

## Application of the urban water use model for urban water use management purposes

D. Costa dos Santos and A. Benetti

### ABSTRACT

The aim of this work is to present an application of the urban water use (UWU) model, which is a support decision tool to define the best group of efficient water use measures for UWU management purposes. Therefore, the UWU was developed under integrated urban water management (IUWM) and strategic planning principles to promote a systemic approach for decision taking. The IUWM considers the interfaces between water service systems, while by strategic planning it is possible to elaborate a vision to be achieved in future scenarios. Specifically to define the best measure group of efficient water use, the UWU has many alternatives for these measures, which are based on water demand management, decentralized sanitation, ecological sanitation and sustainable urban drainage system philosophies. In this context, the UWU application presented was developed for Seara city, Santa Catarina State, Brazil. In this application a vision and five scenarios were built. The measure groups were composed by greywater systems, filterstrips, water saving devices in buildings, and water loss reduction in water supply systems and wastewater treatment system. In this context the UWU model was applied. The measure group that presented the highest effectiveness was based on the water demand management and decentralized sanitation strategies.

**Key words** | ecological sanitation, strategic planning, sustainable drainage, systemic approach, water conservation

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### INTRODUCTION

Given the dialectical conflict between a conservative approach on water issues and uncontrollable environmental changes, a new paradigm emerges in which the planning and management of water resources use require a new approach. An integrated vision of urban water systems should be considered, which would be fundamental to conceive management measures towards water sustainability. Therefore, the approach to this interaction should be beyond a conservative analysis, which is only technical and economical. It is necessary to introduce new values that are based on social and environmental issues. These new values could be a guide to efficient water use in urban areas by devising sanitary infrastructure improvement measures and by water users' (designers, managers, end users, etc.) awareness. In this context, how to estimate the water use efficiency is an important issue to provide water sustainability. As a tool to develop this kind of estimation, [Huang \*et al.\* \(2012\)](#) propose the relative water use efficiency framework which enables the operational assessment of

water use efficiency in its application. Regarding sanitary infrastructure improvement measures, it is relevant to consider more sustainable alternatives, of which there are several worldwide experiences. For example, [Sterren \*et al.\* \(2012\)](#) developed an investigation in New South Wales, Australia, based on a simple model that allows the evaluation of the effectiveness of rainwater tanks to minimize stormwater flows and their consequences. [Fujiwara \(2012\)](#) describes a concept, for agricultural areas, of decentralized water reclamation and cascading material-cycle as innovative water management systems, which should include strategies of voluntary collection of bio-resources.

In fact it seems to be the consensus that this new paradigm of dealing with the emerging reality must be able to understand its complexity. This complexity in urban area water use can be illustrated describing the current situation in Brazil, which has different kinds of problems in its sanitary infrastructure that impact on the population's life quality. The origins of these kinds of problems are,

basically, social and economic conditions, engineering design culture, water resources availability and awareness of water use.

Regarding social and economic conditions, it is a fact that the size of population influences the economic feasibility of the sanitary infrastructure projects. The engineering culture regarding the conceptualization and development of sanitary services is also a huge obstacle for designing integrated, optimized and efficient solutions. Some aspects of this culture, such as the fragmented approach to conceive the entire sanitary systems, could lead to problems as commented by Marleni *et al.* (2012). These authors warn that water efficient use measures, despite their important benefits, can affect the sewerage network performance. Notwithstanding, as a way to deal with the lack of awareness from the designer up to the final user, Gato *et al.* (2011) argue that the 'end use' approach enables planners, authorities and end users to know, more accurately, how the water is used in households. This knowledge is fundamental to optimize water conservation measures towards water sustainability.

Problems related to the water resources quality are of deep concern in Brazil. Several drinking water sources in Brazil have had their quality depreciated. The sanitation and drainage systems' inappropriate performance, or even their absence, aggravates this problem. According to the Statistical and Geographic Brazilian Institute (IBGE 2013), in Brazil the coverage of water supply and sanitation for the population is 82.40 and 37.50%, respectively. The effects from this low coverage level can be detected by observing the current infant mortality indicator in Brazil, which is 19.60 deaths/1,000 live births.

