes in the basins topography, increased the rate of soil sealing and the water scarcity, and the solid and liquid wastes are recurring issues without adequate solution. The urban sanitary infrastructure consists of at least three recognizable systems that aim to deal with these issues: the water supply systems, the urban drainage systems and the sewage systems. In addition, the solid waste collection and the public cleaning services (PCS) are also considered an important subject.

The aforementioned components have a strong interface with each other (GESSNER et al., 2014). It means that the urban development should follow based on integrated management approaches. Nevertheless, as highlighted by Neves and Tucci (2008), despite the problems and systems are integrated, it does not occur in the management process which is performed in a sectoral way.

Regarding to the sanitation and urban drainage systems, two different approaches have been hitherto employed. The combined sewer systems in which a single network of pipes drains the rainwater and the wastewater; and the separated sewer systems in which different networks of pipes are used to drain rainwater and wastewater. Figure 3.1 schematically represents the two mentioned approaches.

In the separated sewer systems approach, the stormwater runoff is diffusely discharged into the receiving water bodies, whereas domestic wastewater is conveyed to the Wastewater Treatment Plant (WWTP) and then discharged into the receiving water body (SPERLING, 2005). It is important to note that the use of combined systems requires overflow control. It is essential to prevent hydraulic overloads in the WWTP after an intense rainfall event, because



Source: Brombach, Weiss and Fuchs (2005)

FIGURE 3.1: Traditional sanitation and urban drainage systems: the combined system (left riverbank) and the separated system (right riverbank)

the runoff flowrate can be considerably higher than the wastewater flow and the design flow of the treatment plant. In such situation, the excess flow is diverted and released, with or without treatment, into a receiving water body.

According to Brombach, Weiss and Fuchs (2005) there is a worldwide trend of separated systems usage, which adoption was recommended in the United States of America in 1972 by the *Water Clean Act*. Nowadays, combined systems are considered potentially more polluting and presents a higher risk to public health. Brazilian designers have chosen the separated systems following the global trend. However, as highlighted by Villanueva et al. (2011), despite the adoption of the separated systems, illegal sewage connections in the drainage system are frequent and it is rare to find a separated system properly working in Brazil.

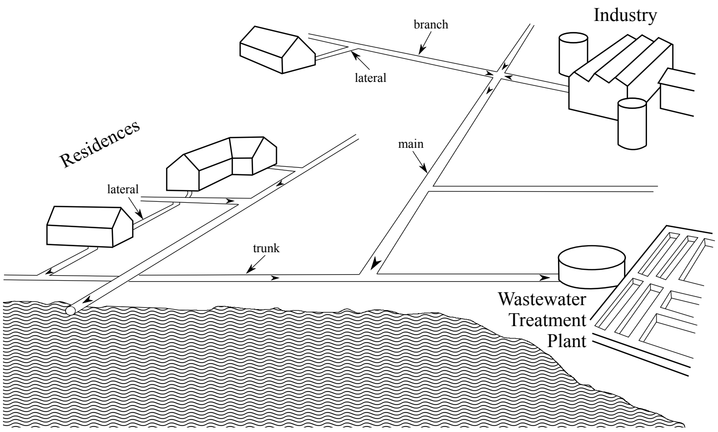
It has contributed to environmental degradation since the wastewater into the drainage system does not receive treatment, and it is directly discharged into water bodies, exposing the population of vulnerable areas — such as the population living in flooding areas — to waterborne diseases besides being responsible for bad odors in the drainage system and water pollution.

3.1.1 Separated Sanitation Systems

The sanitation system can be individual or collective. The individual solution assumes that interventions to control and prevent pollution will be performed on site, or as close as possible, to the wastewater source. According to Sperling (2005), individual systems can be understood as disposing excreta or wastewater from one or a few residences in units that promote their infiltration into the soil. Examples of individual solutions are cesspools, septic tanks, hygienic private, among others.

On the other hand, the collective solution comprises a set of pipes that convey the wastewater to a centralized WWTP and to the final destination. As previously mentioned, Brazilian engineers have assumed the separated systems. The main advantages for the implementations of such systems, as pointed out by Tsutiya and Sobrinho (2011) are: smaller diameter of pipes, smaller implementation costs, increased flexibility in the implementation phase, it could not require the paving of public roads, and it shall not affect the wastewater treatment.

The sanitation system, as a collective solution, comprises the collection network, the interceptors and outfalls, inverted siphons and forced passes, pumping stations, and the wastewater treatment plant (ABNT, 1986a; ABNT, 1986b; ABNT, 1992). The Figure 3.2 presents a schematic sanitation system.



Source: adapted from Ragsdale (2002)

FIGURE 3.2: Scheme of a sanitation system for wastewater collection, transportation and treatment

The sanitation system works as open channel flow, except when allocation of pumping stations are necessary. In Brazil, it is recommended water depths in pipes no greater than 75% of the diameter in order to ensure that the gases generated in the anaerobic decomposition can be transported. However, it is common the occurrence of connections between drainage and the sanitation system. In rain events, the water depth in the pipe can exceed the recommended values and the system may fail.

Despite the aforementioned advantages and the lower costs of separated systems, the sanitation deficit remains large in Brazil. In a recent report (ITB, 2013), the *Instituto Trata Brasil* (ITB), based on 2011 data from the *Sistema Nacional de Informações sobre Saneamento*[1] (SNIS), assessed the situation of sanitation in the 100 largest cities in Brazil. Regarding the wastewater collection, only 36 cities have wastewater collection index greater than 80%, and only 10 cities have wastewater treatment index greater than 80%. Five cities in the State of Paraná (Maringá, Londrina, Curitiba, Ponta Grossa and Foz do Iguaçu) are among the 20 cities with the highest percentages of wastewater treatment.

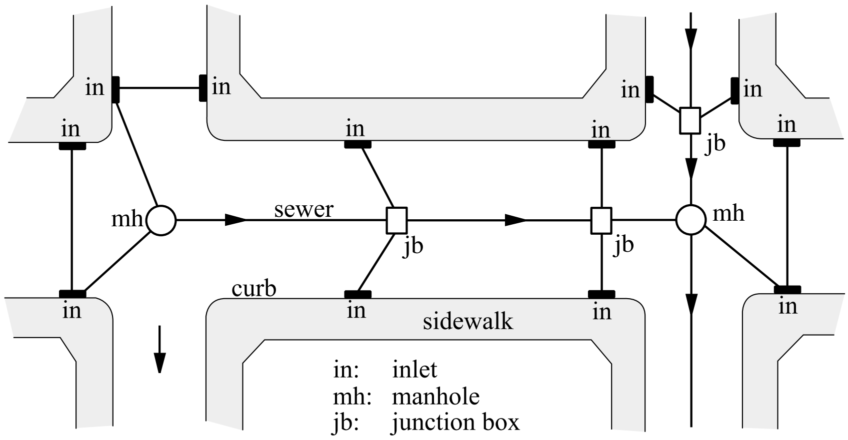
[1]National Information System on Sanitation

Among the indicators of water supply, wastewater collection and treatment, the latter showed the worst results. The report notes that the universalization of wastewater collection and treatment services is still far from completion and that without greater involvement of municipalities, states and the federal government that goal will remain unattainable.

The sanitation deficit is quite worrisome from the environmental point of view. The wastewater has high concentrations of organic matter, which decomposition produces odors gases and cause oxygen depletion when released untreated into receiving water bodies. Also, wastewater is a source of nutrients, particularly nitrogen and phosphorus, which can impact significantly the primary production of water bodies. Nevertheless, they may have high concentrations of pathogenic microorganisms constituting a potential source of waterborne diseases (TCHOBANOGLOUS; BURTON; STENSEL, 2003).

3.1.2 Separated Urban Drainage Systems

The drainage systems can be classified in source control, micro and macro drainage systems. The source control is the drainage within the lots, it generally comprises the gutters to collect the precipitated water on the roofs, vertical and horizontal drains. The micro drainage systems are the primary network and consist of various devices which aim to drain the water from lots and traffic lanes to the macro drainage system. They consist of curbs, manholes, junction boxes, sewers, among others (see Figure 3.3).



Source: adapted from PLANEPAR (apud FENDRICH et al., 1997)

FIGURE 3.3: Scheme of a traditional urban micro drainage system

The macro drainage comprises the galleries, large open or closed channels, hydromechanical equipments, reservoirs and hydraulic structures in parks (SÃO PAULO, 2012a). As highlighted by IPHRS (2005) the method by which the design flow is estimated is a key factor in classifying the urban drainage systems. The Rational Method is used in estimating the runoff flow for micro drainage design whilst hydrological models — which determine the runoff hydrograph — are used for the macro drainage design. Nevertheless, the return period used in macro drainage works is higher than that often used in micro drainage, as shown in Table 3.1.

The *Manual de Drenagem e Manejo de Águas Pluviais do Estado de São Paulo*[2], (SÃO

[2]Handbook of Drainage and Stormwater Management of the State of São Paulo

TABLE 3.1: Return periods often used for urban drainage design in Brazil

Drainage type	Feature	Return period (years)	Usual value (years)
Micro drainage	Residential	2 – 5	2
	Comertial	2 – 5	5
	Public buildings	2 – 5	5
	Airports	5 – 10	5
	Commercial areas and avenues	5 – 10	10
Macro drainage	–	10 – 25	10
Riparian areas	–	5 – 100	100

Source: IPHRS (2005)

PAULO, 2012a) recommends that in planning the micro drainage, the design has to be done to the rainfalls that occur every 10 years. However, for rainfall with higher return periods the system must comprise part of runoff so that damage to property or loss of life are small. Flooding the street pavements is allowed and even sidewalks, under the condition that they are not frequent.

Despite the traditional focus of this handbook, Volume II presents some measures to runoff control, specifically devices of infiltration (permeable pavements, swales), storage (retention basins) and mixed devices (wetlands, filter strips) (SÃO PAULO, 2012b). Nevertheless, Volume I highlights the need for integrated planning regarding to water management in the urban environment (SÃO PAULO, 2012a).

Both the traditional drainage and sanitation systems are widely used in Brazilian cities in order to mitigate the urbanization process impacts. However, these systems are not planned considering any kind of integration as requested by new approaches and it does not take into account other benefits rather than the flood — in the drainage system case — , and pollution mitigation — in the sanitation system case.

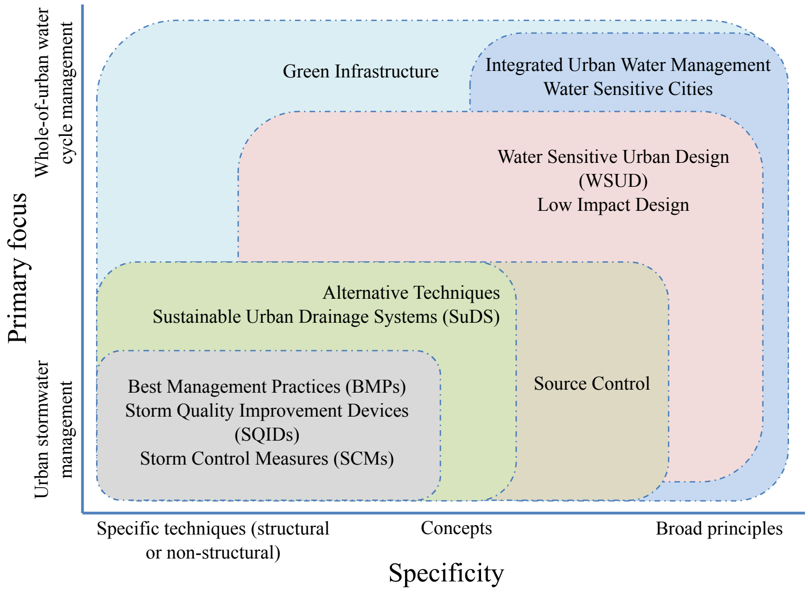
Based on the introductory chapter and section 3.1 of literature review, the following gap was identified: *A few case studies in Brazilian cities by using sustainable drainage systems measures considering their multiple benefits*. The following section describes some of the new approaches and philosophies used in the urban drainage management.

3.2 NEW APPROACHES IN URBAN DRAINAGE

In order to mitigate the impacts of urban runoff, new approaches seek to reinstate the natural hydrological cycle in urban areas and are an alternative for the management of these waters. Such approaches are called best management practices (BMP) or low impact development (LID) systems in the United States of America, low impact urban design and development (LIUDD) in New Zealand, water sensitive urban design (WSUD) in Australia, sustainable drainage systems (SuDS) in the United Kingdom and Compensatory Techniques (CT) or Alternative Techniques (AT) in France.

In Brazil, the term Compensatory Techniques (translated to Portuguese as *Técnicas Compensatórias* or *Medidas Compensatórias*) is often used to describe structures that aim to mitigate the impacts of urban runoff, and to reinstate the natural hydrological cycle in urban areas, as pointed by Baptista, Nascimento and Barraud (2011).

There are many similarities among these approaches, but there are also differences. A recent paper (FLETCHER et al., 2014) discusses the contexts in which terms are used and the main differences among them. For instance, the term green infrastructure (GI) was used in the United States back to 1990's and it comprises other urban structures beyond urban drainage. But now, the term is often used as synonymous for BMPs or LIDs although it can also be used in the original meaning. The authors have developed the Figure 3.4 which intends to classify the drainage terminology.



Source: Fletcher et al. (2014)

FIGURE 3.4: One possible classification of urban drainage terminology, according to their specificity and their primary focus

It is important to note that the terms used in the urban drainage literature evolved concurrently with the urban drainage objectives itself (see Figure 1.2). The authors emphasize that the terms are used in different ways and different terms are used to mean the same thing. Because of that it is important to clarify the meaning of the term when using one of them. Next sections briefly discuss some terms.

3.2.1 Best Management Practices (BMP)

Since the United States of America (USA) have recognized the diffuse pollution as an important aspect in the water management many years ago, they have developed the initial BMP concept in order to deal with this issue. The concept was developed as an on-the-ground practical answer to diffuse pollution problems from all sources and sectors (D'ARCY; FROST, 2001).

Although the term was not mentioned in the Clean Water Act of 1972 (UNITED STATES OF AMERICA, 1972), it is often related to this law. In a more recent version of the act (UNITED

STATES OF AMERICA, 2002), the term was described as a control measure of rainwater runoff from urban areas focusing on separate storm sewer systems by using innovative technologies in order to reduce pollutant loading rates.

The BMPs are defined by Braune and Wood (1999) as "a multi-disciplinary approach in applying appropriate technology to preserve the natural environment, enhance living standards and improve the quality of life". It is common to classify the BMPs as structural and non-structural measures. Structural measures comprehend structural facilities such as filter strips, detention and retention basins, wetlands and so on. Nonstructural measures include controls such as land-use planning, regulations, public awareness drives and maintenance procedures.

As can be seen in some publications such as Martin, Ruperd and Legret (2007) and Lee et al. (2012), the term is often used as a synonym to sustainable drainage systems and low impact development structures. These approaches also use the same structural measures such as detention ponds, infiltration trenches, swales, green roofs and so on. Therefore the terms can be interchangeably used.

3.2.2 Compensatory Techniques (CTs) and Alternative Techniques (ATs)

The term alternative techniques was initially used in France back in 1980's and it was used to describe a new paradigm of urban drainage which aims not deal solely with flooding issues but also to pollution control and improve quality of life (FLETCHER et al., 2014).

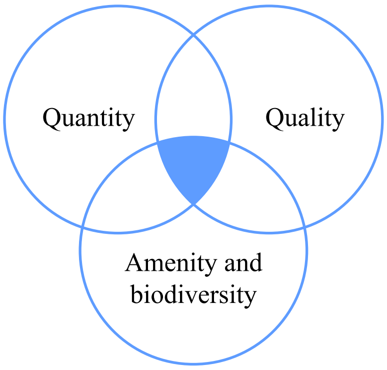
As mentioned by Piel, Pire and Maytraud (2010), there are many stormwater management initiatives in France using the compensatory techniques approach. These initiatives aim to promote the runoff treatment, to convey the runoff and to promote the rainwater use. In the reported case studies, the CTs was used in its original meaning and the structures were implemented aiming to bring multiple benefits such as urban comfort to citizens, and increase biodiversity in urban areas.

On the other hand, the employed solutions using this concept in Brazil focused on centralized, end-of-pipe, concrete made structures, such as stormwater detention basins. The traditional design methodologies were based solely on storing flood volumes in order to limit the runoff peak flow and there is not any consideration about pollution control (NASCIMENTO; ELLIS; BAPTISTA, 1999). It is far from the original intention of this approach. Nevertheless, this approach is still recommended by publications in its original intention (SÃO PAULO, 2012b; NASCIMENTO; BAPTISTA, 2009).

3.2.3 Sustainable Drainage Systems (SuDS)

The SuDS approach was developed in line with the sustainable development ideals and have been designed in order to manage the environmental risks of urban runoff and, where possible, contribute to environmental improvement (WOODS-BALLARD et al., 2007). It uses structural — measures that promote water quality improvement and runoff control, based on the procedures of detention, retention and infiltration — and non-structural measures — corresponding to prevention measures, public awareness policies, and management practices (MARTIN; RUPERD; LEGRET, 2007) in order to cope with stormwater runoff.

The objectives by using SuDS is to minimize the impact of urban environment development in the quali-quantitative characteristics of runoff when trying to replicate the existing natural drainage before the basin urbanization (DIETZ; CLAUSEN, 2008). In other words, is to reduce urban runoff volume, to reduce pollutant loads and to promote amenity and biodiversity in urban areas (Figure 3.5).



Source: Woods-Ballard et al. (2007)

FIGURE 3.5: Sustainable drainage systems' objectives

The hydrograph peak attenuation can be achieved by decentralized structures like detention and infiltration basins and permeable pavements. In regards to pollutant loading rate reduction, the SuDS approach uses biological treatment based structures like filter strips and constructed wetlands in order to promote nitrogen and phosphorus plant uptake and reduce organic and solid loads by means of sedimentation processes. The amenity and biodiversity components are a consequence by using natural treatment systems in the urban areas which can provide new ecosystems to species' development.

Despite the term compensatory techniques are widely used in Brazil, it is equivalent — it can be interchangeably used — to sustainable drainage systems. In this study the term SuDS was adopted, from the United Kingdom literature. This choice was made because of the wide usage of the term SuDS in recent literature compared with the term Compensatory Techniques.

3.2.4 Low Impact Development (LID) Systems

According to USEPA (2000), LID is "a site design strategy with a goal of maintaining or replcating the pre-development hydrologic regime through the use of design techniques to create a functionally equivalent hydrologic landscape". The LID structures are used to source control, and the measures have to be distributed throughout the site.

On the other hand, Elliott and Trowsdale (2007) uses the terms LID and LIUDD as a synonymous for SuDS. The authors mention that the structural LID measures "are designed to detain, store, infiltrate, or treat urban runoff, and so reduce the impact of urban development". As in SuDS and BMPs, the LID systems are also divided into structural and non-structural measures.

Emphasizing the source control and micro-scale use of LIDs structures, USEPA (2000) mentions that they can reduce or eliminate the need for a centralized best management practice structures in order to control stormwater runoff. As pointed out by Fletcher et al. (2014) there are different meaning of the term among countries. While in the United States of America the original intent of this approach was to restore the natural hydrological cycle in urban areas, in New Zealand the emphasis is in pollution control rather than flow regime control.

3.2.5 Water Sensitive Urban Design (WSUD)

The water sensitive urban design approach started to be used in Australia in 1990's (FLETCHER et al., 2014). It is considerably broader than those previously mentioned approaches. Hoyer et al. (2011) defines WSUD as an "interdisciplinary cooperation of water management, urban design, and landscape planning". The urban design is an important issue in WSUD approach and the strategies considers ecological, economical, social, and cultural aspects.

According to NSW EPA (1998) the main goals of water sensitive urban design are: (i) preservation of existing topographic and natural features; (ii) protection of surface water and groundwater resources; and (iii) integration of public open space with stormwater drainage corridors. The same publication highlights its broad principles, that are:

1. minimizing impervious areas;
2. minimizing use of formal drainage systems;
3. encouraging infiltration;
4. encouraging stormwater use.

Morgan et al. (2013) mentioned that in this approach all elements of the water cycle are considered concurrently. It is important to consider the management of the water demand and supply, wastewater and pollution, rainfall and runoff, watercourses and water resources and flooding and water pathways in an integrated way. Furthermore, this approach seeks to provide resource security and resilience to the cities.

3.2.6 Green Infrastructure (GI)

According to Fletcher et al. (2014), the term green infrastructure was first used in the USA in the 1990's. This term was originally related to parkland, forests, wetlands, greenbelts, or floodways in and around cities that provided improved quality of life or ecosystem services, but currently, the term is often related to environmental or sustainability goals that cities are trying to achieve through a mix of natural approaches (FOSTER; LOWE; WINKELMAN, 2011).

The term is defined by Benedict and Mcmahon (2002) as "the nation's natural life support system — an interconnected network of waterways, wetlands, woodlands, wildlife habitats, and other natural areas; greenways, parks and other conservation lands; working farms, ranches and forests; wilderness and other open spaces that support native species, maintain natural ecological processes, sustain air and water resources and contribute to the health and quality of life for communities and people".

In this approach, there is concern in linking people with the places in which they live, and a set of other benefits such as flooding mitigation, micro climate control, maintenance of biodiversity, maintenance of ecosystem services, *et cetera* (ECOTEC, 2008). As in the SuDS, BMPs and LID approaches, the green infrastructure also uses decentralized measures to deal with the stormwater (CNT, 2010) and the term can be used interchangeably with them.

3.3 STRUCTURAL MEASURES FOR URBAN DRAINAGE

There are many structures available that can be used in the context of sustainable drainage. The structures can be classified, in a general manner, as to their use in pretreatment structures, draining structures, source, local or regional control, and can be prioritized based on their treatment efficiency and hydraulic performance (WOODS-BALLARD et al., 2007). Some structure measures that could be used in rainwater management are briefly commented below.

3.3.1 Infiltration trenches

Infiltration trenches (IT) are shallow excavations filled with crushed stone or other support materials. They aim to temporary store the stormwater and runoff, and to promote water infiltration into the soil. They are designed to receive lateral contribution from an adjacent impervious area, but they allow point source contributions.

The infiltration trenches generally have one to two meters deep (WOODS-BALLARD et al., 2007), being much longer than wide. They are relatively easy to build on adjacent to impervious areas and should be used for infiltration of runoff generated in relatively small areas, less than four acres (DUCHENE; MCBEAN; THOMSON, 1994). They are structures that can replace conventional pipe lines. If combined with filter strips, for instance, they can replace curbs when the system is located along the streets or sidewalks. It is not recommended the usage of these structures in basins' downstream because of the high runoff flow volume.

The main disadvantage of these structures, as highlighted in Woods-Ballard et al. (2007) is its high potential for clogging due to solids accumulation. Notwithstanding, the maintenance of these structures is often neglected, increasing the risk of failure. Another disadvantage concerns to the high cost of replacement of the support material when fouling occurs. However, if it is associated with other SuDS solutions, can be quite efficient.

3.3.2 Permeable pavement

As the green roofs, porous and permeable pavements (PP) are considered source control structures. In general, it consists of a porous surface with a sand and a rock sub-base to collect, treat and infiltrate the rainwater into the soil (SCHOLZ; GRABOWIECKI, 2007) or simply promote its storage (YONG; MCCARTHY; DELETIC, 2013). When there is concern about the migration of pollutants into groundwater, it is possible to build reservoirs with a waterproof membrane. Subsequently, the stored water must be discharged into a suitable drainage system.

The main advantages by using permeable pavements is related to its good treatment and runoff flow reducing capacity. It can be deployed in urban areas with high population density, it has a simple maintenance procedure and it can turn the gutters unnecessary. Another important aspect is that it has good acceptance by the population, and that it does not require additional area once it can be deployed in parking lots or sidewalks.

In a performance evaluation of four permeable pavement systems located in Renton, Washington, Brattebo and Booth (2003) reported very positive results in regards to runoff control. The system was able to infiltrate all precipitation, even during the most intense storms. The main disadvantage is the possibility of clogging when there is a high sediment load in the basin and an insufficient structure maintenance (WOODS-BALLARD et al., 2007).

3.3.3 Rainwater Harvesting

The rainwater harvesting (RWH) is considered a source control measure which consists of collecting the rainwater from roofs, for instance, and its use on-site for non-potable purposes such as flushing toilets, irrigation, among others. Selection and siting these systems depend on environmental conditions — rainfall distribution over the year — and the intended use of the collected rainwater (WOODS-BALLARD et al., 2007). Moreover, these systems can contribute in reducing urban flooding because the collected rainwater is stored.

Ghisi, Bressan and Martini (2007) studied the potable water savings by using rainwater harvesting systems in the southeastern Brazil. The authors reported that for the cities of Belo Horizonte, Rio de Janeiro, Vitória, and São Paulo, the water saving potential varies from 4% in June–August to 83% in December. By using data from 195 cities, the authors reported that the potential for water saving varies from 12% in August to 79% in January, on average. The overall average for the southeast region was 41%.

Regarding the runoff flow reduction, six pilot buildings localized in the south of Italy were studied by Campisano et al. (2014) using water balance simulations of the rainwater tanks. The authors observed a peak flow reduction for a number of rainfall events. The reported peak flow reductions were between 30% and 65% for at least 50% of the events. Peak flow reduction is reported by other researchers such as Coombes and Kuczera (2003), Hardy, Coombes and Kuczera (2004), and Farahbakhsh, Despins and Leidl (2009).

3.3.4 Stormwater Detention basins

The detention basin (DB) differs from infiltration basin because it stays dry during most of the time, being flooded only during and immediately after a rain event. These structures aim to mitigate runoff by providing a temporary storage and controlled release of stored water. The main advantages of these structures are the simplicity of design and construction. Moreover, during periods without rain the area of deployment can be used for other purposes, such as parking lots, playgrounds or playing sports (WOODS-BALLARD et al., 2007).

In Brazil, operational problems observed over time have decreased the detention basins usage, especially when it is a centralized solution. However, it is a popular measure in São Paulo, where there are several detention basins planned to be implemented — beyond those currently in operation (BRAGA; PORTO; SILVA, 2006). Nascimento, Ellis and Baptista (1999) report that the deployment of these structures in Belo Horizonte dates back to the 1940's, with the primary purpose of flood control.

Due to unplanned urbanization in catchments, detention basins implemented in Belo Horizonte experienced many operational problems, mainly related to siltation due to the large inflow of settleable solids. Moreover, the contribution of solid waste and the wastewater discharge are frequent problems (NASCIMENTO; ELLIS; BAPTISTA, 1999). Braga, Porto and Silva (2006) mention that the problems observed in the detention basins emphasize the importance of a multidisciplinary and integrated approach to water management in the urban environment, in which the solid waste management should be part of.

3.3.5 Bioretention devices

The bioretention devices (BR) are "shallow landscaped depressions that can reduce runoff rates and volumes, and treat pollution through the use of engineered soils and vegetation" (WOODS-BALLARD et al., 2015). A series of structures are considered bioretention devices such as the rain gardens, raised planters, bioretention tree pits, bioretention swales and trenches, and anaerobic bioretention systems.

These devices are widely used in the urban areas in order to contribute to manage stormwater mainly by reducing peak flows and pollutant loading rates (DAVIS, 2008; HUNT et al., 2008; Le COUSTUMER et al., 2012; LUCKE; NICHOLS, 2015). The stormwater treatment is achieved by filtering it through biologically active plants and soils which provides pollutant removal and, at the same time, they can provide other benefits such as amenity and biodiversity (TROWSDALE; SIMCOCK, 2011).

Besides the possibility of removing urban pollutants and the runoff flow, other advantages of using bioretention are that it has a flexible layout to fit into the landscape, it can be used in highly impervious areas, and it has a good retrofit capacity. On the other hand, the main disadvantages comprise the landscape and management requirements, the susceptibility to clogging, and it is not suitable for areas with steep slopes (WOODS-BALLARD et al., 2007).

3.3.6 Constructed wetlands

According to Woods-Ballard et al. (2007), the constructed wetlands (CW) are flooded structures that promotes the growth of aquatic plants aiming the runoff flow treatment — in the urban drainage context. When it is well designed and properly maintained, it can bring important benefits as the aesthetic amenity and provide an environment for the establishment of wildlife. They are generally designed to promote significant runoff attenuation and the its temporary storage. The constructed wetlands require a continuous flow basis for sustaining aquatic macrophytes and microorganisms.

According to Kadlec and Knight (1996), the constructed wetlands can be classified as surface flow or subsurface flow. The surface flow wetland is densely vegetated with a variety of plant species and have depths of water less than 0.4 m. The subsurface flow uses a support medium, soil or gravel for plant growth and water flows through the support medium in contact with the community of microorganisms and the roots of macrophytes.

To pollution control, the most important process in the constructed wetlands is related to removal of suspended solids and pollutants associated with them. The pollutant removal is achieved by a combination of processes such as sedimentation, filtration and adhesion of solids in macrophytes (SOMES; FABIAN; WONG, 2000). In addition to these processes, the macrophytes roots create an extensive network, giving cohesion to the soil particles and creating a large surface area for absorption of nutrients and ions (SHUTES, 2001).

3.3.7 Green roofs

Green Roofs (GR) are structures that perform the source control and promote the detention of the precipitated water on the buildings roofs (SÃO PAULO, 2012b). The multilayer systems contain generally a support medium for the growth of a plant cover, geotextile, a drainage layer and, if necessary, an irrigation system. From the urban drainage point of view, green roofs are designed to intercept and temporally store the rainfall, reducing runoff volume with consequent attenuation of peak flows (BERNDTSSON, 2010) besides being able to improve the runoff water quality (GREGOIRE; CLAUSEN, 2011).

Moreover, many other benefits may be provided by green roofs, for example by reducing the proportion of solar radiation that directly affects the structure of the roof, reducing energy demand for heating and cooling, the mitigation of urban heat islands, improving air quality, replacement of landscape, biodiversity enhancement, acoustic insulation, among others (SANTAMOURIS et al., 2007; YANG; YU; GONG, 2008; CASTLETON et al., 2010; CURRIE; BASS, 2010).

The main disadvantages mentioned in Woods-Ballard et al. (2007) are the high cost of deployment, it is not suitable for steep slope roofing, it depends on the roof structure, it has limited deployment in some buildings, and the maintenance of vegetation, which should be constant.

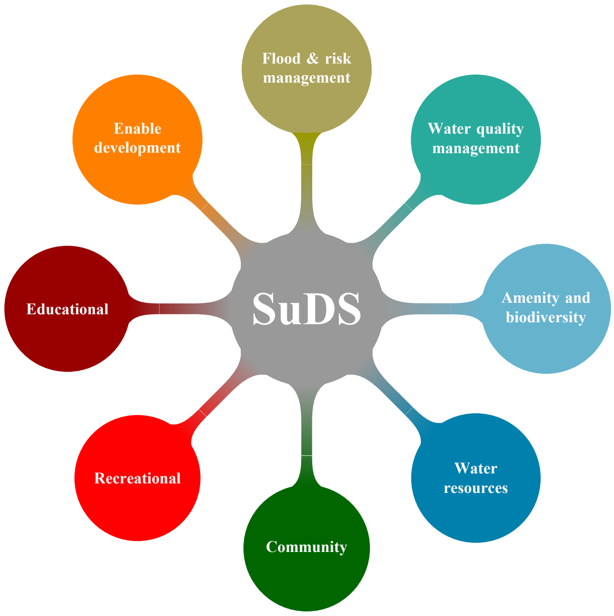
3.4 SUSTAINABLE DRAINAGE SYSTEMS BENEFITS

The traditional drainage systems have more limited benefits than the SuDS. However, the use of piped drainage prevails because it is seen as 'less risky' (CIRIA, 2014). On the other hand, it is recognized that sustainable practices can deliver multiple ecological, economic and social benefits or services, which are contributing to the current acceptance of these solutions (CNT, 2010). Dickie et al. (2010) explain a series of related use of SuDS benefits, as can be seen in Figure 3.6.

The flood risk management comprises the runoff peak flow mitigation, which can be achieved with the implementation of structures that promote the infiltration, detention and/or retention of the rainwater. The water quality management is considered in sustainable systems because they could promote the runoff water treatment, which is an often overlooked aspect in traditional micro drainage systems.

Structures such as ponds and constructed wetlands can help in amenity of urban microclimate, locally increasing the relative humidity and providing green areas for biodiversity development. The benefits in water resources can be achieved with the implementation of structures to promote water infiltration into the soil and, consequently, the recharge of aquifers.

Moreover, community benefits can be achieved with the implementation of green areas that could, at the same time, store the runoff water, serve as habitat for the development of animal and plant species, and as a recreational area for local people. It can improve well-being in the surrounding community. SuDS structures can be used for educational purposes, in order to demonstrate, for instance, concepts related to the hydrological cycle. Finally, they could be a benefit for managers and enable development of areas considering an integrated approach. At the same time, sustainable communities could contribute in reducing costs of drainage structures.



Source: adapted from Dickie et al. (2010)

FIGURE 3.6: Sustainable drainage systems' multiple benefits

CNT (2010) also lists a series of benefits that some measures can bring. For instance, in reducing stormwater runoff, energy use and atmospheric carbon dioxide emission, in improving air quality, community livability, habitat and public education, and easing the urban heat island (UHI) effect. As aforementioned, the SuDS structures can bring a wide range of benefits. However, there is a lot of discussion on how to assess them and how to take into account their long-term performance. The evaluation of these aspects is still missing from the practice, although there are some available softwares (CHOW et al., 2014).

As discussed in CIRIA (2014) there are three ways of assessing the benefits: (i) by making qualitative statements, (ii) by making quantitative statements and (iii) determining monetize benefits. The additional benefits of SuDS can be overlooked as the evaluation procedures are unclear and the long-term performance of SuDS is still uncertain to stakeholders.

As can be seen, the structural sustainable drainage measures briefly discussed in section 3.3 can bring multiple benefits to urban areas. However, there is not a standardized way to assess them, and remains debate on how to do it. Therefore, from aforementioned section and this section of the literature review, the following gap was identified: *Uncertainties in how to assess the SuDS multiple benefits*.

3.5 DECISION SUPPORT TOOLS FOR SUSTAINABLE URBAN DRAINAGE

Recent advances in regards to the integrated urban water modeling have facilitated the evaluation of water conservation measures and greatly aided decision-making process. To Bach et al. (2014) the key drivers for the adoption of integrated modeling concerns to the (i) integration of bottom-up approaches and the involvement of stakeholders, (ii) the recent legislative changes — e.g. the European Union (EU) Water Framework Directive (EU, 2000) — and (iii) recent innovations in integrated modeling.

Despite aforementioned advances, there remain difficulties in integrated urban water modeling, as well as in models efficiency evaluation. Bach et al. (2014) highlight four difficulties to be overcome in integrated modeling as mentioned below:

1. *Model complexity*: costs and the effort involved in and integrated modeling is often considered as a barrier and often the outputs can not compensate this;

2. *User friendliness*: some complexity perceived in the model could be assigned to a bad user interface and it can inhibit the model adoption and use. On the other hand, a friendlier interface can greatly increase confidence in the model without the internal structure of the model is known;

3. *Administrative fragmentation*: the split of responsibilities in management of urban water systems has been a common reason for the lack of integration and continues to be a problem today, although it is a matter of less concern than before;

4. *Communication*: Few studies explore higher levels of integration rather they choose to stay with two or three sub-systems. A more effective communication should be promoted and the authors may suggest a systematic approach.

Notwithstanding, there is a lack of decision-support tools to help stakeholders in planning sustainable drainage measures. In this sense, Makropoulos et al. (2008) developed a tool called Urban Water Optioneering Tool (UWOT) which aim to facilitate the selection of water savings strategies in order to bring an integrated and sustainable water management for new developments. The UWOT integrates the Simulink/MATLAB and Microsoft Excel, by means of an application developed in Visual Basic for Applications (VBA).

The tool uses a set of indicators by which the sustainability assessment is done. They were divided into four domains (called sustainability capitals), namely: environmental, economic, social and technical. In the technical domain, for instance, indicators used were performance, reliability, durability and flexibility/adaptability. Other qualitative and quantitative indicators used were acceptability, capital cost, operational cost, land use, among others. It provides a wide range of technologies to be selected, but in planning the drainage it is just possible to select a local or centralized SuDS and the differentiation between them are based on their functionality.

UWOT produces two types of results: (a) a numerical value for all water streams, for instance, potable water demand, wastewater and runoff generated and (b) an assessment using the sustainability indicators. The assessment is done by using a benchmark, which could be a system configuration that considers no recycling or harvesting and traditional structures (end-of-pipe drainage systems, for instance).

Another decision-support system tool, called System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN), was developed by the United States Environmental Protection Agency (USEPA), which aim to evaluate alternative plans for stormwater quality management and volume reduction in urban and developing areas (LEE et al., 2012). The SUSTAIN was built on a base platform interface using ESRI ArcGIS and it provides a land simulation module, a conveyance module, a BMP sitting tool, a cost evaluation module, an optimization module and a post-processor.

The tool can be used to analyze stormwater flow, pollutant discharges and management options. The first step in the tool is to clearly establish the study objectives. GIS data required to run simulations include watershed delimitation, land use and land cover, soils, stream network, Digital Elevation Model (DEM), pollutant source information and so on. Other information, such as long-term climate data and monitored water quality and quantity are also required for calibration and validation processes.

Considering all these input data, the optimization module analyses all information together and it identifies the best or most cost-effective BMP measures that fit the initial established objectives. In the last step, the post-processor analyses the results and develop the cost-effectiveness curves for the measures which can be used to select the best solution to the study area.

Chow et al. (2014) developed a decision support framework to help planners in evaluating different SuDS designs. It was developed using GANetXL which is an Excel add-in for optimization purposes. The framework uses a multi-criteria approach considering four main aspects: water quantity, water quality, energy usage and impact on the surrounding environment. It uses the concept of key performance indicators (KPI) which translates the SuDS design criteria into an indicator.

Furthermore, the framework includes monetary measures. The costs considered are capital expenditure, operational expenditure and land-take costs. The calculations were based on unit cost data collected from various case studies and the module is prepared for applications in the United Kingdom (UK). The authors are working on the framework to bring a better understand to the sensitivity of the performance and monetary costs.

The evaluation is done by visualizing a Pareto-front graph which relates the hydraulic performance and whole life cost of different drainage design options. By using the framework, stakeholders can compare the different design proposals and select the most interesting designs which achieve the management goals.

A new tool developed by Bach (2014) called Urban Biophysical Environments And Technologies Simulator (UrbanBEATS) integrates the urban planning issues and the water sensitive urban design approach to provide users a platform to help decision-makers and engage stakeholders in the modeling process. The tool consists of five major steps which are the processing of input data, the delineation of a spatial map, the characterization of the urban form, the planning of new and adaptation of existing WSUD infrastructure and the performance assessment.

The UrbanBEATS model comprises two modules, the Urban Planning and the WSUD Planning module. The first one uses the GIS based information and the "parameters of planning regulations to reconstruct an abstraction of the urban form in a grid-based representation". The second one follows the water management objectives and the urban planning requirements in order to assess the existing system and design and implement WSUD infrastructure (BACH; MCCARTHY; DELETIC, 2014).

