DELIVERABLE D 8.1:

Library of Models

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Project acronym: demEAUmed

Project full title: Demonstrating integrated innovative technologies for an optimal and safe closed water cycle in Mediterranean tourist facilities

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Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	✓
RE	Restricted to a group specified by the consortium (including Commission Services)	
CO	Confidential, only for members of the consortium (including Commission Services)	

List of acronyms and abbreviations

CA: Consortium Agreement

DM: Dissemination Manager

DoW: Description of Work

EC: European Commission

EM: Exploitation Manager

GA: Grant Agreement

IPR: Intellectual property rights

SC: Steering Committee

S&T Manager: Scientific and Technical Manager

WP: Work Package

WPLs: Work Package Leaders

The research leading to these results has received funding
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1. Project Overview

demEAUmed (Demonstrating integrated innovative technologies for an optimal and safe closed water cycle in Mediterranean tourist facilities) is a European project co-funded by the European Union under the 7th Framework Program within ENV-2013-WATER-INNO-DEMO-1 with a budget of 5,831,908 M € over 42 months, and started officially on January 1st, 2014. The aim of demEAUmed project is the involvement of industry representatives, stakeholders, policy-makers and diverse technical and scientific experts in demonstrating and promoting innovative technologies, for an optimal and safe closed water cycle in Euro-Mediterranean tourist facilities, leading to their eventual market uptake.

The demEAUmed consortium is led by LEITAT, scientifically coordinated by ICRA and is composed of 15 members from different fields - business, research, technology, hotel communities and public agencies and organizations - from seven European countries: Spain, Germany, The Netherlands, Austria, Italy, France and Belgium.

DemEAUmed will face two key challenges: the importance of the tourism economy and water scarcity characteristic of the area. It will be a critical platform for promoting the use of sustainable and innovative technologies in other Euro-Mediterranean tourist facilities in light of also the global tourism market. The project will design a dissemination plan analysing critical stakeholders/customers to adequately transfer demEAUmed results. Creation of new market opportunities to European industry and SMEs will also be addressed. A representative resort placed in Catalonia, Spain, is considered as a DEMO site, where a representative part of all inlet and outlet waters will be characterised, treated with proper innovative technologies, and reused to reduce the carbon footprint of water management in an integrated approach at demonstration level.

2. Objectives of the Deliverable

The objective of this deliverable is to propose a preliminary design of the decision support system (DSS) that will be used to determine the environmental, economic, and social impacts of the installation/incorporation of water-saving and/or water-reuse technologies and practices in hotels.

This document is aimed towards the consortium partners of the demEAUmed project, which will provide information on the life cycle as well as their technologies operation for their subsequent incorporation in the DSS. This document will begin with a preliminary design of the DSS, followed by the summary of the existing research on water use in hotels, as well as existing water cycle models.

Then, using one of the existing water cycle models, a simulation of hotel water use will be summarized to determine the impact of water use technologies on potable water use. Next, the incorporation of a technology library will be explained as well as the progress on its information gathering.

3. Design of the Decision Support System

The main function of the DSS is to evaluate different hotel water consumption scenarios with respect to water treatment technologies for reuse, future climate scenarios, and different water use practices such as water conservation. These scenarios would then be analyzed via their environmental, economic, and social impacts.

Figure 1 illustrates the components that make up the DSS. “Inputs” refers to information provided by the user. This may include hotel characteristics (such as number of rooms, presence of a kitchen and/or laundry, presence of a pool, etc.). However, other information may include weather and climate information. The provided information is then input into the water cycle model, which is a deterministic model that ideally calculates water quality and flows via mass balances throughout the hotel’s water distribution system. The results obtained from the model should at least include potable water use, wastewater production, and greywater production (and use in some cases). These results along with life cycle assessment (LCA) information collected by LEITAT and other partners can be used to estimate the environmental, economic, and social impacts using designated indicators.

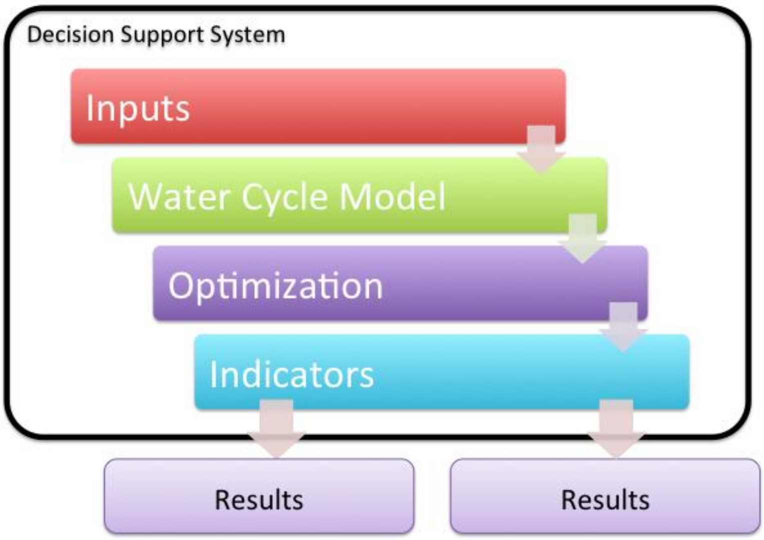

Figure 1. Conceptual scheme of the proposed decision support system (DSS).

The DSS would be packaged as software for use by the hotel industry, water utilities, and water treatment technology companies. While this DSS will be developed based on data from Hotel Samba, it will be able to be applied to other hotels.

4. Hotel Water Use

In order to design a DSS for hotels with respect to water use, background information has to be obtained on the relationship between hotels and water. Therefore, existing peer-reviewed literature was read to better understand this relationship.

Using the database Engineering Village (www.engineeringvillage.com), search terms such as “hotel water use” and “hotel water consumption” were used to look for peer-reviewed journal articles. This search resulted in 9 peer-reviewed articles. Of these articles, 5 focus mainly on water consumption while the other 4 look at water and energy savings. Studies ranged in location including: Hong Kong; Zaragoza, Spain; Shenzhen, China; Oahu, Hawaii, USA; Mallorca, Spain; and Barbados. Studies also considered a range of hotel sizes.

Water consumption-focused studies mainly had the objectives of determining the important hotel characteristics that determine water use and to develop models that can be used to predict water use. The earliest peer-reviewed study analyzed the water use habits of 17 hotels in Hong Kong ranging from 3 to 5 stars (Deng & Burnett, 2002). Results showed that factors such as the number of guests, “food covers” and in-house laundry service were responsible for a large amount of water consumption. In fact, for hotels with an in-house laundry service, laundry was responsible for more than half of the hotel´s water consumption. In hotels with outsourced laundry services, kitchens were responsible for 55% of the total hotel water consumption followed by rooms which were responsible for 45%. A similar study, with different explanatory factors, was conducted in Barbados (Charara, Cashman, Bonnell, & Gehr, 2011). In this case, the number of guests normalized by the nights stayed was shown to be the most important factor in estimating water consumption. For higher level hotels, the number of employees is also a significant factor.