These data demonstrate that current social and environmental sustainability scenarios in Brazil are not satisfactory, and if it does not change, the future water use will be unsustainable. Considering the urgency in changing this delicate sanitary scenario in Brazil, different sectors have been taking actions and proposing changes. To contribute to these efforts, the urban water use (UWU) model was elaborated, which is a mathematical model based on integrated urban water management (IUWM) and strategic planning principles.

The IUWM approach offers contributions which aim to bring responses to these changes through alternatives that face this new paradigm. Therefore, the IUWM considers the systemic approach for water systems such as water supply, sanitation and drainage systems, besides buildings. The strategic planning is composed of three phases which are visioning, scenario development, and

strategy development and measure groups elaboration (SWITCH 2008).

Thus, the aim of this work is to present an application of the UWU model (Santos & van der Steen 2010). In order to achieve its objective, an application for Seara, Santa Catarina State, Brazil, was developed. The water use complexity in Brazil, as mentioned before, is a good case for UWU application. The expected product was to conceive a conceptual base for an efficient water use plan for an urban area under the IUWM principles.

## METHODS

### UWU structure

The UWU model is a tool that aims to give support to elaboration of water management plans for urban areas. This support is, basically, a proposal of measure groups to develop more efficient water use through sanitary infrastructure improvements. For each proposed measure group, for different scenarios, an index that estimates the group's effectiveness is determined. Thus, to achieve these results and to propose a better measure group, the UWU is structured into seven steps which are input data, vision building, scenarios elaboration, measure groups definition, measure groups application, outcomes and final evaluation. Figure 1 illustrates this structure.

The first step is to put the general and specific data that describe the urban area's characteristics into the model. After the data are defined, the second step is to build the vision. It is necessary to select the sustainability indicators providing values and weights that should be expected in the future. The input data are also used, in the third step, to elaborate scenarios determining values for external factors that are beyond human control, such as climate changes, trends in population growth and the behavior of the economy.

After defining the vision and scenarios, in the fourth step, the measure groups are elaborated to improve the sanitary conditions in the future. The UWU model has a framework that allows measures for water conservation in the water supply systems (WSS), the sewage systems (SS) and the urban drainage systems (UDS) to be conceived. For the fifth step, for each scenario, groups of efficient water use measures are applied through mathematical simulations. The sixth step is to obtain and register the outcomes, while in the seventh and last step the results are compared to expected vision values for each scenario. The effectiveness of each proposed measure group is based on the