Further development on the model intend to refine the algorithms in order to consider a wider variety of factors and to prepare the model to applications in a real-world planning context. In the urban planning module it is necessary to overcome some gross overestimations in the roofs area, for instance. In the WSUD planning module, the author emphasizes the need to incorporate of holistic elements in regards to the landscape integration with WSUD infrastructure.

In a recent review Jayasooriya and Ng (2014) described in detail ten tools. It considers five aspects of the models: (i) the sustainable drainage measures available, (ii) spatial scales, (iii) algorithms used for modeling, (iv) data inputs and outputs, and (v) user interface and handling of the tool. The reviewed tools were classified in three categories as follows: (i) models that address the stormwater management ability of green infrastructure in terms of quantity and quality, (ii) models that have the capability of conducting the economic analysis of green infrastructure, and (iii) models that can address both stormwater management and economic aspects together.

Reviewed models were: RECARGA Model, P8 Urban Catchment Model, EPA SWMM, WERF BMP and LID Whole Life Cycle Cost Modelling Tools, GI Valuation Toolkit, CNT Green Values National Stormwater Management Calculator, EPA SUSTAIN Model, MUSIC, LIDRA Tool and WinSLAMM. The authors conducted a comparison among models considering the number of measures that the tool can assess, the approach, the data requirements, the model accuracy, and the applications and limitations of each one.

The authors emphasize that the EPA SWMM is the most complex model which can be used in large-scale projects and to detail design SuDS measures. It can be used in order to model stormwater quality and quantity and to assess the structures' performance. On the other hand, MUSIC was considered the most reliable tool, but once it uses Australian meteorological data, application in other contexts could be a limitation.

The aforementioned tools differ from each other in several aspects. The framework used, the interface, the programming language, the evaluation method itself and so on. Considering the integration between the urban water systems, as discussed in section 3.6 it is important to provide a tool that can evaluate whether drainage measures can affect other water systems.

The main difference of the structure provided by the UWU Model is the possibility to evaluate the drainage measures themselves, but also to assess their impact on other water systems using the indicators provided by the model or implementing indicators that can reflect the integration. Based on this section of the literature review, the following gap was identified: *Lack of an integrated tool to decision-making support when planning mitigation measures for urban drainage*.

3.6 URBAN DRAINAGE INTERFACES

Understanding the urban water interfaces are essential to an integrated urban water management because the water infrastructure can influence each other. In integrated tools, structural or non-structural measures adopted in a water system can influence and alter the other system characteristics. Therefore, to identify such interfaces and relations among the systems is necessary in order to allow an integrated assessment.

Gessner et al. (2014) define urban water interfaces "as the boundary zones between components, subsystems or compartments of the urban water as a whole". Examples of interfaces in urban environment are between surface and ground water, between water collection, treatment and supply systems, between wastewater and the sewer atmosphere and so on. An important issue in water interfaces is that the water quantity and quality change whilst water flows across the interfaces or from one system to another.

In the water supply systems, for instance, the abstracted water from the waterbody is pumped to the Water Treatment Plant (WTP) in which changes in its quality occur. The water is then distributed to the population that uses it and alters its quality again. Then the generated wastewater is routed to the sanitation — or to the urban drainage.

Wastewater quality within the sewer system will change because of the biochemical processes that can occur under anaerobic conditions (ALMEIDA; BUTLER; DAVIES, 1999) and because of the physical processes such as advection and dispersion. Finally, the wastewater can be discharged in a waterbody after passing through the wastewater treatment plant.

Another important interface is one that occurs between the surface and ground water, which is substantially modified as a function of the urbanization process because it imposes multiple pressures in the hydrologic cycle. In a review paper, Shuster et al. (2005) pointed out a series of impacts in hydrologic cycle due to impermeable surfaces:

1. increased hydraulic efficiency in urban basins;
2. decreased capacity to infiltrate precipitation;
3. increased production of runoff;
4. shorter concentration times or lag times;
5. decreased recharge of water tables and in base flows;
6. indirect effects on downstream flooding and on aquatic ecosystems.

Beyond these listed impacts there is some evidence that heavily urbanized areas have altered evapotranspiration regimes and the patterns of precipitation and intensity due to the heat island effect (SHUSTER et al., 2005).

Despite modifications in the water cycle, interfaces between surface and ground water still important in urban areas. As highlighted by Gessner et al. (2014) the ground water influences the technical water infrastructure and it is influenced by them. For instance, leaks in the sewer network, infiltration structures used in rainwater or sanitation systems, and so on. In the other direction unknown amounts of groundwater can infiltrate into the sanitation system, increasing the wastewater volume and may impact the WWTP's.

At the same time, the specific wastewater per capita volume has been decreasing because water saving measures in buildings, whose practice also increase the pollutant concentration in wastewater. Obviously, WWTP's process will be impacted receiving more concentrated effluents.

In the Brazilian context an important aspect to be considered is the influence of domestic wastewater in urban drainage network, even whilst the separate system is used. Despite the limited available data and difficulties in inspection procedures, illegal connections are quite common. For instance, it can be perceived by bad odors exhaled by inlets at the center of many Brazilian cities.

In addition to domestic wastewater, the consideration of the public cleaning services is important for the sustainability of urban drainage system. According to Righetto (2009), the public cleaning services are basically: sweeping, cleaning drainage structures, cleaning streams and collection, transportation and disposal of solid waste generated in cities, whose responsibility is of the municipal administration.

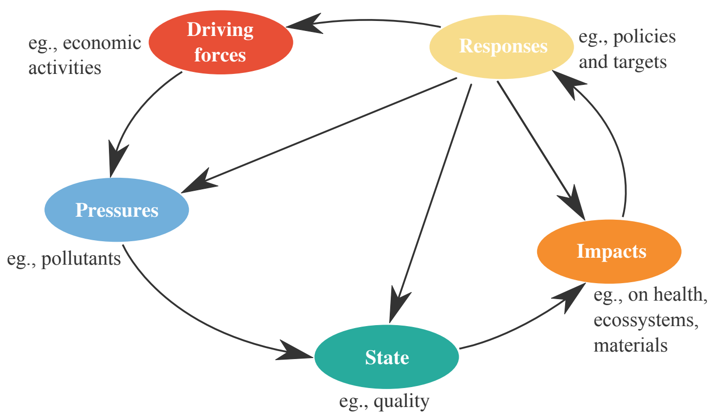
In the absence or failure of municipal solid waste (MSW) collection, the solid waste is often disposed on traffic roads, rivers, streams and wastelands. The main effects of the lack of collection of solid waste is the siltation of rivers and streams, clogging drains, destruction of green areas, smelly and proliferation of disease vectors (JACOBI; BESEN, 2011). Notwithstanding, with rainfall events the MSW disposed in waterways can clog drainage channels and increase flooding problems.

In this sense, it is important to consider the interfaces among urban water systems because the integrated way the UWU Model works. If a drainage measure can affect other water systems beyond drainage indicators — i.e. if it can affect other indicators than those selected to evaluate drainage measures — , the effect has to be described and estimated in order to assess the whole measure effect.

Nonetheless, impacts in other aspects of the urban environment such as in water quality, livability and ecosystem health, have to be considered together with economic aspects in order to bring a broader vision and a less biased assessment.

3.7 URBAN WATER USE MODEL

The Urban Water Use Model (SANTOS; STEEN, 2011) uses an Integrated Urban Water Management approach in order to contribute to respond the nowadays changes in the environment and the socioeconomic pressures. Once based on the IUWM principles, it is based on the DPSIR Framework, which analyses the driving forces related to changes, the resulting pressures, the new state established, the impacts and the responses (see Figure 3.7).



Source: Hák, Moldan and Dah (2007)

FIGURE 3.7: DPSIR framework for reporting on environmental issues

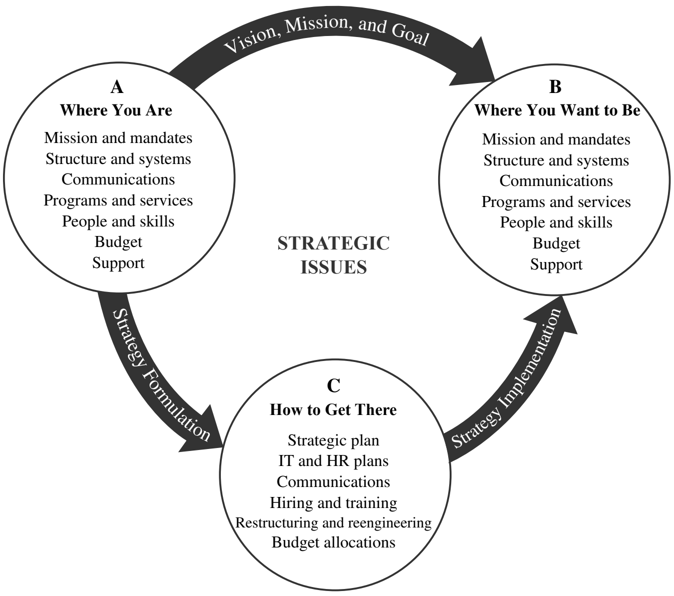
The UWU Model was first developed as an educational tool in order to encourage stakeholders to think and create water management solutions in urban areas. It was intended to motivate them to get involved with activities which provide an attractive environment to learn. Therefore, the tool is structured in a stakeholder platform using strategic planning and implementation and an evaluation system.

The Strategic Planning is an approach that consists of a process to assist decision-makers in choosing methods to be used and objectives to be achieved in order to solve the conflicts of management. More specifically, according to Allison and Kaye (2005), strategic planning can be defined as

> a systematic process through which an organization agrees on — and builds commitment among key stakeholders to — priorities that are essential to its mission and are responsive to the environment. Strategic planning guides the acquisition and allocation of resources to achieve these priorities.

The approach allows that the information obtained in the decision-making process are focused on maximizing safety, minimizing risks and optimizing the results and responses necessary for the management (SIMERSON, 2011). This approach, widely used by the private sector, has been gaining more and more space in the management of public services as well as water management and urban infrastructure.

In general, strategic planning can be understood as a cyclical process, as can be seen in Figure 3.8, which shows the three main issues raised in strategic planning. These issues are inserted into the overall process of the UWU model.



Source: Bryson (2011)

FIGURE 3.8: The ABC's of strategic planning

In the urban water management context, strategic planning is understood as an integrated approach that considers not only the technical and economic aspects related to the implementation and maintenance of urban infrastructure. It also considers the challenges imposed by the dynamics of cities, the ability of institutions to provide essential services to the population, as well as public participation in the management process (MALMQVIST et al., 2006).

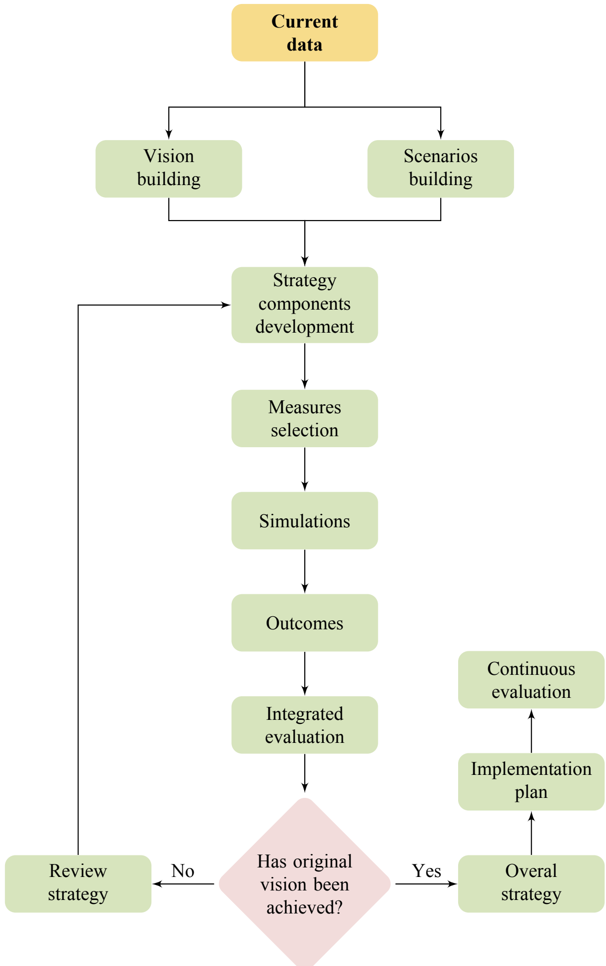
As emphasized in Steen et al. (2010), for strategic planning of urban infrastructure it is important to think about the future and plan measures to cope with the pressures identified in the urban area. Both the public and private sectors have to follow and achieve the goals or the established vision. A strategic plan which was developed and accepted by all stakeholders together becomes a powerful tool to give directions to the annual plans of municipalities, utilities and waterboards.

3.7.1 The model structure

In regards to the UWU Model, it focuses on planning measures to urban water infrastructure and the buildings. It is possible to plan measures considering the water supply, sanitation and urban drainage systems. Into the buildings, the model considers water conservation actions and the rational water use of alternative water sources. The tool was first developed in Microsoft Excel, using an interface in Visual Basic for Applications (VBA).

As mentioned before, the model application is based on a stakeholder platform in order to establish an overall strategy, set out a group of measures and select the indicators. The vision building process should be developed by all groups together, as well as the development of scenarios based on the external factors.

Given a set of input data from a study area and the stakeholder groups discussion, it is important to give a weight for each indicator, prioritizing the indicators that stakeholders deem to be most important and set a vision value to each of them. By selecting the measures, and setting their parameters, it is possible to run simulations and assess how the measures will affect the indicators in each developed scenario. The general steps in UWU Model can be seen in Figure 3.9.



Source: adapted from Santos and Steen (2011)

FIGURE 3.9: General steps in UWU Model

The model comprises of four main stages: (i) the input data; (ii) the equations linking indicators, measures and scenarios; (iii) the outcomes and (iv) the integrated evaluation. A step by step procedure to UWU Model application is described in Santos and Benetti (2014) and can be summarized as follows:

1. Input data: necessary data to characterize the study area such as the current population, the basin area, water supply and sanitation systems capacities and so on;
2. Vision elaboration: to built the vision, a set of indicators have to be selected in order to reflect a desired future for the study area. Once the indicators have been selected, the vision and the weight values can be set. The available indicators in the original model's version are (i) water supply system coverage, (ii) sanitation system coverage, (iii) water supply system energy consumption, (iv) sanitation system energy consumption, (v) flooding flowrate in sewer, (vi) water quality index and (vii) present cost.
3. Scenarios elaboration: the scenarios elaboration takes into account the following external factors: population growth rate (λ), average annual temperature (T) and the economic performance (EP). It is important to note that the scenarios are elaborated totally independent of the vision-building process;
4. Measure groups definition: the measures in the first version of the UWU Model consider the management water demand, decentralized sanitation, ecological sanitation, sustainable drainage systems approaches. The available measures are (i) low-flush toilets, (ii) graywater reuse, (iii) rational water use by awareness, (iv) pipeline water loss reduction, (v) treatment water loss reduction, (vi) expands water system capacity, (vii) expands sanitation system capacity, and (viii) water reuse.
5. Measure groups' application: the groups of measures are evaluated by assessing their impact on the indicators values. This is done by means of a series of equations linking the scenarios, measure groups and indicators.
6. Outcomes: the group of measures changes the indicator values in each formulated scenario. Then, these new values are compared with the established vision and it is counted in how many scenarios the vision was achieved;
7. Effectiveness Index evaluation: considering the vision and the formulated scenarios, the better group of measures is that one in which the vision was achieved in the largest number of scenarios, taking into account, at the same time, the set weight for each indicator.

In regards to the item 3 — scenarios elaboration — , it is important to note that there is no external factor directly related to urban drainage systems. In the original model the following five scenarios are elaborated based on the input external factors data (Table 3.2):

As can be seen, the population growth rate assumes four states: the current value (λ_0), a minimum value (λ_1), a medium value (λ_m) and a maximum value (λ_2). The annual temperature assumes two values: the current value (T_0) and the medium future value (T_m). Finally, the economic performance assumes two values: the current value (EP_0) and the medium future value (EP_m).

TABLE 3.2: Elaborated scenarios by using the original UWU Model approach

External factors	**Scenarios**				
	SC1	**SC2**	**SC3**	**SC4**	**SC5**
Population growth rate	λ_1	λ_m	λ_2	λ_0	λ_0
Annual temperature	T_0	T_0	T_0	T_m	T_0
Economic performance	EP_0	EP_0	EP_0	EP_0	EP_m

Source: Santos and Steen (2011)

As aforementioned, in the evaluation phase results are compared with the expected vision for each indicator for each future scenario. This comparison makes it possible to estimate the Effectiveness Index (EI) of each group of measures. This estimation is performed by Equation 3.1:

$$EI_k = \sum_{i=1}^{n} W_i \times N_{ij} \tag{3.1}$$

where EI_k is the Effectiveness Index of the group of measures k; n is the number of selected indicators; W_i is the weight of the indicator i chosen in visioning step; and N_{ij} is the number of scenarios j in which the indicator i achieved the vision.

The summation is among all the selected indicators in the stakeholder discussion phase. Nevertheless, the index is ranked according to the degree of effectiveness of the measure group, according to the scale in Table 3.3, which had been drawn up to five indicators. In this formulation and classification, the greater the number of scenarios in which an indicator reaches its reference vision value, as well as greater the indicator weight, more effective the group measurements. Consequently, the greater the number of indicators that achieved the vision, more effective and comprehensive set of measures will be in attendance of the various dimensions of water sustainability.

TABLE 3.3: UWU Model's Effectiveness Index Scale

Range of variation	**Categories**
4.60 – 5.00	Excellent
3.60 – 4.50	Good
2.60 – 3.50	Reasonable
1.60 – 2.50	Insufficient
0.00 – 1.50	Poor

Source: Santos and Steen (2011)

The influence of the scenarios on the predictions of the capabilities and scope of the urban water systems are estimated by specific equations. To assess the impact of population growth on the indicators, it is estimated the future population based on the geometric model and the population growth rate in the study area. The temperature changes and the economic performance are related to the per capita water consumption and to the per capita wastewater production.

From section 3.6 and this section of the literature review, considering the aforementioned external factors, measures and indicators which are currently implemented in the UWU Model, the following gap was identified: *Lack of defined interfaces between drainage and other systems into UWU Model as well as lack of external factors, measures and indicators to assess sustainable drainage systems*.

3.8 KNOWLEDGE GAPS

From the literature review, considering the new trends and approaches in the urban drainage management, some gaps have been identified. They are summarized as follows:

1. A few case studies in Brazilian cities by using SuDS measures considering their multiple benefits;
2. Uncertainties in how to assess the SuDS multiple benefits;
3. Lack of an integrated tool to decision-making support when planning mitigation measures for urban drainage;
4. Lack of defined interfaces between drainage and other systems into UWU Model as well as lack of external factors, measures and indicators to assess sustainable drainage systems.

This work proposes the usage of the UWU Model (SANTOS; STEEN, 2011) structure to assess effectiveness of sustainable drainage systems implementation. By means of indicators, the model could be adapted to be able in assessing the benefits by using SuDS in order to support decision-making process when planning mitigation measures in urban drainage system and to establish management actions for the conservation of water in urban and peri-urban Brazilian areas.

Although the present work focus only on urban runoff and drainage systems, it is important to note that the model allows to conceive water conservation actions considering the three urban water systems, Sewage Systems, Urban Drainage Systems, Water Supply Systems, besides the buildings. Therefore, relations between the drainage system and the water supply and sanitation systems have to be addressed. In this sense and based on the identified knowledge gaps, the chapter 4 states the research questions which guide the thesis development.

4 RESEARCH QUESTIONS

Despite current efforts in urban drainage modernization, the solutions hitherto implemented often overlook sustainability issues in Brazilian cities. With rare exceptions, the decision-makers have chosen a traditional drainage systems implementation — gray infrastructure — and a hard engineering approach, although such solutions are being widely criticized around the world.

Considering the current population growth, the urbanization trend and its inherent consequences as mentioned in previous chapters, sustainable approaches — which could deal with runoff peak flows and at the same time contribute to pollution control and the urban amenity — must be considered seriously as an alternative solution.

On the other hand, the lack of specific strategies and tools which can contribute to the decision-making process whilst planning sustainable drainage measures stills an impediment to change. Therefore, this proposal aims to answer the following question:

How the UWU Model can be used to support the evaluation of sustainable drainage measures in cities of the Curitiba Metropolitan Region and support decision-making process?

Based on the identified knowledge gaps, the main question is followed by:

1. **Which** and **how** the external factors could be used in order to formulate future scenarios to evaluate drainage measures by using the structure provided by UWU Model?
2. **Which** indicators could be used to assess sustainable drainage systems additional benefits by using the structure provided by UWU Model?
3. **What** are the interfaces between urban drainage measures and water supply system and how they can influence each other?
4. **How** the UWU Model application can be used to support decision-making in urban drainage system?

This page was intentionally left blank

5 METHODOLOGICAL APPROACH

This chapter describes the proposed methodology in order to answer the formulated research questions. The methodology was divided into two main phases which were the drainage module development using the UWU Model structure (Phase 1) and the case study application (Phase 2). The research methodology is summarized in the Figure 5.1.

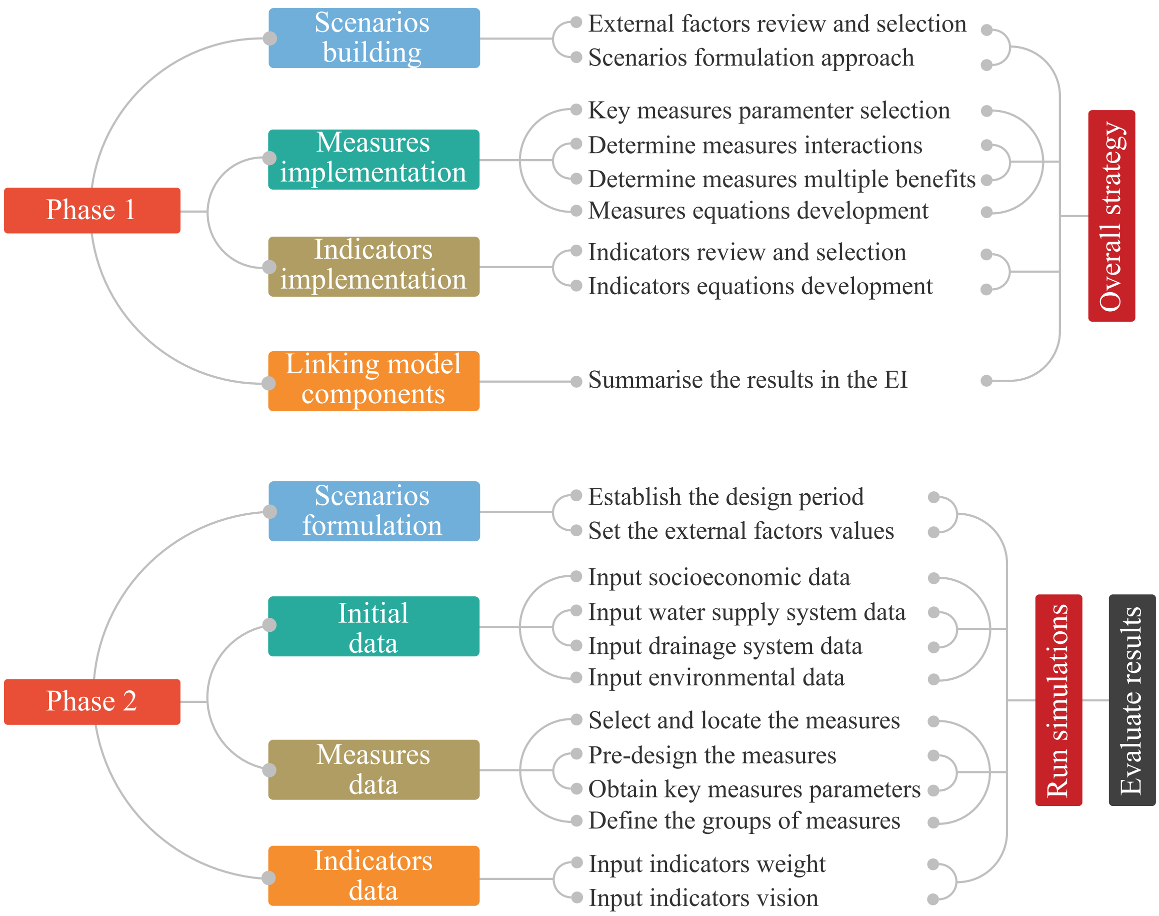


FIGURE 5.1: Methodological approach flowchart

The UWU Model structure had to be first adapted to allow the sustainable drainage measures evaluation. To do so, external factors related to urban drainage were incorporated into the basic model's structure in order to formulate plausible scenarios.

Thereafter, a set of SuDS structural measures was selected and implemented in the model. As the model does not intend to support SuDS design, it was considered the key aspects in designing each structure (area, depth, or volume, for instance), which were the input parameter for them. To consider the SuDS multiple benefits, indicators that take into account such benefits had to be reviewed and implemented. The equations relating the implemented measures and their effects in each scenario were developed.

In summary, the measures evaluation was done by means of the scenarios formulation — which uses the external factors — , and the indicators — which values in each scenario were compared with the vision' values and expressed in the Effectiveness Index, as described in section 3.7. The general structure of the proposed tool is shown in Figure 5.2.

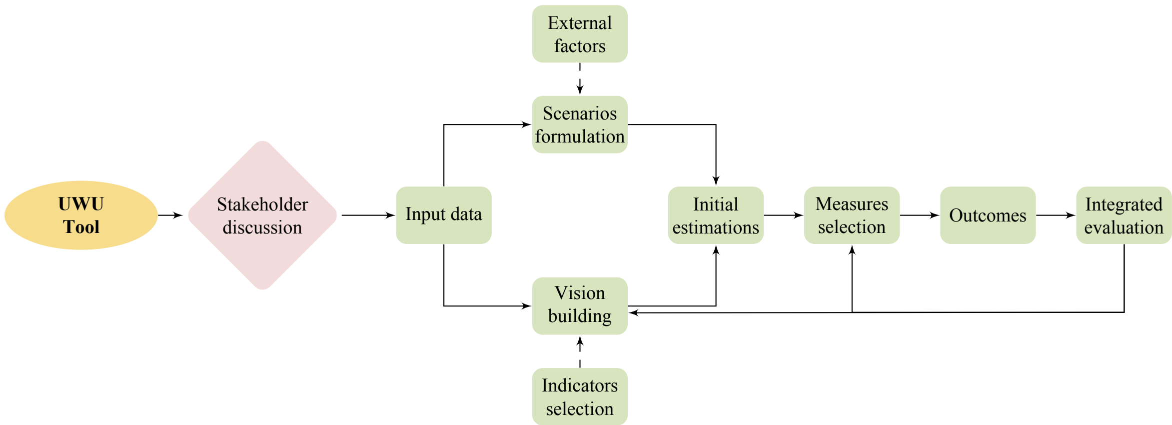


FIGURE 5.2: Proposed framework using the UWU Model's structure to evaluate sustainable drainage measures

Once the UWU Model is an integrated tool which considers other systems than the drainage, it was important to identify the interfaces between drainage measures and other system indicators and describe how they could be affected, if there was any degree of interaction.

After building the tool, a case study application was performed in the Curitiba Metropolitan Region in order to test the whole model. By using the case study results it is possible to formulate a general framework to give directions to decision-makers in evaluating sustainable drainage measures and support their choices. Next sections describe in more details the methodology.

5.1 PHASE 1: UWU TOOL DEVELOPMENT

This section describes the methodology to address the research questions regarding to UWU Tool development. As can be seen in Figure 5.1, a series of steps were proposed in order to develop the module. These methodology sections followed the steps in aforementioned figure.

5.1.1 Scenarios building

This section describes the methodology used in order to answer the following research question: *Which and how the external factors could be used in order to formulate future scenarios to evaluate drainage measures by using the structure provided by UWU Model?*

***

The scenarios formulation was developed based on external factors already implemented in UWU Model — population growth rate, average annual temperature, and the economic performance — , but it was necessary to implement an external factor which is directly related to the drainage system measures.

Therefore, the scenarios were elaborated taking into account four external factors. The challenge was to ensure that the scenarios are representative and at the same time, the number of formulated scenarios cannot be too large. The scenarios formulation's implementation followed the chart in Figure 5.3. The steps are described below.

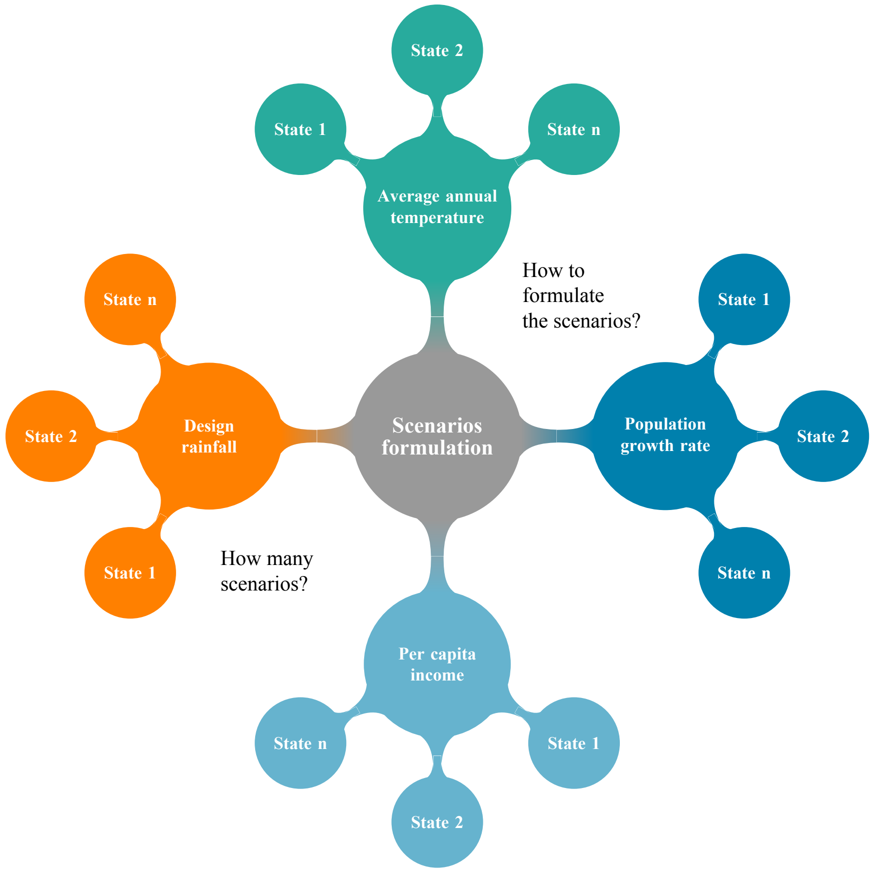


FIGURE 5.3: Scenarios formulation's flowchart

Step 1. External factor selection: Once the design rainfall is absolutely necessary in drainage planning, it was considered its implementation in the scenarios formulation phase. To do so, a set of equations was formulated in order to express its relationship with the indicators values. It was done concomitantly with the indicators development.

Step 2. Formulation approach: It is possible to formulate the scenarios by using multiple different approaches and external factors. Then, the first step was to review and select an approach, establish how the values had to be arranged to formulate the future scenarios, and define the equations and/or methods that had to be used in order to set the future values. The formulated scenarios had to be consistent with the available scenarios and data provided by the international community, such as the IPCC, in order to incorporate climate change issues in the decision-making process.

Step 3. Number of scenarios: Once it was defined the formulation approach, it was necessary to define how many states had to be set for each external factor and how many scenarios are formulated — if there is not a fixed number of scenarios in the selected approach.

5.1.2 Measures implementation

This section describes the methodology used in order to select the drainage measures to implement in the UWU Model and to answer the following research question: *What are the interfaces between urban drainage measures and other urban water systems and how they can influence each other?*

***

There are two structural measures for urban drainage already implemented in the UWU Model — filter strips and permeable pavements. Both of them are concerned with reducing the runoff flow by increasing the water infiltration. The measures are evaluated by the 'flooding flowrate in sewer' indicator.

The input data for these two structures is the 'impermeability reduction', in percentage. Considering that sustainable drainage measures can bring other benefits, a more general feature had to be used in order to characterize the measure because the 'impermeability reduction' is a consequence, or a benefit itself. The measures review followed the chart in Figure 5.4. The steps are described below.

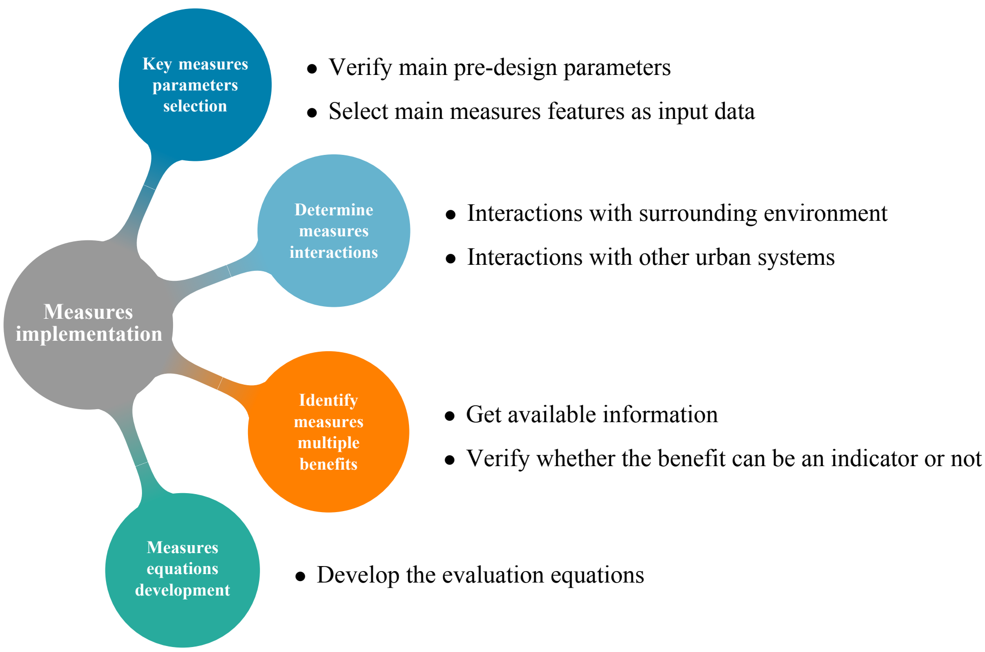


FIGURE 5.4: Sustainable drainage measures review flowchart

Step 1. Main features selection: As the SuDS measures can differ greatly from one another, it is important to identify the main features for each of them that can affect the indicators values. If a specific measure can promote runoff treatment, the objective is to know if the SuDS volume, area, length and/or slope is the main feature responsible by its. After pre-designing a SuDS structure, the input data in UWU Model should be the main features responsible for bringing the benefits assessed by the indicators. To incorporate their characteristics into the model such as pollutant removal and runoff reduction efficiencies, for instance, values reported in the literature were considered. Publications such as Pötz and Bleuzé (2012) and Woods-Ballard et al. (2015), and specific publications about each measure were considered.

Step 2. Identifying the multiple benefits for each measure: To identify the multiple benefits for each measure publications such as ECOTEC (2008), CNT (2010), Wise et al. (2010), CIRIA (2014), among others, were considered. Once the recognized benefits for each SuDS structure had been determined, some of these benefits were "translated" into quantitative indicators that could be used using the UWU structure. The indicators are discussed in subsection 5.1.3.

Step 3. Identifying the key interfaces with other systems: To achieve this aim and answer the above question, it was necessary to describe the main interactions that occurs between each drainage measure and the water supply and the sanitation systems indicators. The interactions were described quantitatively, by means of equations or relations that indicates how measures were affecting other systems components. Despite some interactions are widely known, as can be seen in section 3.6, it is not clear how it could be taken into account when planning drainage measures by using UWU Model structure. In fact, to incorporate these aspects into the UWU Model, the interactions had to be described by specific equations in order to quantify the drainage measures' effects in other systems indicators.

Step 4. Identifying the environmental characteristics which can affect measures: The surrounding measure environment can affect the measures efficiency because of the interaction between them. The soil characteristics can influence in the infiltration rate of some sustainable drainage measures, for instance. Therefore, the physical characteristics affecting the measures have to be considered whilst inputting initial data into the model. To identify the main characteristics publications like Woods-Ballard et al. (2007) and specific publications about each measure were considered.

5.1.3 Indicators implementation

This section describes the methodology to be used in order to answer the following research questions: *Which indicators could be used to assess sustainable drainage systems additional benefits by using the structure provided by UWU Model?*

***

To improve the model, it is proposed to implement indicators that consider at least the flooding, and water quality aspects related to urban drainage measures. Using the indicators it is intended to help decision-makers to choose the best group of measures to a study area. It is important to note that once the UWU Model is an integrated model, the indicators have to be linked with the other systems' measures if they can be affected by them. The indicators review followed the chart in Figure 5.5, considering the steps described below.

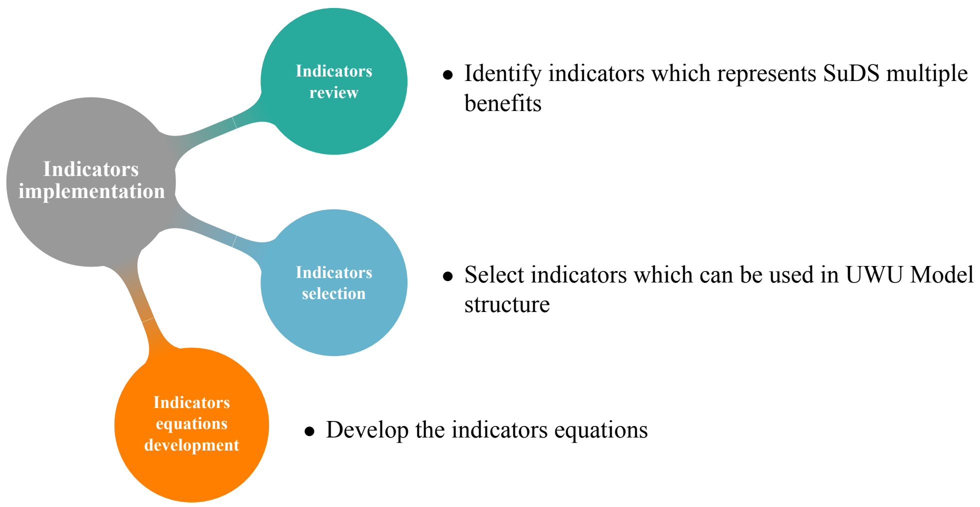


FIGURE 5.5: Indicators' review flowchart

Step 1. Identifying the indicators: To identify and select the indicators, publications such as Kolsky and Butler (2002), Makropoulos et al. (2008), ECOTEC (2008), Kellagher and Udale-Clarke (2008), CNT (2010), Lee et al. (2012), CIRIA (2014), Chow et al. (2014), among others, will be considered. Once there are several multiple benefits, as briefly discussed in section 3.4, the indicators should reflect at least the flooding and water quality aspects.