Other consumption-based studies resulted in the development of models for hotel water use predictions. Gopalakrishnan & Cox (2003) used data obtained from hotels in Oahu, Hawaii, USA to create a linear regression model that would estimate water use based on hotel characteristics. The numbers of rooms, pools, and restaurants as well as the presence of a golf course were all significant factors in the resultant equation. Another model was made using data from hotels in Mallorca, Spain, yielding similar results to those found in the aforementioned study. For instance, the number of hotel rooms and pools also had a significant influence on water use in this study. Other factors such as average annual occupancy rate, the months the hotel is open, and the management system (chain affiliation) also significantly contribute to overall water use (Deyà Tortella & Tirado, 2011). Blokker (2009) used a different modelling methodology by determining the functional rooms or rooms where water is being used. Based on this model, hotel rooms use the most water followed by meeting rooms, the kitchen, and cleaning.

Water savings-based studies mainly quantified the degree to which water-saving technologies can minimize water usage in a hotel. For instance, Gatt & Schranz (2015) documented the results of the replacement of water using devices with their more efficient counterparts. Retrofits included aerators, showers, and toilet cistern volume displacers, which were all responsible for a 48% drop in total hotel water consumption. Barberán, Egea, Gracia-de-Rentería, & Salvador (2013) estimated the water and economic savings of retrofitting a hotel in Zaragoza via a linear regression model that took into account hotel characteristics including number of guests, event attendance, meal attendees, retrofits and season. Retrofits included tap replacement, aerators, discs added to shower heads, new pre-wash shower heads, and devices that control water flow to dishwashers. This retrofit was responsible for a water usage savings of about 21%. Styles, Schoenberger, & Galvez-Martos (2015) analyzed the effects of retrofits to different types of hotels or lodging by developing a model to estimate water use for a standard 100-room hotel and campsite with 80 spaces with and without water-saving retrofits. For a 100-room hotel, implementation of water-saving technologies could reduce potable water use about 75%. Meanwhile for a campsite, water use can be reduced up to 70%. Also, depending on the technology added, water savings may also translate to energy savings. This was the case with a study conducted in Shenzen, China that examined the feasibility of the installation of a solar water heating system in a hotel. Results showed that a solar water heating system could support most of the rooms in a 400-room hotel with a 5-star rating (Chan, Li, Mak, & Liu, 2013).

5. Water cycle models

5.1. Summary of considered models

5.1.1. Dynamic metabolism modelling (DMM)

Dynamic metabolism modelling (DMM) is a Microsoft Excel-Based model that was the result of collaboration between researchers at Karlstadt University in Sweden and the Norwegian University of Science and Technology. The intended purpose of this software is to quantify the environmental and economic impacts of certain decisions regarding municipal water systems. The user inputs annual data (i.e. water flows, population, expenditures, and resource consumption) into an Excel spreadsheet, which is linked to other spreadsheets containing formulas, constants, and “intermediate files”(Figure 1). The model´s result file then shows the impacts of changes to the water management system. Results include economic, environmental, and social impact metrics. This model was used to analyze future water management for the city of Oslo, Norway for the next 30 years (Venkatesh, Sægrov, & Brattebø, 2014).

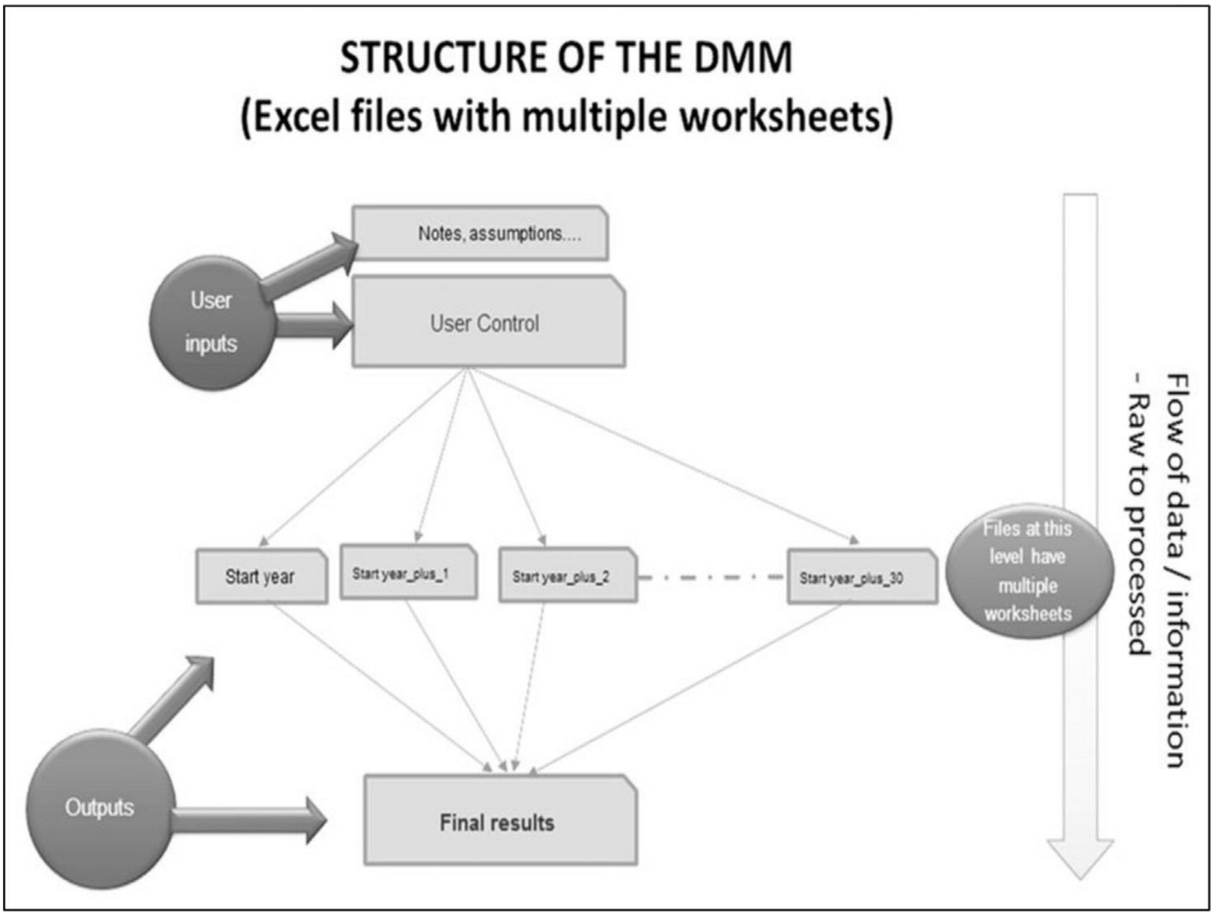

Figure 1: Diagram of the structure of the DMM (Venkatesh et al., 2014)

5.1.2. DUWSim

DUWSim is a water cycle modelling software that is the result of the integration of three types of models: climate, land use, and urban water balance (Figure 2). The climate model, LARS-WG, uses historical weather data to produce future weather estimations. MOLAND, the land use model, uses cellular automata to project the most likely land development based on past population and economic trends. Both the climate and land use models are connected to the water balance model, DUWSiM-WB. The basic unit of land use is a land use cell which represents a square of 4 ha area and contains the land use type, the land cover, and information on water use & supply. The model can be run at the land use cluster scale, neighbourhood scale, and the city scale. Outputs include environmental, economic, and social metrics. This model has been used to simulate the effects of water management solutions for the city of Dublin, Ireland (Willuweit & O'Sullivan, 2013).

