WATER FOOTPRINT OF COASTAL TOURISM FACILITIES IN SMALL ISLAND DEVELOPING STATES: A CASE-STUDY OF A BEACH RESORT IN THE MALDIVES

by

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Abstract

Research on climate change indicates that the risk of water scarcity at many remote tourist destinations will increase in the next few decades. Tourism development puts strong pressure on freshwater resources, the availability of which is especially limited in remote areas. At locations with no access to conventional water sources, tourism facilities require supply alternatives, such as desalinated or imported water, which implies elevated energy demands and carbon emissions. In this context, a shift in the way freshwater use is assessed is crucial for moving toward a more sustainable model of water management for tourism development. This research adapts the Water Footprint framework to the design of tourism facilities and explains how and why this is a promising model for water accounting in isolated locations. Defined as 'an indicator of freshwater resources appropriation', the Water Footprint concept was introduced by Hoekstra in 2002. This methodology goes beyond the conventional direct water use assessment model, upon which most common benchmarking systems in sustainable tourism are based. Measuring the water footprint of a tourism facility allows operators and design teams to understand the environmental and socio-economic impacts associated with its direct and indirect water uses. Furthermore, this methodology enables a holistic consideration of all the water system components: supply, demand, and wastewater. Based on this framework, this thesis presents a Water Footprint Design Tool (Tool) for designers to use in the early stages of design. This Tool enables design teams to run various scenarios and understand how different water system designs can impact the footprint of a project. A case-study of a beach resort in the Maldives illustrates the application of the Tool in a specific context. The results showed that significant desalinated water footprint reductions (75.5%, 80.6% and 95.5%, depending on the precipitation year) could be achieved through the application of a series of water-saving strategies. Finally, this research introduces a three-scale process to be applied in new tourism development operations. This framework allows designers to easily identify which areas need improvement in order to achieve more ambitious water goals that would help make tourism development more sustainable in the future.

Preface

This thesis is an original intellectual product of the author, M. Orellana. The case-study reported in Chapter 5 was covered by UBC Behavioral Ethics Certificate number H12-01373.

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1 INTRODUCTION

WATER AND TOURISM DEVELOPMENT IN SMALL ISLAND DEVELOPING STATES

The expected growth in tourist arrivals (UNWTO, 2000) and research on climate change indicate that the risk of water scarcity at many destinations will increase in the next decades (IPCC, 2007). The problem becomes extreme in very small islands, whose surface area impedes the existence of surface water streams (Kerr, 2005) and makes groundwater bodies vulnerable to seawater intrusion (Kim *et al.*, 2003). In addition, beach resorts, typical of these locations, offer numerous water-intense services making their water demand higher when compared with other tourism segments (Pigram, 2001). These conditions make of desalination the only alternative of water supply for these tourism facilities, which results in increased energy demands and carbon emissions (Anderson, 2009). In this context, a shift in the role that water management plays into the design of resorts in very small island destinations is crucial for moving toward more sustainable forms of tourism development. At these destinations, the most challenging water-related goals need to be incorporated into the design of tourism facilities. This chapter explains this problem in detail and proposes the research questions that are addressed in this thesis. The goal and scope of the study are also defined. Finally, the methodology applied in the following chapters is described.

1.1 Problem Statement

Tourism has rapidly grown in the last decades and has become one of the largest businesses in the world (Perera, Hirsch, & Fries, 2003) (Fig. 1.1). Today, it is one of the top five export categories for more than 83% of countries worldwide and the main source of foreign exchange earnings for more than 38% of them (UNEP cited in Dodds & Kuehnel, 2010). The number of tourist arrivals is estimated to keep increasing in the following years (Fig. 1.2). According to United Nations World Tourism Organization (UNWTO) *Tourism Vision 2020*, international arrivals will be 1561 million in 2020, compared to 565 million in 1995, with an average growth rate of 4.1% between these two years (UNWTO, 2012b). Despite the potential of this industry for generating economic prosperity and employment worldwide, this rapid growth has also produced a heavy burden on local environments, uncontrolled tourism being a threaten for many of the most sensitive areas of the planet (Perera *et al.*, 2003). Also, due to the intensity of the tourism activity, which often takes place in a limited geographical area, its environmental consequences are more immediately evident (Miller, 2003 cited in Williams & Ponsford, 2009). But the tourism industry, if developed responsibly, can also bring benefits to the communities where it takes place, such as employment opportunities, infrastructure or help to preserve the local environment (Dodds & Kuehnel, 2010). In order to avoid the negative effects of tourism activity and maximize its benefits, a more responsible planning and development is necessary.