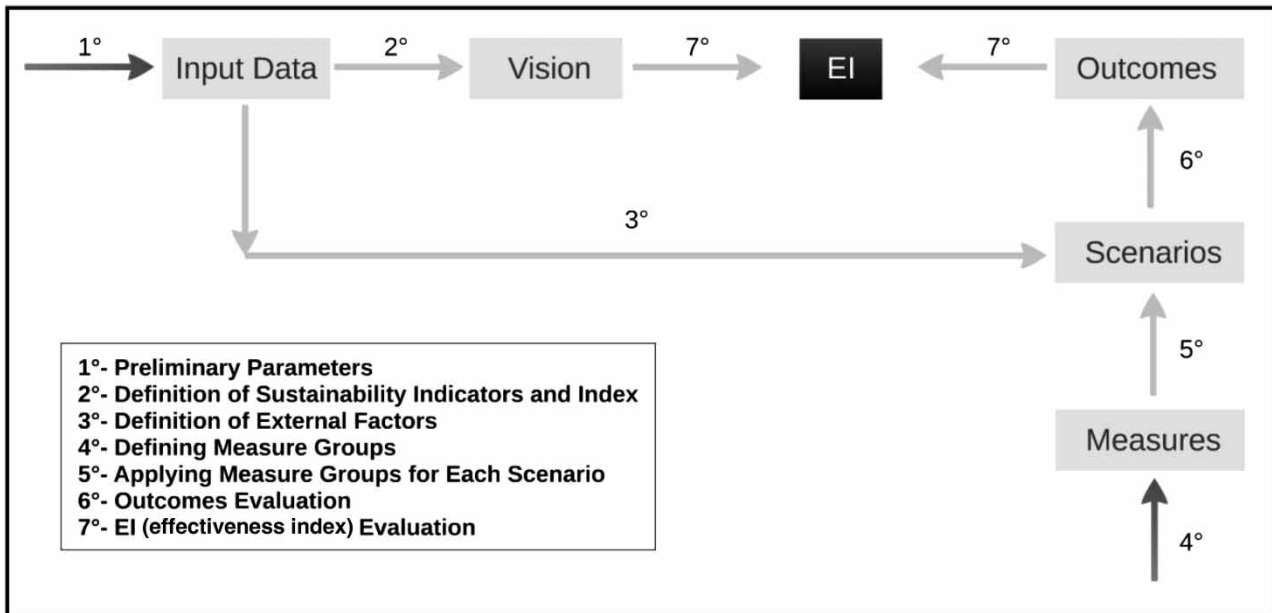


Figure 1 | UWU structure.

number of scenarios that each vision sustainability indicator achieves. Thus, the bigger the number of scenarios where the vision sustainability indicators are achieved, the more effective the measure groups.

**UWU steps description**

**First step – input data**

The input data are composed of preliminary parameters which are necessary to be considered in order to characterize the study area. The Appendix (available online at <http://www.iwaponline.com/wst/070/229.pdf>) presents Table A1 with data specification.

**Second step – vision elaboration**

In the vision building process, it is important to choose indicators and set the respective values that could be achieved in the scenarios. The purpose is to set indicators in the UWU model which reflect the desired reality. In this way, these indicators refer to population coverage by water supply and sanitation systems, costs, energy consumption, sludge production, occupied areas, health risks, greenhouse gas emissions, agriculture production by water reuse, dissolved oxygen in rivers, trophic level, flooding flowrate and infant mortality, according to Table A2 in the Appendix. Figure 2 shows the structure to elaborate the vision.

**Third step – scenarios elaboration**

The scenarios are based on the external factors, such as population growth rate ( $\lambda g$ ), environmental temperature ( $T_{an}$ ) and gross domestic product (GDP) per capita. The population growth rate was chosen as external factor because it is a very important variable to make decisions on projects. Environmental temperature is also very important considering the concerns about climate change, while GDP per capita reflects the economic performance of a society, which affects many other important variables related to sustainability. Figure 3 illustrates this structure. There are equations that express the relation between some variables and scenarios, as given in Table A3 in the Appendix.

It is important to be attentive in this structure because the scenarios are elaborated in a way that is totally independent of the vision building process, and the scenarios

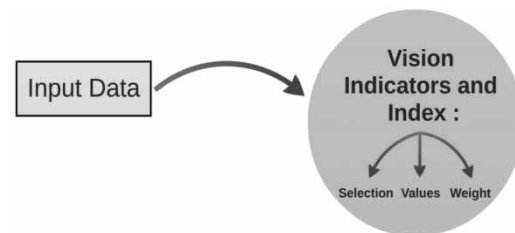


Figure 2 | Vision elaboration structure.

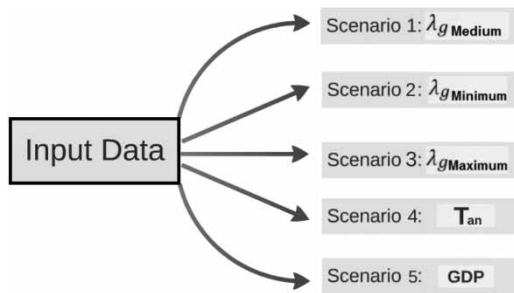


Figure 3 | Scenarios elaboration structure.

elaboration depends on a critical analysis of the external factors despite the aspirations admitted in the vision.