Step 2. Identifying the interfaces with other measures: After the selection of a set of indicators, the next issue was to describe, by means of equations, how the measures could affect the indicators values. Then, it was important to determine if there was some interaction among the drainage indicators and other systems measures. This step considered publications such as Gessner et al. (2014), Fletcher, Andrieu and Hamel (2013), Braud, Fletcher and Andrieu (2013), among others.

The structure of the drainage module was developed in Microsoft Excel, using a VBA's interface. Once the model was working well to evaluate drainage measures alone, the integration with the other systems — specifically with the water supply system — was implemented. A summary of the measures, inputs, indicators, equations and the used references for each assumption were provided in the model development chapter.

5.1.4 Linking model components

To link the scenarios, drainage measures, and the indicators, the relation among every model parameter had to be established. There were two main questions to be answered. The first one was related to whether a specific external factor can affect a specific indicator. Once the answer was 'yes', the next question was 'how?' and a set of empirical equations had to be selected in order to reflect it. The Figure 5.6 shows and schematic relation among external factors and indicators.

On the other hand, after estimating all indicators values using the external factors input data, the next step was to determine whether a specific measure could affect the value of a specific indicator. Considering the same logic, once the answer was 'yes', the next step was to determine 'how' the indicator value had to be changed by the measure (Figure 5.6).

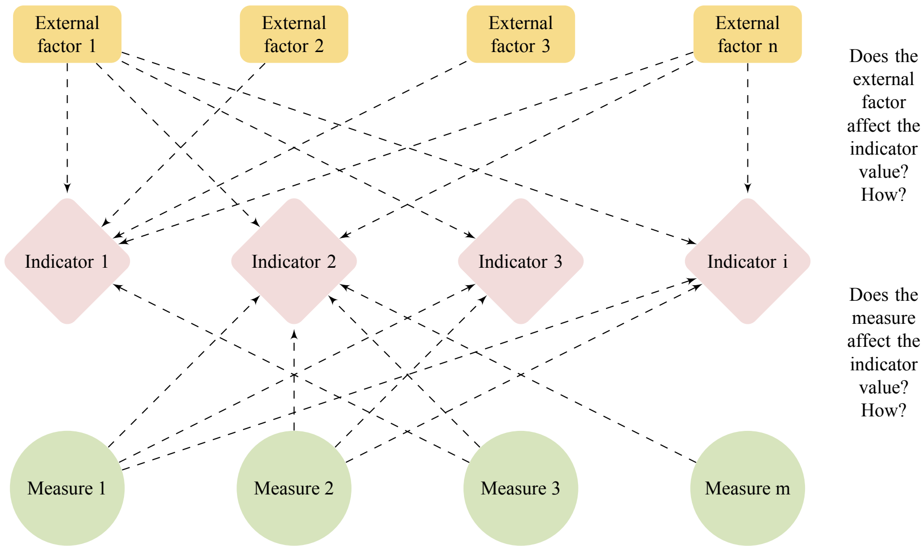


FIGURE 5.6: Hypothetical example of existing links between external factors, indicators, and urban drainage measures

Importantly, the final value of a specific indicator varies by scenarios and by the sum of the effects of the measures contained in a group of measures. Finally, the indicator value was compared with the established vision and the effectiveness index could be estimated.

5.2 PHASE 2: CASE STUDY APPLICATION

This section describes the methodology to address the following research question: *How the UWU Model application can be used to support decision-making in urban drainage system?* As can be seen in Figure 5.1, a series of steps were proposed in order to address the question. The following methodology sections followed the steps in aforementioned figure.

***

5.2.1 Overview of the Curitiba city and the study area

The selected study area is within the Curitiba city, more specifically in the northern region within the Belém River basin. The city is located in the southern Brazil. It has an area of 437.42 km^2 and its estimated population in the last census was $1,751,907$ inhabitants (IBGE, 2013). Population over the years in Curitiba is shown in Table 5.1.

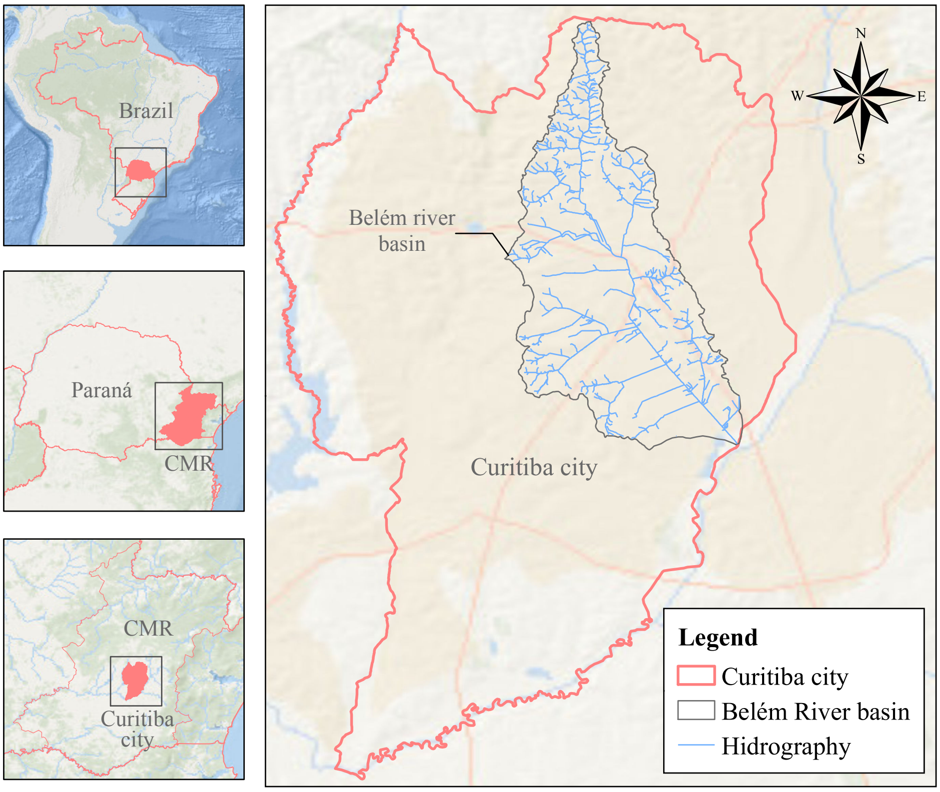
TABLE 5.1: Historical population for Curitiba city

Year	**1991**	**1996**	**2000**	**2010**	**2015**
Population (*inh*)	1,315,035	1,465,504	1,587,315	1,751,907	1,879,355

Source: IBGE (2013)

The city integrates the called Curitiba Metropolitan Region which is the ninth most populous urban agglomeration in Brazil with 3,223,836 inhabitants (IBGE, 2013). It is the fifth largest metropolitan region in number of cities conurbation.

It is located within the Alto Iguaçu basin and there are five sub-basins within its area: the Atuba, Barigui, Belém, Passaúna and Ribeirão das Padilhas river basins. The Belém river basin is one of the most important because of its increasing urbanization rate experienced in the past decades, the high population density and the pollution issues. Notwithstanding, it has its headwaters and mouth within the Curitiba city area and could be classified as an urban basin. The Curitiba Metropolitan Region, the Curitiba city, and the Belém river basin location are shown in Figure 5.7.



Source: The author with data from IPPUC and ESRI®

FIGURE 5.7: Curitiba Metropolitan Region, city of Curitiba, and Belém river basin location

The average annual temperature in Curitiba is 16.8 $°C$ according to available data from National Institute of Meteorology (INMET, 2015). It is located in the temperate climate zone, classified as Cfb — oceanic climate according to the Köppen-Geiger classification (PEEL; FINLAYSON; MCMAHON, 2007) — , and it has four well-defined seasons.

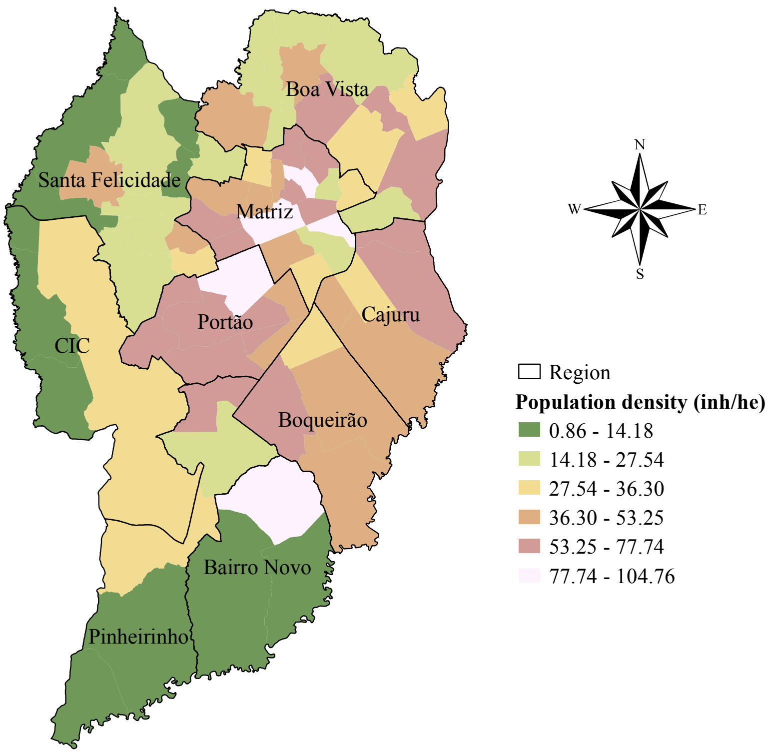
Despite the good average situation in the sanitation coverage compared with the Brazilian average, there are concerns in regards to the water quality in important river basins within the Curitiba urban area. In the Belém river basin, for instance, the Instituto Ambiental do Paraná (IAP) has classified the Belém river as polluted according to its criteria (IAP, 2009). As reported by Edwiges (2007) the maximum dissolved oxygen concentration in rain events was 3.8 $mg\ L^{-1}$. The minimum total phosphorus concentration reported was 1.80 $mg\ L^{-1}$ and the minimum total

Kjehldahl nitrogen concentration was 8.2 $mg\ L^{-1}$.

Kramer et al. (2015) have reported average concentration and the standard deviation for dissolved oxygen, total phosphorus, nitrite, nitrate, ammonia nitrogen, and dissolved organic carbon, in the Belém River. Reported concentrations (values in $mg\ L^{-1}$) and standard deviations were: 0.46 ± 0.54, 4.81 ± 3.15, 0.07 ± 0.01, 0.14 ± 0.06, 23.49 ± 14.67, and 19.01 ± 12.65, respectively. The authors comment that the results indicate the presence of labile organic carbon, which combined with the low concentration of dissolved oxygen and high levels of ammonia nitrogen and total phosphorus, indicates the presence of domestic sewage in the Belém River.

In regards to the urban water infrastructure Curitiba has a satisfactory sanitary coverage compared with the Brazilian reality. Official data from the Paraná sanitation company (SANEPAR), shows that in 2014 the wastewater collection coverage was equal to 65%, and the wastewater treatment coverage was equal to 99.5% — i.e. the wastewater treatment coverage in the Curitiba city was equal to 64.7%. The water supply system coverage was equal to 100%, according to the official data. On the other hand, the national averages are equal to 48.6%, 39.0%, and 82.5%, respectively (ITB, 2013; SNIS, 2013).

Despite there are big differences among neighborhoods the population density of Curitiba is about 39.93 inh/ha. The region called *Matriz* is the most densely populated of Curitiba, and it is the region in which are located three of the five most densely populated neighborhoods: the city center — 98.86 inh/ha — , Juvevê — 91.72 inh/ha — and Cristo Rei — 91.27 inh/ha. The population density by neighborhood can be seen in Figure 5.8.

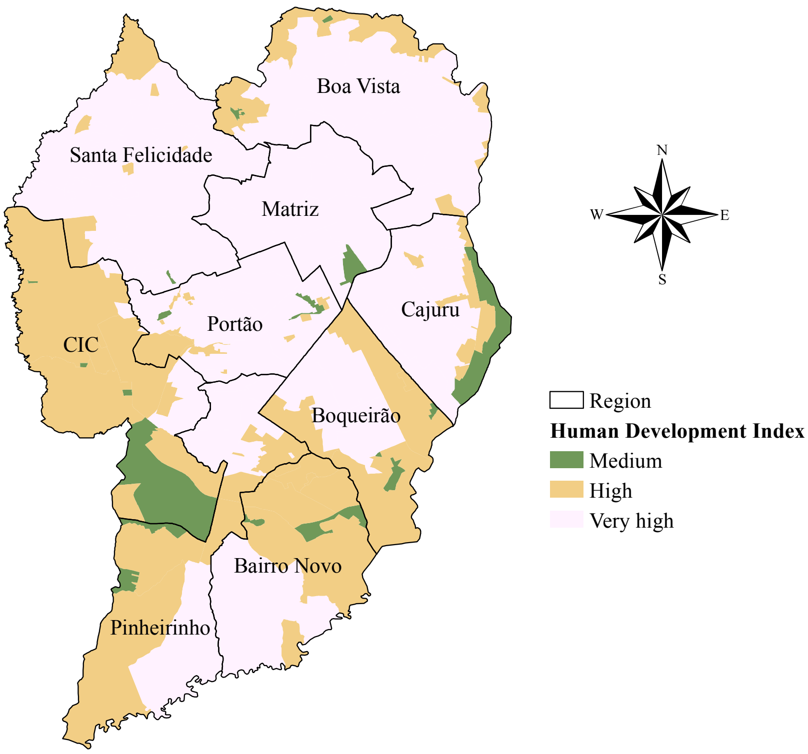


Source: The author with data from IBGE (2013)

FIGURE 5.8: Population density distribution by neighborhood and region within the Curitiba city area

The Água Verde, within the *Portão* region, is the most densely populated neighborhood with 104.76 inh/ha. Another densely populated neighborhood is the Sítio Cercado, within the *Bairro Novo* region, with 92.10 inh/ha.

The Curitiba's Municipal Human Development Index (MHDI) is equal to 0.823 (IBGE, 2013), which is considered very high development. Its MHDI is above the average for the Paraná state, which is equal to 0.749. The MHDI distribution by census tract can be seen in Figure 5.9.



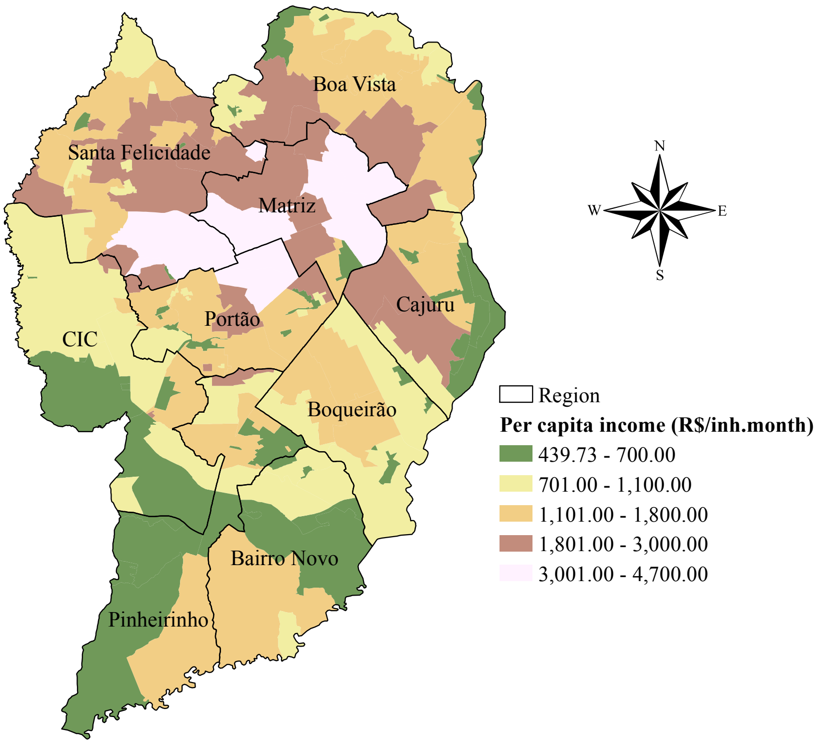
Source: The author with data from IBGE (2013)

FIGURE 5.9: Human Development Index distribution by census tract and region within the Curitiba city area

The MHDI of the most census tracts within the Belém river is considered 'very high' — it varies from 0.80 to 1.00 — but there are areas such as the Vila das Torres, Vila Parolin and Parque Náutico census tracts in which the MHDI are equal to 0.623 — i.e. 'medium' development — , Belenzinho in which the MHDI is equal to 0.704, and Hauer (east) in which the MHDI is equal to 0.772 — i.e. 'high' development.

Other important aspect in characterizing the Curitiba city is its average per capita income, which is equal to $1,587.61$ $R\$/inh \cdot month$ (IBGE, 2013). It is higher than the Paraná state per capita income, which is equal to $1,210.00$ $R\$/inh \cdot month$ and considerably higher than the Brazilian average, which is equal to 919.82 $R\$/inh \cdot month$. The Curitiba per capita income distribution by census tract can be seen in Figure 5.10.

As can be seen, the *Matriz* region has the highest per capita incomes — varying from $1,801.00$ $R\$/inh \cdot month$ to $4,700.00$ $R\$/inh \cdot month$. The exceptions are the Vila da Torres and Rebouças census tracts in which the per capita incomes are equal to 439.73 $R\$/inh \cdot month$ and $1,182.01$ $R\$/inh \cdot month$, respectively.



Source: The author with data from IBGE (2013)

FIGURE 5.10: Per capita income distribution by census tract and region within the Curitiba city area

The Batel, Jardim Social, Eduardo Sprada, Jardim Schaffer and Água Verde census tracts have the highest income per capita of Curitiba city — more than 4,000.00 $R\$/inh \cdot month$. On the other hand, the Vila das Torres, Parque Náutico, Nossa Senhora da Glória and Vila São José, among others, census tracts have the lowest per capita income — 439.73 $R\$/inh \cdot month$.

About the physical characteristics of the Curitiba city, Giusti (1989) has determined and reported the permeability coefficient of the three lithologies within the city. The reported coefficients for the Belém River basin, subdivided by main types of sediments, can be seen in Table 5.2.

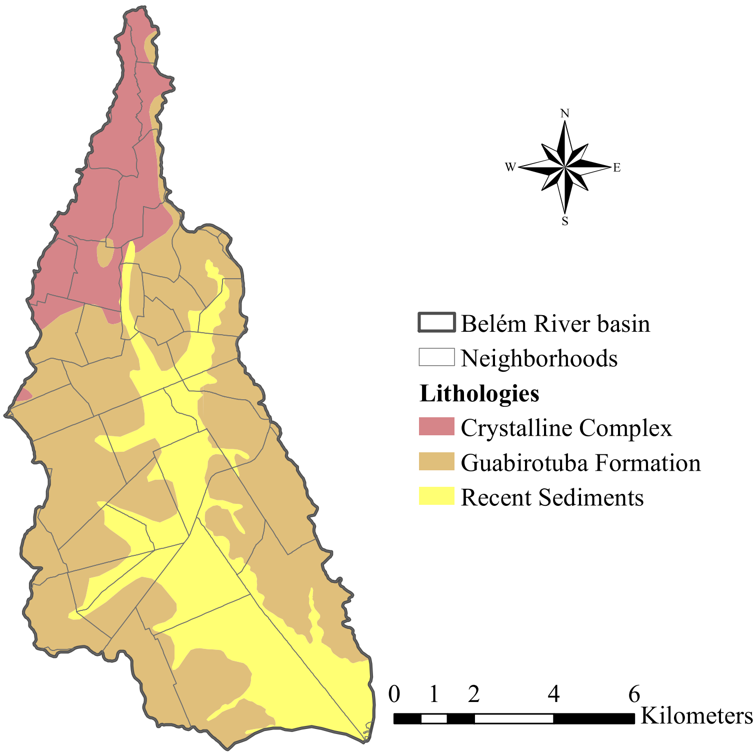
TABLE 5.2: Permeability coefficient of the main lithologies in Curitiba city

Lithology	**Sediments**	**Permeability coefficient (cm/s)**
Crystalline complex	Altered	10^{-4} to 10^{-5}
	Fractured	10^{-3} to 10^{-5}
Guabirotuba formation	Claystones and siltstones	10^{-6}
	Sandstones	10^{-4}
Recent sediments	Sandy-clay peat	10^{-5}
	Coarse	5×10^{-4}

Source: Giusti (1989)

The author conducted geophysical and hydrogeological studies highlighting the structure and geological interfaces, the topographical configuration of the crystalline complex, and groundwater as well as the groundwater direction flows.

By knowing the permeability coefficient is an important aspect whilst planning the drainage measures because a low soil permeability can turn the implementation of some measures unfeasible. Moreover, the measures efficiency estimations have to take it into account. These three lithologies are found in the Belém River basin as shown in Figure 5.11.



Source: The author with data from Giusti (1989)

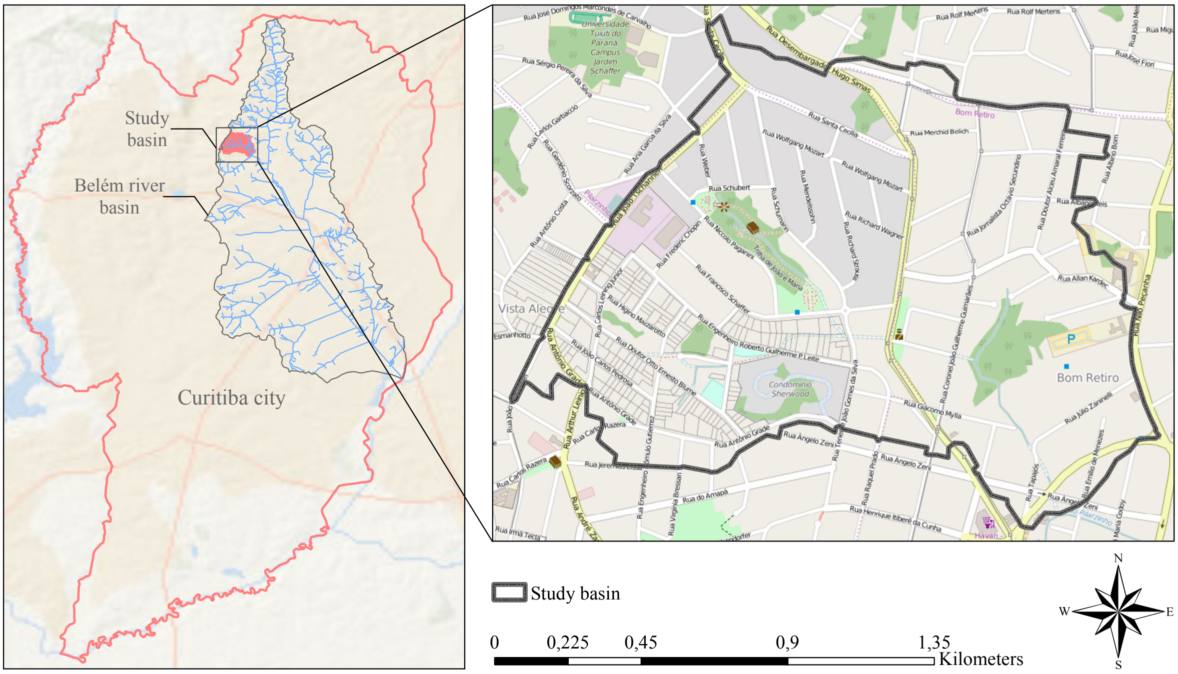
FIGURE 5.11: Lithologic subdivision of the Belém river basin

As can be seen in Figure 5.11, in the northern portion of the Belém river basin the Crystalline Complex is predominant. In the most central part of the basin, especially in the vicinity of major rivers and streams, Recent Sediments are predominant. On the other hand, the Guabirotuba Formation is predominant in east and west parts of the basin.

5.2.1.1 Selected study area

The model application was used in order to test the whole model and give directions on possible changes in the model operation. The area selection took into account that the areas had to be easily isolated from adjacent areas — i.e. it has an easily recognizable basin mouth — , easy access to information about its infrastructure, it had to have a drainage system already implemented. By taking it into account the Instituto de Pesquisa e Planejamento Urbano de Curitiba (IPPUC) chose an area for model test. The chosen area is shown in Figure 5.12.

The study area is located within the CRM in the Belém river basin. The Belém river



Source: The author with data from IPPUC and OpenStreetMaps®

FIGURE 5.12: Study area location within Curitiba city and the Belém river basin

basin has 87.85 km^2 and its main tributaries are the Ivo, Juvevê and Água Verde rivers. Aforementioned concerns in urban areas are recurring problems faced in the study area and the Belém river is currently considered as “polluted” by the IAP (IAP, 2009), the state environmental regulatory agency. In order to assess the group of sustainable drainage measures and contribute to urban sustainability, it was delimited a small residential area within the Bom Retiro, Vista Alegre, and Pilarzinho (to a lesser extent) neighborhoods. It is enclosed by the Cláudio Manoel da Costa, Nilo Peçanha, Ângelo Zeni and João Tschannerl streets and it encloses the Desembargador Hugo Simas avenue.

It is important to note that there are a lot of tasks which are independent to be done before running the UWU Model. These tasks require data collection, field survey, contact stakeholders, among others to feed the model with the initial information. To proceed the UWU Model application, it was proposed a series of steps which were summarized as follows (see also Figure 5.1):

Step 1. To obtain the input data for the model: This step was done with field survey, contacting the municipality and the water supply company to obtain the input data. Considering that it was intended to make an integrated assessment, data from the water supply system and the drainage system was obtained. The water supply system data was important because some measures related with the urban drainage could affect its — e.g. the rainwater harvesting. Information about the environment was also important when planning measures since their efficiencies depend on soil characteristics, climate, hydrology, among others. Maps showing the roads and the use and occupation of land were obtained for planning of measures. The geographic data was stored and processed in the ESRI® ArcGIS® environment. The input data are shown in section 7.1.

Step 2. To set the external factors to formulate the scenarios: The scenarios were formulated considering all the external factors — population growth, rainfall intensity, per capita income, and average annual temperature — to test the drainage module. To set the values, historical data from the Curitiba area and reported future estimations by IBGE (2013), IPCC (2007a), among others, were used. All used data are shown in section 7.2.

Step 3. To select the drainage measures: Once the urban environment had been characterized, the selection of measures was carried out considering their applicability and the available areas for their implementation. Maps were prepared showing the structures' location and suggested interventions. In this phase, it was obtained the key features for each measure which are the input data for the measures in UWU Model. The measures were first tested one by one and just after the group of measures will be formulated. Different group of measures was tested in order to assess whether they are not overlapping each other. The selection and grouping the measures are shown in section 7.4.

Step 4. To select the indicators of interest: When testing the drainage measures, the selected indicators were related with the drainage systems only to check the model outputs and whether the indicators were expressing the SuDS multiple benefits. After the first test and the group of measures formulation, an indicator of the water supply system was selected to test the whole model. All discussion concerning the indicators are presented in section 7.5.

Step 4.1. To establish the vision for each indicator: The first step was defining the planning horizon, in other words, to select how many years in the future the simulations are looking for. After that, based on the municipality data, budget and master plan, the vision value was set for the future.

Step 4.2. To establish the weight for each indicator: The weight of each indicator will be established considering the characteristics of the study area. If the area suffers from constant flooding problems, a greater weight should be assigned to this type of indicator, or if it is established that the main issue in the study area is the water pollution, a greater weight should be assigned to this type of indicator. It is important to discuss with stakeholders what is the main concern in the study area and make a priority list to set the indicators weight.

Step 5. To run the simulations: As aforementioned, many simulations have to be done to test the model. First, simulations took into account the drainage module parameters only in order to calibrated and debug the module. After, simulations considering the other model' modules will be processed.

Step 6. To evaluate the outcomes: The outcomes were evaluated using the Effectiveness Index approach. It is important to evaluate the sensitivity of the index due to the input parameters and assess how the index behaves changing the initial parameters state. Based on the simulation results, further model improvements were suggested.

6 MODEL IMPROVEMENT AND DEVELOPMENT

The model conceptualization took into account philosophies and approaches mentioned in chapter 3. The model was built by making some assumptions based on excel/VBA platform limitations, and the limitations imposed by the model itself. Once the model does not incorporate geographic information, the applied SuDS measures had to consider additional data about the area which influences a specific structure.

Notwithstanding, considering that the formulated scenarios did not consider the rainfall intensity as an external factor, the scenarios building method had to be improved. The new building scenario methodology is discussed in the section 6.2. Necessary initial input data is discussed in the section 6.3. The section 6.4 shows the main links between external factors, indicators and measures. The indicators and the sustainable drainage system measures implementation are discussed in section 6.5 and section 6.6, respectively.

The main menu's interface, built in Excel/VBA, can be seen in Appendix A, Figure A.1, by means of which it is possible to access every model's phase. The External factors and the introductory parameters input data; the formulated scenarios and the indicators selection and visioning; the group of measures selection and the results. Other information about the model can be assessed in additional information part. Moreover, it is possible to exit the UWU Model in the main menu interface.

6.1 Brief note on the adopted symbols

The adopted symbols to represent the external factors can assume three states — current, maximum and minimum — , therefore the index varies from 0 to 2 ($f = 0, \ldots 2$) the adopted notation is: the symbol which has index 0, assumes the value for the current situation in the study area. The symbol with index 1 assumes the minimum value and the symbol with index 2 assumes the maximum value stated in the external factors input data. It can be noted in Table 6.1 and Table 6.2.

Almost the same was adopted for the symbols which represent estimated parameters directly related to the indicators, but once they can assume five states the index varies from 0 to 4 ($j = 0, \ldots 4$). If the symbol has index 0, it means that the estimated value is for the current situation in the study area. If a symbol has index 1, it means that the estimated value is for the future situation represented by the scenario 1. If a symbol has index 2, it means that the estimated value is for the future situation represented by the scenario 2, and so on. For instance, the runoff coefficient variable is represented by Rv_j. The runoff coefficient estimated by the current situation is represented by Rv_0. The runoff coefficient estimated by the scenario 1 situation is represented by Rv_1. The runoff coefficient estimated by the scenario 2 situation is represented by Rv_2, and so on until the index 4.

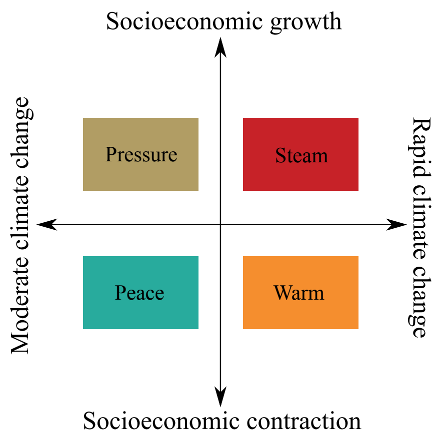
On the other hand, a specific notation was used in equations for the measures because of the number of estimated parameters for them. In measures implementation section, each symbol has two indexes. The subscript index is a numeric value which depends on the number of planned structures in the area ($m = 0, \ldots n$). On the other hand, the superscript index assumes a string value which represents the measure.

6.2 Scenarios building improvement

This section discusses main concerns in current scenarios building procedure in UWU Model and addresses the first formulated question in chapter 4: *Which and how the external factors could be used in order to formulate future scenarios to evaluate drainage measures by using the structure provided by UWU Model?*

***

The new approach of building the scenarios into the UWU Model followed the scenarios formulation in Bruggeman and Dammers (2013), as depicted in Figure 6.1.



Source: adapted from Bruggeman and Dammers (2013)

FIGURE 6.1: The scenarios formulation approach used in UWU Model to evaluate sustainable drainage measures

The UWU Model originally built the future scenarios as shown in section 3.7, Table 3.2. By using that formulation only one parameter changes by scenario. The first three scenarios (SC1, SC2, and SC3) keep two external factors — annual temperature and economic performance — unchanged or, in other words, these external factors are assumed to keep the current value. Therefore, the population growth rate is the only external factor which changes.

Then, the scenario four (SC4) keeps the current population growth rate and economic performance and it changes just the annual temperature. The last scenario (SC5) keeps the current population growth rate and medium annual temperature and it changes the economic performance. This kind of formulation was considered unrealistic and it could not represent a viable future. Nevertheless, the model did not take into account the rainfall intensity, which is a key parameter in planning drainage measures.

Considering the new approach only four scenarios, instead of five as originally in UWU Model, are built. The formulation considers that the external factors could assume four states as follow: moderate climate change or fast climate change and socioeconomic retraction or socioeconomic growth. The new input data form to the external factors in the UWU Model has the structure shown in Table 6.1.

TABLE 6.1: New UWU Model's external factors input data considering three states by external factor

External factors	**Unit**	**States**		
		Current	**Minimum**	**Maximum**
Population growth rate	$\%/year^1$	λ_0	λ_1	λ_2
Average annual temperature	$^\circ C$	T_0	T_1	T_2
Per capita income	$R\$/inh \cdot year$	EP_0	EP_1	EP_2
Design rainfall	mm/h	I_0	I_1	I_2

[1]Except the linear rate, given in $inh/year$.

The input data interface built in Excel/VBA can be seen in Appendix A, Figure A.2. In the *Urban Sprawl* frame three cells have to be filled: the current population growth rate, and the minimum and maximum future states. Moreover, to estimate the future population three models were implemented in UWU Model: the linear, the exponential and the logistic model. In the case of the logistic model selection, the population's saturation level (P_s) has to be informed as well.

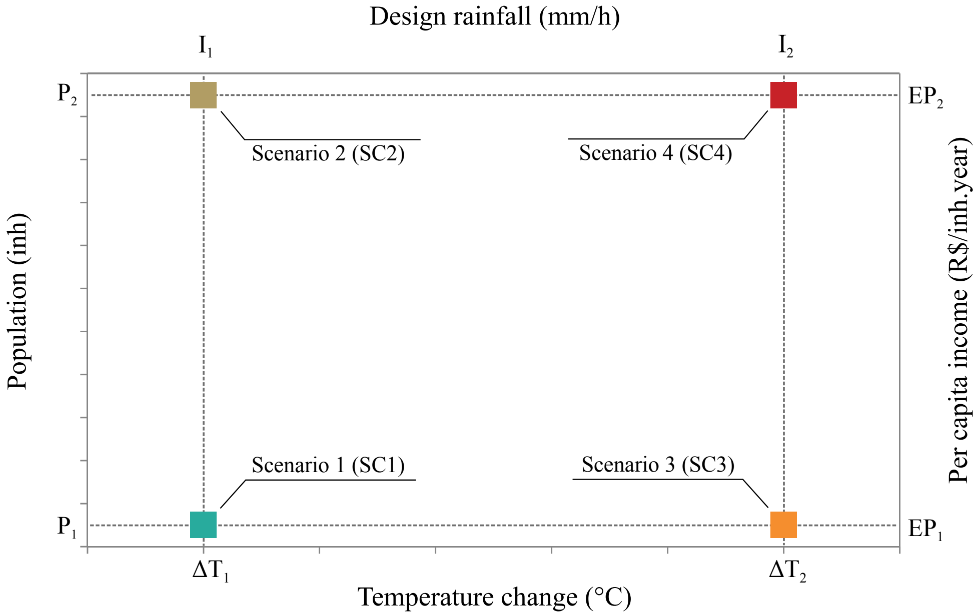
In the *Climate change* frame, the current annual temperature and two future states — minimum and maximum — , have to be informed. The same information is requested to the design rainfall. In the *Economic factors* frame, the current income per capita has to be informed as well as the two future states — minimum and maximum. After the data input, the UWU Model build the scenarios following the Table 6.2 scheme.

TABLE 6.2: Four elaborated scenarios in UWU Model by considering the four external factors and the new approach

External factors	**Scenarios**				
	Current	**SC1**	**SC2**	**SC3**	**SC4**
Population (inh)	P_0	P_1	P_2	P_1	P_2
Annual temperature ($^\circ C$)	T_0	T_1	T_1	T_2	T_2
Per capita income ($R\$/inh \cdot year$)	EP_0	EP_1	EP_2	EP_1	EP_2
Design rainfall (mm/h)	I_0	I_1	I_1	I_2	I_2

As can be seen, the SC1 uses the minimum values whilst the SC4 uses the maximum values for each external factor. Therefore, these scenarios can be seen as the more favorable and the critical scenarios, respectively. The SC2 and SC3 are intermediate scenarios. The SC2 uses the maximum values of the socioeconomic variables. In other words, it represents a scenario in which socioeconomic growth occurs, but the climate change is moderate. On the other hand, the SC3 uses the maximum values for the climate variables. Therefore, it represents a scenario in which rapid climate change occurs, although the socioeconomic experiences contraction.

In the scenarios formulation phase, other input data are necessary — in *time* frame — , as the current year (t_0) and the future year (t_1), for which the measures are being planned (see Appendix A, Figure A.2). In order to represent the formulated scenarios, a four axes graph was built in Excel. In Figure 6.2 each square in the graph represents one scenario. Each scenario has four associated values, one for each external factor state.



Source: the author based on Bruggeman and Dammers (2013) approach

FIGURE 6.2: Scenarios representation in UWU Model

It is important to note that in the Figure 6.2 the *x* axis do not show the absolute temperature values for each scenario, it shows, in fact, how many degrees the temperature increased (or decreased). All other graph axis show the absolute values for each formulated scenario. These are all scenarios in which the UWU Model performs simulations and uses to evaluate the measures effectiveness.

As mentioned before, by using the population growth rate values and the current population in the study area, the future population is estimated by the equations in Table 6.3. The estimated population is used to estimate other parameters in the model. Note that the estimated population in scenarios 1 and 3 are equal, as well as the estimated population in scenarios 2 and 4.

The current design rainfall has to be defined by the Intensity-Duration-Frequency curve (IDF-Curve) to the study area. The IDF-curve relates the rainfall intensity, the duration of the precipitation (d) and the return period (R) as follow:

$$I_0 = \frac{K \times R^a}{(d+b)^n} \tag{6.1}$$

where K, a, b and n are coefficients varying with location.

In defining the rainfall intensity by the IDF-Curve it is important to consider that the duration of the precipitation is equal to the study area concentration time, which is an assumption

TABLE 6.3: Future population estimation by scenario and selected method

Scenarios	Model		
	Linear	Exponential	Logistic[1]
Current	–	–	–
SC1	$P_1 = P_0 + \lambda_1 \times (t_1 - t_0)$	$P_1 = P_0 \times e^{\lambda_1 \times (t_1 - t_0)}$	$P_1 = \dfrac{P_s}{1 + c \times e^{\lambda_1 \times (t_1 - t_0)}}$
SC2	$P_2 = P_0 + \lambda_2 \times (t_1 - t_0)$	$P_2 = P_0 \times e^{\lambda_2 \times (t_1 - t_0)}$	$P_2 = \dfrac{P_s}{1 + c \times e^{\lambda_2 \times (t_1 - t_0)}}$
SC3	$P_1 = P_0 + \lambda_1 \times (t_1 - t_0)$	$P_1 = P_0 \times e^{\lambda_1 \times (t_1 - t_0)}$	$P_1 = \dfrac{P_s}{1 + c \times e^{\lambda_1 \times (t_1 - t_0)}}$
SC4	$P_2 = P_0 + \lambda_2 \times (t_1 - t_0)$	$P_2 = P_0 \times e^{\lambda_2 \times (t_1 - t_0)}$	$P_2 = \dfrac{P_s}{1 + c \times e^{\lambda_2 \times (t_1 - t_0)}}$

[1] $c = (P_s - P_0)/P_0$

to the Rational Method application.