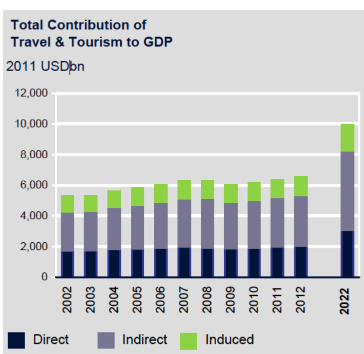


Fig. 1.1. Travel and tourism contribution to GDP. Source: WTTC, 2012.

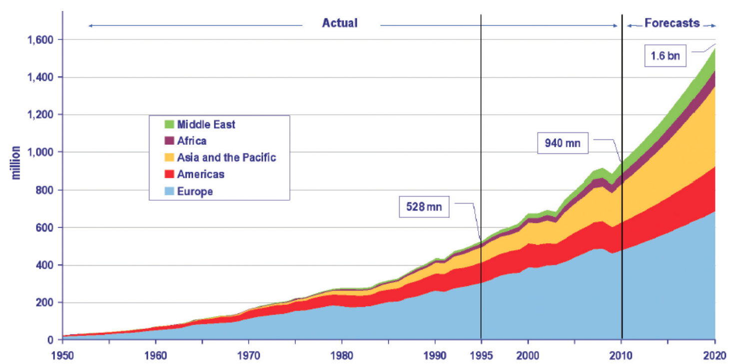


Fig. 1.2. International tourist arrivals by region. ©UNWTO 9284403613 .

TOURISM IN DEVELOPING COUNTRIES

Developing countries present a higher economic dependence on the hospitality industry than developed states (Table. 1.1). An excessive dependence on the income generated by tourism activity can lead to prioritizing profit maximization over social and environmental concerns (Carbone, 2005). In order to attract foreign investors, regulations are not always enforced and environmental protection becomes a secondary priority and just a voluntary option for owners and operators (Gössling, 2000), whose role becomes fundamental in reducing the negative impacts of tourism development (Mowforth & Munt, 2008). Regulation is nevertheless necessary due to the lack of capacity of individual companies to induce change by themselves (Forsyth, 1997) and local authorities appear as the best placed agents to manage tourism at a destination and contribute to a more responsible development (UNEP & ICLEI, 2003 cited in Dodds & Butler, 2010).

Country grouping	Travel as % of total exports in services	Travel as % of total exports in goods & services
OECD	28.1%	5.9%
EU	28.6%	6.3%
Developing countries	43.3%	6.5%
Least Developed Countries	70.6%	15.3%

Table 1.1. Tourism as part of exports of goods and services in 2000 by country group. Source: UNWTO, 2004.

But a lack of regulation is not the only problem that developing countries present for protecting the environment from tourism development. The very few destinations that have established policies aimed at preventing overdevelopment have generally found it difficult to implement them due to the problems associated with the hospitality business, such as the "often unreliable tourism growth predictions and the short-term view of operators within the tourism industry" (Dodds & Butler, 2010, p. 37). Moreover, developing regions do not always have the necessary expertise and/or commitment to applying either incentives or sanctions that promote resource conservation (Pigram, 2001). Furthermore, measures that aim to protect the environment are generally too expensive or require such long consultation processes that they lead to a substantial loss of revenue (Carbone, 2005). However, this point of view is focused only on the economic benefit that businesses and governments can extract from tourism activity, without considering the benefits that a healthy environment offers to the human population, directly or indirectly, both at the local and global levels (Bolund & Hunhammar, 1999). A wider approach that does not focus only on income generation is thus necessary to encourage governments and operators to move toward less damaging forms of tourism development.