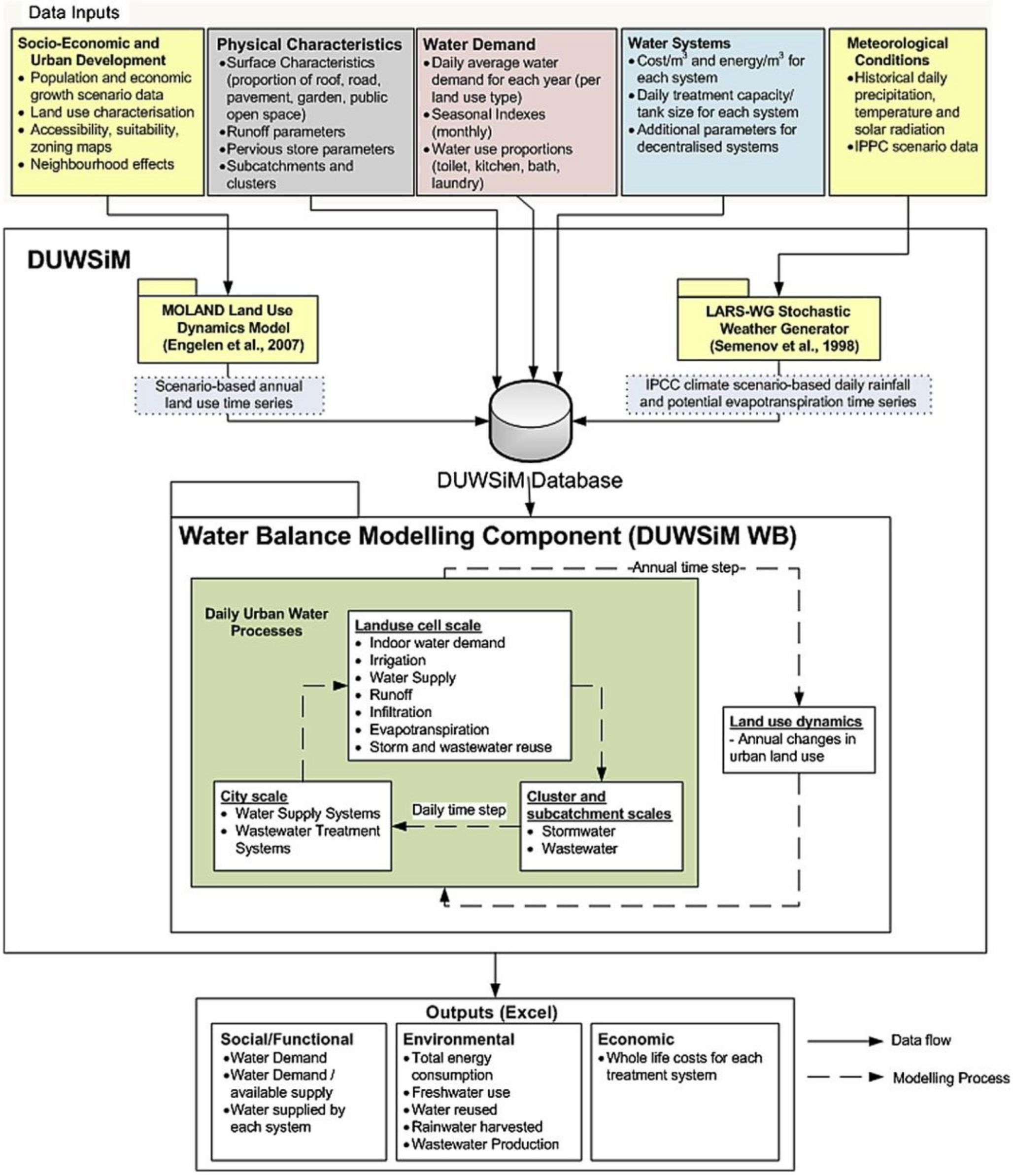

Figure 2: Organization of the modelling software DUWSim (Willuweit & O'Sullivan, 2013)

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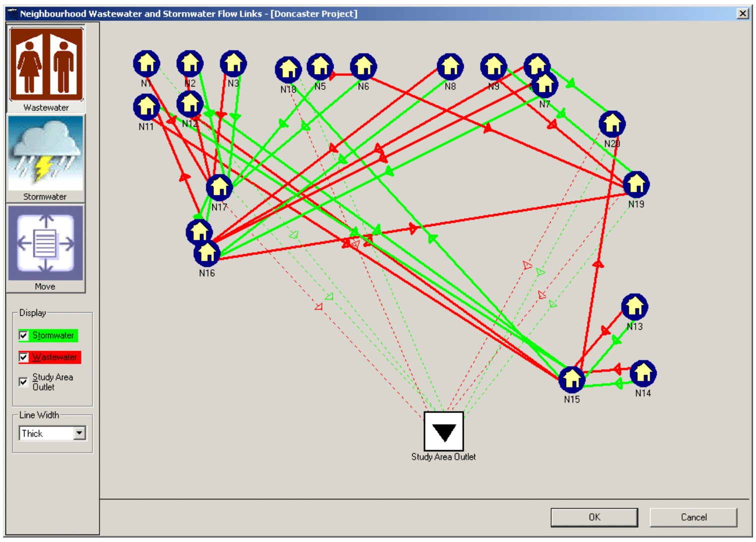
5.1.3. City Water Balance (CWB)

City Water Balance (CWB) is a modelling software that simulates water management systems. Its basic modelling unit is the unit block, which contains information on the storage, use, and transmission of water, the water demand, the amount of pervious and impervious area, and pollutant loads. Simulations are done at the daily time step. Unit blocks can then be aggregated into neighbourhoods and subsequently into subcatchments. At the neighbourhood and subcatchment levels, the amount and quality of water running through water mains, runoff, and the presence of natural systems (i.e. bodies of water) can be simulated. With respect to water quality, only 4 contaminants can be modelled throughout the system simultaneously. These contaminants are assumed to be conservative, and with respect to indoor water use, are modelled as loadings while as input streams are modelled as concentrations. In addition, energy and cost of water management systems can be calculated via connections with spreadsheets that contain life cycle cost and energy factors for technologies and components of the water management system. Alternative water management solutions can be simulated in the model including: green roofs, rainwater, wastewater, septic tanks and boreholes. Mackay & Last (2010) applied this model to the city of Birmingham, UK.