6.2.1 Considerations about the UWU Model evaluation scale

As mentioned in section 3.7, Table 3.3, the UWU Model's scale varies from 0 to 5. That is because the number of formulating scenarios in the original model is equal to five and the Effectiveness Index equation. Once there are just four formulated scenarios in the new formulation approach, the *EI* will vary from 0 to 4. The new ranges of variation and classifications are shown in Table 6.4.

TABLE 6.4: UWU Model's Effectiveness Index scale considering four formulated scenarios

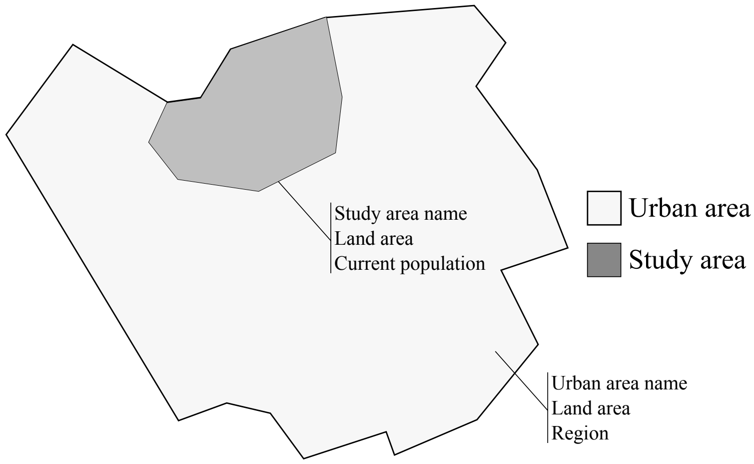
Range of variation	Categories
3.70 – 4.00	Excellent
2.90 – 3.60	Good
2.10 – 2.80	Reasonable
1.30 – 2.00	Insufficient
0.00 – 1.20	Poor

This formulation considered the same variation ranges of the aforementioned model's scale — i.e. the new variation ranges are proportional to the scale in Table 3.3.

6.3 Initial input data

After the scenarios formulation phase, the introductory data are requested to the UWU Model simulations. It is requested informative data about the urban area, despite it is not used in any calculation. The requested information is: urban area name, the land area and the region.

Hereafter, the input data from study area is requested. The requested information is: name of the area, the land area of the study area (A) and the current population living in the study area (P_0). The input data form can be seen in Appendix A, Figure A.3. The Figure 6.3 shows a hypothetical urban area and a study area within it.



Source: the author

FIGURE 6.3: Input data approach in UWU Model

To perform some simulations, environmental data are requested as well. In regards to the runoff water quality, it is requested the average pollutant concentrations ($L_{0,\,l}$) in the study area. The UWU Model assumes value concentrations reported in Fuchs, Brombach and Weis (2004), but it is possible to change such values if there are reported values for the study area.

The requested data is: the total suspended solids average concentration ($L_{0,\,TSS}$), the biochemical oxygen demand average concentration ($L_{0,\,BOD}$), the total phosphorus average concentration ($L_{0,\,TP}$), and the total Kjeldahl nitrogen average concentration ($L_{0,\,TKN}$). See Appendix A, Figure A.4.

Another important input data is the soil permeability coefficient (k) in the study area. This information is used in steps in order to estimate infiltration capacity for some measures. The input data interface can be seen in Appendix A, Figure A.3, in *Physical environment data* frame.

6.4 Linking UWU Model components

Once the external factors and the scenario formulation method were established, seven indicators were selected — water supply system coverage ($Cwss_i$), maximum flowrate in the critical sewer ($Qmax_j$), equivalent permeable area ($PAeq_j$), BOD specific loading rate ($WE_{j,\,BOD}$), TSS specific loading rate ($WE_{j,\,TSS}$), TP specific loading rate ($WE_{j,\,TP}$), and TKN specific loading rate ($WE_{j,\,TKN}$) — and five sustainable drainage measures which were implemented into the tool. To do so, it was initially determined the possible relationships among component as can be seen in Figure 6.4.

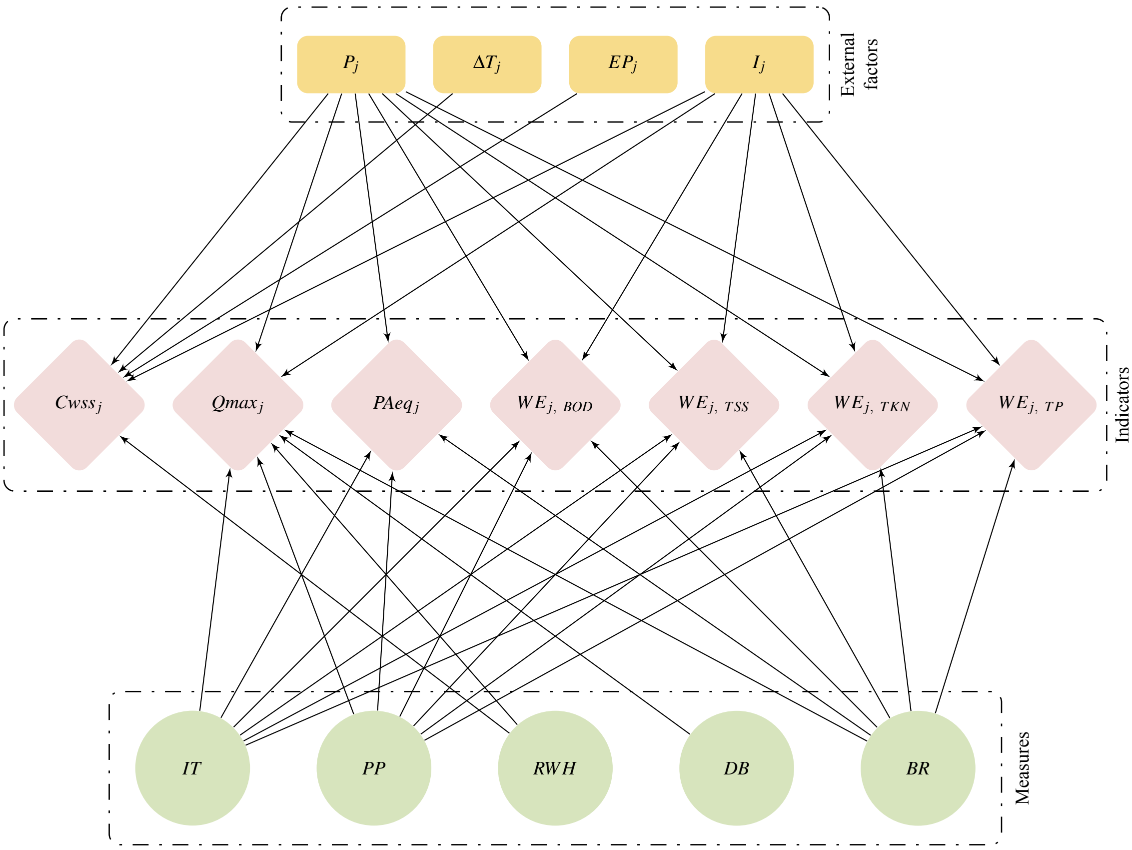


FIGURE 6.4: Established links between external factors, indicators, and urban drainage measures

The population growth can be directly or indirectly related to every selected indicator. On the other hand, the average annual temperature and the per capita income were related to the water supply system indicator only. Despite it could be argued that the temperature could affect the flooding flowrate, the option was to reflect any change by the design rainfall because changes in the last one are related to temperature changes.

Finally, the design rainfall is directly related to the flooding flowrate and the pollutant loads — considering that a higher precipitation will produce a higher runoff flow and a greater pollutant transport capacity, consequently.

On the other hand, the indicators values can be changed by the measures implementation. Taking into account the main characteristics of each selected measure (see section 3.3) it was established that the infiltration devices could reduce the flooding flowrate indicator and consequently reduce the pollutant loads. At the same time, if the infiltration device is implemented on a previously impermeabilized area, it can increase the permeable equivalent area indicator.

The detention basin was just considered as a flooding control measure, despite it could contribute in reducing the pollutant loads. Moreover, the rainwater harvesting for on-site use, could contribute in reducing the flooding flowrate indicator and increase the water supply system indicator.

6.5 Drainage indicators development

This section discusses indicators implementation and their associated vision and weight values and addresses the second formulated question in chapter 4: *Which indicators could be used to assess sustainable drainage systems additional benefits by using the structure provided by UWU Model?*

***

As can be seen in section 3.4 the sustainable drainage systems can bring a set of multiple benefits to the urban areas. By considering the UWU Model structure these benefits have to be *translated* into indicators in order to evaluate the drainage measures. After selecting an indicator, there are two associated values to it into the model. The *vision* — which is an abstraction about a desired future — , and the *weight* — which represents the relative importance for a given indicator. A brief recommendation about the vision definition for each indicator is performed in the specific subsection, whilst necessary.

6.5.1 Maximum flowrate in the critical sewer

In order to evaluate the maximum flowrate in the critical sewer ($Qmax_j$), it is important to recognize some limitations in the model. The runoff estimation is made by using the Rational Method, which means that the evaluation have to be made in a micro drainage context. Nonetheless, it is not possible to evaluate the drainage pipes one by one once the UWU Model does not intend to simulate the drainage network.

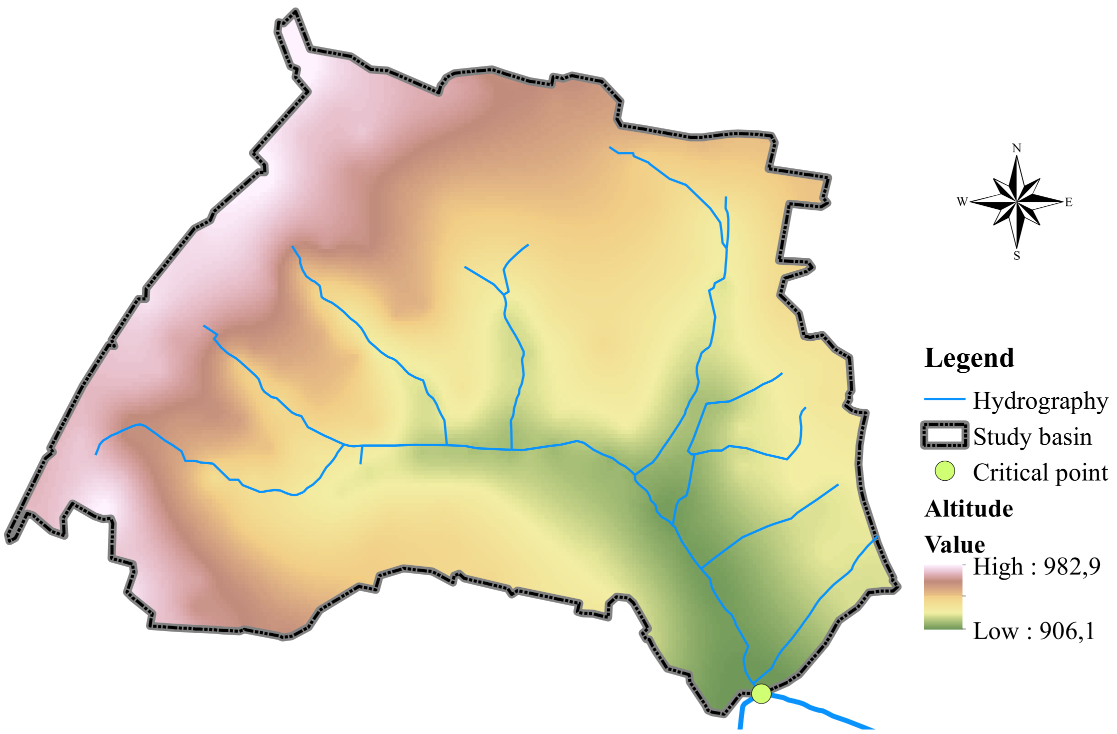
The vision has to be set for the critical point in the study area. It is considered a critical point the lowest point in a delimited area or drainage system, in other words, the critical point has to be located at the basin's mouth. The Figure 6.5 shows an example of a study area in which it is intended to evaluate flooding issues. Considering that the study area has a traditional drainage system already, the critical point is the one indicated in the figure.

To set the vision value, information about the implemented system are requested. For instance, the vision value can be set as the current system capacity at the critical point (or sewer). Another possibility is to consider if there are any planned intervention at the critical point and set the vision as the new sewer planned capacity. Despite these suggestions in defining the vision value, it is important to note that these definitions have to be done before the UWU Model application by using a stakeholder group discussion.

To estimate the indicator values the first step is to estimate the runoff coefficient (Rv_j) in the study area. To do so, it was proposed to use a series of empirical equations. Campana and Tucci (1994) establish an equation which relates the population density (D_j) and the impermeable area (IA_j) in an urban basin. Therefore, the initial data are used in order to estimate the population density as follow:

$$D_j = \frac{P_j}{A \times 100} \tag{6.2}$$

where D_j is the population density in inh/ha.



Source: the author with data from IPPUC

FIGURE 6.5: Example of critical point in a study area

Then, using the estimated population density the impermeable area can be estimated by using the Campana and Tucci (1994) equation:

$$IA_j = 0.49 \times D_j \tag{6.3}$$

to $D_j \leq 120\ inh/ha$

Equation 6.3 is a linear generalization from Figure 6.6.

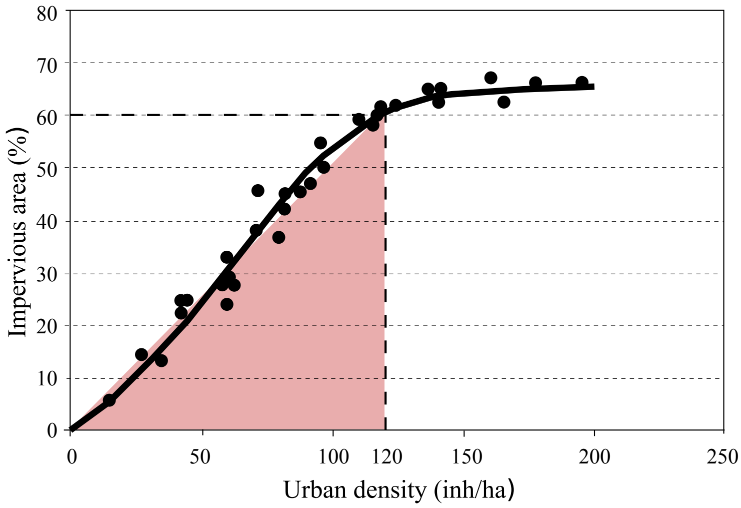
It is important to note that this equation was estimated based on Porto Alegre, São Paulo and Curitiba data. To the Porto Alegre city, the updated equation is (FILHO; TUCCI, 2012):

$$IA_j = 13 + 0.57 \times D_j \tag{6.4}$$

to $D_j \leq 100\ inh/ha$

By default, the UWU Model uses Equation 6.4 to estimate the impermeable area. The next step is to estimate the runoff coefficient itself. To perform studies in the Curitiba Metropolitan Region, the SUDERHSA (2002) proposed relation is used. Evidently, regressions based on local data are preferred and it is possible to change the equation coefficients in order to perform studies in other areas.

$$Rv_j = 0.15 + 0.8 \times IA_j \tag{6.5}$$



Source: Campana and Tucci (1994)

FIGURE 6.6: Impervious area and urban density relation based on data from São Paulo, Curitiba and Porto Alegre (Brazil)

where $0 \leq IA_j \leq 1$

Once the runoff coefficient was estimated, it is possible to calculate the runoff flow by using the Rational Method as follows:

$$Qmax_j = 0.2778 \times Rv_j \times I_j \times A \tag{6.6}$$

with $Qmax_j$ given in m^3/s.

Future runoff flow estimations

To estimate the runoff flow by scenario, the above set of equations are used. The model assumes that, once the population is growing in the study area, the runoff coefficient value will change in the future due to the urbanization process. As a consequence, the runoff flow will change as well. The parameters which changes the runoff flow future value are the rainfall intensity and the population.

The rainfall intensity parameter is directly given by the scenarios formulation phase. The future population is estimated based on the current population, the population growth rate in each scenario and on the selected method of estimation (see Table 6.3). After the population in each scenario has been estimated, the next steps are to estimate the population density, the impermeable area, the runoff coefficient, and the runoff flow in each scenario using the aforementioned equations. The equations by scenarios are shown in Table 6.5:

Once the rainfall intensity is estimated by considering that the rainfall duration is equal to the time of concentration in the study area, the Q_i values are supposed to be measured in the defined critical point.

TABLE 6.5: Future impermeable area, runoff coefficient, and runoff flow estimations by scenario

Scenarios	Parameters			
	Population density (inh/ha)	Impermeable area (%)	Runoff coefficient	Runoff flow (m^3/s)
Current	$D_0 = \frac{P_0}{A \times 100}$	$IA_0 = 13 + 0.57D_0$	$Rv_0 = 0.15 + 0.8\ IA_0$	$Q_0 = 0.2778 \times Rv_0 \times I_0 \times A$
SC1	$D_1 = \frac{P_1}{A \times 100}$	$IA_1 = 13 + 0.57D_1$	$Rv_1 = 0.15 + 0.8\ IA_1$	$Q_1 = 0.2778 \times Rv_1 \times I_1 \times A$
SC2	$D_2 = \frac{P_2}{A \times 100}$	$IA_2 = 13 + 0.57D_2$	$Rv_2 = 0.15 + 0.8\ IA_2$	$Q_2 = 0.2778 \times Rv_2 \times I_1 \times A$
SC3	$D_3 = \frac{P_3}{A \times 100}$	$IA_3 = 13 + 0.57D_3$	$Rv_3 = 0.15 + 0.8\ IA_3$	$Q_3 = 0.2778 \times Rv_3 \times I_2 \times A$
SC4	$D_4 = \frac{P_4}{A \times 100}$	$IA_4 = 13 + 0.57D_4$	$Rv_4 = 0.15 + 0.8\ IA_4$	$Q_4 = 0.2778 \times Rv_4 \times I_2 \times A$

6.5.2 Equivalent permeable area

The equivalent permeable area ($PAeq_j$) is a sum of the natural and unnatural permeable areas in an urban basin. By using the estimated impermeable area (IA_j) — see Table 6.5 — , it is possible to estimate the permeable area (PA_j) as follow:

$$PA_j = 100 - IA_j \tag{6.7}$$

Then, the equivalent permeable area can be estimated by adding the permeable surfaces in the study area and the areas of the measures which can contribute in infiltrating water into the soil and/or measures that promotes water storage. The equivalent permeable area is estimated by:

$$PAeq_j = PA_j + \sum_{m=1}^{n} PA_m \tag{6.8}$$

where PA_m represents the permeable area for each planned measure. Importantly, when planning storage measures permeable area is considered the inflow area to a measure.

Future equivalent permeable area

It is important to note that the component $\sum_{m=1}^{n} PA_m$ of the above equation is equal to zero in the first estimations because there are no implemented measures when starting the simulations. In summary, the estimations by scenarios can be done by the equations in Table 6.6.

TABLE 6.6: Equivalent permeable area estimation by scenario

Scenarios	Parameters			
	Population density (inh/ha)	**Impermeable area (%)**	**Permeable area (%)**	**Equivalent permeable area (%)**
Current	$D_0 = \frac{P_0}{A \times 100}$	$IA_0 = 13 + 0.57D_0$	$PA_0 = 100 - IA_0$	$PAeq_0 = PA_0$
SC1	$D_1 = \frac{P_1}{A \times 100}$	$IA_1 = 13 + 0.57D_1$	$PA_1 = 100 - IA_1$	$PAeq_1 = PA_1$
SC2	$D_2 = \frac{P_2}{A \times 100}$	$IA_2 = 13 + 0.57D_2$	$PA_2 = 100 - IA_2$	$PAeq_2 = PA_2$
SC3	$D_3 = \frac{P_3}{A \times 100}$	$IA_3 = 13 + 0.57D_3$	$PA_3 = 100 - IA_3$	$PAeq_3 = PA_3$
SC4	$D_4 = \frac{P_4}{A \times 100}$	$IA_4 = 13 + 0.57D_4$	$PA_4 = 100 - IA_4$	$PAeq_4 = PA_4$

6.5.3 Pollutant loading rate in control point

In order to estimate the pollutant loading rate from the study area the Schueler equation (SCHUELER, 1987) is used, which is a simple method to estimate urban stormwater pollutant loads:

$$W_{j,l} = 0.01 \times R_j \times Rf \times Rv_j \times L_l \times A \tag{6.9}$$

where $W_{j,l}$ is the pollutant loading rate given in kg; R_j is the precipitation given in mm; Rf is the fraction of the rainfall that produces runoff — adopted as been equals to 1 once the R_j value is for a single event; and L_l is the pollutant concentration ($mg\ L^{-1}$).

The precipitation (R_j) is estimated by multiplying the design rainfall (I_j) by the duration of the precipitation (d), which must be equal to the time of concentration (tc) of the drainage area:

$$R_j = I_j \times \frac{d}{60} \tag{6.10}$$

The pollutant concentration values are taken from the input data (see section 6.3). Thereafter, it is possible to estimate total suspended solids, biochemical oxygen demand, total phosphorus and total nitrogen loads.

Future pollutant loads estimations

To estimate the pollutant loads by scenario, the same equations are used. However, by considering the Equation 6.6 and Equation 6.10, the Schueler equation can be rewritten, after adjusting the units, as:

$$W_{j,\,l} = 0.06 \times Q_j \times d \times L_l \tag{6.11}$$

with $W_{j,\,l}$ given in kg, Q_j in m^3/s, d in min, and L_l in $mg\ L^{-1}$.

After estimating the pollutant loading rates, the specific pollutant loading rates ($WE_{j,\,l}$) are estimated by the following equation:

$$WE_{j,l} = \frac{W_{j,l}}{A} \tag{6.12}$$

with $WE_{j,l}$ given in kg/km^2.

Table 6.7 and Table 6.8 summarize the equations used in estimating the future pollutant loads and future specific pollutant loads by scenarios, respectively.

TABLE 6.7: Future pollutant loads estimation by event in each scenario

Scenarios	Parameters			
	Total suspended solids (kg)	**Biochemical oxygen demand (kg)**	**Total Kjeldahl nitrogen (kg)**	**Total phosphorus (kg)**
Current	$W_{0,\ TSS} = 0.06 \times Q_0 \times d \times L_{TSS}$	$W_{0,\ BOD} = 0.06 \times Q_0 \times d \times L_{BOD}$	$W_{0,\ TKN} = 0.06 \times Q_0 \times d \times L_{TN}$	$W_{0,\ TP} = 0.06 \times Q_0 \times d \times L_{TP}$
SC1	$W_{1,\ TSS} = 0.06 \times Q_1 \times d \times L_{TSS}$	$W_{1,\ BOD} = 0.06 \times Q_1 \times d \times L_{BOD}$	$W_{1,\ TKN} = 0.06 \times Q_1 \times d \times L_{TN}$	$W_{1,\ TP} = 0.06 \times Q_1 \times d \times L_{TP}$
SC2	$W_{2,\ TSS} = 0.06 \times Q_2 \times d \times L_{TSS}$	$W_{2,\ BOD} = 0.06 \times Q_2 \times d \times L_{BOD}$	$W_{2,\ TKN} = 0.06 \times Q_2 \times d \times L_{TN}$	$W_{2,\ TP} = 0.06 \times Q_2 \times d \times L_{TP}$
SC3	$W_{3,\ TSS} = 0.06 \times Q_3 \times d \times L_{TSS}$	$W_{3,\ BOD} = 0.06 \times Q_3 \times d \times L_{BOD}$	$W_{3,\ TKN} = 0.06 \times Q_3 \times d \times L_{TN}$	$W_{3,\ TP} = 0.06 \times Q_3 \times d \times L_{TP}$
SC4	$W_{4,\ TSS} = 0.06 \times Q_4 \times d \times L_{TSS}$	$W_{4,\ BOD} = 0.06 \times Q_4 \times d \times L_{BOD}$	$W_{4,\ TKN} = 0.06 \times Q_4 \times d \times L_{TN}$	$W_{4,\ TP} = 0.06 \times Q_4 \times d \times L_{TP}$

TABLE 6.8: Future specific pollutant loads estimation by event in each scenario

Scenarios	Parameters			
	Total suspended solids (kg/km^2)	**Biochemical oxygen demand (kg/km^2)**	**Total Kjeldahl nitrogen (kg/km^2)**	**Total phosphorus (kg/km^2)**
Current	$WE_{0,\ TSS} = \frac{W_{0,\ TSS}}{A}$	$WE_{0,\ BOD} = \frac{W_{0,\ BOD}}{A}$	$WE_{0,\ TKN} = \frac{W_{0,\ TN}}{A}$	$WE_{0,\ TP} = \frac{W_{0,\ TP}}{A}$
SC1	$WE_{1,\ TSS} = \frac{W_{1,\ TSS}}{A}$	$WE_{1,\ BOD} = \frac{W_{1,\ BOD}}{A}$	$WE_{1,\ TKN} = \frac{W_{1,\ TN}}{A}$	$WE_{1,\ TP} = \frac{W_{1,\ TP}}{A}$
SC2	$WE_{2,\ TSS} = \frac{W_{2,\ TSS}}{A}$	$WE_{2,\ BOD} = \frac{W_{2,\ BOD}}{A}$	$WE_{2,\ TKN} = \frac{W_{2,\ TN}}{A}$	$WE_{2,\ TP} = \frac{W_{2,\ TP}}{A}$
SC3	$WE_{3,\ TSS} = \frac{W_{3,\ TSS}}{A}$	$WE_{3,\ BOD} = \frac{W_{3,\ BOD}}{A}$	$WE_{3,\ TKN} = \frac{W_{3,\ TN}}{A}$	$WE_{3,\ TP} = \frac{W_{3,\ TP}}{A}$
SC4	$WE_{4,\ TSS} = \frac{W_{4,\ TSS}}{A}$	$WE_{4,\ BOD} = \frac{W_{4,\ BOD}}{A}$	$WE_{4,\ TKN} = \frac{W_{4,\ TN}}{A}$	$WE_{4,\ TP} = \frac{W_{4,\ TP}}{A}$

6.5.4 Water supply system coverage

To take into account drainage measures which can contribute to water savings in buildings, it is proposed to link the drainage module with the water supply system module by means of the water consumption parametrization by appliance. Dias, Martinez and Libânio (2010) have estimated ten equations by means of which it is possible to estimate the water consumption based on the per capita income. Considering the ten equations presented by the authors, the following is used by default in the model:

$$qe_0 = 0.0943\ EP_0 + 88.071 \tag{6.13}$$

where qe_0 is the current per capita water consumption ($L/inh \cdot day$) and EP_0 is the current per capita income in study area ($R\$/inh \cdot year$).

Once it was estimated the building effective drinkable water per capita consumption the Table 6.9 can be built.

TABLE 6.9: Building medium water consumption per appliance

Appliances	**Consumed specific flowrate (L/s)**	**Use frequency ($1/inh \cdot day$)**	**Use duration (min)**	**Consumed water (L/day)**
Handbasin	a_{11}	a_{12}	a_{13}	$a_{14} = (a_{11} \times a_{12} \times a_{13}) \times 60$
Toilet (Box)[1]	a_{21}	a_{22}	–	$a_{24} = a_{21} \times a_{22}$
Toilet (Valve)	a_{31}	a_{32}	a_{33}	$a_{34} = (a_{31} \times a_{32} \times a_{33}) \times 60$
Shower	a_{41}	a_{42}	a_{43}	$a_{44} = (a_{41} \times a_{42} \times a_{43}) \times 60$
Washing Machine[2, 3]	a_{51}	a_{52}	–	$a_{54} = a_{51} \times a_{52}$
Kitchen Sink	a_{61}	a_{62}	a_{63}	$a_{64} = (a_{61} \times a_{62} \times a_{63}) \times 60$
Garden	a_{71}	a_{72}	a_{73}	$a_{74} = (a_{71} \times a_{72} \times a_{73}) \times 60$
Outside	a_{81}	a_{82}	a_{83}	$a_{84} = (a_{81} \times a_{82} \times a_{83}) \times 60$
Total				$\sum_{i=1}^{8} a_{i4}$

[1] consumed volume per flush (L/flush)
[2] consumed volume per wash (L/wash)
[3] uses per week in a building

The second column is a fixed value depending on the appliance characteristics and manufacturer. To fill the third and fourth columns some estimation and/or reported literature values are needed. The last column is calculated by the displayed equations. It is important to note that the sum of the last column has to be a value equals to the estimated building effective drinkable water per capita consumption (Equation 6.13).

In the original model the Table 6.9 has to be filled manually until the sum of the consumed water is equal to the estimated building effective drinkable water per capita consumption, which is a time consuming procedure. A suggested improvement is to consider the uncertainties in estimating the usage duration time of a specific appliance in a building. Then, by inserting a range of values to it — a minimum and a maximum value — , the issue is to solve the following:

$$\sum_{i=1}^{8} a_{i4} = qe_0$$

subject to:

$$\begin{aligned}
&x_{min} \leq a_{13} \leq x_{max} \\
&a_{23} = 0 \\
&y_{min} \leq a_{33} \leq y_{max} \\
&z_{min} \leq a_{43} \leq z_{max} \\
&a_{53} = 0 \\
&k_{min} \leq a_{63} \leq k_{max} \\
&w_{min} \leq a_{73} \leq w_{max} \\
&u_{min} \leq a_{83} \leq u_{max}
\end{aligned}$$

where x, y, z, k, w, and u, represent the input use duration values for handbasin, toilet (valve), shower, kitchen sink, garden and outside tap, respectively. The a_{23} and a_{53} values are set equal to zero because the use duration does not matter once there are a fixed value for each os them.

In order to solve the above statements a VBA code was written which uses the Solver tool in Excel environment. Water conservation measures into the buildings alters the Table 6.9 values and consequently the water supply indicators. The input data form can be seen in Appendix A, Figure A.6.

Therefore, by using the current per capita income value, it is estimated the current per capita water consumption. Current total per capita water consumption is estimated by:

$$qt_0 = \frac{qe_0}{(1 - Id_0)} \tag{6.14}$$

Current area water consumption ($Qwss_0$) is estimated by:

$$Qwss_0 = \frac{3qt_0 \times P_0}{100} \tag{6.15}$$

where $Qwss_j$ is the area water consumption in scenario j ($m^3/month$).

The current water supply system coverage indicator ($Cwss_0$) is an input data based on the Water Supply Company data.

Future water consumption estimations

The future water consumptions are estimated based on the assumptions that the water consumption changes by changing the medium temperature and the per capita income. Therefore, it is used the same relation previously used — from Dias, Martinez and Libânio (2010) —

but taking into account the temperature change.

By using data from the city of Phoenix in Arizona, Balling and Gober (2007) determined that by increasing 1 $^{\circ}C$ the annual temperature the water consumption increases by 60.76 $L/inh \cdot day$. This relation was estimated by simple regression. Other estimations (STAATS, 2014) determined that the water consumption could increase by 34 $L/inh \cdot day$ by increasing 1 $^{\circ}C$ in the average daily temperatures during July and August months. New York city data showed that when the temperature is above 25 $^{\circ}C$ the per capita increases by 11 $L/inh \cdot day$ (PROTOPAPAS; KATCHAMART; PLATONOVA, 2000). To take into account the temperature change it was generalized the (STAATS, 2014) data. Therefore, the future per capita water consumptions are estimated by the following equation:

$$qe_j = (0.0943\, EP_j + 88.071) + 5.6\Delta T_j \tag{6.16}$$

where qe_j is the per capita water consumption in scenario j ($L/inh \cdot day$), EP_j is the per capita income in the study area in scenario j ($R\$/inh \cdot year$) and ΔT_j is the change in average annual temperature in scenario j ($^{\circ}C$).

This is the standard equation by which the UWU Model estimates the future water per capita consumption influenced by the per capita income and temperature changes. However, it is possible to change the parameters values if there are available data from the study area. By using the estimated qe_j the building total drinkable water per capita consumption can be estimated by:

$$qt_j = \frac{qe_j}{(1 - Id_j)} \tag{6.17}$$

By knowing the current and future scenarios population the area water consumption was estimated by:

$$Qwss_j = \frac{3qt_j \times P_j}{100} \tag{6.18}$$

where $Qwss_j$ is the area water consumption in scenario j ($m^3/month$).

The future water supply system coverage indicator ($Cwss_i$) is estimated considering the current indicator value and the expected future consumption:

$$Cwss_j = \frac{Cwss_0 \times Qwss_0}{Qwss_j} \tag{6.19}$$

The water supply system coverage indicator estimation by scenarios can be done by using the equations in Table 6.10.

TABLE 6.10: Future per capita water consumption by scenarios and future water water supply coverage indicator

Scenarios	**Parameters**			
	Water per capita consumption ($L/inh \cdot day$)	**Total water per capita consumption** ($L/inh \cdot day$)	**Water consumption** ($m^3/month$)	**Water supply coverage** (%)
Current	$qe_0 = 0.0943\ EP_0 + 88.071$	$qt_0 = \frac{qe_0}{(1-Id)}$	$Qwss_0 = \frac{3qt_0 \times P_0}{100}$	*set*
SC1	$qe_1 = (0.0943\ EP_1 + 88.071) + 5.6\ \Delta T_1$	$qt_1 = \frac{qe_1}{(1-Id)}$	$Qwss_1 = \frac{3qt_1 \times P_1}{100}$	$Cwss_1 = \frac{Cwss_0 \times Qwss_0}{Qwss_1}$
SC2	$qe_2 = (0.0943\ EP_2 + 88.071) + 5.6\ \Delta T_1$	$qt_2 = \frac{qe_2}{(1-Id)}$	$Qwss_2 = \frac{3qt_2 \times P_2}{100}$	$Cwss_2 = \frac{Cwss_0 \times Qwss_0}{Qwss_2}$
SC3	$qe_3 = (0.0943\ EP_1 + 88.071) + 5.6\ \Delta T_2$	$qt_3 = \frac{qe_3}{(1-Id)}$	$Qwss_3 = \frac{3qt_3 \times P_3}{100}$	$Cwss_3 = \frac{Cwss_0 \times Qwss_0}{Qwss_3}$
SC4	$qe_4 = (0.0943\ EP_2 + 88.071) + 5.6\ \Delta T_2$	$qt_4 = \frac{qe_4}{(1-Id)}$	$Qwss_4 = \frac{3qt_4 \times P_4}{100}$	$Cwss_4 = \frac{Cwss_0 \times Qwss_0}{Qwss_4}$

6.6 Sustainable Drainage measures implementation

This section discusses sustainable drainage measures implementation by using their main associated features and addresses the third formulated question in chapter 4: *What are the interfaces between urban drainage measures and other urban water systems how one can influence each other?*

***

Once the UWU Model intends to evaluate planned sustainable drainage measures to a study area, measures location and design have to be done before running it. An example of the structures design and location, as well as an evaluation of the group of measures, will be provided in the chapter 7.

After pre-designing the measures, it is necessary to provide key information about them in order to assess their effectiveness by using the UWU Model approach. As the measures have different characteristics, the key information varies depending on the type of structure and their operating mode. Once the Excel/VBA version of the UWU Model has limitation once it does not incorporate geographic data and it does not use any king of database structure, there are limitations in how many measures and in the how the key information for each planned measure is provided.

The main interface for SuDS selection can be seen in Appendix A, Figure A.7. Next subsections present the necessary key parameter for each measure and how the UWU Model uses these parameters in order to change the indicator values in each scenario and in the last instance, evaluates the measures effectiveness.

The initial drainage measures implemented in UWU Model were focused on infiltration devices which can contribute to restoring pre-urbanization hydrologic cycle. However, future developments could consider more detention measures. Note that despite the soil infiltration rates in Curitiba are low (see Table 5.2), the Crystalline complex lithology has enough infiltration capacity for measures implementation. On the other hand, the Guabirotuba formation, mainly on claystones/siltstones sediments area, infiltration devices may not be efficient, as widely argued by Fendrich (2002).

6.6.1 Infiltration trenches

To evaluate the effectiveness in using the infiltration trenches, the necessary input data are the quantity of infiltration trenches planned for the study area, their dimensions, and the contributing area (Ac_m^{IT}) to each structure. By calling L_m^{IT} the length of the infiltration trench, W_m^{IT} its width, and D_m^{IT} its depth, the infiltration area for each structure (A_m^{IT}) can be calculated by

$$A_m^{IT} = [(W_m^{IT} \times D_m^{IT}) \times 2] + [(L_m^{IT} \times D_m^{IT}) \times 2] + (W_m^{IT} \times L_m^{IT}) \tag{6.20}$$

The infiltration capacity of the trenches (Qs_m^{IT}) is calculated by using the following equation:

$$Qs_m^{IT} = \alpha \times k \times A_m^{IT} \tag{6.21}$$

where α is the factor of safety, which have to take into account the clogging effect, and k is the soil permeability coefficient.

Next step is to estimate the input flooding flowrate in the infiltration trench (Qi_m^{IT}), which can be done by considering the contribution area, the street runoff coefficient and the design rainfall:

$$Qi_m^{IT} = 0.2778 \times Rvp_0 \times I_j \times Ac_m^{IT} \tag{6.22}$$

Then, it is possible to verify whether an overflow (Qf_m^{IT}) occurs or not by using the following equation:

$$Qf_m^{IT} = Qi_m^{IT} - Qs_m^{IT} \tag{6.23}$$

If the Qs_m^{IT} is greater than Qi_m^{IT} there is not overflow in the infiltration trench — i.e. all generated influent area runoff is infiltrated and therefore $Qf_m^{IT} = 0$. On the other hand, if Qi_m^{IT} is greater than Qs_m^{IT}, there is overflow. The impact of the infiltration trenches implementation in the flooding flowrate in sewer indicator is estimated by

$$Qs_{Total}^{IT} = \sum_{m=1}^{n} Qs_m^{IT} - \sum_{m=1}^{n} Qf_m^{IT} \tag{6.24}$$

6.6.2 Permeable pavements

It is important to note that there are three possibilities in building a permeable pavement structures according to Woods-Ballard et al. (2007). The implemented system in UWU Model is the *type A* system. It considers that the sub-base have sufficient permeability to infiltrate all the design rainfall — all runoff is dealt with on site. By knowing this, almost the same approach used to estimate the infiltration capacity to the infiltration trenches is used to estimate the permeable pavements capacity. The necessary input data are the quantity of permeable pavements planned in the study area, their dimensions, and the contributing area (Ac_m^{PP}) to each structure.