#### Fourth step – measure groups definition

To conceive the efficient water use measures, the UWU considers management water demand (Kayaga & Smout 2011), decentralized sanitation (Crites & Tchobanoglous 1998), ecological sanitation (ECOSAN) (Winblad *et al.* 2004), sustainable urban drainage system (SUDS) (Woods-Ballard *et al.* 2007) and water sensitive urban design (Hoyer *et al.* 2011) philosophies. The correspondent measure specifications are shown on Table A4 in the Appendix. In this way, considering these measures, it is possible to compose several groups to promote efficient water use in urban areas. The idea is to compose groups with different types of measures in order to improve the indicators towards the achievement of the vision in the scenarios. Figure 4 illustrates this step.

#### Fifth step – measure groups application

In order to operate these measures, it is necessary to relate them to indicators and external factors. These relations are described according to Table A5 in the Appendix, which are equations to estimate capacities of water supply, sanitation system and urban drainage systems. For buildings, the equations are based on daily per capita water

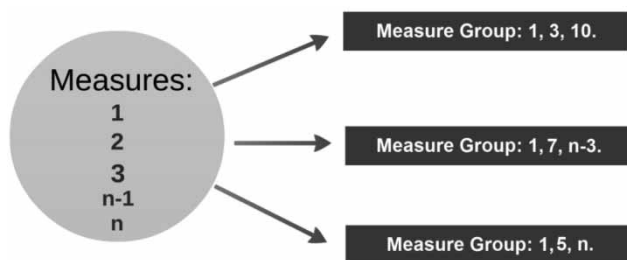


Figure 4 | Measure groups definition.

consumption and daily per capita wastewater production. Other equations are considered to estimate generation of sludge, occupied areas by sanitary systems, dissolved oxygen in the river, trophic level and agricultural production, among other indicators. The influences of the scenarios on these estimates are evaluated by specific equations. To estimate the impact of population growth rate and future populations, geometric models are used with respective rates for each scenario. For GDP per capita and environmental temperature impacts, the daily per capita consumption of water and the associated contribution of daily per capita wastewater are considered.

#### Sixth step – outcomes

Figure 5 shows the outcomes format. According to this figure the measure group outcomes from each indicator for each scenario are compared to vision indicator values in order to check the number of scenarios where these vision indicators were achieved. This process is developed for all measure groups and for all indicators and, in the final evaluation, the effectiveness index (EI) is determined. Table A6 in the Appendix presents an example of this format.

#### Seventh step – effectiveness index evaluation

With vision and scenarios established, the challenge is to propose measure groups with the expectation that the vision could be achieved in the largest number of scenarios possible. It is evaluated comparing the outcome indicators to vision indicator values, such as in the previous approach. The respective effectiveness level is estimated by the EI as presented in Table A7 in the Appendix, while the corresponding level scale is in Table A8. This final evaluation is a comparison of EIs estimated for each measure group simulated to indicate which is more efficient. After that, it is possible to establish a hierarchy among these measure groups. Figure 6 presents the EI evaluation structure.

		Outcomes for:				
Measure Group	Indicators and Index	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
MG 1	A	✓	✗	✓	✓	✓
	B	✗	✓	✓	✗	✗
	C	✓	✓	✓	✗	✗
MG n	A	✓	✗	✗	✓	✗
	B	✗	✓	✓	✗	✗
	C	✓	✓	✗	✗	✗

MG: Measure Group; A, B and C: vision indicators; ✓ vision indicator achieved in scenario; ✗ vision indicator not achieved in scenario.

Figure 5 | Outcomes format.

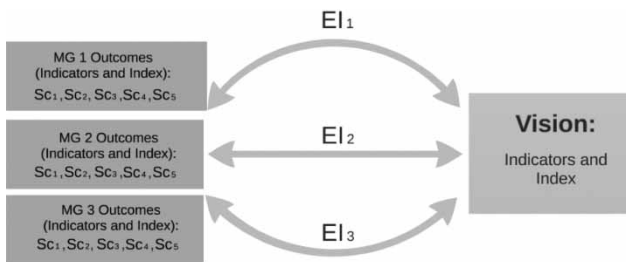


Figure 6 | EI evaluation structure.