Fig. 1.3. SIDS (Small island developing states) map. By Osiris (Own work). CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0), via Wikimedia Commons.

SMALL ISLAND DEVELOPING STATES

Small Island Developing States (SIDS) (Fig. 1.3) were first formally recognized as a group sharing unique challenges associated with sustainable development at the United Nations Conference on Environment and Development that took place in Rio de Janeiro in 1992 (United Nations Department of Economic and Social Affairs, 2010). Among these challenges are these islands' limited resources as a consequence of their small size, and their reduced economic competitiveness because of their isolation from major markets (SIDSnet, 2013). Furthermore, SIDS are especially vulnerable to global issues (Fig. 1.4), such as sea-level rise as a consequence of climate change, whose long-term effects may even lead to the disappearance of some of these countries (SIDSnet, 2013).

As far as tourism is concerned, SIDS are also especially vulnerable to overdevelopment for several reasons. On the one hand, small islands combine the attributes of mainland coastal areas with the special qualities associated with their geography (Tourtellot, 2007 cited in Smith *et al.*, 2011). These unique features increase tourist demand, which, in turn, raises concerns about the island states' environments and cultures (Smith, Henderson, Chong, Tay, & Jingwen, 2011). On the other hand, the previously mentioned economic dependence of some countries on the hospitality industry reaches its highest levels in SIDS (Fig. 1.5), whose economies present the highest rates of tourism contribution to gross domestic product (GDP).

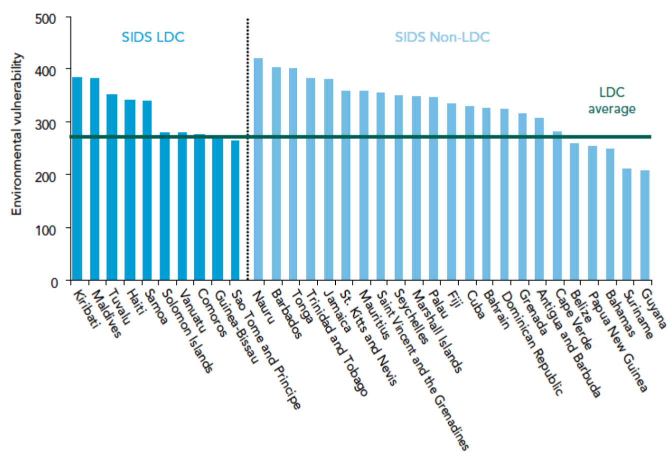


Fig. 1.4. Environmental Vulnerability Index for 33 SIDS. Difference between Least Developed Countries (LDC) and non-LDC. Source: UN DESA, 2010, based on UNEP/SOCAP methodology.

WATER

This research focuses on this type of destination for the previous reasons and also for the additional challenges they face in order to provide the required conditions for a more responsible tourism development. Water management is especially important in the context of sustainable tourism in SIDS for several reasons. First, freshwater supply suffers from the limited availability of this resource in SIDS. Second, the water demand of tourism facilities at this type of destination places intense pressure on this scarce resource. Finally, the lack of facilities for treating the often excessive generation of wastewater from tourism can lead to its discharge into the sea, which can significantly damage the fragile surrounding marine environment (Pigram, 2001).