By calling L_m^{PP} the length of the permeable pavement, and W_m^{PP} its width, the infiltration area for each structure (A_m^{PP}) can be calculated by:

$$A_m^{PP} = [(W_m^{PP} \times D_m^{PP}) \times 2] + [(L_m^{PP} \times D_m^{PP}) \times 2] + (W_m^{PP} \times L_m^{PP}) \tag{6.25}$$

Once the permeable pavement surface infiltration rate should be significantly greater than the design rainfall intensity (WOODS-BALLARD et al., 2007), it is not considered in the UWU Model. Then, the infiltration rate into the soil is the only parameter which has to be taken into account. Therefore, the infiltration capacity of the permeable pavements (Qs_m^{PP}) is calculated by using the following equation:

$$Qs_m^{PP} = \alpha \times k \times A_{TOT}^{PP} \tag{6.26}$$

where α is the factor of safety, which have to take into account the clogging effect, and k is the soil permeability coefficient.

Then, following the same approach used in the infiltration trenches, next step is to estimate the input flooding flowrate in the permeable pavement (Qi_m^{PP}), which can be done by considering the contribution area, the street runoff coefficient and the design rainfall:

$$Qi_m^{PP} = 0.2778 \times Rvp_0 \times I_j \times Ac_m^{PP} \tag{6.27}$$

Then, it is possible to verify whether an overflow (Qf_m^{PP}) occurs or not by using the following equation:

$$Qf_m^{PP} = Qi_m^{PP} - Qs_m^{PP} \tag{6.28}$$

If the Qs_m^{PP} is greater than Qi_m^{PP} there is not overflow in the permeable pavement, therefore $Qf_m^{PP} = 0$. On the other hand, if Qi_m^{PP} is greater than Qs_m^{PP}, there is overflow. The impact of the permeable pavements implementation on the flooding flowrate in sewer indicator is estimated by

$$Qs_{Total}^{PP} = \sum_{m=1}^{n} Qs_m^{PP} - \sum_{m=1}^{n} Qf_m^{PP} \tag{6.29}$$

The *type B* system, — consider that the sub-base have some permeability but it is not enough to infiltrate all generated runoff, and *type C* system — consider that there is no infiltration into the soil — can be further implemented in de UWU Model.

6.6.3 Rainwater harvesting

To evaluate the effectiveness in using the rainwater harvesting devices, the necessary input data are the average harvesting area per building (A_{AV}^{RWH}), average roofs runoff coefficient (Rv_{AV}^{RWH}), the measure degree of acceptance in the area (Da_m), and the average people per building (P_{av}) information. Then, it is possible to estimate the total harvesting area (A_{TOT}^{RWH}) by doing:

$$A_{TOT}^{RWH} = A_{AV}^{RWH} \times \frac{P_j}{P_{av}} \times Da_m \tag{6.30}$$

By using data from Australia, Coombes and Kuczera (2003) estimates that the runoff peak reduction can vary from 40% to 45%. On the other hand, another Australian study performed by Hardy, Coombes and Kuczera (2004) showed that the reduction can vary from 60% to 90%. Estimates performed in Canada by Farahbakhsh, Despins and Leidl (2009) and TRCA (2010) demonstrates reductions by 89% and varying from 23% to 46%, respectively. All studies considered a supply of water for both indoor and outdoor uses.

To estimate the peak flow reduction by using the rainwater harvesting devices, the option was to fix the reduction value in 40%, from Coombes and Kuczera (2003) estimations. Then, it is possible to estimate the runoff flow reduction (Q_s^{RWH}) by using the following equation:

$$Qs_{Total}^{RWH} = 2.78 \times 10^{-7}[(Rv_{AV}^{RWH} \times I_j \times A_{TOT}^{RWH}) \times 0.4] \tag{6.31}$$

The rainwater can be used in a building for non-potable purposes. In this sense it is possible to use the rainwater in order to supply the toilet devices and to garden irrigation. On the other hand, it is also possible to consider the measure without any non-potable use in the building. In this case, it does not contribute to water savings in buildings.

By considering that the rainwater will be used in the building, it is important to verify whether it is possible to supply the toilet and garden appliances by just using the rain water or not. Once this condition is satisfied, the components a_{24} — or a_{34} — a_{74}, and a_{84} can be considered as being equal to zero. Therefore, the Table 6.9 can be built as follows:

TABLE 6.11: Building medium water consumption per appliance and per capita drinkable water estimation after rainwater harvesting measure application

Appliances	**Consumed specific flowrate (L/s)**	**Use frequency ($1/inh \cdot day$)**	**Use duration (min)**	**Consumed water (L/day)**
Handbasin	a_{11}	a_{12}	a_{13}	$a_{14} = (a_{11} \times a_{12} \times a_{13}) \times 60$
Toilet (Box)[1]	a_{21}	a_{22}	–	0
Toilet (Valve)	a_{31}	a_{32}	a_{33}	0
Shower	a_{41}	a_{42}	a_{43}	$a_{44} = (a_{41} \times a_{42} \times a_{43}) \times 60$
Washing Machine[2, 3]	a_{51}	a_{52}	–	$a_{54} = a_{51} \times a_{52}$
Kitchen Sink	a_{61}	a_{62}	a_{63}	$a_{64} = (a_{61} \times a_{62} \times a_{63}) \times 60$
Garden	a_{71}	a_{72}	a_{73}	0
Outside	a_{81}	a_{82}	a_{83}	0
Total				$\sum_{m=1}^{8} a_{m4}$

[1] consumed volume per flush (L/flush)
[2] consumed volume per wash (L/wash)
[3] uses per week in a building

Then, the drinkable water consumption after rainwater harvesting implementation is estimated by:

$$qe_{j,m} = a_{i4} + a_{44} + a_{54} + a_{64} \tag{6.32}$$

Next step is to estimate total drinkable water consumption:

$$qt_{j,m} = \frac{qe_{j,m}}{(1 - Id_0)} \tag{6.33}$$

Current area water consumption ($Qwss_0$) is estimated by:

$$Qwss_{j,m} = \frac{3qt_{j,m} \times P_j}{100} \tag{6.34}$$

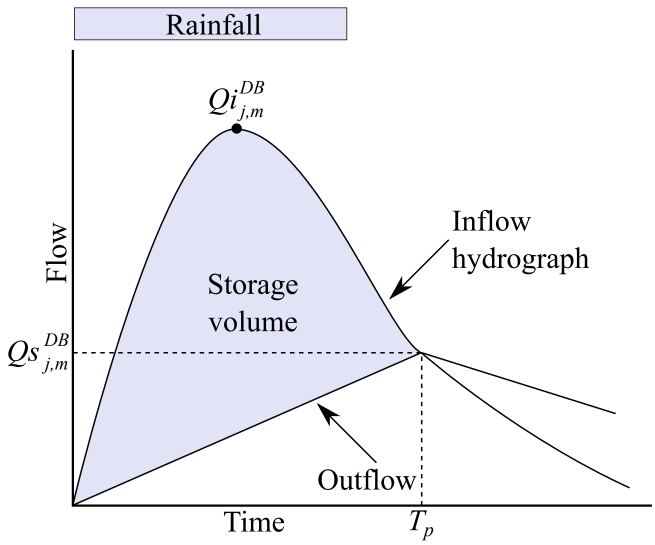
where $Qwss_{j,m}$ is the area drinkable water consumption in scenario j after the rainwater harvesting measure ($m^3/month$).

The water supply system coverage indicator ($Cwss_{j,m}$) can be estimated by:

$$Cwss_{j,m} = \frac{Cwss_0 \times Qwss_0}{Qwss_{j,m}} \tag{6.35}$$

6.6.4 Stormwater Detention basins

After locating the stormwater detention basin, the input data to its evaluation are: the detention storage volume (V_m^{DB}), its contribution area (Ac_m^{DB}), the average runoff coefficient to the contribution area of the stormwater detention basin (Rv_m^{DB}), and the time of concentration for the inflow area of the detention basin (tc_m^{DB}).Then, the Federal Aviation Administration (FAA) method (Figure 6.7) is used.



Source: adapted from Guo (1999)

FIGURE 6.7: Hydrograph volumetric method of detention volume sizing

Importantly, the design storm duration for a detention basin has to be longer than the estimated precipitation duration (d) used in Rational Method for conveyance designs. Therefore, by knowing that:

$$M = \frac{1}{2}\left(1 + \frac{tc_m^{DB}}{td_m^{DB}}\right) \tag{6.36}$$

where td_m^{DB} is the precipitation duration for designing the detention basin m; and M is a constant between 0.80 and 0.90 for all storm events — it was adopted 0.80.

Then, it is possible to estimate the td_m^{DB} and, as a consequence, the outflow runoff as follows:

$$Qs_m^{DB} = 60\,\frac{V_m^{DB}}{td_m^{DB}} \tag{6.37}$$

Thereafter, the stormwater detention basin inflow runoff ($Qi_{j,m}^{DB}$) is estimated by:

$$Qi_{j,m}^{DB} = 0.2778 \times Rv_m^{DB} \times I_j \times Ac_m^{DB} \tag{6.38}$$

Finally, it is possible to estimate the runoff flow reduction (Qf_m^{DB}) by using the following equation:

$$Qf_m^{DB} = Qi_{j,m}^{DB} - Qs_m^{DB} \tag{6.39}$$

The impact of the detention basin measures implementation in the flooding flowrate in sewer indicator is estimated by:

$$Qs_{Total}^{DB} = \sum_{m=1}^{n} Qs_m^{DB} - \sum_{m=1}^{n} Qf_m^{DB} \tag{6.40}$$

6.6.5 Bioretention

By calling A_m^{BR} the area of the bioretention device, and D_m^{BR} its depth, the infiltration capacity of the bioretention systems, Qs_m^{BR}, is calculated by using the following equation:

$$Qs_m^{BR} = k \times A_m^{BR} \times \frac{h_m^{BR} + D_m^{BR}}{D_m^{BR}} \tag{6.41}$$

where k is the soil permeability coefficient, and h_m^{BR} is the extended detention depth (above filter).

Next step is to estimate the input flooding flowrate in the bioretention device (Qi_m^{BR}), which can be done by considering the contribution area (Ac_m^{BR}), the street runoff coefficient and the design rainfall:

$$Qi_m^{BR} = 0.2778 \times Rvp_0 \times I_j \times Ac_m^{BR} \tag{6.42}$$

Then, it is possible to verify whether an overflow (Qf_m^{BR}) occurs or not by using the following equation:

$$Qf_m^{BR} = Qi_m^{BR} - Qs_m^{BR} \tag{6.43}$$

Once more, if the Qs_m^{BR} is greater than Qi_m^{BR} there is not overflow in the bioretention device — i.e. all generated influent area runoff is infiltrated and therefore $Qf_m^{BR} = 0$. On the other hand, if Qi_m^{BR} is greater than Qs_m^{BR}, there is overflow. The impact of the bioretention devices implementation in the flooding flowrate in sewer indicator is estimated by

$$Qs_{Total}^{BR} = \sum_{m=1}^{n} Qs_m^{BR} - \sum_{m=1}^{n} Qf_m^{BR} \tag{6.44}$$

This page was intentionally left blank

7 CURITIBA METROPOLITAN REGION CASE STUDY

This section discusses a case study performed in the Curitiba Metropolitan Region by using the UWU Model and addresses the third formulated question in chapter 4: *How the case studies using the UWU Model can be used to support decision-making in urban drainage system?*

***

In the section 7.1 is described all initial data which had to be input into the model. section 7.2 presents used data and the scenarios formulation to the case study. The section 7.4 presents the results in selection, location and the input parameters obtained. In section 7.5 the indicators are selected and it is presented the discussion in visioning and weighting each indicator. Finally, the section 7.6 summarizes the results presenting the effectiveness index for each group of measures and the final discussion about the model results.

7.1 Initial input data

The delimited study area (see Figure 5.12) has a land area $A = 208.44$ *hectares* (2.08 km^2). Estimated current population (P_0) was set at $3,959$ *inhabitants* and it was considered an average of 3 *inhabitants* per building (IBGE, 2013). Thereafter, it was estimated that the number of buildings in study area is equal to 1,330. The water loss in the distribution system (Id_0) was set at 30% and it was assumed that this value remains constant over the years. Moreover, the current water supply system coverage ($Cwss_0$) in the area is 100%.

The average roofs runoff coefficient (Rv_{AV}^{RH}) and the pavement runoff coefficient (Rv_{AV}^{PV}) were assumed equal to 0.80 and 0.85, respectively. For the rainwater harvesting measure it was considered that the toilet flushing, garden watering and sidewalks washing. Notwithstanding, it was adopted an average infiltration coefficient equals to 5×10^{-3} m/s. This value is for the Crystalline complex lithology for which the K values vary from 10^{-3} to 10^{-5} m/s (see Table 5.2).

The pollutant concentrations in the runoff flow were adopted based on values reported in literature. It was assumed the Brombach, Weiss and Fuchs (2005) average values for separated drainage systems. Adopted values were 13 $mg\ L^{-1}$, 141 $mg\ L^{-1}$, 2.4 $mg\ L^{-1}$, and 0.42 $mg\ L^{-1}$ to Biochemical Oxygen Demand, Total Suspended Solids, Total Kjeldahl Nitrogen, and Total Phosphorus, respectively. All input data are shown in Appendix B, section B.3.

7.2 Scenarios formulation

The first step in formulating the scenarios is to determine the design period. The interventions were estimated as going to be implemented over the next 30 years, which means that $t_0 = 2016$ and $t_1 = 2046$. The current population growth rate was established based on Instituto Brasileiro de Geografia e Estatística[1] (IBGE) data.

The last IBGE census estimated that the population living in Curitiba in 2010 was equal to 1,751,907 inhabitants (IBGE, 2013). The living population in 2000 was equal to 1,587,315 inhabitants (IBGE, 2002). By using these data the current geometric population growth rate can be estimated:

$$\lambda_0 = \left[\left(\sqrt[10]{\frac{P_{2010}}{P_{2000}}} \right) - 1 \right] \times 100 \tag{7.1}$$

The estimated current population growth rate was $\lambda_0 = 0.99$. Table 7.1 shows the population growth rate from 2001 to 2030 in Brazil and in Paraná State.

TABLE 7.1: Projection of the exponential population growth rate in Brazil and Paraná state over the years

Location	Years									
	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Brazil	1.40	1.36	1.31	1.27	1.22	1.18	1.14	1.09	1.05	1.01
Paraná	1.25	1.20	1.15	1.11	1.06	1.02	0.98	0.94	0.91	0.87

Location	Years									
	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Brazil	0.97	0.93	0.90	0.86	0.83	0.80	0.77	0.73	0.70	0.67
Paraná	0.85	0.83	0.80	0.77	0.73	0.71	0.70	0.67	0.64	0.61

Location	Years									
	2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Brazil	0.64	0.61	0.58	0.55	0.52	0.49	0.46	0.44	0.41	0.38
Paraná	0.57	0.53	0.51	0.48	0.45	0.42	0.38	0.35	0.32	0.30

Source: IBGE (2013)

As can be seen in Table 7.1, the current exponential population growth rate in Paraná state is equal to 0.71 and there is a tendency in decreasing its over the years. By considering a linear decreasing trend, the population growth rate becomes negative in 2040. It was considered in order to set the other values to the population growth rate.

Considering that the population growth rate in Curitiba will decrease at the same linear rate of that experienced in the Paraná state, the minimum value was set at 0.60 — the average

[1] Brazilian Institute of Geography and Statistics

population growth rate from 2015 to 2030 in Curitiba. On the other hand, the maximum value was set at 1.2 — a slight increase in population growth rate in Curitiba is not expected, however, it was considered to formulate a critical scenario.

In regards to the temperature, it was considered an expected increase in the average annual temperature as reported by IPCC (2007b). As can be seen in Table 7.2, to the southern South America a temperature increase is expected both in summer and winter seasons in the next decades.

TABLE 7.2: Projected temperature changes for broad sub-regions of Central and South America

Changes in temperature (°C)	**Period**	**Year**		
		2020	**2050**	**2080**
Central America	Dry season	+0.4 to +1.1	+1.0 to +3.0	+1.0 to +5.0
	Wet season	+0.5 to +1.7	+1.0 to +4.0	+1.3 to +6.6
Amazonia	Dry season	+0.7 to +1.8	+1.0 to +4.0	+1.8 to +7.5
	Wet season	+0.5 to +1.5	+1.0 to +4.0	+1.6 to +6.0
Southern South America	Winter	+0.6 to +1.1	+1.0 to +2.9	+1.8 to +4.5
	Summer	+0.8 to +1.2	+1.0 to +3.0	+1.8 to +4.5

Summer: December/January/February; Winter: June/July/August
Source: IPCC (2007b)

It was considered the 2050 projections (once the design period was set at 30 years) as the reference data to the scenarios formulation. As can be seen, the projections show that the temperature in the southern South America can increase of 1.0 $°C$ to 2.9 $°C$ in the winter and of 1.0 $°C$ to 3.0 $°C$ in the summer season.

Once in the external factors input data to the scenarios formulation in the UWU Model the requested temperature is the average annual temperature, it was assumed that the summer and winter temperature will increase at the same rate, and that the change in temperature in the autumn and spring seasons are not noticeable.

By doing so, the temperature increase value was set as 1.0 $°C$ in the most favorable scenario and as 2.9 $°C$ in the critical scenario, following the aforementioned range of values. The annual average temperature was estimated according to Table 7.3. Thereafter, the minimum value to the future average annual temperature was set as 17.3 $°C$, and the maximum value was set as 18.2 $°C$.

Once there are major differences between the per capita income in different neighborhoods/census tracts in Curitiba city (as can be seen in subsection 5.2.1, Figure 5.10), the current per capita income was estimated as the weighted arithmetic mean of the per capita incomes of the census tracts within the study area. Therefore, the current average per capita income was set at $35,000.00\ R\$/inh \cdot year$[2] (IBGE, 2013).

To set the maximum value for average per capita income, the increasing trend in the average per capita income to Curitiba was considered, as can be seen in Table 7.4. Assuming the same increasing rate for the study area, it was estimated the future value for the year 2046. The data generalization can be seen in Appendix B, section B.2.

[2]The current exchange rate is approximately R$ 3.90 to US$ 1.00.

TABLE 7.3: Future average annual temperature estimations

Parameter	**Months**												
	Jan	**Feb**	**Mar**	**Apr**	**Mai**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
Average Temperature	20.4	20.6	19.6	17.2	14.5	13.1	12.9	14.1	15.0	16.5	18.2	19.3	16.8
Favourable Scenario +1	21.4	21.6	19.6	17.2	14.5	14.1	13.9	15.1	15.0	16.5	18.2	20.3	17.3
Critical Scenario +2.9	23.3	23.5	19.6	17.2	14.5	16.0	15.8	17.0	15.0	16.5	18.2	22.2	18.2

TABLE 7.4: Average per capita income to Curitiba

Parameter	**Years**				
	2000	**2007**	**2008**	**2009**	**2010**
Average per capita income ($R\$/month$)	1,430.96	2,469.89	2,615.61	2,728.34	2,889.59

Therefore, to formulate the critical scenario the value was set at $58.000,00\ R\$/inh \cdot year$. On the other hand, it was considered that the economy will not continue growing at the same current rate, suffering a contraction in the coming decades. Then, the minimum value was estimated at an intermediate value between the current and the maximum future value and it was set at $45.000,00\ R\$/inh \cdot year$.

The current design rainfall was estimated by using the IDF-curve to Curitiba considering a duration of the precipitation equals to 30 min — the estimated basin concentration time was equals to 30 min, see Appendix B, section B.1 — and a return period equals to 5 $years$, which is a value widely used in designing the micro drainage network in residential areas. Estimations were made by equation (FENDRICH, 2008):

$$I_j = \frac{5,726.64 \times R^{0.159}}{(d+41)^{1.041}} \tag{7.2}$$

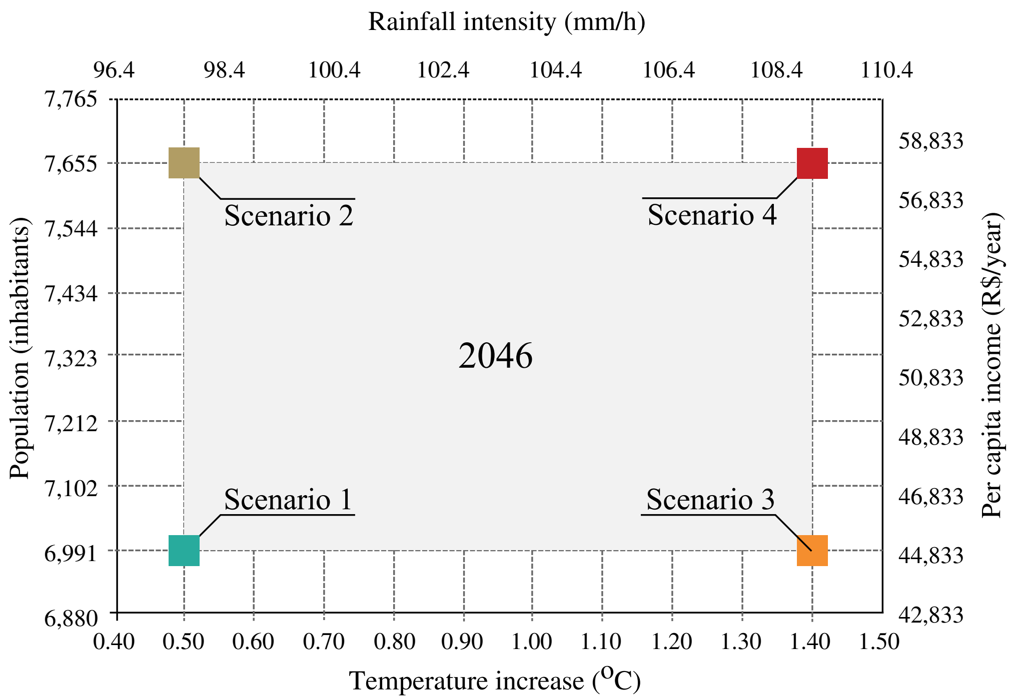
The future scenarios considered the Intergovernmental Panel on Climate Change (IPCC) projections for the southern region of Brazil. According to Marengo (2007), it is expected an increase in the rainfall intensities in the next decades. Then, using the Equation 7.2 it was estimated the design rainfall using a return period equals to 10 $years$ and 15 $years$. The input data to the scenarios formulation is summarized in Table 7.5.

The external factors input data lead to the formulation of four scenarios. The scenario 1 is the most favorable scenario in which both the socioeconomic and climate change assumes the minimum values. The scenario 2 assumes the minimum climate change values and the maximum socioeconomic values. On the other hand, scenario 3 assumes the maximum climate change values and the minimum socioeconomic values. Scenarios 2 and 3 may be understood as intermediate scenarios. Finally, the scenario 4 is the critical scenario in which both the so-

TABLE 7.5: External factors input data to the study area

External factors	States		
	Current	Minimum	Maximum
Population growth rate ($\%/year$)	0.99	0.60	1.20
Annual temperature ($°C$)	16.8	17.3	18.2
Per capita income ($R\$/inh \cdot year$)	35,000.00	45,000.00	58,000.00
Design rainfall (mm/h)	87.47	97.67	109.04

cioeconomic and climate change assumes the maximum values. These are all scenarios in which the simulations are performed. Exponential method was used for future population estimation in the area. The formulated future scenarios are represented in Figure 7.1.



Source: the author

FIGURE 7.1: Formulated scenarios for the year 2046 based on two states of four external factors

7.3 Initial estimations

Initial estimation shows that the current study area population density is 18.99 inh/ha, the impermeable area is 23.83%, and the current runoff coefficient is 0.34. Fendrich (2002) had estimated the impermeable area and the runoff coefficient to Bom Retiro, Vista Alegre and Pilarzinho neighborhoods. Reported values to year 2000 were: 31.33% and 0.33; 28.11% and 0.30; and 35.89% and 0.37, respectively. The estimated values by UWU Model are in accordance with previous estimates.

The current building effective drinkable water per capita consumption (qe_0) was estimated at 363.11 $L/inh \cdot day$. It is considerably higher than the estimated average in the Curitiba municipality which is at 163.9 $L/inh \cdot day$ (SNIS, 2013). It is explained by the high per capita income in the area — most of the study area buildings have a pool in their yard, for example. On the other hand, other relations between the per capita income and the per capita water consumption could be tested in order to better estimate this value.

Pollutants production in the area was estimated at 348.92, 3,784.5, 64.42 and 11.27 kilograms of BOD, TSS, TKN and TP by event, respectively. There are large uncertainties in the estimates of transported pollutant loading rates during precipitation events since there is not available site specific data. Moreover, there are large variations in the pollutants mean concentration in the runoff flow. For instance, Brites and Gastaldini (2005) studying an urban basin in Santa Maria-RS with a population density equals to 36.53 inh/ha and the impermeable area equals to 35%, reported event mean concentration (EMC) values ranging from 20.25 to 244.38 $mg\ L^{-1}$ and from 7.53 to 5,803.4 $mg\ L^{-1}$ to TSS and BOD, respectively. Table 7.6 summarizes the current indicator estimations.

TABLE 7.6: Indicators estimations for the current situation in the basin area

Indicators	**Current scenario**
Water Supply System coverage (%)	100
Flooding flowrate at sewer (m^3/s)	14.88
Equivalent permeable area (%)	76.17
TSS specific loading rate (kg/km^2)	1918.47
BOD specific loading rate (kg/km^2)	167.75
TKN specific loading rate (kg/km^2)	30.97
TP specific loading rate (kg/km^2)	5.42

The Curitiba drainage master plan proposes that the pre-urbanization situation should be maintained in order to prevent flooding and impact transfer to downstream areas (SUDERHSA, 2002). Therefore, these initial estimations are important because they can help and guide setting the vision for each indicator (section 7.5).

As can be seen in Table 7.6, the area is not highly urbanized once the permeable area is quite high. Considering the formulated scenarios and taking into account that no measures will be implemented within the study area over the next thirty years, it is expected an indicators values deterioration, it can be seen in Figure 7.2. On the other hand, following the master plan recommendations, the initial estimations should be more or less kept.

7.4 Measures selection and definition

It was proposed five groups of sustainable drainage measures for the delimited study area. The drainage measures considered in this work were permeable pavements; rainwater harvesting; infiltration trenches, bioretention and detention basin. The measures data can be seen in Appendix B, section B.4. Infiltration trenches data are in subsection B.4.1, Permeable pavements data are in subsection B.4.2, the bioretention data are in subsection B.4.4, rainwater harvesting data are in subsection B.4.5 and section B.5, and detention basin data are in subsection B.4.3. The measures groups composition was set as follows:

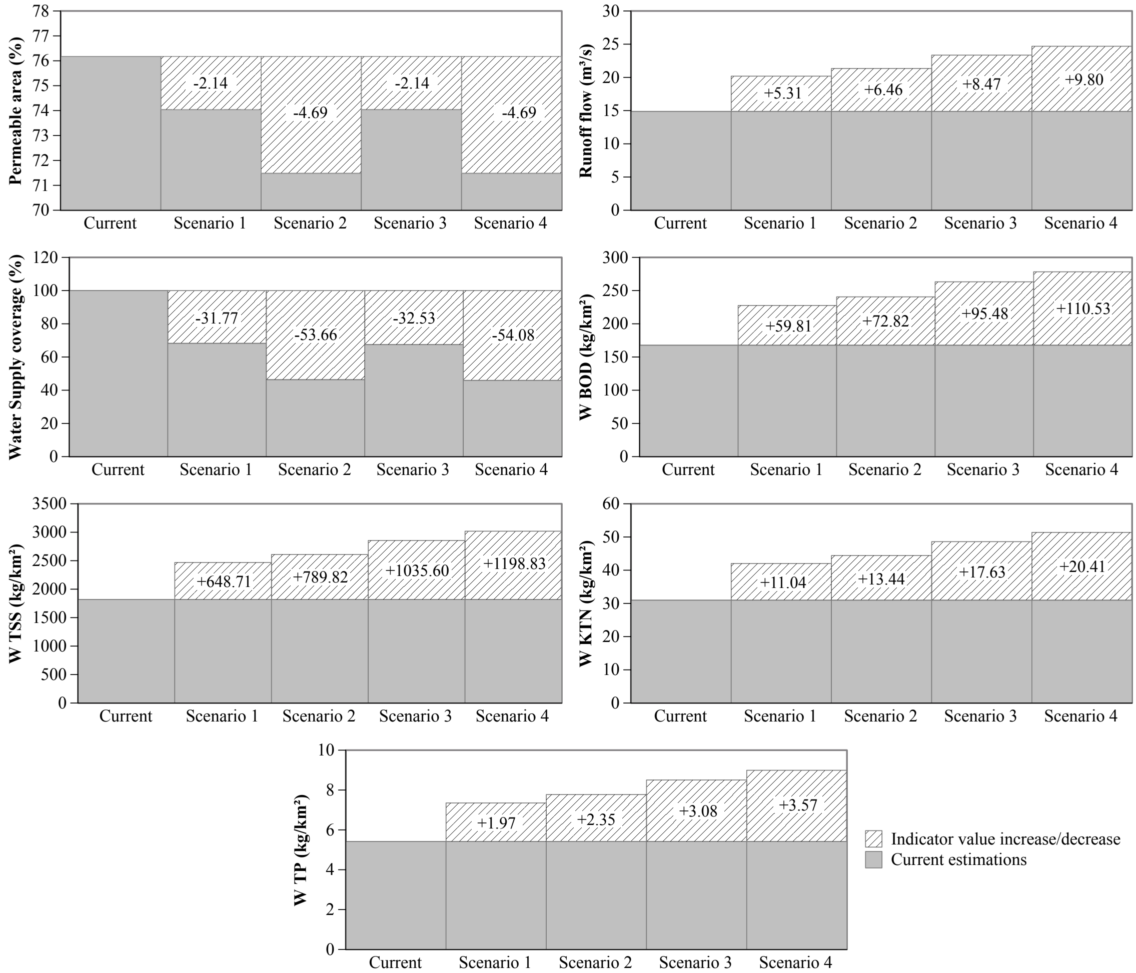


FIGURE 7.2: Initial results summary and urban area deterioration over the years

Group of measures 0 (*GM*$_0$): It considers that no intervention will be adopted in the study area — i.e. it is a control group of measures.

Group of measures 1 (*GM*$_1$): It consists of infiltration trenches, permeable pavements and Rainwater harvesting. Infiltration trenches were implemented along streets (35 interventions) on the sidewalks; Permeable pavements were implemented in parking lots, along streets and in low traffic flux streets (20 interventions); for rainwater harvesting into buildings it was considered an acceptance of 60% and uses for toilet flushing, garden watering and sidewalks washing.

Group of measures 2 (*GM*$_2$): It consists of detention basins, bioretention and rainwater harvesting. Detentions basins were implemented in basin lower areas (08 interventions); bioretention implemented on sidewalks (33 interventions for bioretention); for rainwater harvesting, it was considered an acceptance of 70% and the same uses as aforementioned.

Group of measures 3 (*GM*$_3$): It consists of bioretention, infiltration trenches, and permeable pavements. Bioretention implemented on sidewalks (33 interventions for bioretention); Infiltration trenches were implemented along streets (35 interventions) on the sidewalks; Permeable pavements were implemented in parking lots, along streets and in low traffic flux streets (20 interventions);

Group of measures 4 (GM_4): It consists of rainwater harvesting, detention basins, and infiltration trenches. For rainwater harvesting, it was considered an acceptance of 80% and the same uses as aforementioned; detentions basins were implemented in basin lower areas (08 interventions); infiltration trenches were implemented along streets (35 interventions) on the sidewalks.

Group of measures 5 (GM_5): It is consists of all measures together. For rainwater harvesting into buildings it was considered an acceptance of 90% and the same uses as aforementioned; permeable pavements implemented in parking lots along streets and in low traffic flux streets (20 interventions); infiltration trenches along streets (35 interventions); bioretention implemented on sidewalks (33 interventions), and detentions basins were implemented in basin lower areas (08 interventions).

The maximum permeable pavements depth was set at 0.5 m. For all measures it was considered that the overflow will be drained by the traditional micro drainage system already implemented in the area. The infiltration trenches depth was set at 1.0 m. They were located along the streets on the sidewalks where there was enough space to ensure system implementation and pedestrian flow. The bioretention systems were also located on the sidewalks where there was enough space.

7.5 Indicators selection and visioning

To set the vision values, the estimated current indicators values (Table 7.6) and recommendations from SUDERHSA (2002) were used. It was assumed that the current situation should remain more or less unchanged. It was admitted a variation ranging between 10 to 15% on current estimates. On the other hand, to set the water supply system coverage vision it was considered that as the population grows, water scarcity is likely to increase. Then, assuming that the vision has to be achieved by only the rainwater harvesting measure, the option was to establish a lower vision.

In other words, it does not consider the water supply system improvement over the years and/or non-structural measures. Therefore, it is assumed that the remaining necessary water to universalization should be contemplated by water supply system measures — e.g. by reducing the distribution water loss or water conservation measures. Therefore, in this application it was assumed that the following vision would be attractive and could be achieved, as shown in Table 7.7.

TABLE 7.7: Selected indicators and established vision for simulation 1

Indicators	**Vision**	**Weight**
Water Supply System coverage (%)	80.0	0.15
Flooding flowrate at sewer (m^3/s)	20.0	0.35
Equivalent permeable area (%)	75.0	0.05
TSS specific loading rate (kg/km^2)	2110.0	0.15
BOD specific loading rate (kg/km^2)	185.0	0.15
TKN specific loading rate (kg/km^2)	35.0	0.05
TP specific loading rate (kg/km^2)	7.0	0.1

Note that the sum of the weights of the indicators must be equal to 1. The selected weights reflect the fact that the drainage measure must ensure that no flooding will be experienced in the area (it has the biggest weight). Nonetheless, it is considered very important the water issues in the area as well as the TSS and BOD transport. On the other hand, the *PAeq* indicator was set at the lower value. It was because the current area situation is very favorable and it is admitted a small decrease in the current indicator value.

The TP loading rate was considered more important and it was given a greater weight than TKN loading rate. The established vision for each pollutant loading rate took into account that the area contribution can be considered low given the high current permeable area. Then, it was assumed that the loading rates could be maintained more or less constant throughout the years. It will ensure that the Belém river pollutant concentrations will not be affected by diffuse pollution from the study area.

7.6 Results of the UWU Model simulations

7.6.1 Simulation results for established indicators, visions and weights – simulation 1

Intermediate results from measures application can be seen in Appendix B, section B.4 and section B.5. The main outputs from UWU Model application can be seen in Table 7.8.

Considering that no intervention will be adopted (GM_0), the results show a considerable deterioration in the current area situation. Water supply system coverage will decrease from 100% to 68.2% in the favorable scenario, or to 45.9% considering the critical scenario. It means that between 1,506 and 3,069 *inhabitants* will experience water scarcity in the area.

Implementation of measures that ensure water savings, reduce the water loss in the WSS, and non-structural measures are an important aspect which has to be considered in cities in order to ensure sustainability. On the other hand, considering that there are identified interfaces among urban water systems (GESSNER et al., 2014) the present application of the UWU Model tried to demonstrate the impact of a drainage measure — rainwater harvesting — in a water system indicator.

The proposed groups of measures were able to increase the water supply system coverage indicator by 18.1% (GM_1), 22.4% (GM_2), 27.1% (GM_4), and 32.4% (GM_5) on average. Once the GM_3 does not consider the rainwater harvesting measure, it does not alter the indicator value. The vision was not achieved by any group of measures in the critical scenario indicating that if the critical scenario occurs, some flexibility in the groups is necessary to ensure the population does not suffer from lack of water. For example, it could be considered measures to reduce the water losses in the system. These measures are important because they can prevent that more water has to be collected and treated, creating more pressure on water resources.

With regards to the permeable area, it will be reduced from 76.2% to 74.0% – 71.5% depending on the considered scenario. In this sense, the study area has large green areas, mainly due to the presence of the "Bosque do Alemão" and protected areas. Although the estimation method is not site specific, there is a good estimate of this parameter. The values are between the expected considering estimates made by Fendrich (2002).

The better groups of measures were groups 2, 4, and 5 (GM_2, GM_4, and GM_5), which could increase the permeable area value above the established vision in all scenarios. These three measures groups have in common the detention basin measure. It could indicate that, despite it

TABLE 7.8: Summary of results for simulation 1 for all group of measures, indicators and scenarios

Group of Measures	Indicators	Scenarios				Vision	N*
		SC1	SC2	SC3	SC4		
GM_0	$Cwss$ (%)	68.2	46.3	67.5	45.9	80.0	0
	$Qmax$ (m^3/s)	20.2	21.3	23.4	24.7	20.0	0
	$PAeq$ (%)	74.0	71.5	74.0	71.5	75.0	0
	WE_{TSS} (kg/ha)	2468.2	2609.3	2855.1	3018.3	2110.0	0
	WE_{BOD} (kg/ha)	227.6	240.6	263.2	278.3	185.0	0
	WE_{TKN} (kg/ha)	42.0	44.4	48.6	51.4	35.0	0
	WE_{TP} (kg/ha)	7.4	7.8	8.5	9.0	7.0	0
GM_1	$Cwss$ (%)	88.6	62.5	87.6	61.9	80.0	2
	$Qmax$ (m^3/s)	18.1	19.0	20.9	22.0	20.0	2
	$PAeq$ (%)	76.1	73.8	76.1	73.8	75.0	2
	WE_{TSS} (kg/ha)	2208.6	2317.7	2554.9	2681.2	2110.0	0
	WE_{BOD} (kg/ha)	203.6	213.7	235.6	247.2	185.0	0
	WE_{TKN} (kg/ha)	37.6	39.5	43.5	45.6	35.0	0
	WE_{TP} (kg/ha)	6.6	6.9	7.6	8.0	7.0	2
GM_2	$Cwss$ (%)	93.2	66.4	92.1	65.7	80.0	2
	$Qmax$ (m^3/s)	16.7	17.5	19.2	20.2	20.0	3
	$PAeq$ (%)	81.1	78.9	81.1	78.9	75.0	4
	WE_{TSS} (kg/ha)	2035.5	2139.3	2340.2	2460.4	2110.0	1
	WE_{BOD} (kg/ha)	187.7	197.2	215.8	226.8	185.0	0
	WE_{TKN} (kg/ha)	34.6	36.4	39.8	41.9	35.0	1
	WE_{TP} (kg/ha)	6.1	6.4	7.0	7.3	7.0	3
GM_3	$Cwss$ (%)	68.2	46.3	67.5	45.9	80.0	0
	$Qmax$ (m^3/s)	18.8	19.9	21.7	23.1	20.0	2
	$PAeq$ (%)	74.8	72.2	74.8	72.2	75.0	0
	WE_{TSS} (kg/ha)	2291.1	2431.9	2650.7	2813.6	2110.0	0
	WE_{BOD} (kg/ha)	211.2	224.2	244.4	259.4	185.0	0
	WE_{TKN} (kg/ha)	39.0	41.4	45.1	47.9	35.0	0
	WE_{TP} (kg/ha)	6.8	7.2	7.9	8.4	7.0	1
GM_4	$Cwss$ (%)	98.3	70.8	97.2	70.0	80.0	2
	$Qmax$ (m^3/s)	16.8	17.6	19.3	20.2	20.0	3
	$PAeq$ (%)	81.4	79.2	81.4	79.2	75.0	4
	WE_{TSS} (kg/ha)	2048.1	2146.7	2354.7	2468.7	2110.0	1
	WE_{BOD} (kg/ha)	188.8	197.9	217.1	227.6	185.0	0
	WE_{TKN} (kg/ha)	34.9	36.5	40.1	42.0	35.0	1
	WE_{TP} (kg/ha)	6.1	6.4	7.0	7.4	7.0	2
GM_5	$Cwss$ (%)	104.1	75.7	102.9	75.0	80.0	2
	$Qmax$ (m^3/s)	15.5	16.2	17.8	18.7	20.0	4
	$PAeq$ (%)	82.2	80.1	82.2	80.1	75.0	4
	WE_{TSS} (kg/ha)	1888.0	1981.3	2169.8	2277.7	2110.0	2
	WE_{BOD} (kg/ha)	174.1	182.7	200.1	210.0	185.0	2
	WE_{TKN} (kg/ha)	32.1	33.7	36.9	38.8	35.0	2
	WE_{TP} (kg/ha)	5.6	5.9	6.5	6.8	7.0	4

*it is number of scenarios in which the vision was achieved.

is a measure that cannot account for green areas in the basin, the detention basin inflow area is greater than for the other measures.