5.1.4. UVQ

UVQ is an Excel-based urban water modelling tool that was developed by CSIRO. This tool was designed to analyze water and contaminants throughout the water management system as well as the effects of the incorporation of new technologies or practices. Like CWB, this model runs at a daily time step. Simulations can only be applied to Australia and Europe. The basic modelling unit is the urban block, which represents a different type of land use including: residential, industrial, commercial, and open space. Urban blocks can be aggregated to represent neighbourhoods and even cities. Different water management infrastructure designs ranging from centralized to decentralized can be modelled (Mitchell & Diaper, 2010). A screenshot associated with this tool is shown in Figure 3.



Neighbourhood Wastewater and Stormwater Flow Links - [Doncaster Project]

Display

☑ Stormwater

☑ Wastewater

☑ Study Area Outlet

Line Width: Thick

Figure 3: Screen setup of UVQ (Mitchell & Diaper, 2010)

5.1.5. Urban Water Optioneering Tool (UWOT)

UWOT is a .NET-based software that was developed by the University of Exeter for the purpose of modelling water management at different spatial and time scales (Figure 4). Water management can be modelled at time steps as small as 15 minutes. Water demand is driven by water-using appliances, building or room occupancy, and the number of units. Residential and non-residential buildings can be modelled. The software even has built-in daily water consumption patterns. Climate and weather data can also be added to the simulations. Water management simulations can be carried out at different scales, from the building scale to the city scale. In addition, decentralized and centralized water, wastewater, greywater, and rainwater management/treatment technologies can be incorporated. Water quality is also taken into account, but it is modelled as categories (i.e. potable water, greywater, greenwater, wastewater) as opposed to concentrations of contaminants. An application of this program to a site in the UK has been published by Makropoulos, Natsis, Liu, Mittas, & Butler (2008).

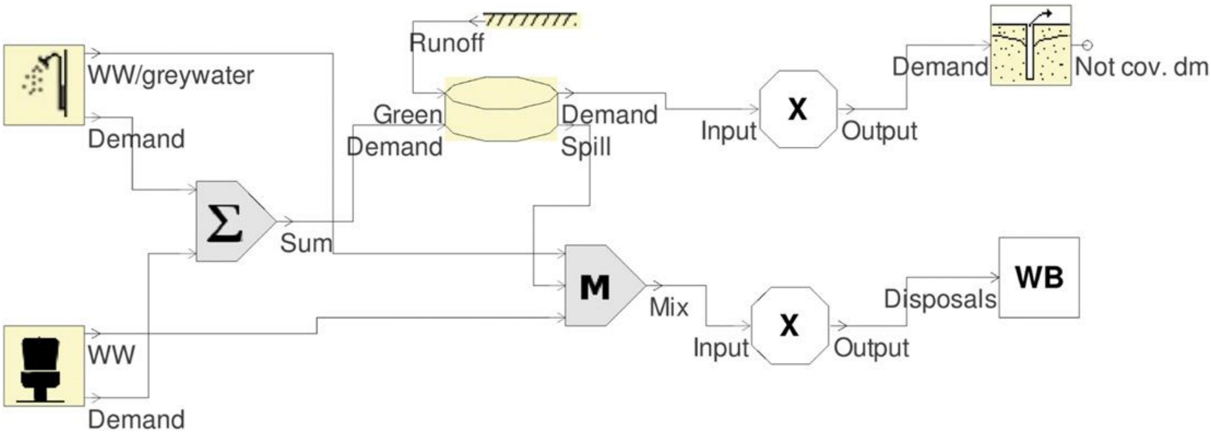


Figure 4: UWOT Setup (Makropoulos et al., 2008)

5.1.6. WESTforIndustry

This steady-state model was mainly developed by CEIT to model water treatment for industrial plants. Modelica was used to program the software. The model consists of a library of different technologies, which are represented by equations that estimate the removal of contaminants as well as costs. These models are visually represented as model blocks which can be connected in a visual interface to simulate a water or wastewater treatment plant. In the model, about 63 different contaminants can be accounted for. This software has been used to analyze the treatment of wastewater in a paper mill in Madrid (Lizarralde et al., 2012).

5.1.7. WaterMet^2

Like UWOT, WaterMet^2 was also developed by the University of Exeter using .NET to model urban water management. However, this software also has an urban metabolism component that accounts for the embodied energies of associated materials and chemicals. Users can define inputs ranging from the water source, the distribution system, the number of houses and other types of buildings connected to the water management system (Figure 5). Specific information such as piping materials and treatment chemicals can also be added. Per-capita water use values as well as percentages of water use for certain water using devices can be defined. Water quality simulations can be done, but only for wastewater treatment and discharge. Simulations of water management systems can be done at different scales ranging from the household to the entire city. Behzadian & Kapelan (2015) used this software to simulate a northern European city.

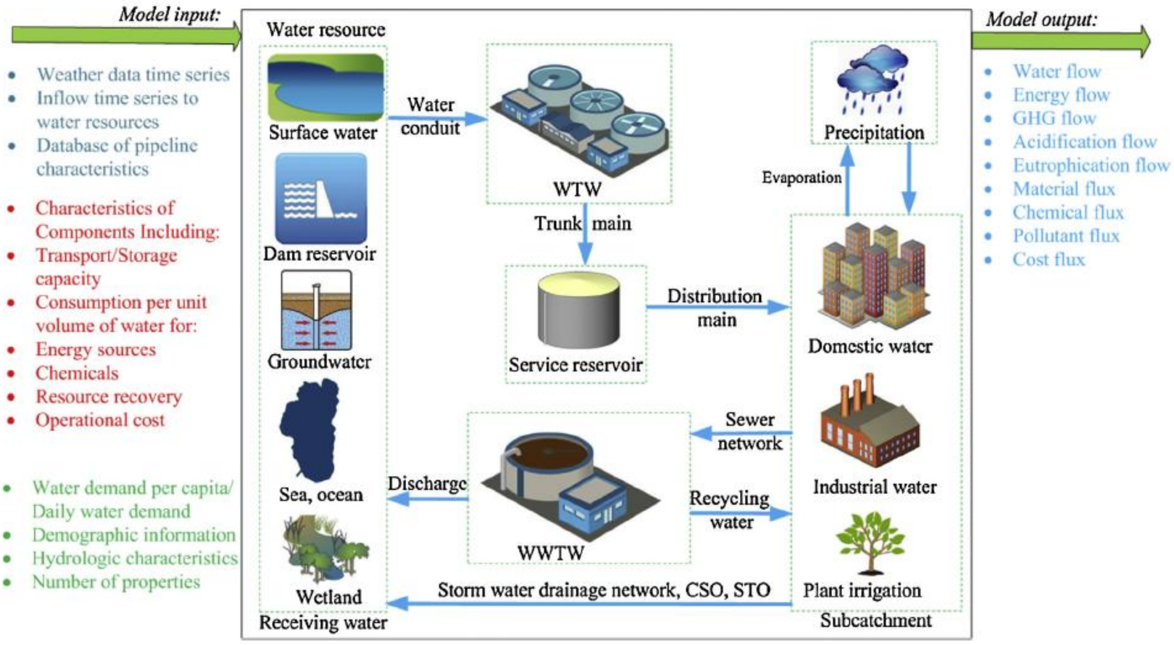


Figure 5: WaterMet2 Model framework (Behzadian & Kapelan, 2015)

5.1.8. Urban Developer

Urban Developer is a commercial urban water management software that is used to model urban water systems. Programmed in C#, this software has short time steps, can include stochastic modelling, and can incorporate climate/weather data. The model can be applied to individual buildings up to the neighbourhood or "cluster scale". In addition, water quality can also be included.