## UWU application

### Input data

The city of Seara is located in Santa Catarina State, Brazil, as shown in Figure 7. Nowadays, the town's current population is 17,827 inhabitants, based on 2009 data. This town consists of an urban area, a rural area and an irregular occupation area. The urban area is composed of residential and industry zones. According to official data from IBGE (2013), 68.1% of its population lives in urban areas. The population has grown 0.9% per year. The city area is 311.8 km<sup>2</sup> and the respective population density is 57.2 inh/km<sup>2</sup> while its altitude is around 550 m. The infant mortality is approximately 9.8 deaths per year and the Human Development Index is 0.832. Specifically about economic performance, Seara GDP per capita is USD15,199.19/inh · yr and the industrial production is predominantly agro-business. Referring to the natural aspects of Seara, the average temperature is 19 °C and the average intensity of annual rainfall in the region is 1,841 mm/yr.

The water services in Seara are composed of a collective water supply system and onsite wastewater treatment systems. The water supply system population coverage is



Figure 7 | Location of the municipality of Seara.

Table 1 | Vision building

Indicator	Unit	Value	Weight (%)
Population coverage by water supply system	%	99.00	20
Population coverage by sanitation systems	%	80.00	20
Agriculture production in rural area	ton/yr	300.00	20
Phosphorus concentration in the lake in urban area	gP/m <sup>3</sup>	0.001	10
Flooding flowrate at critical area in drainage system	m <sup>3</sup> /s	0.03	20

around 90% and has operational problems, especially related to physical loss of water pipe networks. The onsite wastewater systems are basically composed of septic tanks and soil disposal, which apply to 54% of the population. The urban waste service is public and inefficient. Wastes are disposed on the streets, and, after some rain, these wastes are taken to the drainage system, as well as to the rivers. Thus, the urban drainage system has several problems from flooding. As to the buildings, they do not have any initiative for quantitative and qualitative water conservation.

### Vision building

In this step it was assumed that the following vision would be attractive and could be achieved, as shown in Table 1. Thus, for this application, it was built the vision related to five sustainability indicators.

### Scenarios elaboration

In this step, five scenarios were elaborated based on the external factors, such as annual temperature, population growth rate and GDP per capita, whose values are presented in Table 2.

### Measure groups composition

The measure groups were conceived for all water service components and based on water demand management, decentralized sanitation, ECOSAN and SUDS philosophies. These groups are listed as follows.

- Measure 1 – water consumption reduction by low-flush toilet. The current toilets work with 12 litres per flush and this measure predicts that in 2032 approximately 50% of the population will be using low-flush toilets with 6 litres per flush.

**Table 2** | Scenarios characteristics

Scenarios	External factors		
	$\lambda_1$ (% /yr)	T (C)	GDP per capita (USD/inh · yr)
01	0.9	19	13,000
02	1.4	19	13,000
03	0.5	19	13,000
04	0.9	25	13,000
05	0.9	19	15,000

**Table 3** | Measure groups

Groups	Measures
0	Without measures
1	1; 2; 5; 11
2	1; 6; 7; 9
3	5; 6; 7; 11

- Measure 2 – graywater for toilets, cleaning and irrigation. This measure proposes to use 50% of graywater generated in the building to meet 20% of the population in 2032.
- Measure 5 – reuse of water using treated wastewater for agriculture. The idea of this measure is to divert 50% of the flowrate from the wastewater treatment plant, which was designed in Measure 11, to agriculture production.
- Measure 6 – permeable pavement implantation. This measure proposes to reduce the runoff coefficient to 40%.
- Measure 7 – filterstrips implantation. This measure proposes to reduce the runoff coefficient to 40%.
- Measure 9 – expansion of the current wastewater treatment plant. Whereas the current system meets 54% of the population, this measure may meet 90% of the population in 2032.
- Measure 11 – construction of new wastewater treatment plant. This measure focuses on the construction, for 2032, of the new wastewater treatment plant with a capacity of 30 l/s and composed of an anaerobic reactor, a pond, wetlands and soil disposal system.