By increasing the permeable area using the proposed group of measures it is possible to infiltrate between 1.40 – 6.00 m^3/s into the soil in rain events, contributing to groundwater recharge and consequently reducing the area runoff peak flows. As a consequence, it is possible to reduce the pressure exerted by the increasing urbanization in the local micro drainage system. Importantly, the permeable area values are always equal in scenarios 1 and 3 and in scenarios 2 and 4. Therefore, to reduce the effect of this indicator on the effectiveness index value it was decided to reduce its weight — also considering the basin impermeabilization degree is not a concern.

The TSS, BOD, TKN and TP specific loading rates could increase by 648.7 – 1198.8 kg/km^2, 59.8 – 110.5 kg/km^2, 11.4 – 20.4 kg/km^2, and 1.9 – 3.6 kg/km^2, depending on the considered scenario. The increase in the pollutant loading rates is expected as a result of increased runoff flow due to the increased impermeabilization over the years (increasing the potential for pollutant transport), and the expected increase in precipitation.

The group of measures implementation could contribute in reducing all pollutant specific loading rates, mainly the groups 2 and 5 (GM_2 and GM_5). As mentioned to the water supply system coverage indicator, there is not any group of measures which is able to achieve the vision in the critical scenario for all pollutant loads. Therefore, it is important to consider some degree of flexibility in the measures implementation if the critical scenario occurs to ensure basin sustainability.

Estimations of runoff flow showed an increase by 5.3 – 9.8 m^3/s in the most favorable and critical scenarios, respectively. It was considered that increasing the runoff flow by approximately 5.0 m^3/s, the micro drainage network could overflow in the study area downstream. Thus, measures that can contribute in decreasing runoff peak flows are required even if the most favorable scenario occurs.

The GM_2, GM_4, and GM_5 were the best groups since they achieved the flooding flowrate at the critical sewer vision value in three scenarios, at least. The group of measures 1 and 3 (GM_1 and GM_3) had achieved the vision value in just two scenarios. The decentralized drainage measures were effective in reducing runoff flow and could contribute to urban basin sustainability. Furthermore, the measures could avoid the need to increase the pipes diameter or the implementation of new big centralized "gray infrastructure".

In order to summarize the simulation results and to rank the groups of measures, the Table 7.9 shows the EI and the classification according to the model's scale. It is important to note that the higher the EI, the better the group of measures.

As can be seen, the GM_0 has the lowest EI. It represents the area sustainability deterioration over the years, considering the selected indicators, induced by the pressure imposed by urban growth and climate change. Assuming that no measure will be implemented, there is not any indicator which achieved the vision in the formulated scenarios resulting in an EI equals to zero.

The GM_3 was classified as 'poor' according to the UWU Model's scale. Especially in regards to the pollution control both groups of measures were very inefficient and, once it does not consider the rainwater harvesting measure, it could not achieve the vision for the $Cwss$ indicator. The GM_1 and GM_4 were classified as 'insufficient' according to the UWU Model's

TABLE 7.9: Integrated evaluation based on the Effectiveness Index for simulation 1

Group of measures	**Effectiveness Index (EI)**	**Category**
GM_0	0.00	Poor
GM_1	1.30	Insufficient
GM_2	2.05	Reasonable
GM_3	0.80	Poor
GM_4	1.95	Insufficient
GM_5	3.00	Good

scale. The pollution control was very inefficient for these groups, although they are reasonably good on controlling the other indicators.

The GM_2 was classified as 'reasonable'. The group achieved a high score once it was able to cope with impermeabilization issues and flooding issues, although it was not efficient at removing pollutant loading rates. On the other hand, by grouping all formulated measures (GM_5) it was possible improve basin sustainability in at least two scenarios, resulting in the highest EI — it was classified as 'good'. Notwithstanding, other aspects should be taken into consideration when planning the sustainable drainage measures, such as the possibility of aesthetic amenity or other benefits for urban areas. In this sense, it is possible to implement other indicators into the model in order to assess the SuDS broader benefits.

As could be seen, it is not necessary to achieve the vision for all indicators in all scenarios to a group of measures be considered as 'good'. In fact, it is not necessary to achieve the vision in the critical scenario because the drainage measures are not planned for the most critical situation, but for those in which the cost-benefit is acceptable. On the other hand, the critical scenario should be taken into account to find solutions in a timely manner, if such scenario occurs.

By means of the Effectiveness Index it was possible to summarize into a single value the set of outputs from the UWU Model. The whole method can help decision-makers when planning drainage interventions in an urban area and encourage the adoption of new practices for runoff flow management. Notwithstanding, the tool can encourage discussion by stakeholders and engage the public in the urban drainage measures selection.

Despite the GM_5 has been the most effective group of measures in promoting the area sustainability, the measures implementation is subject to the municipal budget. Then, when planning the measures it is important to consider the costs involved and elaborate feasible groups of measures. In addition, the selected group of measures to be implemented in the area requires implementation and monitoring plans. Nevertheless, given the uncertainties involved in formulating future scenarios, measures must be flexible and adaptable to account for no elaborated scenarios.

Moreover, it is clear that GM_5 is the most expensive group of measures once it combines all measures together. Given the budget constraints, an economic indicator could decrease the GM_5 effectiveness index. It is suggested the evaluation of the costs based on net present value as presented in Woods-Ballard et al. (2015). Further model development should prioritize the addition of an economic indicator.

7.6.2 Effect of indicators and weights change on the effectiveness index value – simulations 2, 3, and 4

In order to test whether the change of the indicators weights values can affect the ranking of the groups measures or not, three more simulations were performed. The new indicators weights for the simulations can be seen in Table 7.10.

TABLE 7.10: Selected indicators and established weights for simulations 2, 3, and 4

Indicators	**Weights**		
	Simulation 2	**Simulation 3**	**Simulation 4**
Water Supply System coverage (%)	0.05	0.05	0.15
Flooding flowrate at sewer (m^3/s)	0.50	0.05	0.35
Equivalent permeable area (%)	0.05	0.05	–
TSS specific loading rate (kg/km^2)	0.10	0.30	0.15
BOD specific loading rate (kg/km^2)	0.10	0.15	0.15
TKN specific loading rate (kg/km^2)	0.10	0.20	0.10
TP specific loading rate (kg/km^2)	0.10	0.20	0.10

Importantly, all other parameters were kept constant for these simulations. In the case of the simulation 4, besides the change of weights the equivalent permeable area was not considered in the evaluation. The outputs from UWU Model application can be seen in Appendix B.6, Table B.23, Table B.24, and Table B.25 for simulations 2, 3, and 4, respectively. The groups of measures ranking are shown in Table 7.11.

TABLE 7.11: Integrated evaluation based on the Effectiveness Index for simulations 2, 3 and 4

Group of	**Simulation 1**		**Simulation 2**		**Simulation 3**		**Simulation 4**	
measures	**EI**	**Category**	**EI**	**Category**	**EI**	**Category**	**EI**	**Category**
GM_0	0.00	Poor	0.00	Poor	0.00	Poor	0.00	Poor
GM_1	1.30	Insufficient	1.40	Insufficient	0.70	Poor	1.20	Poor
GM_2	2.05	Reasonable	2.30	Reasonable	1.55	Insufficient	1.90	Insufficient
GM_3	0.80	Poor	1.10	Poor	0.30	Poor	0.80	Poor
GM_4	1.95	Insufficient	2.20	Reasonable	1.35	Insufficient	1.80	Insufficient
GM_5	3.00	Good	3.30	Good	2.60	Reasonable	2.90	Good

By comparing the EI values from simulations 1 and 2, it could be seen that by prioritizing the flooding flowrate in sewer indicator even more — i.e. by increasing its weight — , the groups of measures EI increased. On the other hand, only GM_4 changes its category. The EI increase was expected because all groups of measures were able to achieve this indicator vision in at least two scenarios, whilst the vision for all the pollutant loading rates indicators were achieved by just GM_5.

It is entirely consistent with results from simulation 3, in which the weights for the pollutant loading rates indicators were bigger. Once the visions were more difficult to achieve, the EI value should decrease for all groups of measures. In this case, GM_1, GM_2, and GM_5 change their categories.

Finally, on simulation 4 the EI for all groups of measures were reduced as well. The only change was a small increase in TKN loading rate weight. There was changes in GM_1 and GM_2 categories. It can be explained by taking into account that the permeable equivalent area indicator — which was removed in this simulation — vision is achieved in two and four scenarios by these groups of measures, respectively. On the other hand, the TKN loading rate indicator vision was not achieved in any scenario by GM_1, and just in one scenario by GM_2.

As demonstrated, the EI values can be changed depending on the set indicators weights and depending on the indicators themselves. Therefore, when planning the area interventions it is important to discuss with all stakeholders together in order to prioritize the indicators which are being considered in the analysis. Notwithstanding, it is recommended a bottom-up approach (DIAS; CURWELL; BICHARD, 2014) when planning the measures to avoid that projects fail because of non-acceptance of the community.

7.6.3 Effect of reduction of distribution water losses on the effectiveness index value – simulations 5, and 6

Two other simulations were performed in order to verify the UWU Model response whist changing the group of measures. Once the first simulation considered no measures in water supply system, it was assumed that over the next thirty years the sanitation company could invest on distribution water loss control in order to reduce it to the level of developed countries. Thereafter, it was assumed a 20% reduction in water losses in the next thirty years.

In simulation 5, the groups of measures were kept the same and it was added the water loss reduction. On the other hand, simulation 6 considered the effect of the distribution water loss reduction only — i.e. the groups of measures do not have rainwater harvesting as a measure. All other parameters were kept the same as the simulation 1.

The outputs from UWU Model application can be seen in Appendix B.6, Table B.26, and Table B.27 for simulations 5, and 6, respectively. New effectiveness index for all groups of measures are shown in Table 7.12.

TABLE 7.12: Integrated evaluation based on the Effectiveness Index for simulations 5, and 6

Group of	Simulation 1		Simulation 5		Simulation 6	
measures	EI	Category	EI	Category	EI	Category
GM_0	0.00	Poor	0.00	Poor	0.00	Poor
GM_1	1.30	Insufficient	1.45	Insufficient	0.65	Poor
GM_2	2.05	Reasonable	2.35	Reasonable	1.30	Insufficient
GM_3	0.80	Poor	1.10	Poor	1.10	Poor
GM_4	1.95	Insufficient	2.25	Insufficient	1.30	Insufficient
GM_5	3.00	Good	3.30	Good	1.40	Insufficient

As can be seen, the EI values from simulation 5 increased for all groups of measures despite it did not affect their category. The small change in EI values is probably related to the fact that the distribution water loss reduction over the years just changes the water supply system coverage indicator and it has not a high weight in this simulation, which means that it does not greatly contribute in the final EI values. Despite of that, simulation 5 showed the best results from all simulations.

On the other hand, simulation 6 showed the worst results of all the performed simulations. As can be inferred, the rainwater harvesting measure was one of the most efficient to control the indicators values. In the flooding flowrate control, it is important to note that it was considered an efficiency of 40% following the literature data. Local research should be conducted in order to ascertain whether such reduction rate are acceptable. Nevertheless, the parameter could be changed and more simulations could be performed to verify its effect on the EI values.

Another important issue was the effective drinkable water per capita consumption estimation. Although the study area presents a rather high per capita income, the estimated qe_j values were very high for future scenarios. The main problems with these estimates are related to the fact that the equations are linear and long-term studies can be overestimated. To ensure better estimations on water consumption, site specific data has to be collected and the equations parameters have to be site specific.

Despite of that, once the qe_j estimations are proportional by scenario, changing the equation parameters will modify all the values in the scenarios and it will affect all groups of measures. Therefore, it is possible to say that the results will be proportional and the group of measures ranking will remain the same, despite it could change the group of measures categories once it will reduce the EI values.

As aforementioned, the detention measures — stormwater detention basins and the rainwater harvesting — were the most effective to control the runoff flow as well as the pollutant loading rates in the study area. However, these measures cannot account for other important aspects when planning SuDS measures such as amenity and biodiversity aspects. Indicators implementation that can express these aspects could be interesting in order to better evaluate the measures by considering their multiple benefits.

8 FINAL REMARKS

Thesis main contribution was to adapt the UWU Model and provide a general methodology in order to evaluate sustainable drainage measures in a strategic and integrated environment. The model results could be used to help decision-making and support urban planning in the basin context with a more sustainable vision on provided sanitation services. Notwithstanding, model application can encourage stakeholder engagement in coping with urbanization and impermeabilization issues in urban areas. Finally, from the results and discussion chapters (chapter 6 and chapter 7) it was possible to answer the main formulated questions, which have guided the development of this thesis, as follow:

1. By using the structure provided by UWU Model, it was possible to evaluate groups of drainage measures changing the original scenarios formulation approach. Firstly, the design rainfall external factor was added, which was essential to scenarios formulation and on drainage measures evaluation. The formulation approach led to the elaboration of four future scenarios by a combination of two states — a minimum and a maximum — for each external factor. The states for each external factor were established based on reported data by appropriate agencies in order to provide credible scenarios for the measures evaluation. At the same time, a current scenario was formulated to compare the results and show the worsening of the indicators over the years.

2. The implemented indicators were the maximum flowrate in the critical sewer, the equivalent permeable area, and the pollutant loading rates in a control point. It was considered the following pollutants: total suspended solids, biochemical oxygen demand, total Kjeldahl nitrogen, and total phosphorus. These indicators cover only the flooding mitigation, water quality and flow regime restoration aspects. Therefore, additional indicators can be added to reflect other SuDS benefits such as recreation, aesthetics and microclimate amelioration as mentioned in section 3.4. Further development should also implement an economic indicator to better rank the group of measures taking into account their cost-benefit.

3. The main links between the drainage measures, indicators, and external factors were determined. In the rainwater harvesting measure case, the link with the water supply system coverage indicator was done using the water consumption by appliance parametrization table in order to estimate the effect in using the rainwater on-site. Considering the rainwater usage for toilet flushing, garden watering, and other outside usages, it was possible to estimate the reduction in effective drinkable water per capita consumption and generalize the data for the area in order to estimate the new area water consumption. Finally, the measure impact on water supply system could be estimated by the water supply system coverage indicator.

4. The UWU Model provides an environment to plan and select the best group of measures to contribute to urban areas' sustainability. The main steps are the scenarios formulation, which should take into account projections made by appropriate agencies and organizations. Then, considering current estimations and the desired future for the study area, indicators have to be selected and the weights have to be set. In this step, stakeholder discussion and community engagement can be used to determine the priorities. Next step is to locate, plan and pre-design all the drainage measures that could be implemented within the area. Again, the community engagement is overriding because they will be directly affected by the measures implementation. Finally, the simulations can be performed in order to rank the groups of measures and help decision-making. The best group of measure is the one that has the greatest EI. On the other hand, it does not mean that such a group must be the one that will be implemented in the area because a cost analysis should be performed, but the ranking points the group of measures that contributes more to the sustainability of the area. Notwithstanding, other sustainability aspects could be assessed by implementing other indicators.

FINIS

This page was intentionally left blank

REFERENCES

ABNT. **NBR 9648: Estudo de concepção de sistemas de esgoto sanitário**. Rio de Janeiro: Associação Brasileira de Normas Técnicas, 1986. 5 p.

ABNT. **NBR 9649: Projeto de redes coletoras de esgoto sanitário**. Rio de Janeiro: Associação Brasileira de Normas Técnicas, 1986. 7 p.

ABNT. **NBR 12207: Projeto de interceptores de esgoto sanitário**. Rio de Janeiro: Associação Brasileira de Normas Técnicas, 1992. 3 p.

AIDE, T. M.; GRAU, H. R. Globalization, Migration and Latin American Ecosystems. **Science**, v. 305, n. September, p. 1915–1916, 2004.

ALLISON, M.; KAYE, J. **Strategic Planning for Nonprofit Organizations: A Practical Guide and Workbook**. 2. ed. New Jersey, NJ: John Wiley & Sons, Inc., 2005. 480 p. ISBN 978-0-471-44581-4.

ALMEIDA, M. C.; BUTLER, D.; DAVIES, J. W. Modelling in-sewer changes in wastewater quality under aerobic conditions. **Water Science and Technology**, v. 39, n. 9, p. 63–71, 1999.

BACH, P. M. **UrbanBEATS: A virtual urban water system tool for exploring strategic planning scenarios**. 335 p. Thesis (Water for liveability) — Monash University, 2014.

BACH, P. M.; MCCARTHY, D. T.; DELETIC, A. Modelling the Dynamics of Water Sensitive Planning for a Suburban Area in Melbourne, Australia. In: **13th International Conference on Urban Drainage, Urban drainage in the context of Integrated Urban Water Management: A bridge between developed and developing countries**. Kuching, Sarawak, Malaysian Borneo: IWA/IAHR, 2014. p. 1–8.

BACH, P. M. et al. A critical review of integrated urban water modelling - Urban drainage and beyond. **Environmental Modelling & Software**, v. 54, p. 88–107, abr. 2014. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S1364815213003216>.

BALLING, R. C.; GOBER, P. Climate variability and residential water use in the city of Phoenix, Arizona. **Journal of Applied Meteorology and Climatology**, v. 46, n. 7, p. 1130–1137, 2007.

BAPTISTA, M.; NASCIMENTO, N.; BARRAUD, S. **Técnicas Compensatórias em Drenagem Urbana**. 2. ed. Porto Alegre, RS: ABRH, 2011. 318 p. ISBN 9788588686151.

BARBOSA, A. E.; FERNANDES, J. N.; DAVID, L. M. Key issues for sustainable urban stormwater management. **Water Research**, v. 46, n. 20, p. 6787–6798, dez. 2012. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/22687523>.

BENEDICT, M. A.; MCMAHON, E. A. **Green Infrastructure: Linking Landscapes and Communities**. 1. ed. Washington, DC: Island Press, 2006. 320 p. ISBN 978-1559635585.

BENEDICT, M. A.; MCMAHON, E. T. **Green Infrastructure: Smart Conservation for the 21st Century**. Washington, DC, 2002. 36 p. Available at: <http://www.sprawlwatch.org-/green/>.

BERNDTSSON, J. C. Green roof performance towards management of runoff water quantity and quality: A review. **Ecological Engineering**, v. 36, n. 4, p. 351–360, abr. 2010. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S0925857410000029>.

BRAGA, B. P. F.; PORTO, M. F. A.; SILVA, R. T. Water Management in Metropolitan São Paulo. **Water Resources Development**, v. 22, n. 2, p. 337–352, jun. 2006. Available at: <http://www.tandfonline.com/doi/abs/10.1080/07900620600649850>.

BRASIL. **Lei nº 11.445, de 5 de Janeiro de 2007. Estabelece diretrizes nacionais para o saneamento básico**. Brasilia, DF: Diário Oficial da União, 2007.

BRATTEBO, B. O.; BOOTH, D. B. Long-term stormwater quantity and quality performance of permeable pavement systems. **Water Research**, v. 37, n. 18, p. 4369–4376, nov. 2003. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/14511707>.

BRAUD, I.; FLETCHER, T.; ANDRIEU, H. Hydrology of peri-urban catchments: Processes and modelling. **Journal of Hydrology**, v. 485, p. 1–4, abr. 2013. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S0022169413001686>.

BRAUNE, M. J.; WOOD, A. Best Management Practices applied to urban runoff quantity and quality control. **Water Science and Technology**, v. 39, n. 12, p. 117–121, 1999.

BRITES, A. P. Z.; GASTALDINI, M. d. C. C. Avaliação da Carga Difusa da Drenagem Pluvial Urbana na Bacia Hidrográfica Cancela. In: **23º Congresso Brasileiro de Engenharia Sanitária e Ambiental**. Campo Grande, MS: ABES, 2005. p. 1–8.

BROMBACH, H.; WEISS, G.; FUCHS, S. A new database on urban runoff pollution: comparison of separate and combined sewer systems. **Water Science and Technology**, v. 51, n. 2, p. 119–28, jan. 2005. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/15790235>.

BRUGGEMAN, W.; DAMMERS, E. **Deltascenario's voor 2050 en 2100**. [S.l.], 2013. 65 p.

BRYSON, J. M. **Strategic Planning for Public and Nonprofit Organizations: A Guide to Strengthening and Sustaining Organizational Achievement**. 4. ed. San Francisco, CA: Jossey-Bass, 2011. 576 p. ISBN 0470392517.

BURN, S.; MAHEEPALA, S.; SHARMA, A. Utilising integrated urban water management to assess the viability of decentralised water solutions. **Water Science and Technology**, v. 66, n. 1, p. 113–21, jan. 2012. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/22678207>.

BUTLER, D.; DAVIES, J. W. **Urban Drainage**. 2nd. ed. London: Spon Press, 2004. 543 p. ISBN 0203149696.

CAMPANA, N. A.; TUCCI, C. E. M. Estimativa da área impermeável de macro-bacias urbanas. **Revista Brasileira de Engenharia**, v. 12, n. 2, p. 79–94, 1994.

CAMPISANO, A. et al. Potential for peak flow reduction by rainwater harvesting tanks. **Procedia Engineering**, v. 89, p. 1507–1514, 2014. Available at: <http://dx.doi.org/10.1016/j-.proeng.2014.11.441>.

CASTLETON, H. F. et al. Green roofs; building energy savings and the potential for retrofit. **Energy and Buildings**, v. 42, n. 10, p. 1582–1591, out. 2010. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S0378778810001453>.

CHOW, J.-f. et al. Using a Systematic, Multi-criteria Decision Support Framework to Evaluate Sustainable Drainage Designs. **Procedia Engineering**, v. 70, p. 343–352, 2014. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S1877705814000411>.

CIRIA. **Demonstrating the multiple benefits of SuDS - a business case**. [S.l.], 2014. 45 p.

CNT. **The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental and Social Benefits**. [S.l.], 2010. 80 p.

COOMBES, P. J.; KUCZERA, G. Analysis of the Performance of Rainwater Tanks in Australian Capital Cities. In: **28th International Hydrology and Water Resources Symposium**. Wollongong, Australia: Institution of Engineers, 2003. p. 1–8.

CRUZ, M. A. S.; SOUZA, C. F.; TUCCI, C. E. M. Control of urban drainage in Brazil: advances and mechanisms for its sustainability. In: **Proceedings of XVII Brazilian Symposium on Water Resources**. São Paulo: CD-ROM, 2007.

CURRIE, B. A.; BASS, B. **Using Green Roofs to enhance Biodiversity in the City of Toronto**. Toronto, CA: Toronto, 2010. 47 p.

D'ARCY, B.; FROST, A. The role of best management practices in alleviating water quality problems associated with diffuse pollution. **The Science of the total environment**, v. 265, n. 1-3, p. 359–67, jan. 2001. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/11227278>.

DAVIS, A. P. Field Performance of Bioretention: Hydrology Impacts. **Journal of Hydrologic Engineering**, v. 13, n. 2, p. 90–95, 2008.

DIAS, D. M.; MARTINEZ, C. B.; LIBÂNIO, M. Avaliação do impacto da variação da renda no consumo domiciliar de água. **Engenharia Sanitaria e Ambiental**, v. 15, n. 2, p. 155–166, 2010.

DIAS, N.; CURWELL, S.; BICHARD, E. The Current Approach of Urban Design, its Implications for Sustainable Urban Development. **Procedia Economics and Finance**, v. 18, p. 497–504, 2014. Available at: <http://linkinghub.elsevier.com/retrieve/pii-/S221256711400968X>.

DICKIE, S. et al. **Planning for SuDs – making it happen (C687)**. CIRIA, 2010. 112 p.

DIETZ, M. E.; CLAUSEN, J. C. Stormwater runoff and export changes with development in a traditional and low impact subdivision. **Journal of Environmental Management**, v. 87, p. 560–566, 2008.

DUCHENE, M.; MCBEAN, E. A.; THOMSON, N. R. Modeling of infiltration from trenches for storm-water control. **Journal of Water Resources Planning and Management**, v. 120, n. 3, p. 276–293, 1994.

ECOTEC. **The economic benefits of Green Infrastructure: The public and business case for investing in Green Infrastructure and a review of the underpinning evidence**. England, 2008. 98 p.

EDWIGES, T. **Avaliação temporal da carga orgânica transportada no Rio Belém, estação Prado Velho, Curitiba/PR, em eventos de chuvas**. 82 p. Thesis (Dissertation) — Pontifícia Universidade Católica do Paraná, 2007.

ELLIOTT, A. H.; TROWSDALE, S. A. A review of models for low impact urban stormwater drainage. **Environmental Modelling & Software**, v. 22, n. 3, p. 394–405, mar. 2007. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S1364815206000053>.

EU. **Water Framework Directive 2000/60/EC**. United Nations, 2000.

FARAHBAKHSH, K.; DESPINS, C.; LEIDL, C. Innovative Approaches to Stormwater Management in Canada. **Water Quality Research Journal of Canada**, v. 44, n. 1, p. 92–102, 2009.

FENDRICH, R. **Coleta, armazenamento, utilização e infiltração das águas pluviais na drenagem urbana**. 546 p. Thesis (PhD) — Federal University of Paraná, 2002.

FENDRICH, R. **Canais de drenagem em pequenas bacias hidrográficas**. 1st. ed. Curitiba: Fendrich, 2008. 121 p.

FENDRICH, R. et al. **Drenagem e controle da erosão urbana**. 4. ed. Curitiba: Champagnat, 1997. 486 p.

FILHO, F. C. M. d. M.; TUCCI, C. E. M. Alteração na relação entre densidade habitacional e área impermeável: Porto Alegre-RS. **Revista de Gestão de Água da América Latina**, v. 9, n. 1, p. 49–55, 2012.

FLETCHER, T. D.; ANDRIEU, H.; HAMEL, P. Understanding, management and modelling of urban hydrology and its consequences for receiving waters: A state of the art. **Advances in Water Resources**, v. 51, p. 261–279, 2013. Available at: <http://dx.doi.org/10.1016/j-.advwatres.2012.09.001>.

FLETCHER, T. D. et al. SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. **Urban Water Journal**, p. 1–18, jul. 2014. Available at: <http://www.tandfonline.com/doi/abs/10.1080/1573062X.2014.916314>.

FOSTER, J.; LOWE, A.; WINKELMAN, S. **The value of Green Infrastructure for urban climate adaptation**. Washington, DC, 2011. 52 p.

FUCHS, S.; BROMBACH, H.; WEIS, G. New database on urban runoff pollution. In: **Novatech, 5th International Conference on Sustainable Techniques and Strategies for Urban Water Management**. Lyon, France: IWA Publishing, 2004. p. 145–152.

GERMANO, A.; TUCCI, C. E. M.; SILVEIRA, A. L. L. Estimativa dos parâmetros do modelo IPH II para algumas bacias urbanas brasileiras. **Revista Brasileira de Recursos Hídricos**, v. 3, n. 4, p. 103–120, 1998.

GESSNER, M. O. et al. Urban water interfaces. **Journal of Hydrology**, v. 514, p. 226–232, jun. 2014. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S0022169414002959>.

GHISI, E.; BRESSAN, D. L.; MARTINI, M. Rainwater tank capacity and potential for potable water savings by using rainwater in the residential sector of southeastern Brazil. **Building and Environment**, v. 42, n. 4, p. 1654–1666, 2007.

GIUSTI, D. A. **Contribuição a geologia ambiental no município de Curitiba – PR**. 115 p. Thesis (Dissertation) — Universidade de São Paulo, 1989.

GOLDENFUM, J. A. et al. Challenges for the Sustainable Urban Stormwater Management in Developing Countries: From basic education to technical and institutional issues. In: **Novatech, 6th International Conference on Sustainable Techniques and Strategies for Urban Water Management**. Lyon, France: IWA Publishing, 2007. p. 1–8.

GREGOIRE, B. G.; CLAUSEN, J. C. Effect of a modular extensive green roof on stormwater runoff and water quality. **Ecological Engineering**, v. 37, n. 6, p. 963–969, jun. 2011. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S0925857411000693>.

GUO, J. C. Y. Detention basin sizing for Small urban catchments. **Journal of Water Resources Planning and Management**, v. 125, n. 6, p. 5, 1999.

HADDAD, E. A.; TEIXEIRA, E. Economic impacts of natural disasters in megacities: The case of floods in São Paulo, Brazil. **Habitat International**, v. 45, p. 106–113, 2015. Available at: <http://dx.doi.org/10.1016/j.habitatint.2014.06.023>.

HÁK, T.; MOLDAN, B.; DAH, A. L. **Sustainability Indicators: A Scientific Assessment**. 1. ed. Washington, DC: Island Press, 2007. 448 p. ISBN 1597261319.

HARDY, M. J.; COOMBES, P. J.; KUCZERA, G. An investigation of estate level impacts of spatially distributed rainwater tanks. In: **WSUD 2004: Cities as Catchments; International Conference on Water Sensitive Urban Design**. Adelaide: Barton, A.C.T.: Engineers Australia, 2004. p. 492–503.

HOYER, J. et al. **Water Sensitive Urban Design: Principles and Inspiration for Sustainable Stormwater Management in the City of the Future**. 1. ed. Hamburg: JOVIS Verlag, 2011. 118 p. ISBN 978-3868591064.

HUNT, W. F. et al. Pollutant Removal and Peak Flow Mitigation by a Bioretention Cell in Urban Charlotte, N.C. **Journal of Environmental Engineering**, v. 134, n. 5, p. 403–408, 2008.

IAP. **Monitoramento da qualidade das águas dos rios da Bacia do Alto Iguaçu, na Região Metropolitana de Curitiba, no período de 2005 a 2009**. Curitiba, 2009. 114 p.

IBGE. **Censo Demográfico 2000**. Rio de Janeiro, 2002.

IBGE. **Censo Demográfico 2010**. Rio de Janeiro, 2013.

INMET. **Normais climatológicas do Brasil, período 1961-1990**. 2015.

IPCC. **Climate Change 2007: Synthesis Report**. Valencia, Spain, 2007a. 52 p.

IPCC. **Climate Change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change**. Cambridge, UK, 2007b. 976 p.

IPHRS. **Plano diretor de drenagem urbana: Manual de drenagem urbana**. Porto Alegre, RS, 2005. VI, 167 p.

ITB. **Ranking do Saneamento**. [S.l.], 2013. 86 p. Available at: <http://www.tratabrasil.org-.br/datafiles/uploads/pdfs/relatorio-completo-GO.pdf>.

JACOBI, P. R.; BESEN, G. R. Gestão de resíduos sólidos em São Paulo: desafios da sustentabilidade. **Estudos Avançados**, v. 25, n. 71, p. 135–158, 2011.

JAYASOORIYA, V. M.; NG, A. W. M. Tools for Modeling of Stormwater Management and Economics of Green Infrastructure Practices: a Review. **Water Air & Soil Pollution**, v. 225, n. 8, p. 2055, jul. 2014. Available at: <http://link.springer.com/10.1007/s11270-014-2055-1>.

KADLEC, R. H.; KNIGHT, R. L. **Treatment wetlands**. Boca Raton, Florida: CRC Press/Lewis Publishers, 1996. 893 p. ISBN 0-87371-930-1.

KAREIVA, P. et al. Domesticated nature: shaping landscapes and ecosystems for human welfare. **Science**, v. 316, n. 5833, p. 1866–9, jun. 2007. Available at: <http://www.ncbi.nlm-.nih.gov/pubmed/17600209>.

KELLAGHER, R.; UDALE-CLARKE, H. Sustainability Criteria for the Design of Stormwater Drainage Systems for the 21st Century. In: **11th International Conference on Urban Drainage**. Edingburgh, Scotland, UK: IWA, 2008. p. 1–10.

KOLSKY, P.; BUTLER, D. Performance indicators for urban storm drainage in developing countries. **Urban Water**, v. 4, p. 137–144, 2002.

KRAMER, R. D. et al. Determinação de anti-inflamatórios na água e sedimento e suas relações com a qualidade da água na bacia do Alto Iguaçu, Curitiba-PR. **Revista Brasileira de Recursos Hídricos**, v. 20, n. 3, p. 657–667, 2015.

Le COUSTUMER, S. et al. The influence of design parameters on clogging of stormwater biofilters: A large-scale column study. **Water Research**, v. 46, n. 20, p. 6743–6752, 2012.

LEE, J. G. et al. A watershed-scale design optimization model for stormwater best management practices. **Environmental Modelling & Software**, v. 37, p. 6–18, nov. 2012. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S1364815212001387>.

LEE, T. R. Urban water management for better urban life in Latin America. **Urban Water**, v. 2, p. 71–78, mar. 2000. Available at: <http://linkinghub.elsevier.com/retrieve/pii-/S1462075800000418>.

LIU, Y. B.; SMEDT, F. D. Flood Modeling for Complex Terrain Using GIS and Remote Sensed Information. **Water Resources Management**, v. 19, p. 605–624, 2005.

LUCKE, T.; NICHOLS, P. W. B. The pollution removal and stormwater reduction performance of street-side bioretention basins after ten years in operation. **Science of the Total Environment**, v. 536, p. 784–792, 2015. Available at: <http://dx.doi.org/10.1016/j.scitotenv-.2015.07.142>.

MAKROPOULOS, C. et al. Decision support for sustainable option selection in integrated urban water management. **Environmental Modelling & Software**, v. 23, n. 12, p. 1448–1460, dez. 2008. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S1364815208000698>.

MALMQVIST, P.-A. et al. **Strategic Planning of Sustainable Urban Water Management**. 1. ed. London: IWA Publishing, 2006. 284 p. ISBN 9781843391050.

MARENGO, J. A. **Mudanças Climáticas Globais e seus Efeitos sobre a Biodiversidade**. 2nd. ed. Brasília: Ministério do Meio Ambiente, 2007. 213 p. ISBN 8577380386.

MARLOW, D. R. et al. Towards sustainable urban water management: A critical reassessment. **Water Research**, v. 47, n. 20, p. 7150–7161, out. 2013. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/24210506>.

MARTIN, C.; RUPERD, Y.; LEGRET, M. Urban stormwater drainage management: The development of a multicriteria decision aid approach for best management practices. **European Journal of Operational Research**, v. 181, n. 1, p. 338–349, ago. 2007. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S0377221706004358>.

MEENE, S. J. van de; BROWN, R. R.; FARRELLY, M. A. Towards understanding governance for sustainable urban water management. **Global Environmental Change**, v. 21, n. 3, p. 1117–1127, ago. 2011. Available at: <http://linkinghub.elsevier.com/retrieve/pii-/S095937801100063X>.

MILLER, S. N. et al. Integrating landscape assessment and hydrologic modeling for land cover change analysis. **Journal Of The American Water Resources Association**, v. 38, n. 4, p. 915–929, 2002.

MITCHELL, V. G. Applying Integrated Urban Water Management Concepts: A Review of Australian Experience. **Environmental Management**, v. 37, n. 5, p. 589–605, 2006.

MORGAN, C. et al. **Water Sensitive Urban Design in the UK: ideas for built environmental practitiones**. London, 2013. 20 p.

MOSTERT, E. Integrated Water Resources Management in The Netherlands: How Concepts Function. **Journal of Contemporary Water Research & Education**, n. 135, p. 19–27, 2006.

NASCIMENTO, N. O.; BAPTISTA, M. B. Técnicas Compensatórias em Águas Pluviais. In: RIGHETTO, A. M. (Ed.). **Manejo de Águas Pluviais Urbanas**. 1. ed. ABES, Rio de Janeiro: Projeto PROSAB, 2009. cap. 4, p. 149–197.

NASCIMENTO, N. O.; ELLIS, J. B.; BAPTISTA, M. B. Using detention basins: operational experience and lessons. **Urban Water**, v. 1, p. 113–124, 1999.

NEVES, M. G. F. P. das; TUCCI, C. E. M. Resíduos Sólidos na Drenagem Urbana: Aspectos Conceituais. **Revista Brasileira de Recursos Hídricos**, v. 13, p. 125–135, 2008.

NIRUPAMA, N.; SIMONOVIC, S. P. Increase of Flood Risk due to Urbanisation: A Canadian Example. **Natural Hazards**, v. 40, n. 1, p. 25–41, set. 2007. Available at: <http://www.springerlink.com/index/10.1007/s11069-006-0003-0>.

NSW EPA. **Managing Urban Stormwater: Source Control**. Sydney, Australia, 1998. 88 p.

PEEL, M. C.; FINLAYSON, B. L.; MCMAHON, T. A. Updated world map of the Köppen-Geiger climate classification. **Hydrology and Earth System Sciences**, v. 11, n. 5, p. 1633–1644, oct 2007. Available at: <http://www.hydrol-earth-syst-sci.net/11/1633/2007/>.

PIEL, C.; PIRE, M.; MAYTRAUD, T. La maîtrise, le traitement et la récupération des eaux pluviales, supports d'une ville bioclimatique: 4 études de cas. In: **Novatech, 7th International Conference on Sustainable Techniques and Strategies for Urban Water Management**. Lyon, France: IWA Publishing, 2010. p. 1–10.

PLANEPAR. **Relatório preliminar de combate à erosão de Astorga**. Curitiba, 1977. 64 p.

POLETO, C. SUDS (Sustainable Urban Drainage Systems): Uma Contextualização Histórica. **Revista Thema**, v. 08, n. 01, p. 1–12, 2011.

PORTMANN, F. T. Hydrological runoff modelling by the use of remote sensing data with reference to the 1993-1994 and 1995 floods in the River Rhine Catchment. **Hydrological Processes**, v. 11, p. 1377–1392, 1997.

PÖTZ, H.; BLEUZÉ, P. **Urban green-blue grids for sustainable and dynamic cities**. 1. ed. Delft, Netherlands: Coop for Life, 2012. 608 p. ISBN 978-90-8188-040-4.

PROTOPAPAS, A. L.; KATCHAMART, S.; PLATONOVA, A. Weather effects on daily water use in New York city. **Journal of Hydrologic Engineering**, v. 5, n. 3, p. 332–338, 2000.