5.1.9. SIMBA

This commercial software programmed in C# has mainly been used to model wastewater treatment at the process level. Similar to WESTforINDUSTRY, it consists of model libraries which contain equations that estimate pollutant removal rates. Using a visual interface, users can connect "model blocks" to simulate a wastewater treatment plant or wastewater treatment system (Figure 6). Users can also define their own model blocks. While this software mainly focuses on wastewater management, it can be adapted to model water treatment systems.

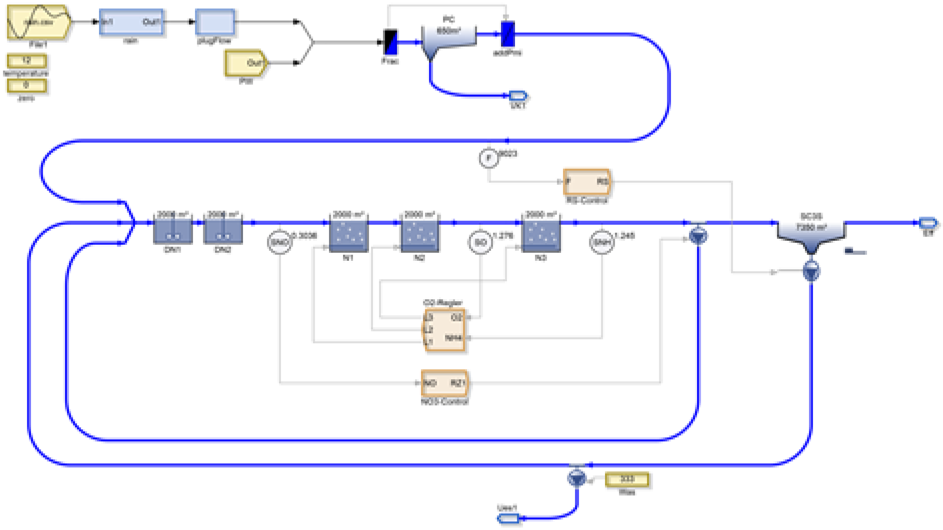


Figure 6: Example SIMBA model setup (https://simba.ifak.eu/en/content/simba-sharp-water)

5.2. Building Scale Modelling Capacity

Water management solutions for hotels will most likely be managed at the building scale. As a result, the water cycle modelling software used has to at least be able to feasibly model the flows, technologies, and the specific water quality of water within a hotel. While the lowest scale for most of the reviewed software is either the building or the city block, the main purpose of much of the software is for a more neighbourhood or city-scale analysis of water management scenarios. In DUWSim, the land use cell is an area of about 4ha that may have more than one building on it. Yet, while land use cell-level water balance calculations are detailed to the point that the user can actually simulate different on-site water management alternatives, this software is mainly used for larger-scale water management analyses as it relies on GIS maps (Willuweit & O'Sullivan, 2013). The case is similar for CWB, in which at the building scale, the user can assign demand profiles, contaminant loadings, and the amount of pervious/impervious area. However, the lack of detail assigned to this basic unit shows that this water cycle model is more appropriate for community or neighbourhood scale analyses or higher (Mackay & Last, 2010).

Conversely, UWOT can model water management at the building scale. In fact, depending on the building, there are two methods that can be used. The user can either model only one building by designating the "appliances" in the building, its occupancy, and its onsite water management technologies, or model the building as a neighbourhood (such as a hotel), modelling each room as a separate building. A similar setup can also be applied to WaterMet[2] by modelling large buildings as subcatchments.

The most ideal models for water management of individual buildings are WESTforINDUSTRY and SIMBA. WESTforINDUSTRY and SIMBA rely on the user´s setting up flowcharts in which the arrows and lines represent flows and boxes represent treatment processes or demands. As a result, different configurations of onsite water management in buildings can be more accurately modelled. However, these programs mainly focus on wastewater treatment. Therefore, some improvisation would be needed to adapt this software to all aspects of water management. Also, certain water management alternatives such as rainwater harvesting and alternative stormwater management may be a challenge to simulate with these programs.

5.3. Addition of New Technologies

Almost all models with the exception of DUWSim have the ability to incorporate new technologies. In the case of SIMBA and WESTforINDUSTRY, new models can be added to the model libraries by calculating pollutant removal and cost equations for new model blocks. UWOT is also able to incorporate new technologies via modification of a connected spreadsheet file. For WaterMet^2, specific treatment technologies cannot be added as water and wastewater treatment are simulated at the plant level. Still, alternative treatment facilities can be simulated by specifying the associated chemicals, energy use, as well as the contaminant removal rates. CWB and UVQ can also incorporate new technologies; however, the degree of detail to which they can be simulated is unknown.

5.4. Energy, Cost, and Other Impacts

Some of the reviewed water cycle models include some type of built-in peripheral analysis (i.e. cost, environmental impacts, energy). WaterMet^2 actually calculates the “metabolism” of a water management system by letting the user define the embodied energy factors for all aspects of the system. DUWSiM and DMM use sustainability indicators to determine the environmental impacts associated with the scenarios (Venkatesh et al., 2014; Willuweit & O’Sullivan, 2013). Both models are connected to spreadsheets with factors to calculate sustainability analyses or life cycle assessments. Both include life cycle costing. Spreadsheets are also used for life cycle costing and energy analyses for CWB (Mackay & Last, 2010). Included in the results of UWOT is an energy analysis; however this may most likely be related to the electricity use associated with water use.

6. Case study simulation

6.1. Introduction

During the 1990´s Hotel Samba, demonstration site of demEAUmed project, installed a greywater reuse system to save water and achieve a green certification. This system collects water from the hotel room showers, baths, and sinks that is gridded and sent to a collection tank where chlorine is added for disinfection. The treated water is then sent back to the hotel room toilets for flushing. The following case study aims to estimate the effect of the installation of this greywater reuse system on potable water use and energy use. The water cycle modelling software, UWOT, due to its abilities to model an individual building and incorporate water reuse technology, has been applied.

6.2. Methods

6.2.1. Data Collection

Needed data to carry out the study included: number of hotel rooms, number of bathrooms, other services, and the size of the hotel. All of this information was provided by the hotel. Hotel rooms were divided into 5 categories: individual, double, double (shower only), family, and suites. The water-using devices in each of the rooms are tabulated in Table 1.