Considering these measures described, in 2012, it is possible to elaborate the measure groups. Group 0 considers

**Table 4** | Outcomes from measures application

Simulation	Indicators	Scenarios					Vision	N
		01	02	03	04	05		
Measure group 0 IE = 0.0	WSSC (%)	35	31	37	38	19	99	0
	SSC (%)	45	41	49	49	24	80	0
	AP (ton/yr)	0	0	0	0	0	300	0
	PC (gP/m <sup>3</sup> )	0.018	0.012	0.011	0.012	0.013	0.010	0
	FF (m <sup>3</sup> /s)	0.34	0.037	0.31	0.34	0.34	0.03	0
Measure group 1 IE = 2.3	WSSC (%)	100	100	100	100	66	99	4
	SSC (%)	100	100	100	100	100	80	4
	AP (ton/yr)	255	255	255	255	255	300	0
	PC (gP/m <sup>3</sup> )	0.010	0.010	0.010	0.010	0.010	0.010	0
	FF (m <sup>3</sup> /s)	0.34	0.37	0.31	0.34	0.34	0.03	0
Measure group 2 IE = 0.9	WSSC (%)	94	85	100	100	51	99	2
	SSC (%)	54	49	58	57	34	80	0
	AP (ton/yr)	0	0	0	0	0	300	0
	PC (gP/m <sup>3</sup> )	0.012	0.012	0.011	0.012	0.013	0.010	0
	FF (m <sup>3</sup> /s)	0.43	0.43	0.43	0.43	0.43	0.03	0
Measure group 3 IE = 1.3	WSSC (%)	41	37	44	44	24	99	0
	SSC (%)	100	100	100	100	77	80	4
	AP (ton/yr)	255	255	255	255	255	300	0
	PC (gP/m <sup>3</sup> )	0.010	0.010	0.010	0.010	0.011	0.010	0
	FF (m <sup>3</sup> /s)	0.43	0.43	0.43	0.43	0.43	0.03	0

WSSC: WSS coverage; SSC: SS coverage; AP: agriculture production; PC: phosphorus concentration; FF: flooding flowrate; N: number of scenarios in which the vision was achieved.

the situation where no measure will be designed and implemented in the next 20 years. The other groups, named Groups 1, 2 and 3, were designed to obtain the highest possible EI for 2032. Table 3 shows these groups.

## RESULTS AND DISCUSSION

The outcomes from UWU application are presented in Table 4.

In total, four simulations were conducted. For Measure Group 0, without measures, the indicators were not achieved in any scenario, EI being equal to 0.0. For Group 1, in which measures 1, 2, 5 and 11 would be implemented, the WSS and SS coverage indicators would be achieved in the vision in four scenarios. The agriculture production, phosphorus concentration and flooding flowrate indicators were not achieved in any scenario. In this way, the resultant EI was 2.3, which is considered reasonable. For measures 1, 6, 7 and 9, which are components of Group 2, the coverage indicator of WSS would be achieved in the vision in two scenarios only. The other indicators were not achieved in any scenario. Consequently, the EI was 0.9, i.e., inadequate. In Group 3 the SS coverage indicator overcame the vision values in four scenarios. The other indicators were not achieved in any scenario and, in this case, the EI was 1.3, which indicates an inadequate condition.

## CONCLUSION

Based on Measure Group 1, which presented the highest EI value, it is possible to observe that the best strategies are water demand management and decentralized sanitation. Thus, with corresponding measures related to water demand management and decentralized sanitation, it was possible to build a management plan for efficient water use in Seara. This plan highlights actions such as reduction in water consumption per capita reduction and implementation of decentralized wastewater treatment plants. These measures are cheaper and promote good technical results. It is also important to observe that the UWU application has demonstrated some flexibility to manage several variables. That is because it is easy to review the vision and to change external factors. However, it is very important to observe the input data step and to adjust coefficients in

equations according to each reality studied. And for the final evaluation, it is recommended to be sensible and wise to make good decisions to promote efficient water use.

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