RAGSDALE, F. **Wastewater System Operator's Manual**. Texas, 2002. 1-34 p. Available at: <http://www.ragsdaleandassociates.com/WastewaterStudy.htm>.

RIGHETTO, A. M. **Manejo de águas pluviais urbanas**. Rio de Janeiro: Projeto PROSAB: ABES, RiMa, 2009. 396 p. ISBN 978-85-7022-162-9.

RIJSBERMAN, F. R. Water scarcity: Fact or fiction? **Agricultural Water Management**, v. 80, n. 1-3, p. 5–22, fev. 2006. Available at: <http://linkinghub.elsevier.com/retrieve/pii-/S0378377405002854>.

SÃO PAULO. **Manual de drenagem e manejo de águas pluviais - Gerenciamento do sistema de drenagem urbana**. São Paulo, SP, 2012a. 168 p.

SÃO PAULO. **Manual de drenagem e manejo de águas pluviais - Aspectos tecnológicos: Fundamentos**. São Paulo, SP, 2012b. 220 p.

SAGHAFIAN, B. et al. Flood Intensification due to Changes in Land Use. **Water Resources Management**, v. 22, n. 8, p. 1051–1067, ago. 2007. Available at: <http://www.springerlink-.com/index/10.1007/s11269-007-9210-z>.

SANTAMOURIS, M. et al. Investigating and analysing the energy and environmental performance of an experimental green roof system installed in a nursery school building in Athens, Greece. **Energy**, v. 32, n. 9, p. 1781–1788, set. 2007. Available at: <http://linkinghub-.elsevier.com/retrieve/pii/S036054420600329X>.

SANTOS, D. C. dos; BENETTI, A. Application of the urban water use model for urban water use management purposes. **Water Science and Technology**, v. 70, n. 3, p. 407–13, jan. 2014. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/25098868>.

SANTOS, D. C. dos; STEEN, P. van der. **Understanding the IUWM principles: An Activity Based on Role Play Approach (for facilitator and specialists)**. Delft, Netherlands, 2011. 66 p.

SCHOLZ, M.; GRABOWIECKI, P. Review of permeable pavement systems. **Building and Environment**, v. 42, n. 11, p. 3830–3836, nov. 2007. Available at: <http://linkinghub-.elsevier.com/retrieve/pii/S0360132306004227>.

SCHUELER, T. **Controlling urban runoff: a practical manual for planning and designing urban BMPs**. Washington, DC, 1987.

SHUSTER, W. D. et al. Impacts of impervious surface on watershed hydrology: A review. **Urban Water Journal**, v. 2, n. 4, p. 263–275, dez. 2005. Available at: <http://www-.tandfonline.com/doi/abs/10.1080/15730620500386529>.

SHUTES, R. B. E. Artificial wetlands and water quality improvement. **Environment international**, v. 26, n. 5-6, p. 441–447, maio 2001. ISSN 0160-4120. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/11392764>.

SILVEIRA, A. L. L. Problems of modern urban drainage in developing countries. **Water Science and Technology**, v. 45, n. 7, p. 31–40, jan. 2002. Available at: <http://www.ncbi-.nlm.nih.gov/pubmed/11989890>.

SIMERSON, B. K. **Strategic Planning: A Practical Guide to Strategy Formulation and Execution**. 1. ed. Santa Barbara, CA: Praeger Publishers, 2011. 282 p. ISBN 0313384800.

SITZENFREI, R.; MÖDERL, M.; RAUCH, W. Assessing the impact of transitions from centralised to decentralised water solutions on existing infrastructures-integrated city-scale analysis with VIBe. **Water Research**, v. 47, n. 20, p. 7251–63, dez. 2013.

SNIS. **Diagnóstico dos serviços de água e esgotos: Sistema Nacional de Informações sobre Saneamento 2013**. Brasilia, 2013.

SOMES, N. L. G.; FABIAN, J.; WONG, T. H. F. Tracking pollutant detention in constructed stormwater wetlands. **Urban Water**, v. 2, p. 29–37, 2000.

SPERLING, M. von. **Princípios do Tratamento Biológico de Águas Residuárias: Introdução à qualidade das águas e ao tratamento de esgotos**. Belo Horizonte: Universidade Federal de Minas Gerais, Departamento de Engenharia Sanitária e Ambiental, 2005. 452 p.

STAATS, M. **Water avaliability and climate change: Chapman Creek Water System, Sunshine Coast, BC**. Thesis (Master) — University of British Columbia, 2014. Available at: <https://blogs.ubc.ca/mstaats8/>.

STEEN, P. van der et al. **SWITCH Approach to Strategic planning for Integrated Urban Water Management (IUWM)**. Delft, Netherlands, 2010. 39 p.

SUDERHSA. **Manual de Drenagem Urbana: Região Metropolitana de Curitiba/PR**. Curitiba, 2002. 1-150 p.

SURIYA, S.; MUDGAL, B. Impact of urbanization on flooding: The Thirusoolam sub watershed – A case study. **Journal of Hydrology**, v. 412-413, p. 210–219, jan. 2012. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S0022169411003180>.

TCHOBANOGLOUS, G.; BURTON, F. L.; STENSEL, H. D. **Wastewater engineering: treatment and reuse**. 4. ed. New York, NY: Metcalf & Eddy Inc - McGraw-Hill, 2003. 1819 p. ISBN 0-07-041878-0.

TRCA. **Performance Evaluation of Rainwater Harvesting Systems**. Toronto, Ontario, 2010. 75 p.

TROWSDALE, S. A.; SIMCOCK, R. Urban stormwater treatment using bioretention. **Journal of Hydrology**, v. 397, n. 3-4, p. 167–174, 2011. Available at: <http://dx.doi.org/10.1016/j-.jhydrol.2010.11.023>.

TSUTIYA, M. T.; SOBRINHO, P. A. **Coleta e Transporte de Esgoto Sanitário**. 3. ed. Rio de Janeiro: ABES - Associação Brasileira de Engenharia Sanitária e Ambiental, 2011. 548 p. ISBN 857022168-1.

TUCCI, C. E. M. **Integrated flood management - Brazil: flood management in Curitiba Metropolitan Area**. Curitiba, 2004. 10 p.

UNITED NATIONS. **Our common future**. New York, NY, 1987. 318 p.

UNITED NATIONS. **World Urbanization Prospects: The 2011 Revision**. New York, NY, 2011. 50 p.

UNITED NATIONS. **Human Development Report 2013 - The Rise of the South: Human Progress in a Diverse World**. New York, NY, 2013. 216 p.

UNITED STATES OF AMERICA. **Clean Water Act**. 1972. 816-903 p.

UNITED STATES OF AMERICA. **Clean Water Act**. 2002. 1-234 p.

USEPA. **Low Impact Development (LID): A Literature Review**. Washington, DC, 2000. 41 p.

VILLANUEVA, A. O. N. et al. Gestão da drenagem urbana, da formulação à implementação. **REGA**, v. 8, n. 1, p. 5–18, 2011.

WILLEMS, P. Parsimonious pollutant washoff and sewer transport modelling. In: **6th International Conference on Urban Drainage Modelling-UDM'04**. Dresden, Germany: Institute for Urban Water Management, 2004. p. 461–468.

WISE, S. et al. Integrating Valuation Methods to Recognize Green Infrastructure's Multiple Benefits. **Low Impact Development**, p. 1–21, 2010.

WONG, T. H. F. Water Sensitive Urban Design - the Journey Thus Far. **Australian Journal of Water Resources**, v. 10, n. 3, p. 213–222, 2006.

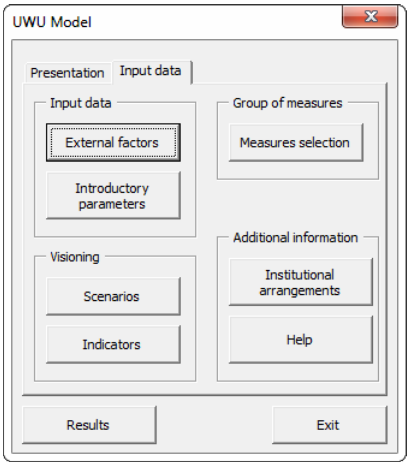
WOODS-BALLARD, B. et al. **The SuDS manual**. London: CIRIA, 2007. 606 p. ISBN 9780860176978.

WOODS-BALLARD, B. et al. **The SUDS manual**. London: CIRIA, 2015. 968 p. ISBN 9780860177609.

YANG, J.; YU, Q.; GONG, P. Quantifying air pollution removal by green roofs in Chicago. **Atmospheric Environment**, v. 42, n. 31, p. 7266–7273, out. 2008. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S1352231008006262>.

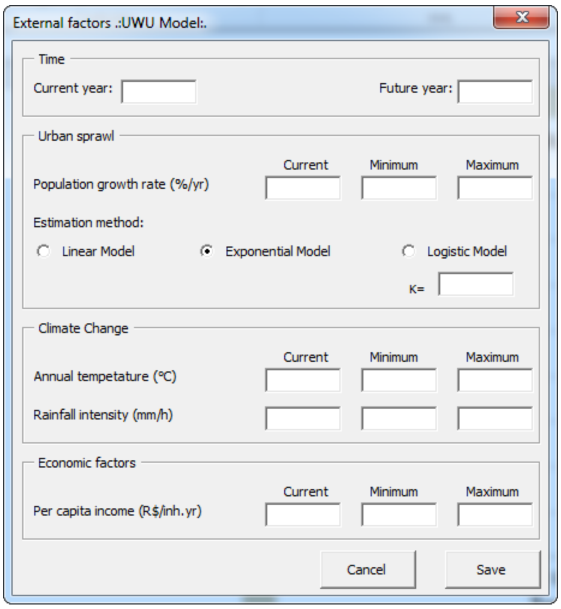
YONG, C. F.; MCCARTHY, D. T.; DELETIC, A. Predicting physical clogging of porous and permeable pavements. **Journal of Hydrology**, v. 481, p. 48–55, fev. 2013. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S0022169412010694>.

APPENDIX A – UWU MODEL'S INTERFACE



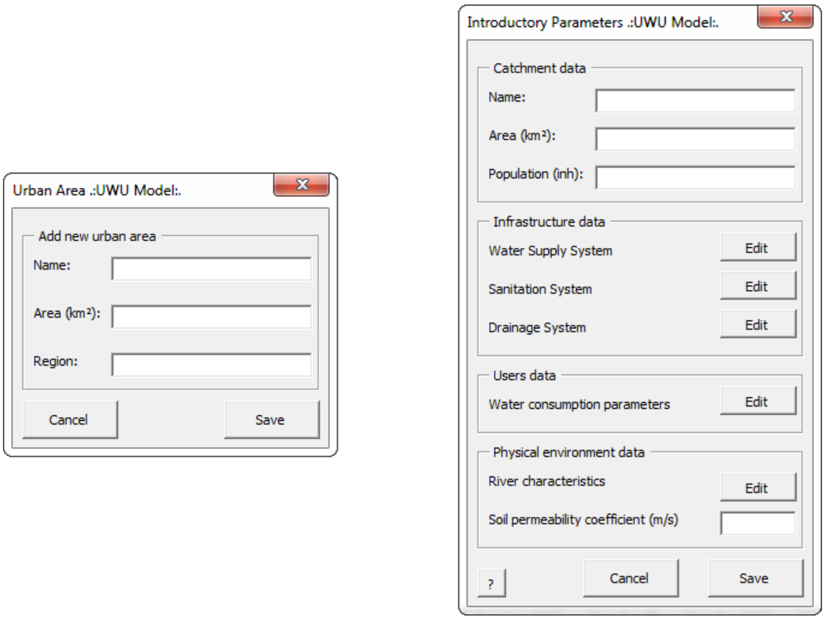
Source: the author

FIGURE A.1: UWU Model main menu's interface



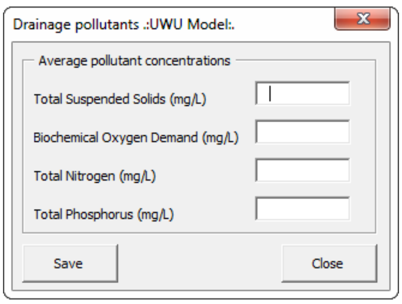
Source: the author

FIGURE A.2: External factors input data form



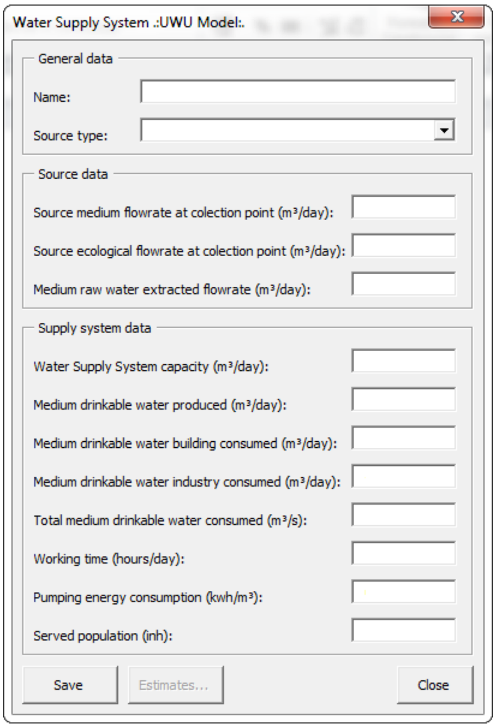
Source: the author

FIGURE A.3: Introductory parameters input data form



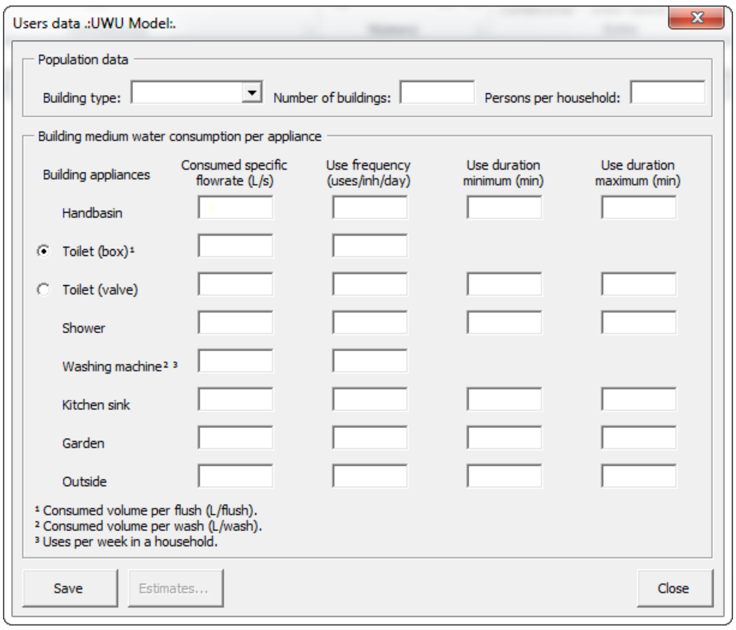
Source: the author

FIGURE A.4: Average drainage pollutant concentrations input data form



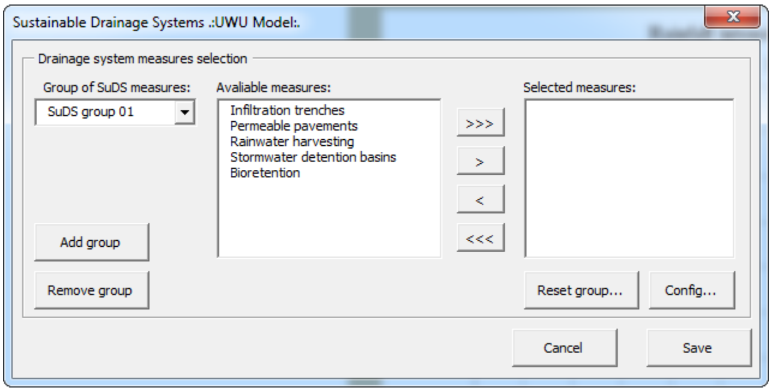
Source: the author

FIGURE A.5: Water supply systems input data form



Source: the author

FIGURE A.6: Parametrisation input data form



Source: the author

FIGURE A.7: SuDS selection interface

APPENDIX B – SUPPLEMENTARY MATERIAL

B.1 Basin concentration time estimation

Using data from 28 urban basins in Brazil, Germano, Tucci and Silveira (1998) have obtained the following empirical equation for the time of concentration:

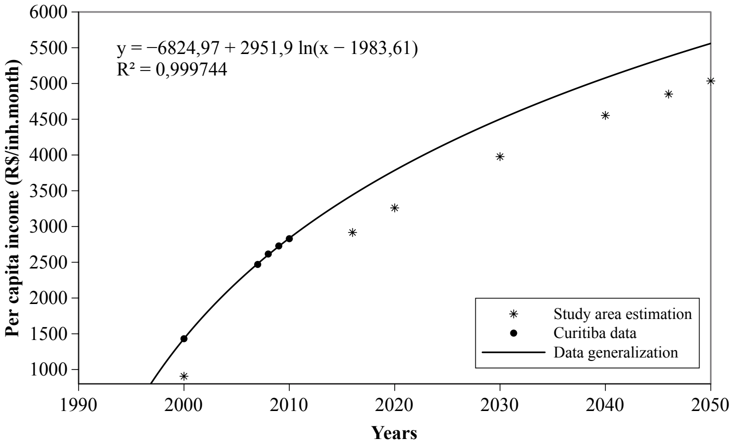
$$tc = 18.628 \times \frac{FL^{0.882}}{IA^{0.272}} \tag{B.1}$$

where tc is in min; FL is flow length in km; IA is the impervious basin area in km^2. The equation was obtained with $R^2 = 0.815$. Then, considering $FL = 1.4\ km$ and $IA = 0.497\ km^2$, it was possible to estimate the tc as follow:

$$tc = 18.628 \times \frac{1.4^{0.882}}{0.497^{0.272}}$$

$$tc \approx 30\ min$$

B.2 Per capita income generalization



Source: the author with data from IBGE (2013)

FIGURE B.1: Area per capita income generalization by using the Curitiba data

B.3 Summary of input data

TABLE B.1: Historical population for the current area of Curitiba

Parameter	**Value**
Current year (*inh*)	2016
Future year (*inh*)	2046
Current population (*inh*)	3959
People per building ($inh/building$)	3
Basin concentration time (*min*)	30
Precipitation duration (*min*)	30
Study basin land area (*he*)	208.44
Distribution water loss (%)	30
Area water supply system coverage (%)	100
Average roofs runoff coefficient	0.8
Average streets runoff coefficient	0.9
Infiltration coefficient (m/s)	0.005
BOD average concentration ($mg\ L^{-1}$)	13
TSS average concentration ($mg\ L^{-1}$)	141
TKN average concentration ($mg\ L^{-1}$)	2.4
TP average concentration ($mg\ L^{-1}$)	0.42

B.4 Drainage measures data

B.4.1 Infiltration trenches input data and estimations

TABLE B.2: Infiltration trenches input data and initial estimations

Infiltration trenches	**Length** (m)	**Width** (m)	**Depth** (m)	**Area** (m^2)	**Infiltr** (m^2)	Q_s (m^3/s)	**Input** (m^2)
IT_1	66.5	1.5	1.00	99.75	167.75	0.083875	2957
IT_2	15.3	1.5	1.00	22.95	39.75	0.019875	319
IT_3	19.9	1.1	1.00	21.89	42.89	0.021445	192
IT_4	8	1.1	1.00	8.80	17.9	0.00895	553
IT_5	15	1.1	1.00	16.50	32.6	0.0163	445
IT_6	28.3	1.1	1.00	31.13	60.53	0.030265	226
IT_7	20	1.1	1.00	22.00	43.1	0.02155	256
IT_8	25	1.8	1.00	45.00	71.8	0.0359	571
IT_9	68	1.8	1.00	122.40	192.2	0.0961	638
IT_{10}	49	1.2	1.00	58.80	109	0.0545	410
IT_{11}	15	1.1	1.00	16.50	32.6	0.0163	158
IT_{12}	24.3	1.1	1.00	26.73	52.13	0.026065	104
IT_{13}	68	1.8	1.00	122.40	192.2	0.0961	702
IT_{14}	31	1	1.00	31.00	63	0.0315	395
IT_{15}	33.5	1.3	1.00	43.55	78.35	0.039175	1081
IT_{16}	30.5	1.3	1.00	39.65	71.45	0.035725	348
IT_{17}	28.2	1.1	1.00	31.02	60.32	0.03016	313
IT_{18}	26.4	1.1	1.00	29.04	56.54	0.02827	257
IT_{19}	14.4	0.8	1.00	11.52	26.72	0.01336	303
IT_{20}	22.8	1.1	1.00	25.08	48.98	0.02449	243
IT_{21}	25	1.1	1.00	27.50	53.6	0.0268	210
IT_{22}	30.2	1.1	1.00	33.22	64.52	0.03226	143
IT_{23}	27.9	1.1	1.00	30.69	59.69	0.029845	165
IT_{24}	26.4	1.3	1.00	34.32	62.02	0.03101	231
IT_{25}	14.3	1.3	1.00	18.59	34.19	0.017095	182
IT_{26}	28.1	1.1	1.00	30.91	60.11	0.030055	123
IT_{27}	26.4	1.3	1.00	34.32	62.02	0.03101	154
IT_{28}	28.1	1.1	1.00	30.91	60.11	0.030055	161
IT_{29}	14.6	1.3	1.00	18.98	34.88	0.01744	131
IT_{30}	12.7	1.1	1.00	13.97	27.77	0.013885	181
IT_{31}	25.2	1.3	1.00	32.76	59.26	0.02963	219
IT_{32}	27.1	1.1	1.00	29.81	58.01	0.029005	211
IT_{33}	30.4	1.1	1.00	33.44	64.94	0.03247	231
IT_{34}	29.1	1.1	1.00	32.01	62.21	0.031105	211
IT_{35}	12.5	1.1	1.00	13.75	27.35	0.013675	161

TABLE B.3: Input flooding flowrate in the infiltration trenches devices by scenario

Infiltration	**Input flooding flowrate (m^3/s)**				
Trenches	**Current**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
IT_1	0.05590	0.07221	0.07221	0.08353	0.08353
IT_2	0.00603	0.00779	0.00779	0.00901	0.00901
IT_3	0.00363	0.00469	0.00469	0.00542	0.00542
IT_4	0.01045	0.01350	0.01350	0.01562	0.01562
IT_5	0.00841	0.01087	0.01087	0.01257	0.01257
IT_6	0.00427	0.00552	0.00552	0.00638	0.00638
IT_7	0.00484	0.00625	0.00625	0.00723	0.00723
IT_8	0.01079	0.01394	0.01394	0.01613	0.01613
IT_9	0.01206	0.01558	0.01558	0.01802	0.01802
IT_{10}	0.00775	0.01001	0.01001	0.01158	0.01158
IT_{11}	0.00299	0.00386	0.00386	0.00446	0.00446
IT_{12}	0.00197	0.00254	0.00254	0.00294	0.00294
IT_{13}	0.01327	0.01714	0.01714	0.01983	0.01983
IT_{14}	0.00747	0.00965	0.00965	0.01116	0.01116
IT_{15}	0.02044	0.02640	0.02640	0.03054	0.03054
IT_{16}	0.00658	0.00850	0.00850	0.00983	0.00983
IT_{17}	0.00592	0.00764	0.00764	0.00884	0.00884
IT_{18}	0.00486	0.00628	0.00628	0.00726	0.00726
IT_{19}	0.00573	0.00740	0.00740	0.00856	0.00856
IT_{20}	0.00459	0.00593	0.00593	0.00686	0.00686
IT_{21}	0.00397	0.00513	0.00513	0.00593	0.00593
IT_{22}	0.00270	0.00349	0.00349	0.00404	0.00404
IT_{23}	0.00312	0.00403	0.00403	0.00466	0.00466
IT_{24}	0.00437	0.00564	0.00564	0.00653	0.00653
IT_{25}	0.00344	0.00444	0.00444	0.00514	0.00514
IT_{26}	0.00233	0.00300	0.00300	0.00347	0.00347
IT_{27}	0.00291	0.00376	0.00376	0.00435	0.00435
IT_{28}	0.00304	0.00393	0.00393	0.00455	0.00455
IT_{29}	0.00248	0.00320	0.00320	0.00370	0.00370
IT_{30}	0.00342	0.00442	0.00442	0.00511	0.00511
IT_{31}	0.00414	0.00535	0.00535	0.00619	0.00619
IT_{32}	0.00399	0.00515	0.00515	0.00596	0.00596
IT_{33}	0.00437	0.00564	0.00564	0.00653	0.00653
IT_{34}	0.00399	0.00515	0.00515	0.00596	0.00596
IT_{35}	0.00304	0.00393	0.00393	0.00455	0.00455

TABLE B.4: Verification of overflow occurrence in the infiltration trenches devices by scenario

Infiltration	Overflow flowrate (m^3/s)				
Trenches	**Current**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
IT_1	-0.02798	-0.01167	-0.01167	-0.00035	-0.00035
IT_2	-0.01384	-0.01209	-0.01209	-0.01086	-0.01086
IT_3	-0.01782	-0.01676	-0.01676	-0.01602	-0.01602
IT_4	0.00150	0.00455	0.00455	0.00667	0.00667
IT_5	-0.00789	-0.00543	-0.00543	-0.00373	-0.00373
IT_6	-0.02599	-0.02475	-0.02475	-0.02388	-0.02388
IT_7	-0.01671	-0.01530	-0.01530	-0.01432	-0.01432
IT_8	-0.02511	-0.02196	-0.02196	-0.01977	-0.01977
IT_9	-0.08404	-0.08052	-0.08052	-0.07808	-0.07808
IT_{10}	-0.04675	-0.04449	-0.04449	-0.04292	-0.04292
IT_{11}	-0.01331	-0.01244	-0.01244	-0.01184	-0.01184
IT_{12}	-0.02410	-0.02353	-0.02353	-0.02313	-0.02313
IT_{13}	-0.08283	-0.07896	-0.07896	-0.07627	-0.07627
IT_{14}	-0.02403	-0.02185	-0.02185	-0.02034	-0.02034
IT_{15}	-0.01874	-0.01278	-0.01278	-0.00864	-0.00864
IT_{16}	-0.02915	-0.02723	-0.02723	-0.02589	-0.02589
IT_{17}	-0.02424	-0.02252	-0.02252	-0.02132	-0.02132
IT_{18}	-0.02341	-0.02199	-0.02199	-0.02101	-0.02101
IT_{19}	-0.00763	-0.00596	-0.00596	-0.00480	-0.00480
IT_{20}	-0.01990	-0.01856	-0.01856	-0.01763	-0.01763
IT_{21}	-0.02283	-0.02167	-0.02167	-0.02087	-0.02087
IT_{22}	-0.02956	-0.02877	-0.02877	-0.02822	-0.02822
IT_{23}	-0.02673	-0.02582	-0.02582	-0.02518	-0.02518
IT_{24}	-0.02664	-0.02537	-0.02537	-0.02448	-0.02448
IT_{25}	-0.01365	-0.01265	-0.01265	-0.01195	-0.01195
IT_{26}	-0.02773	-0.02705	-0.02705	-0.02658	-0.02658
IT_{27}	-0.02810	-0.02725	-0.02725	-0.02666	-0.02666
IT_{28}	-0.02701	-0.02612	-0.02612	-0.02551	-0.02551
IT_{29}	-0.01496	-0.01424	-0.01424	-0.01374	-0.01374
IT_{30}	-0.01046	-0.00947	-0.00947	-0.00877	-0.00877
IT_{31}	-0.02549	-0.02428	-0.02428	-0.02344	-0.02344
IT_{32}	-0.02502	-0.02385	-0.02385	-0.02304	-0.02304
IT_{33}	-0.02810	-0.02683	-0.02683	-0.02594	-0.02594
IT_{34}	-0.02712	-0.02595	-0.02595	-0.02514	-0.02514
IT_{35}	-0.01063	-0.00974	-0.00974	-0.00913	-0.00913

TABLE B.5: Flowrate subtraction by infiltration trench device by scenario

Infiltration	**Flowrate subtraction (m^3/s)**				
Trenches	**Current**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
IT_1	0.05590	0.07221	0.07221	0.08353	0.08353
IT_2	0.00603	0.00779	0.00779	0.00901	0.00901
IT_3	0.00363	0.00469	0.00469	0.00542	0.00542
IT_4	0.00895	0.00895	0.00895	0.00895	0.00895
IT_5	0.00841	0.01087	0.01087	0.01257	0.01257
IT_6	0.00427	0.00552	0.00552	0.00638	0.00638
IT_7	0.00484	0.00625	0.00625	0.00723	0.00723
IT_8	0.01079	0.01394	0.01394	0.01613	0.01613
IT_9	0.01206	0.01558	0.01558	0.01802	0.01802
IT_{10}	0.00775	0.01001	0.01001	0.01158	0.01158
IT_{11}	0.00299	0.00386	0.00386	0.00446	0.00446
IT_{12}	0.00197	0.00254	0.00254	0.00294	0.00294
IT_{13}	0.01327	0.01714	0.01714	0.01983	0.01983
IT_{14}	0.00747	0.00965	0.00965	0.01116	0.01116
IT_{15}	0.02044	0.02640	0.02640	0.03054	0.03054
IT_{16}	0.00658	0.00850	0.00850	0.00983	0.00983
IT_{17}	0.00592	0.00764	0.00764	0.00884	0.00884
IT_{18}	0.00486	0.00628	0.00628	0.00726	0.00726
IT_{19}	0.00573	0.00740	0.00740	0.00856	0.00856
IT_{20}	0.00459	0.00593	0.00593	0.00686	0.00686
IT_{21}	0.00397	0.00513	0.00513	0.00593	0.00593
IT_{22}	0.00270	0.00349	0.00349	0.00404	0.00404
IT_{23}	0.00312	0.00403	0.00403	0.00466	0.00466
IT_{24}	0.00437	0.00564	0.00564	0.00653	0.00653
IT_{25}	0.00344	0.00444	0.00444	0.00514	0.00514
IT_{26}	0.00233	0.00300	0.00300	0.00347	0.00347
IT_{27}	0.00291	0.00376	0.00376	0.00435	0.00435
IT_{28}	0.00304	0.00393	0.00393	0.00455	0.00455
IT_{29}	0.00248	0.00320	0.00320	0.00370	0.00370
IT_{30}	0.00342	0.00442	0.00442	0.00511	0.00511
IT_{31}	0.00414	0.00535	0.00535	0.00619	0.00619
IT_{32}	0.00399	0.00515	0.00515	0.00596	0.00596
IT_{33}	0.00437	0.00564	0.00564	0.00653	0.00653
IT_{34}	0.00399	0.00515	0.00515	0.00596	0.00596
IT_{35}	0.00304	0.00393	0.00393	0.00455	0.00455

B.4.2 Permeable pavements input data and estimations

TABLE B.6: Permeable pavements input data and initial estimations

Permeable Pavement	Length (m)	Width (m)	Area (m^2)	IArea (m^2)	R	n	Depth (m)	Sup.Inf (m^2)	Qs (m^3/s)
PP_1	30.6	2.8	85.68	175	2.04	0.03	0.5	102.38	0.05119
PP_2	55.4	11.5	637.1	1026	1.61	0.03	0.5	670.55	0.335275
PP_3	80.8	2.1	169.68	348	2.05	0.03	0.5	211.13	0.105565
PP_4	27.2	2.1	57.12	305	5.34	0.03	0.5	71.77	0.035885
PP_5	84	6	504	1143	2.27	0.03	0.5	549	0.2745
PP_6	115	40	4600	4600	1.00	0.03	0.5	4677.5	2.33875
PP_7	124	6	744	1585	2.13	0.03	0.5	809	0.4045
PP_8	10.4	2.1	21.84	55.2	2.53	0.03	0.5	28.09	0.014045
PP_9	35.4	2.1	74.34	297	4.00	0.03	0.5	93.09	0.046545
PP_{10}	87	2.1	182.7	531	2.91	0.03	0.5	227.25	0.113625
PP_{11}	12	4.2	50.4	223	4.42	0.03	0.5	58.5	0.02925
PP_{12}	26.7	3.3	88.11	174.1	1.98	0.03	0.5	103.11	0.051555
PP_{13}	21.8	3.3	71.94	149.8	2.08	0.03	0.5	84.49	0.042245
PP_{14}	80	2.1	168	399	2.38	0.03	0.5	209.05	0.104525
PP_{15}	-	-	860	1072	1.25	0.03	0.5	860	0.43
PP_{16}	115	6	690	2367	3.43	0.03	0.5	750.5	0.37525
PP_{17}	90	6	540	1737	3.22	0.03	0.5	588	0.294
PP_{18}	60.2	4.5	270.9	312	1.15	0.03	0.5	303.25	0.151625
PP_{19}	28	2.1	58.8	976	16.60	0.03	0.5	73.85	0.036925
PP_{20}	41	6	246	1043	4.24	0.03	0.5	269.5	0.13475

TABLE B.7: Input flooding flowrate in the permeable pavements devices by scenario

Infiltration	Input flooding flowrate (m^3/s)				
Trenches	Current	Scenario 1	Scenario 2	Scenario 3	Scenario 4
PP_1	0.00331	0.00427	0.00427	0.00494	0.00494
PP_2	0.01940	0.02505	0.02505	0.02898	0.02898
PP_3	0.00658	0.00850	0.00850	0.00983	0.00983
PP_4	0.00577	0.00745	0.00745	0.00862	0.00862
PP_5	0.02161	0.02791	0.02791	0.03229	0.03229
PP_6	0.08696	0.11233	0.11233	0.12994	0.12994
PP_7	0.02996	0.03870	0.03870	0.04477	0.04477
PP_8	0.00104	0.00135	0.00135	0.00156	0.00156
PP_9	0.00561	0.00725	0.00725	0.00839	0.00839
PP_{10}	0.01004	0.01297	0.01297	0.01500	0.01500
PP_{11}	0.00422	0.00545	0.00545	0.00630	0.00630
PP_{12}	0.00329	0.00425	0.00425	0.00492	0.00492
PP_{13}	0.00283	0.00366	0.00366	0.00423	0.00423
PP_{14}	0.00754	0.00974	0.00974	0.01127	0.01127
PP_{15}	0.02027	0.02618	0.02618	0.03028	0.03028
PP_{16}	0.04475	0.05780	0.05780	0.06686	0.06686
PP_{17}	0.03284	0.04242	0.04242	0.04907	0.04907
PP_{18}	0.00590	0.00762	0.00762	0.00881	0.00881
PP_{19}	0.01845	0.02383	0.02383	0.02757	0.02757
PP_{20}	0.01972	0.02547	0.02547	0.02946	0.02946

TABLE B.8: Verification of overflow occurrence in the permeable pavements devices by scenario

Infiltration	Overflow flowrate (m^3/s)				
Trenches	Current	Scenario 1	Scenario 2	Scenario 3	Scenario 4
PP_1	-0.04788	-0.04692	-0.04692	-0.04625	-0.04625
PP_2	-0.31588	-0.31022	-0.31022	-0.30629	-0.30629
PP_3	-0.09899	-0.09707	-0.09707	-0.09573	-0.09573
PP_4	-0.03012	-0.02844	-0.02844	-0.02727	-0.02727
PP_5	-0.25289	-0.24659	-0.24659	-0.24221	-0.24221
PP_6	-2.25179	-2.22642	-2.22642	-2.20881	-2.20881
PP_7	-0.37454	-0.36580	-0.36580	-0.35973	-0.35973
PP_8	-0.01300	-0.01270	-0.01270	-0.01249	-0.01249
PP_9	-0.04093	-0.03929	-0.03929	-0.03816	-0.03816
PP_{10}	-0.10359	-0.10066	-0.10066	-0.09863	-0.09863
PP_{11}	-0.02503	-0.02380	-0.02380	-0.02295	-0.02295
PP_{12}	-0.04826	-0.04730	-0.04730	-0.04664	-0.04664
PP_{13}	-0.03941	-0.03859	-0.03859	-0.03801	-0.03801
PP_{14}	-0.09698	-0.09478	-0.09478	-0.09325	-0.09325
PP_{15}	-0.40973	-0.40382	-0.40382	-0.39972	-0.39972
PP_{16}	-0.33050	-0.31745	-0.31745	-0.30839	-0.30839
PP_{17}	-0.26116	-0.25158	-0.25158	-0.24493	-0.24493
PP_{18}	-0.14573	-0.14401	-0.14401	-0.14281	-0.14281
PP_{19}	-0.01847	-0.01309	-0.01309	-0.00936	-0.00936
PP_{20}	-0.11503	-0.10928	-0.10928	-0.10529	-0.10529

TABLE B.9: Flowrate subtraction by permeable pavement devices by scenario

Infiltration	**Flowrate subtraction (m^3/s)**				
Trenches	**Current**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
PP_1	0.00331	0.00427	0.00427	0.00494	0.00494
PP_2	0.01940	0.02505	0.02505	0.02898	0.02898
PP_3	0.00658	0.00850	0.00850	0.00983	0.00983
PP_4	0.00577	0.00745	0.00745	0.00862	0.00862
PP_5	0.02161	0.02791	0.02791	0.03229	0.03229
PP_6	0.08696	0.11233	0.11233	0.12994	0.12994
PP_7	0.02996	0.03870	0.03870	0.04477	0.04477
PP_8	0.00104	0.00135	0.00135	0.00156	0.00156
PP_9	0.00561	0.00725	0.00725	0.00839	0.00839
PP_{10}	0.01004	0.01297	0.01297	0.01500	0.01500
PP_{11}	0.00422	0.00545	0.00545	0.00630	0.00630
PP_{12}	0.00329	0.00425	0.00425	0.00492	0.00492
PP_{13}	0.00283	0.00366	0.00366	0.00423	0.00423
PP_{14}	0.00754	0.00974	0.00974	0.01127	0.01127
PP_{15}	0.02027	0.02618	0.02618	0.03028	0.03028
PP_{16}	0.04475	0.05780	0.05780	0.06686	0.06686
PP_{17}	0.03284	0.04242	0.04242	0.04907	0.04907
PP_{18}	0.00590	0.00762	0.00762	0.00881	0.00881
PP_{19}	0.01845	0.02383	0.02383	0.02757	0.02757
PP_{20}	0.01972	0.02547	0.02547	0.02946	0.02946

B.4.3 Detention basins input data and estimations

TABLE B.10: Detention basins input data and initial estimations

Detention basin	**Area (m^2)**	**Depth (m)**	**Vol (m^3)**	**InpArea (m^2)**	**Qs (m^3/s)**
DB_1	172	1	172	15601	0.09556
DB_2	140	1.5	210	15342	0.11667
DB_3	72	1	72	10321	0.04000
DB_4	120	1.5	180	14403	0.10000
DB_5	140	1	140	13347	0.07778
DB_6	137	1	137	14381	0.07611
DB_7	90	1.5	135	14441	0.07500
DB_8	115	1	115	12348	0.06389