In addition to the hotel rooms were the service rooms or service areas located inside the hotel. They included: restaurant, bar, conference room, administration, pool, laundry, and reception. Each of these places has at least a water-using device. The characteristics of each of these service rooms are shown in

Table 2.

Table 1: Water use devices in each type of hotel room

Type of Room	Toilet	Shower	Bath	Handbasin
Double	✓	✓	✓	✓
Double (shower only)	✓	✓		✓
Suite	✓	✓	✓	✓
Individual	✓	✓		✓
Family	✓	✓	✓	✓

Table 2: Water use devices in each hotel service room or area

Appliance	Restaurant	Bar	Conference Room	Administration	Pool	Laundry	Reception
Washing Machine						✓	
Toilet		✓	✓	✓		✓	✓
Shower							
Bath							
Handbasin		✓	✓	✓		✓	✓
Kitchen Sink	✓	✓					
Dishwasher		✓					
Garden							
Outside Use					✓		

6.2.2. Assumptions

In UWOT, the hotel was modelled as a neighbourhood. Specifically, the rooms were modelled as domestic buildings while the services were modelled as non-domestic buildings. Room occupancy rates were assumed to be 80%, which translated into 1.6 people for a suite; 0.8 people for an individual room; 3.2 for both types of double rooms; and 4.8 for a family room. Other hotel services were modelled as non-domestic buildings. Occupancies were based on the assumptions presented in Table 3. Water using devices were set at the default use frequencies and leakage rates set by UWOT. Daily water use patterns were also default for domestic buildings and non-domestic buildings. As a result, this may affect the simulation accuracy as the model assumes services are closed during the weekend. While this might be true for hotel administration, other services are still available during the weekend, which could explain discrepancies between the hotel´s real and modelled water use.

6.2.3. Scenarios

There are two scenarios that are modelled in this case study. The first scenario, referred to as business as usual (BAU), refers to the hotel without the water reuse technology. In this scenario, only potable water is used for all water use devices. The second scenario will be referred to as the water reuse scenario in which greywater from hotel rooms is sent to a greywater tank, gridded, disinfected and then sent back to the hotel room´s toilets.

Table 3: Assumptions of occupancy rate for each hotel service (total guest number is 1346).

Public Areas	Number of People	Comments
Pool	94	7% of all guests use the pool
Laundry	135	10% of a person's wash
Bar	404	30% of guests use the bar
Conference Room	50	50 people use the conference room
Administration	10	10 people work in the administration of the hotel
Reception	274	20% of guests
Restaurant	404	30% of guests use the restaurant

6.3. Results

A comparison between the potable water use percentages by water use device is shown in Figure 7. Since treated greywater is used for toilet flushing, the 25% of potable water that is used for toilet flushing in the BAU scenario is halved in the water reuse scenario. This shows that treated greywater can actually impact a significant use of potable water.

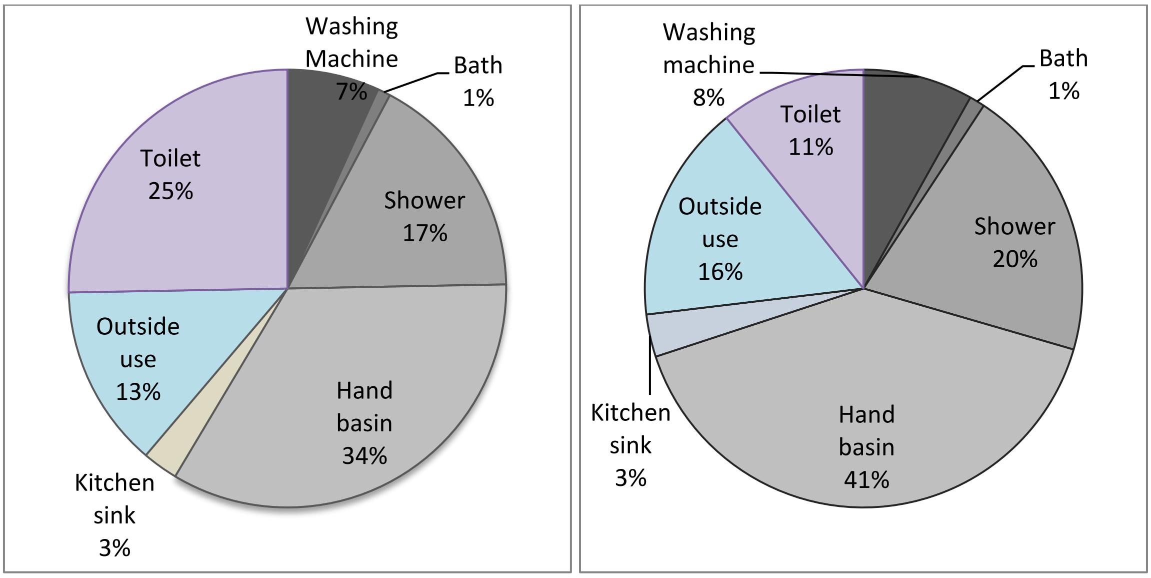


Figure 7: Percentage total simulated hotel potable water use by water using device for the BAU (right) and Water Reuse (left) scenarios. Note that the percentage of potable water use is halved in the water reuse scenario due to use of treated greywater for toilet flushing

Figure 8 illustrates the comparison in terms of water, wastewater, and energy uses between the two scenarios. As expected, potable water and wastewater values decrease about 16% and 19%, respectively, when greywater is reused. In the BAU scenario, the used shower and sink water would be directly sent to the wastewater treatment plant. Therefore, the incorporation of greywater reuse technology actually moves the greywater to a storage tank for its subsequent treatment, thus resulting in a decrease in wastewater production. Conversely, energy use actually increases about 6% in the water reuse scenario. This is mainly due to the installation of a new onsite technology that uses energy for pumping and mixing.

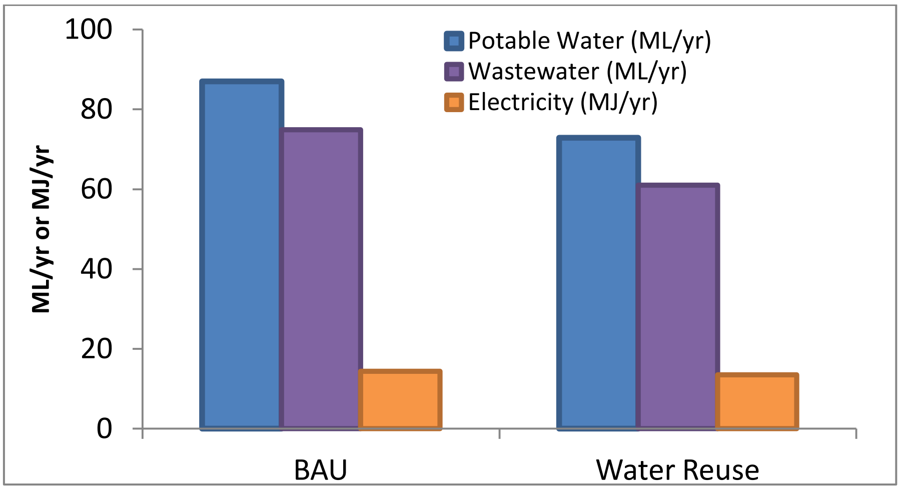


Figure 8: Comparison of potable water, wastewater, and energy uses by scenario

6.4. Discussion

A 16% savings in potable water is significant for a hotel. However, currently, there are no real economic or energy incentives to carry out this water savings in the hotel industry. For example, water costs are only responsible for about 4% of total hotel expenses on average in Mallorca (Deyà Tortella & Tirado, 2011). In the case of this hotel, water is only about 1.4% of the total maintenance cost. Also addition of a new technology would require not only additional cost but could even consume more energy. Nevertheless, while the energy bill for hotel Samba is about 2.6 times the water bill, this is still relatively small when compared to the rest of the hotel expenses (3.6% of the total budget).

UWOT´s method of water use estimation and its ability to dynamically simulate water use were the main reasons it was considered as a water cycle model for the DSS. Water use estimations are done via “appliances” or water-using devices. The user can specify water treatment technologies, incorporate water reuse, and account for alternative sources of water. Even energy use can be taken into account. Simulations can take place over a range of timescales and durations. However, UWOT also has some limitations. The main limitation is the lack of specific water quality data. Water quality is characterized by category (i.e. potable water, wastewater, greywater, and greenwater). Appliances change water from one category to another. For instance, potable water used in the kitchen, shower, and hand basin is converted to greywater. However, behind these labels there are no contaminant concentrations. As a result, feasibility studies on the incorporation of new water use technologies would be limited. Therefore, if this model is to be considered, a more specific water quality sub-model will have to be defined to take into account the concentrations/values of specific water quality parameters.

7. Integration and Assessment of Water-Reuse Technologies

The ability to integrate new technologies is a necessary feature of the water cycle model in the DSS. This is proposed to be done via “library of models” which consists of algorithms that are able to simulate the operation, cost, energy use, and the environmental impact of water reuse technologies provided by the partners. The integration of this library with a design that takes into account future expansion will help partners better understand the economic, social and environmental implications of integrating their technologies into a hotel´s water management system.

7.1. Integration of water reuse technologies in the water cycle model

Based on the review of existing water quality models, the best means of integration of water reuse technologies is through “model blocks”, which is the concept that is used in the programs WESTforINDUSTRY and SIMBA. Each “block” represents a water treatment technology. Contained within the “blocks” are equations that calculate: the influent and effluents of state variables; the dosages of treatment chemicals; the costs of the construction, operation, and maintenance of the technology; and the associated environmental impacts. All of this can be normalized by the flow of water through the treatment process. An example is illustrated in Table 4 for one of the technologies of demEAUmed project (MBR, ICRA).

Table 4: Explanatory water quality and cost equations for Smart Air MBR

Type of Equation	Operational Equations
Constituent Removal	$X_b = f_{bulk\_TOT}\left(\frac{Y_H}{f_{bulk\_TOT}}\left(DOB_{in} - DOB_{\max\_ef}\right)\right)$ $X_{i,ef} = f_{bulk\_TOT}\left(\frac{HRT}{\left(f_{bulk\_TOT}\right)^2} \cdot f_{end} \cdot b_H \cdot Y_H\left(DOB_{in} - DOB_{\max\_ef}\right) + X_{I,in}\right)$ $C_{b,ef} = f_{bulk\_TOT}\left(f_{C\_COD} \cdot BOD_{\max\_ef}\right)$ $C_{i,ef} = f_{bulk\_TOT}\left(C_{i,inf}\right)$ $S_{f,ef} = \left(1 - f_{C\_COD}\right)BOD_{\max\_ef}$
Cost Variables	$IC_{MBBR} = C_{SAMBR}\left(\frac{Q_{inf}COD_{inf}}{1000}\right)^{K_{MBBR}}$ $OP_{MBBR} = P_{SAMBR}\left(\frac{Q_{inf}COD_{inf}}{1000}\right)^{K_{OP}}$

*X_b – Particulate biodegradeable COD; $X_{i,ef}$ – Particulate Inert COD effluent; $C_{b,ef}$ – Colloidal biodegradeable COD effluent; $C_{i,ef}$ – Colloidal inert COD effluent; $S_{f,ef}$ – Solid biodegradeable COD effluent; IC_{AMBR} – Investment cost; OP_{AMBR} – Operation cost

Model blocks can be integrated into the water cycle model between components. For instance, in Hotel Samba, the current water management situation can be modelled by inserting the model block for a membrane bioreactor between greywater effluent and influent toilet water (case A in Figure 9). In addition, as treatment may rely on the coordination of various treatment processes, additional model blocks can be added to simulate treatment processes in series or even in parallel (Figure 9, B and C).