TABLE B.11: Input flooding flowrate in the detention basins by scenario

Bioretention devices	**Input flooding flowrate (m^3/s)**				
	Current	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
DB_1	0.22938	0.29631	0.29631	0.34276	0.34276
DB_2	0.22558	0.29139	0.29139	0.33707	0.33707
DB_3	0.15175	0.19603	0.19603	0.22675	0.22675
DB_4	0.21177	0.27355	0.27355	0.31644	0.31644
DB_5	0.19624	0.25350	0.25350	0.29323	0.29323
DB_6	0.21145	0.27314	0.27314	0.31595	0.31595
DB_7	0.21233	0.27428	0.27428	0.31727	0.31727
DB_8	0.18155	0.23452	0.23452	0.27129	0.27129

TABLE B.12: Overflow from detention basin devices by scenario

Infiltration Trenches	**Overflow flowrate (m^3/s)**				
	Current	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
DB_1	0.13383	0.20075	0.20075	0.24720	0.24720
DB_2	0.13002	0.19583	0.19583	0.24151	0.24151
DB_3	0.05620	0.10047	0.10047	0.13120	0.13120
DB_4	0.11621	0.17800	0.17800	0.22088	0.22088
DB_5	0.10069	0.15794	0.15794	0.19768	0.19768
DB_6	0.11589	0.17758	0.17758	0.22040	0.22040
DB_7	0.11677	0.17872	0.17872	0.22171	0.22171
DB_8	0.08600	0.13897	0.13897	0.17573	0.17573

B.4.4 Bioretention devices input data and estimations

TABLE B.13: Bioretention input data and initial estimations

Bioretention devices	**Depth** (m)	**Area** (m^2)	**Inf.Sup.** (m^2)	**Qs** (m^3/s)	**InArea** (m^2)
BR_1	0.5	24.5	24.5	0.02695	709
BR_2	0.5	20.6	20.6	0.02266	300
BR_3	0.5	25.3	25.3	0.02783	226
BR_4	0.5	23.2	23.2	0.02552	798
BR_5	0.5	70.0	70.0	0.077	732
BR_6	0.5	146.0	146.0	0.1606	491
BR_7	0.5	75.6	75.6	0.08316	985
BR_8	0.5	66.1	66.1	0.07271	1462
BR_9	0.5	103.0	103.0	0.1133	870
BR_{10}	0.5	137.0	137.0	0.1507	1877
BR_{11}	0.5	83.3	83.3	0.09163	1117
BR_{12}	0.5	26.8	26.8	0.02948	454
BR_{13}	0.5	58.4	58.4	0.06424	342
BR_{14}	0.5	97.7	97.7	0.10747	488
BR_{15}	0.5	36.6	36.6	0.04026	369
BR_{16}	0.5	14.7	14.7	0.01617	692
BR_{17}	0.5	56.2	56.2	0.06182	505
BR_{18}	0.5	92.7	92.7	0.10197	733
BR_{19}	0.5	15.1	15.1	0.01661	219
BR_{20}	0.5	12.4	12.4	0.01364	471
BR_{21}	0.5	37.1	37.1	0.04081	631
BR_{22}	0.5	81.5	81.5	0.08965	1166
BR_{23}	0.5	28.1	28.1	0.03091	569
BR_{24}	0.5	67.6	67.6	0.07436	1292
BR_{25}	0.5	66.2	66.2	0.07282	1279
BR_{26}	0.5	71.1	71.1	0.07821	1246
BR_{27}	0.5	63.8	63.8	0.07018	868
BR_{28}	0.5	88.6	88.6	0.09746	492
BR_{29}	0.5	39.7	39.7	0.04367	1256
BR_{30}	0.5	88.9	88.9	0.09779	1240
BR_{31}	0.5	86.2	86.2	0.09482	401
BR_{32}	0.5	30.1	30.1	0.03311	1083
BR_{33}	0.5	52.5	52.5	0.05775	889

TABLE B.14: Input flooding flowrate in the bioretention devices by scenario

Bioretention	Input flooding flowrate (m^3/s)				
devices	**Current**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
BR_1	0.01340	0.01731	0.01731	0.02003	0.02003
BR_2	0.00567	0.00733	0.00733	0.00847	0.00847
BR_3	0.00427	0.00552	0.00552	0.00638	0.00638
BR_4	0.01509	0.01949	0.01949	0.02254	0.02254
BR_5	0.01384	0.01788	0.01788	0.02068	0.02068
BR_6	0.00928	0.01199	0.01199	0.01387	0.01387
BR_7	0.01862	0.02405	0.02405	0.02782	0.02782
BR_8	0.02764	0.03570	0.03570	0.04130	0.04130
BR_9	0.01645	0.02124	0.02124	0.02458	0.02458
BR_{10}	0.03548	0.04584	0.04584	0.05302	0.05302
BR_{11}	0.02112	0.02728	0.02728	0.03155	0.03155
BR_{12}	0.00858	0.01109	0.01109	0.01282	0.01282
BR_{13}	0.00647	0.00835	0.00835	0.00966	0.00966
BR_{14}	0.00923	0.01192	0.01192	0.01378	0.01378
BR_{15}	0.00698	0.00901	0.00901	0.01042	0.01042
BR_{16}	0.01308	0.01690	0.01690	0.01955	0.01955
BR_{17}	0.00955	0.01233	0.01233	0.01426	0.01426
BR_{18}	0.01386	0.01790	0.01790	0.02071	0.02071
BR_{19}	0.00414	0.00535	0.00535	0.00619	0.00619
BR_{20}	0.00890	0.01150	0.01150	0.01330	0.01330
BR_{21}	0.01193	0.01541	0.01541	0.01782	0.01782
BR_{22}	0.02204	0.02847	0.02847	0.03294	0.03294
BR_{23}	0.01076	0.01389	0.01389	0.01607	0.01607
BR_{24}	0.02442	0.03155	0.03155	0.03650	0.03650
BR_{25}	0.02418	0.03123	0.03123	0.03613	0.03613
BR_{26}	0.02355	0.03043	0.03043	0.03520	0.03520
BR_{27}	0.01641	0.02120	0.02120	0.02452	0.02452
BR_{28}	0.00930	0.01201	0.01201	0.01390	0.01390
BR_{29}	0.02374	0.03067	0.03067	0.03548	0.03548
BR_{30}	0.02344	0.03028	0.03028	0.03503	0.03503
BR_{31}	0.00758	0.00979	0.00979	0.01133	0.01133
BR_{32}	0.02047	0.02645	0.02645	0.03059	0.03059
BR_{33}	0.01681	0.02171	0.02171	0.02511	0.02511

TABLE B.15: Verification of overflow occurrence in the bioretention devices by scenario

Bioretention	**Overflow flowrate (m^3/s)**				
devices	**Current**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
BR_1	-0.01355	-0.00964	-0.00964	-0.00692	-0.00692
BR_2	-0.01699	-0.01533	-0.01533	-0.01419	-0.01419
BR_3	-0.02356	-0.02231	-0.02231	-0.02145	-0.02145
BR_4	-0.01043	-0.00603	-0.00603	-0.00298	-0.00298
BR_5	-0.06316	-0.05912	-0.05912	-0.05632	-0.05632
BR_6	-0.15132	-0.14861	-0.14861	-0.14673	-0.14673
BR_7	-0.06454	-0.05911	-0.05911	-0.05534	-0.05534
BR_8	-0.04507	-0.03701	-0.03701	-0.03141	-0.03141
BR_9	-0.09685	-0.09206	-0.09206	-0.08872	-0.08872
BR_{10}	-0.11522	-0.10486	-0.10486	-0.09768	-0.09768
BR_{11}	-0.07051	-0.06435	-0.06435	-0.06008	-0.06008
BR_{12}	-0.02090	-0.01839	-0.01839	-0.01666	-0.01666
BR_{13}	-0.05777	-0.05589	-0.05589	-0.05458	-0.05458
BR_{14}	-0.09824	-0.09555	-0.09555	-0.09369	-0.09369
BR_{15}	-0.03328	-0.03125	-0.03125	-0.02984	-0.02984
BR_{16}	-0.00309	0.00073	0.00073	0.00338	0.00338
BR_{17}	-0.05227	-0.04949	-0.04949	-0.04756	-0.04756
BR_{18}	-0.08811	-0.08407	-0.08407	-0.08126	-0.08126
BR_{19}	-0.01247	-0.01126	-0.01126	-0.01042	-0.01042
BR_{20}	-0.00474	-0.00214	-0.00214	-0.00034	-0.00034
BR_{21}	-0.02888	-0.02540	-0.02540	-0.02299	-0.02299
BR_{22}	-0.06761	-0.06118	-0.06118	-0.05671	-0.05671
BR_{23}	-0.02015	-0.01702	-0.01702	-0.01484	-0.01484
BR_{24}	-0.04994	-0.04281	-0.04281	-0.03786	-0.03786
BR_{25}	-0.04864	-0.04159	-0.04159	-0.03669	-0.03669
BR_{26}	-0.05466	-0.04778	-0.04778	-0.04301	-0.04301
BR_{27}	-0.05377	-0.04898	-0.04898	-0.04566	-0.04566
BR_{28}	-0.08816	-0.08545	-0.08545	-0.08356	-0.08356
BR_{29}	-0.01993	-0.01300	-0.01300	-0.00819	-0.00819
BR_{30}	-0.07435	-0.06751	-0.06751	-0.06276	-0.06276
BR_{31}	-0.08724	-0.08503	-0.08503	-0.08349	-0.08349
BR_{32}	-0.01264	-0.00666	-0.00666	-0.00252	-0.00252
BR_{33}	-0.04094	-0.03604	-0.03604	-0.03264	-0.03264

TABLE B.16: Flowrate subtraction by permeable pavement devices by scenario

Bioretention devices	**Flowrate subtraction (m^3/s)**				
	Current	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
BR_1	0.01340	0.01731	0.01731	0.02003	0.02003
BR_2	0.00567	0.00733	0.00733	0.00847	0.00847
BR_3	0.00427	0.00552	0.00552	0.00638	0.00638
BR_4	0.01509	0.01949	0.01949	0.02254	0.02254
BR_5	0.01384	0.01788	0.01788	0.02068	0.02068
BR_6	0.00928	0.01199	0.01199	0.01387	0.01387
BR_7	0.01862	0.02405	0.02405	0.02782	0.02782
BR_8	0.02764	0.03570	0.03570	0.04130	0.04130
BR_9	0.01645	0.02124	0.02124	0.02458	0.02458
BR_{10}	0.03548	0.04584	0.04584	0.05302	0.05302
BR_{11}	0.02112	0.02728	0.02728	0.03155	0.03155
BR_{12}	0.00858	0.01109	0.01109	0.01282	0.01282
BR_{13}	0.00647	0.00835	0.00835	0.00966	0.00966
BR_{14}	0.00923	0.01192	0.01192	0.01378	0.01378
BR_{15}	0.00698	0.00901	0.00901	0.01042	0.01042
BR_{16}	0.01308	0.01617	0.01617	0.01617	0.01617
BR_{17}	0.00955	0.01233	0.01233	0.01426	0.01426
BR_{18}	0.01386	0.01790	0.01790	0.02071	0.02071
BR_{19}	0.00414	0.00535	0.00535	0.00619	0.00619
BR_{20}	0.00890	0.01150	0.01150	0.01330	0.01330
BR_{21}	0.01193	0.01541	0.01541	0.01782	0.01782
BR_{22}	0.02204	0.02847	0.02847	0.03294	0.03294
BR_{23}	0.01076	0.01389	0.01389	0.01607	0.01607
BR_{24}	0.02442	0.03155	0.03155	0.03650	0.03650
BR_{25}	0.02418	0.03123	0.03123	0.03613	0.03613
BR_{26}	0.02355	0.03043	0.03043	0.03520	0.03520
BR_{27}	0.01641	0.02120	0.02120	0.02452	0.02452
BR_{28}	0.00930	0.01201	0.01201	0.01390	0.01390
BR_{29}	0.02374	0.03067	0.03067	0.03548	0.03548
BR_{30}	0.02344	0.03028	0.03028	0.03503	0.03503
BR_{31}	0.00758	0.00979	0.00979	0.01133	0.01133
BR_{32}	0.02047	0.02645	0.02645	0.03059	0.03059
BR_{33}	0.01681	0.02171	0.02171	0.02511	0.02511

B.4.5 Rainwater harvesting input data and estimations

TABLE B.17: Rainwater harvesting input data and initial estimations for 60%, 70%, 80%, and 90% of acceptance

Parameter	Current	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Acceptance	0.6	0.6	0.6	0.6	0.6
Average harvesting area (m^2)	160	160	160	160	160
Total harvesting area (m^2)	126688.00	151673.07	181585.64	151673.07	181585.64
Qs (m^3/s)	0.85152	1.31690	1.57661	1.52332	1.82375
Water consumption ($m^3/month$)†	41307.1987	60866.2337	86223.4663	61572.9444	87069.5527
Cwss (%)†	130.51	88.57	62.52	87.55	61.91
PAeq (m^2)†	25337.6	30334.6	36317.1	30334.6	36317.1
Acceptance	0.7	0.7	0.7	0.7	0.7
Average harvesting area (m^2)	160	160	160	160	160
Total harvesting area (m^2)	147802.67	176951.92	211849.91	176951.92	211849.91
Qs (m^3/s)	0.99344	1.53638	1.83938	1.77721	2.12771
Water consumption ($m^3/month$)†	39207.0288	57842.8948	81206.5853	58518.0875	82014.9378
Cwss (%)†	137.50	93.20	66.38	92.12	65.73
PAeq (m^2)†	29560.5	35390.4	42370.0	35390.4	42370.0
Acceptance	0.8	0.8	0.8	0.8	0.8
Average harvesting area (m^2)	160	160	160	160	160
Total harvesting area (m^2)	168917.33	202230.76	242114.18	202230.76	242114.18
Qs (m^3/s)	1.13537	1.75586	2.10215	2.03110	2.43167
Water consumption ($m^3/month$)†	37106.8589	54819.5560	76189.7043	55463.2306	76960.3228
Cwss (%)†	145.28	98.34	70.76	97.20	70.05
PAeq (m^2)†	33783.5	40446.2	48422.8	40446.2	48422.8
Acceptance	0.9	0.9	0.9	0.9	0.9
Average harvesting area (m^2)	160	160	160	160	160
Total harvesting area (m^2)	190032.00	227509.61	272378.46	227509.61	272378.46
Qs (m^3/s)	1.27729	1.97535	2.36492	2.28499	2.73562
Water consumption ($m^3/month$)†	35006.6889	51796.2171	71172.8233	52408.3737	71905.7079
Cwss (%)†	154.00	104.08	75.74	102.86	74.97
PAeq (m^2)†	38006.4	45501.9	54475.7	45501.9	54475.7

† all estimated values depend on parametrization data — see Appendix B section B.5

B.5 Water consumption parametrization data

TABLE B.18: Current scenario medium water consumption per appliance estimation and rain-water harvesting measure effect on estimated drinkable water per capita consumption

Appliances	**Consumed specific flowrate (L/s)**	**Use frequency ($1/inh \times day$)**	**Use duration (min)**	**Water consumption (L/day)**	**New water consumption† (L/day)**
Handbasin	0.25	5	0.1	7.5	7.5
Toilet (Valve)	1.5	4	0.05	18.0	–
Shower	0.075	2	16.55	148.96	148.96
Washing Machine	120	0.43	–	51.43	51.43
Kitchen Sink	0.25	5	11.01	13.76	13.76
Garden	0.2	0.43	5.17	26.6	–
Outside	0.25	0.29	22.60	96.86	–
Total				363.11	221.65

† estimated values after applying the rainwater harvesting measure

TABLE B.19: Scenario 01 medium water consumption per appliance estimation and rainwater harvesting measure effect on estimated drinkable water per capita consumption

Appliances	**Consumed specific flowrate (L/s)**	**Use frequency ($1/inh \times day$)**	**Use duration (min)**	**Water consumption (L/day)**	**New water consumption† (L/day)**
Handbasin	0.25	5	0.1	7.5	7.5
Toilet (Valve)	1.5	4	0.05	18.0	–
Shower	0.075	2	22.3	200.72	200.72
Washing Machine	120	0.43	–	51.43	51.43
Kitchen Sink	0.25	5	11.81	14.76	14.76
Garden	0.2	0.43	8.46	43.5	–
Outside	0.25	0.29	25.34	108.6	–
Total				444.50	274.4

† estimated values after applying the rainwater harvesting measure

TABLE B.20: Scenario 02 medium water consumption per appliance estimation and rainwater harvesting measure effect on estimated drinkable water per capita consumption

Appliances	**Consumed specific flowrate (L/s)**	**Use frequency ($1/inh \times day$)**	**Use duration (min)**	**Water consumption (L/day)**	**New water consumption† (L/day)**
Handbasin	0.25	5	0.3	22.5	22.5
Toilet (Valve)	1.5	4	0.2	72.0	–
Shower	0.075	2	24.64	221.8	221.8
Washing Machine	120	0.43	–	51.43	51.43
Kitchen Sink	0.25	5	12.13	15.17	15.17
Garden	0.2	0.43	9.80	50.38	–
Outside	0.25	0.29	26.45	113.38	–
Total				546.65	310.89

† estimated values after applying the rainwater harvesting measure

TABLE B.21: Scenario 03 medium water consumption per appliance estimation and rainwater harvesting measure effect on estimated drinkable water per capita consumption

Appliances	**Consumed specific flowrate (L/s)**	**Use frequency ($1/inh \times day$)**	**Use duration (min)**	**Water consumption (L/day)**	**New water consumption† (L/day)**
Handbasin	0.25	5	0.1	7.5	7.5
Toilet (Valve)	1.5	4	0.05	18.0	–
Shower	0.075	2	22.66	203.92	203.92
Washing Machine	120	0.43	–	51.43	51.43
Kitchen Sink	0.25	5	11.86	14.82	14.82
Garden	0.2	0.43	8.66	22.55	–
Outside	0.25	0.29	25.51	109.33	–
Total				449.54	277.67

† estimated values after applying the rainwater harvesting measure

TABLE B.22: Scenario 04 medium water consumption per appliance estimation and rainwater harvesting measure effect on estimated drinkable water per capita consumption

Appliances	**Consumed specific flowrate (L/s)**	**Use frequency ($1/inh \times day$)**	**Use duration (min)**	**Water consumption (L/day)**	**New water consumption† (L/day)**
Handbasin	0.25	5	0.3	22.5	22.5
Toilet (Valve)	1.5	4	0.2	72.0	–
Shower	0.075	2	25.0	225.0	225.0
Washing Machine	120	0.43	–	51.43	51.43
Kitchen Sink	0.25	5	12.18	15.23	15.23
Garden	0.2	0.43	10.0	51.43	–
Outside	0.25	0.29	26.62	114.11	–
Total				551.69	314.16

† estimated values after applying the rainwater harvesting measure

B.6 Simulations results

TABLE B.23: Summary of results for simulation 2 for all group of measures, indicators and scenarios

Group of Measures	Indicators	Scenarios				Vision	N*
		SC1	SC2	SC3	SC4		
GM_0	$Cwss$ (%)	68.2	46.3	67.5	45.9	80.0	0
	$Qmax$ (m^3/s)	20.2	21.3	23.4	24.7	20.0	0
	$PAeq$ (%)	74.0	71.5	74.0	71.5	75.0	0
	WE_{TSS} (kg/km^2)	2468.2	2609.3	2855.1	3018.3	2110.0	0
	WE_{BOD} (kg/km^2)	227.6	240.6	263.2	278.3	185.0	0
	WE_{TKN} (kg/km^2)	42.0	44.4	48.6	51.4	35.0	0
	WE_{TP} (kg/km^2)	7.4	7.8	8.5	9.0	7.0	0
GM_1	$Cwss$ (%)	88.6	62.5	87.6	61.9	80.0	2
	$Qmax$ (m^3/s)	18.1	19.0	20.9	22.0	20.0	2
	$PAeq$ (%)	76.1	73.8	76.1	73.8	75.0	2
	WE_{TSS} (kg/km^2)	2208.6	2317.7	2554.9	2681.2	2110.0	0
	WE_{BOD} (kg/km^2)	203.6	213.7	235.6	247.2	185.0	0
	WE_{TKN} (kg/km^2)	37.6	39.5	43.5	45.6	35.0	0
	WE_{TP} (kg/km^2)	6.6	6.9	7.6	8.0	7.0	2
GM_2	$Cwss$ (%)	93.2	66.4	92.1	65.7	80.0	2
	$Qmax$ (m^3/s)	16.7	17.5	19.2	20.2	20.0	3
	$PAeq$ (%)	81.1	78.9	81.1	78.9	75.0	4
	WE_{TSS} (kg/km^2)	2035.5	2139.3	2340.2	2460.4	2110.0	1
	WE_{BOD} (kg/km^2)	187.7	197.2	215.8	226.8	185.0	0
	WE_{TKN} (kg/km^2)	34.6	36.4	39.8	41.9	35.0	1
	WE_{TP} (kg/km^2)	6.1	6.4	7.0	7.3	7.0	3
GM_3	$Cwss$ (%)	68.2	46.3	67.5	45.9	80.0	0
	$Qmax$ (m^3/s)	18.8	19.9	21.7	23.1	20.0	2
	$PAeq$ (%)	74.8	72.2	74.8	72.2	75.0	0
	WE_{TSS} (kg/km^2)	2291.1	2431.9	2650.7	2813.6	2110.0	0
	WE_{BOD} (kg/km^2)	211.2	224.2	244.4	259.4	185.0	0
	WE_{TKN} (kg/km^2)	39.0	41.4	45.1	47.9	35.0	0
	WE_{TP} (kg/km^2)	6.8	7.2	7.9	8.4	7.0	1
GM_4	$Cwss$ (%)	98.3	70.8	97.2	70.0	80.0	2
	$Qmax$ (m^3/s)	16.8	17.6	19.3	20.2	20.0	3
	$PAeq$ (%)	81.4	79.2	81.4	79.2	75.0	4
	WE_{TSS} (kg/km^2)	2048.1	2146.7	2354.7	2468.7	2110.0	1
	WE_{BOD} (kg/km^2)	188.8	197.9	217.1	227.6	185.0	0
	WE_{TKN} (kg/km^2)	34.9	36.5	40.1	42.0	35.0	1
	WE_{TP} (kg/km^2)	6.1	6.4	7.0	7.4	7.0	2
GM_5	$Cwss$ (%)	104.1	75.7	102.9	75.0	80.0	2
	$Qmax$ (m^3/s)	15.5	16.2	17.8	18.7	20.0	4
	$PAeq$ (%)	82.2	80.1	82.2	80.1	75.0	4
	WE_{TSS} (kg/km^2)	1888.0	1981.3	2169.8	2277.7	2110.0	2
	WE_{BOD} (kg/km^2)	174.1	182.7	200.1	210.0	185.0	2
	WE_{TKN} (kg/km^2)	32.1	33.7	36.9	38.8	35.0	2
	WE_{TP} (kg/km^2)	5.6	5.9	6.5	6.8	7.0	4

*it is number of scenarios in which the vision was achieved.

TABLE B.24: Summary of results for simulation 3 for all group of measures, indicators and scenarios

Group of Measures	Indicators	Scenarios SC1	SC2	SC3	SC4	Vision	N*
GM_0	$Cwss$ (%)	68.2	46.3	67.5	45.9	80.0	0
	$Qmax$ (m^3/s)	20.2	21.3	23.4	24.7	20.0	0
	$PAeq$ (%)	74.0	71.5	74.0	71.5	75.0	0
	WE_{TSS} (kg/km^2)	2468.2	2609.3	2855.1	3018.3	2110.0	0
	WE_{BOD} (kg/km^2)	227.6	240.6	263.2	278.3	185.0	0
	WE_{TKN} (kg/km^2)	42.0	44.4	48.6	51.4	35.0	0
	WE_{TP} (kg/km^2)	7.4	7.8	8.5	9.0	7.0	0
GM_1	$Cwss$ (%)	88.6	62.5	87.6	61.9	80.0	2
	$Qmax$ (m^3/s)	18.1	19.0	20.9	22.0	20.0	2
	$PAeq$ (%)	76.1	73.8	76.1	73.8	75.0	2
	WE_{TSS} (kg/km^2)	2208.6	2317.7	2554.9	2681.2	2110.0	0
	WE_{BOD} (kg/km^2)	203.6	213.7	235.6	247.2	185.0	0
	WE_{TKN} (kg/km^2)	37.6	39.5	43.5	45.6	35.0	0
	WE_{TP} (kg/km^2)	6.6	6.9	7.6	8.0	7.0	2
GM_2	$Cwss$ (%)	93.2	66.4	92.1	65.7	80.0	2
	$Qmax$ (m^3/s)	16.7	17.5	19.2	20.2	20.0	3
	$PAeq$ (%)	81.1	78.9	81.1	78.9	75.0	4
	WE_{TSS} (kg/km^2)	2035.5	2139.3	2340.2	2460.4	2110.0	1
	WE_{BOD} (kg/km^2)	187.7	197.2	215.8	226.8	185.0	0
	WE_{TKN} (kg/km^2)	34.6	36.4	39.8	41.9	35.0	1
	WE_{TP} (kg/km^2)	6.1	6.4	7.0	7.3	7.0	3
GM_3	$Cwss$ (%)	68.2	46.3	67.5	45.9	80.0	0
	$Qmax$ (m^3/s)	18.8	19.9	21.7	23.1	20.0	2
	$PAeq$ (%)	74.8	72.2	74.8	72.2	75.0	0
	WE_{TSS} (kg/km^2)	2291.1	2431.9	2650.7	2813.6	2110.0	0
	WE_{BOD} (kg/km^2)	211.2	224.2	244.4	259.4	185.0	0
	WE_{TKN} (kg/km^2)	39.0	41.4	45.1	47.9	35.0	0
	WE_{TP} (kg/km^2)	6.8	7.2	7.9	8.4	7.0	1
GM_4	$Cwss$ (%)	98.3	70.8	97.2	70.0	80.0	2
	$Qmax$ (m^3/s)	16.8	17.6	19.3	20.2	20.0	3
	$PAeq$ (%)	81.4	79.2	81.4	79.2	75.0	4
	WE_{TSS} (kg/km^2)	2048.1	2146.7	2354.7	2468.7	2110.0	1
	WE_{BOD} (kg/km^2)	188.8	197.9	217.1	227.6	185.0	0
	WE_{TKN} (kg/km^2)	34.9	36.5	40.1	42.0	35.0	1
	WE_{TP} (kg/km^2)	6.1	6.4	7.0	7.4	7.0	2
GM_5	$Cwss$ (%)	104.1	75.7	102.9	75.0	80.0	2
	$Qmax$ (m^3/s)	15.5	16.2	17.8	18.7	20.0	4
	$PAeq$ (%)	82.2	80.1	82.2	80.1	75.0	4
	WE_{TSS} (kg/km^2)	1888.0	1981.3	2169.8	2277.7	2110.0	2
	WE_{BOD} (kg/km^2)	174.1	182.7	200.1	210.0	185.0	2
	WE_{TKN} (kg/km^2)	32.1	33.7	36.9	38.8	35.0	2
	WE_{TP} (kg/km^2)	5.6	5.9	6.5	6.8	7.0	4

*it is number of scenarios in which the vision was achieved.

TABLE B.25: Summary of results for simulation 4 for all group of measures, indicators and scenarios

Group of Measures	Indicators	Scenarios				Vision	N*
		SC1	SC2	SC3	SC4		
GM_0	$Cwss$ (%)	68.2	46.3	67.5	45.9	80.0	0
	$Qmax$ (m^3/s)	20.2	21.3	23.4	24.7	20.0	0
	WE_{TSS} (kg/km^2)	2468.2	2609.3	2855.1	3018.3	2110.0	0
	WE_{BOD} (kg/km^2)	227.6	240.6	263.2	278.3	185.0	0
	WE_{TKN} (kg/km^2)	42.0	44.4	48.6	51.4	35.0	0
	WE_{TP} (kg/km^2)	7.4	7.8	8.5	9.0	7.0	0
GM_1	$Cwss$ (%)	88.6	62.5	87.6	61.9	80.0	2
	$Qmax$ (m^3/s)	18.1	19.0	20.9	22.0	20.0	2
	WE_{TSS} (kg/km^2)	2208.6	2317.7	2554.9	2681.2	2110.0	0
	WE_{BOD} (kg/km^2)	203.6	213.7	235.6	247.2	185.0	0
	WE_{TKN} (kg/km^2)	37.6	39.5	43.5	45.6	35.0	0
	WE_{TP} (kg/km^2)	6.6	6.9	7.6	8.0	7.0	2
GM_2	$Cwss$ (%)	93.2	66.4	92.1	65.7	80.0	2
	$Qmax$ (m^3/s)	16.7	17.5	19.2	20.2	20.0	3
	WE_{TSS} (kg/km^2)	2035.5	2139.3	2340.2	2460.4	2110.0	1
	WE_{BOD} (kg/km^2)	187.7	197.2	215.8	226.8	185.0	0
	WE_{TKN} (kg/km^2)	34.6	36.4	39.8	41.9	35.0	1
	WE_{TP} (kg/km^2)	6.1	6.4	7.0	7.3	7.0	3
GM_3	$Cwss$ (%)	68.2	46.3	67.5	45.9	80.0	0
	$Qmax$ (m^3/s)	18.8	19.9	21.7	23.1	20.0	2
	WE_{TSS} (kg/km^2)	2291.1	2431.9	2650.7	2813.6	2110.0	0
	WE_{BOD} (kg/km^2)	211.2	224.2	244.4	259.4	185.0	0
	WE_{TKN} (kg/km^2)	39.0	41.4	45.1	47.9	35.0	0
	WE_{TP} (kg/km^2)	6.8	7.2	7.9	8.4	7.0	1
GM_4	$Cwss$ (%)	98.3	70.8	97.2	70.0	80.0	2
	$Qmax$ (m^3/s)	16.8	17.6	19.3	20.2	20.0	3
	WE_{TSS} (kg/km^2)	2048.1	2146.7	2354.7	2468.7	2110.0	1
	WE_{BOD} (kg/km^2)	188.8	197.9	217.1	227.6	185.0	0
	WE_{TKN} (kg/km^2)	34.9	36.5	40.1	42.0	35.0	1
	WE_{TP} (kg/km^2)	6.1	6.4	7.0	7.4	7.0	2
GM_5	$Cwss$ (%)	104.1	75.7	102.9	75.0	80.0	2
	$Qmax$ (m^3/s)	15.5	16.2	17.8	18.7	20.0	4
	WE_{TSS} (kg/km^2)	1888.0	1981.3	2169.8	2277.7	2110.0	2
	WE_{BOD} (kg/km^2)	174.1	182.7	200.1	210.0	185.0	2
	WE_{TKN} (kg/km^2)	32.1	33.7	36.9	38.8	35.0	2
	WE_{TP} (kg/km^2)	5.6	5.9	6.5	6.8	7.0	4

*it is number of scenarios in which the vision was achieved.

TABLE B.26: Summary of results for simulation 5 for all group of measures, indicators and scenarios

Group of Measures	Indicators	Scenarios SC1	SC2	SC3	SC4	Vision	N*
GM_0	$Cwss$ (%)	68.2	46.3	67.5	45.9	80.0	0
	$Qmax$ (m^3/s)	20.2	21.3	23.4	24.7	20.0	0
	$PAeq$ (%)	74.0	71.5	74.0	71.5	75.0	0
	WE_{TSS} (kg/km^2)	2468.2	2609.3	2855.1	3018.3	2110.0	0
	WE_{BOD} (kg/km^2)	227.6	240.6	263.2	278.3	185.0	0
	WE_{TKN} (kg/km^2)	42.0	44.4	48.6	51.4	35.0	0
	WE_{TP} (kg/km^2)	7.4	7.8	8.5	9.0	7.0	0
GM_1	$Cwss$ (%)	113.9	80.4	112.6	79.6	80.0	3
	$Qmax$ (m^3/s)	18.1	19.0	20.9	22.0	20.0	2
	$PAeq$ (%)	76.1	73.8	76.1	73.8	75.0	2
	WE_{TSS} (kg/km^2)	2208.6	2317.7	2554.9	2681.2	2110.0	0
	WE_{BOD} (kg/km^2)	203.6	213.7	235.6	247.2	185.0	0
	WE_{TKN} (kg/km^2)	37.6	39.5	43.5	45.6	35.0	0
	WE_{TP} (kg/km^2)	6.6	6.9	7.6	8.0	7.0	2
GM_2	$Cwss$ (%)	119.8	85.4	118.4	84.5	80.0	4
	$Qmax$ (m^3/s)	16.7	17.5	19.2	20.2	20.0	3
	$PAeq$ (%)	81.1	78.9	81.1	78.9	75.0	4
	WE_{TSS} (kg/km^2)	2035.5	2139.3	2340.2	2460.4	2110.0	1
	WE_{BOD} (kg/km^2)	187.7	197.2	215.8	226.8	185.0	0
	WE_{TKN} (kg/km^2)	34.6	36.4	39.8	41.9	35.0	1
	WE_{TP} (kg/km^2)	6.1	6.4	7.0	7.3	7.0	3
GM_3	$Cwss$ (%)	87.7	59.6	86.7	59.0	80.0	2
	$Qmax$ (m^3/s)	18.8	19.9	21.7	23.1	20.0	2
	$PAeq$ (%)	74.8	72.2	74.8	72.2	75.0	0
	WE_{TSS} (kg/km^2)	2291.1	2431.9	2650.7	2813.6	2110.0	0
	WE_{BOD} (kg/km^2)	211.2	224.2	244.4	259.4	185.0	0
	WE_{TKN} (kg/km^2)	39.0	41.4	45.1	47.9	35.0	0
	WE_{TP} (kg/km^2)	6.8	7.2	7.9	8.4	7.0	1
GM_4	$Cwss$ (%)	126.4	91.0	125.0	90.1	80.0	4
	$Qmax$ (m^3/s)	16.8	17.6	19.3	20.2	20.0	3
	$PAeq$ (%)	81.4	79.2	81.4	79.2	75.0	4
	WE_{TSS} (kg/km^2)	2048.1	2146.7	2354.7	2468.7	2110.0	1
	WE_{BOD} (kg/km^2)	188.8	197.9	217.1	227.6	185.0	0
	WE_{TKN} (kg/km^2)	34.9	36.5	40.1	42.0	35.0	1
	WE_{TP} (kg/km^2)	6.1	6.4	7.0	7.4	7.0	2
GM_5	$Cwss$ (%)	133.8	97.4	132.3	96.4	80.0	4
	$Qmax$ (m^3/s)	15.5	16.2	17.8	18.7	20.0	4
	$PAeq$ (%)	82.2	80.1	82.2	80.1	75.0	4
	WE_{TSS} (kg/km^2)	1888.0	1981.3	2169.8	2277.7	2110.0	2
	WE_{BOD} (kg/km^2)	174.1	182.7	200.1	210.0	185.0	2
	WE_{TKN} (kg/km^2)	32.1	33.7	36.9	38.8	35.0	2
	WE_{TP} (kg/km^2)	5.6	5.9	6.5	6.8	7.0	4

*it is number of scenarios in which the vision was achieved.

TABLE B.27: Summary of results for simulation 6 for all group of measures, indicators and scenarios

Group of Measures	Indicators	Scenarios SC1	SC2	SC3	SC4	Vision	N*
GM_0	$Cwss$ (%)	68.2	46.3	67.5	45.9	80.0	0
	$Qmax$ (m^3/s)	20.2	21.3	23.4	24.7	20.0	0
	$PAeq$ (%)	74.0	71.5	74.0	71.5	75.0	0
	WE_{TSS} (kg/km^2)	2468.2	2609.3	2855.1	3018.3	2110.0	0
	WE_{BOD} (kg/km^2)	227.6	240.6	263.2	278.3	185.0	0
	WE_{TKN} (kg/km^2)	42.0	44.4	48.6	51.4	35.0	0
	WE_{TP} (kg/km^2)	7.4	7.8	8.5	9.0	7.0	0
GM_1	$Cwss$ (%)	87.7	59.6	86.7	59.0	80.0	2
	$Qmax$ (m^3/s)	19.4	20.6	22.5	23.8	20.0	1
	$PAeq$ (%)	74.7	72.1	74.7	72.1	75.0	0
	WE_{TSS} (kg/km^2)	2369.3	2510.1	2740.8	2903.7	2110.0	0
	WE_{BOD} (kg/km^2)	218.4	231.4	252.7	267.7	185.0	0
	WE_{TKN} (kg/km^2)	40.3	42.7	46.7	49.4	35.0	0
	WE_{TP} (kg/km^2)	7.1	7.5	8.2	8.6	7.0	0
GM_2	$Cwss$ (%)	87.7	59.6	86.7	59.0	80.0	2
	$Qmax$ (m^3/s)	18.2	19.4	21.0	22.3	20.0	2
	$PAeq$ (%)	79.4	76.9	79.4	76.9	75.0	4
	WE_{TSS} (kg/km^2)	2223.0	2363.8	2557.1	2720.0	2110.0	0
	WE_{BOD} (kg/km^2)	205.0	217.9	235.8	250.8	185.0	0
	WE_{TKN} (kg/km^2)	37.8	40.2	43.5	46.3	35.0	0
	WE_{TP} (kg/km^2)	6.6	7.0	7.6	8.1	7.0	1
GM_3	$Cwss$ (%)	87.7	59.6	86.7	59.0	80.0	2
	$Qmax$ (m^3/s)	18.8	19.9	21.7	23.1	20.0	2
	$PAeq$ (%)	74.8	72.2	74.8	72.2	75.0	0
	WE_{TSS} (kg/km^2)	2291.1	2431.9	2650.7	2813.6	2110.0	0
	WE_{BOD} (kg/km^2)	211.2	224.2	244.4	259.4	185.0	0
	WE_{TKN} (kg/km^2)	39.0	41.4	45.1	47.9	35.0	0
	WE_{TP} (kg/km^2)	6.8	7.2	7.9	8.4	7.0	1
GM_4	$Cwss$ (%)	87.7	59.6	86.7	59.0	80.0	2
	$Qmax$ (m^3/s)	18.5	19.7	21.3	22.7	20.0	2
	$PAeq$ (%)	79.4	76.9	79.4	76.9	75.0	4
	WE_{TSS} (kg/km^2)	2262.4	2403.2	2602.5	2765.4	2110.0	0
	WE_{BOD} (kg/km^2)	208.6	221.6	240.0	255.0	185.0	0
	WE_{TKN} (kg/km^2)	38.5	40.9	44.3	47.1	35.0	0
	WE_{TP} (kg/km^2)	6.7	7.2	7.8	8.2	7.0	1
GM_5	$Cwss$ (%)	87.7	59.6	86.7	59.0	80.0	2
	$Qmax$ (m^3/s)	17.4	18.6	20.1	21.4	20.0	2
	$PAeq$ (%)	80.0	77.5	80.0	77.5	75.0	4
	WE_{TSS} (kg/km^2)	2129.0	2269.9	2448.6	2611.5	2110.0	0
	WE_{BOD} (kg/km^2)	196.3	209.3	225.8	240.8	185.0	0
	WE_{TKN} (kg/km^2)	36.2	38.6	41.7	44.5	35.0	0
	WE_{TP} (kg/km^2)	6.3	6.8	7.3	7.8	7.0	2

*it is number of scenarios in which the vision was achieved.