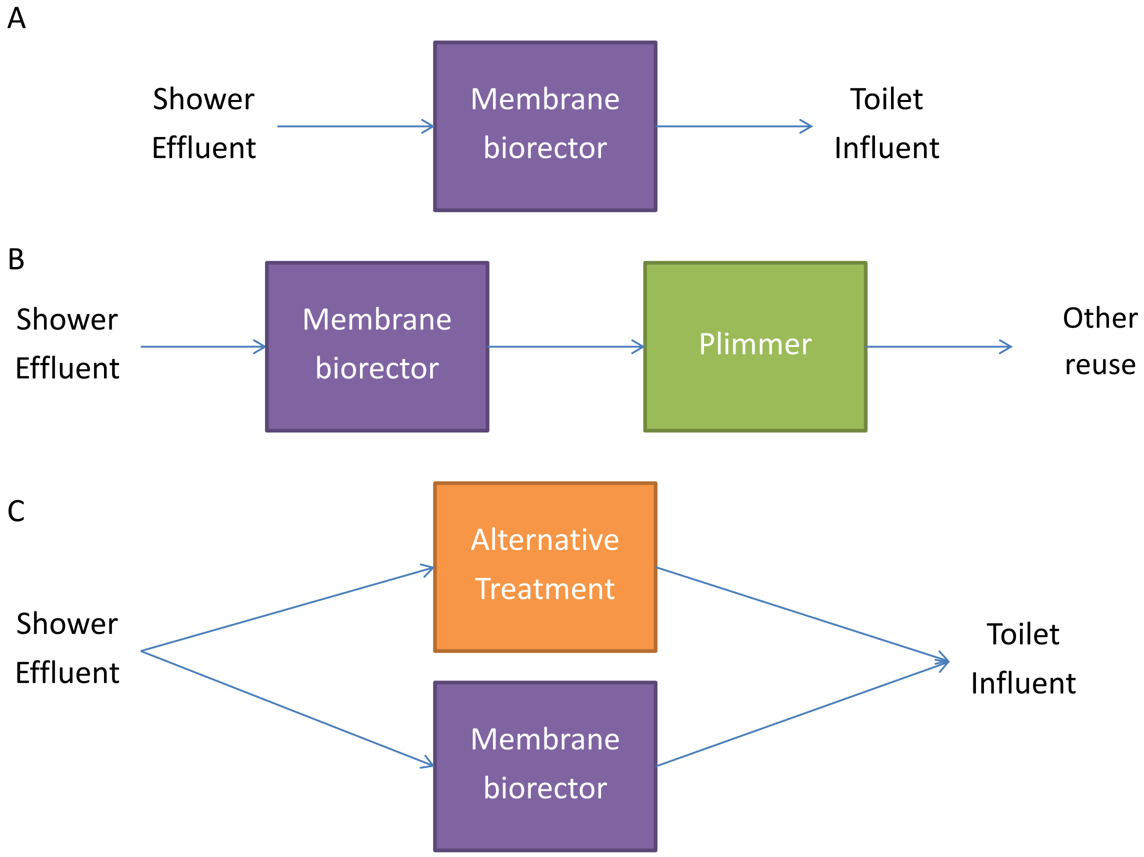


Figure 9: Diagram of different configurations of technologies in the DSS

To estimate the environmental impacts of water management systems, a life cycle inventory will have to be created for each technology of the project. At the same time, ICRA has maintained contact with LEITAT, which will be in charge of conducting a life cycle assessment of the water-reuse technologies provided by the users.

7.2. Progress

After the 14-15 December, 2015 demEAUmed meeting, conversations were maintained with LEITAT about a questionnaire that LEITAT will send out to the partners to request data necessary to create a life cycle inventory. The ICRA group was consulted about adding any additional information about contaminant removal rates to the information request. On 11 February, 2016, modified information request sheets were sent to LEITAT. Currently LEITAT has prepared and sent the modified information request forms to the partners.

8. Conclusions and Future Steps

8.1. Conclusions

Based on the studies and literature review done in the past months four conclusions have been drawn:

- **Hotel water use is varied in nature** – Drivers of hotel water use are mainly based on the individual hotel´s characteristics. While most studies usually cite the rooms and the restaurant as the largest consumers of water in a hotel, the presence and the number of other characteristics can also influence the hotel´s water usage. For instance, the number of restaurants and pools are significant water users. On-site washers and dryers can also make laundry rooms a large water consumer within a hotel. Even the number of stars a hotel has can play a role in water consumption as hotels with more stars generally consume more than those with less stars.
- **Significant water savings can be achieved by more efficient devices and water saving practices** – A few studies have addressed the benefits of the addition of more water efficient technologies and practices. Benefits have ranged from 21%-75% savings in potable water. In addition, water reuse technologies can also save a significant portion of potable water. The Hotel Samba case study, with greywater reused for toilet flushing, estimated a potable water savings of about 16%. Nevertheless, these water savings may not yield a significant benefit as water and energy bills account of only a small amount of a hotel´s expenses. Therefore, another incentive has to be used to justify water savings, whether it is local water issues (i.e. water scarcity) or attaining green certification.
- **A large variety of water cycle models is available to simulate water management.** Coded in different languages and based on different concepts, about 10 distinct water cycle models have been identified. All address water flows as well as water quality and most are dynamic. However, only some are able to model the water management system of an individual building. Of these, only a few can model the specifics such as on-site wastewater treatment train technologies. In addition, some of these models can also estimate environmental impacts, embodied energy, and life cycle costing.
- **The best concept for integration of new technologies is through the model block concept.** Each model block represents the cost, contaminant removal, chemical use, energy use, and environmental impact equations and coefficients of the technology. The modularity of this concept would permit the simulation of different technology configurations as well as the impacts of the reuse of different types of wastewater.

8.2. Future step

One of the main components of the DSS is the water cycle model. This model simulates the flows within the hotel as well as the quality of these flows. Ideally, technologies and certain practices can be simulated with the model too. Therefore, after a review of existing models, the next step should be to choose a model based on the following characteristics.

- **Dynamic** – The model, whether existing or programmed, should have short enough time steps to realistically simulate a water management system. Ideally, these time steps should be less than a day to also capture the daily water use patterns.
- **Can model individual buildings** – As this DSS will mainly be applied to hotels, it has to be able to model the water management system of a building with the appropriate detail. Ideally, this would be a model that can keep track of all the flows as well as their corresponding water qualities within the hotel. This model should also be able to simulate on-site technologies for water and wastewater treatment, water reuse, and alternative water management strategies (i.e. green roofs, rainwater harvesting).
- **Incorporate life cycle assessment** – In addition to keeping track of water flows and water quality, this DSS should also estimate the environmental impacts of water management scenarios. This should include the construction, maintenance and disposal steps. The impacts associated with treatment chemicals and materials, infrastructure materials, energy and fuel use, and effluent treated or untreated wastewater quality should be taken into account.
- **Incorporate the economic aspect** – While many water management decisions make sense environmentally, they may not be economically feasible. Therefore, the water cycle model should give the user the choice to estimate the life cycle cost of the water management system, as well as break down this cost into the different life cycle stages and water management system components. Costing data should be based on the most recent prices and economic data.
- **Addition of new technologies** – As new water treatment technologies are made available, vendors and the hotels themselves will want to determine the impacts of these technologies. Therefore, this water cycle model has to be versatile enough to easily incorporate new technology models. Programming language may be an issue, which merits discussion over whether addition of new technologies can either be a built-in option or something that the user can program in an easy-to-use programming language. Existing programs such as WESTforINDUSTRY and SIMBA already have the capability to integrate new models and are ideal models for an ever-expanding range of water treatment technologies.
- **Weather and climate data** – While indoor water use is not usually influenced by weather, hotels do use a significant amount of water for gardening and pools. Therefore, weather and climate data would be useful in helping model outdoor water use. Climate data is also useful for scenarios such as water shortages, which can be responsible for water restrictions that could play a role in hotel operation.

- **Adaptable to other hotels** – All hotels are different with respect to water use. Hostels consume less water than 4 star hotels. Some hotels have pools. Others have onsite laundry. Many have their own restaurants. This DSS model needs to be able to accurately model the water cycle of all of these hotels regardless of their differences in terms of services, size, and quality. For example, the user can input characteristics such as the number of hotel rooms, pool size, laundry room, etc.

With respect to the water cycle model, there are two options:

- **Use an existing model -** The incorporation of existing model would mean less work in programming a water cycle model. The only needed programming would be integrating the model into a DSS. Also, models such as WaterMet^2 and UWOT have programmer´s toolkits which can facilitate this integration. However, there are a couple drawbacks to this approach. First, many models are written in a complex programming language that requires time to learn if the user wants to integrate the model with another component of the DSS. Second, use of an existing model may require permission from the programmer.
- **Program a model -** On the other hand, programming a water cycle model seems the best option in terms of incorporating all of the aforementioned characteristics in a water cycle model. Yet, programming a model is a complex process especially if the programmer wants to make the model user friendly and amenable to the incorporation of new technologies.

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