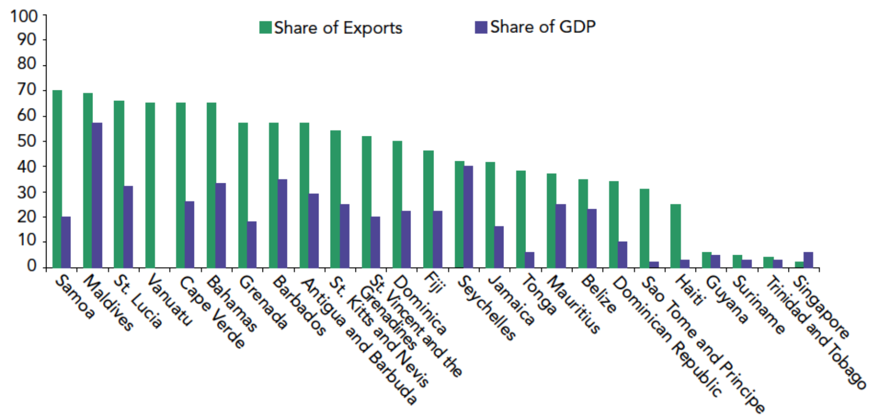


Fig. 1.5. International tourism receipts as percentage of total exports and GDP (2007). Source: World Bank 2010

While the limited availability of freshwater resources is a major issue of SIDS (Peters, 2006) (Fig. 1.6),the alternatives to solve it can increase the environmental damage caused by tourism development. Water source security and supply is a problem that most small islands suffer from, as the small extent of land area, combined in some cases with geological factors, makes runoff flow directly into the sea instead of being stored on the surface (Han & Ki, 2010; Kerr, 2005). Groundwater is in some cases an alternative source to surface freshwater. However, many small islands do not have subsurface water bodies (Han & Ki, 2010; Sazakli, Alexopoulos, & Leotsinidis, 2007) and, when they do, their vulnerability is higher than for mainland aquifers, since excessive extraction causes seawater penetration and therefore high salinity of groundwater (Kim *et al.*, 2003). In low-latitude small islands, the problem is accentuated by high evapotranspiration rates and severe weather events, such as hurricanes, which can damage the infrastructure (Pigram, 2001). Freshwater supply thus becomes a key factor in the context of sustainable tourism development in SIDS (King, 1997 cited in Pigram, 2001).

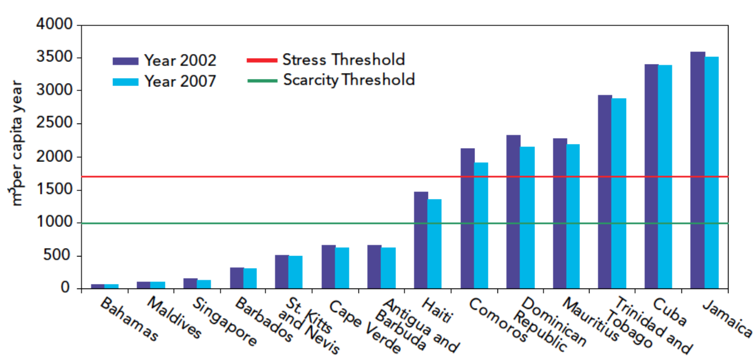
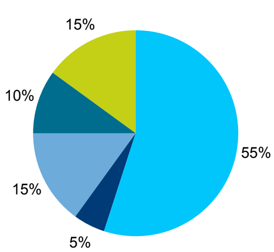


Fig. 1.6. Renewable internal freshwater resource. Source: World Bank, 2009 cited in UN DESA, 2010.

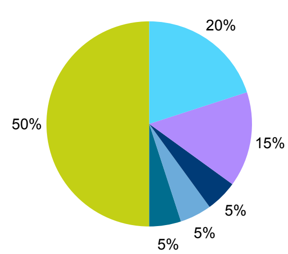
Despite the scarce availability of freshwater supply sources in SIDS, tourism facilities at these locations are generally characterized by a significant demand for this resource. As a consequence, islands with intense tourism activity are more likely to present water-related problems and conflicts, which become more obvious when comparing tourist water consumption to the relatively lower domestic demand (Anderson, 2009). In some islands there is a significant competition for water that can become accentuated when tourism demand for water appears, which makes sustainable use of this resource even more necessary (Pigram, 2001). The problem is accentuated by the seasonal character of tourism, since the higher demand generally occurs during the dry season, when the tourist population is multiplied and water supply is more limited (Kelly & Williams, 2007; Sazakli *et al.*, 2007). Tourism water use is also higher when compared with water consumption by tourists at their places of origin. The average estimated water consumption for international tourists is 300 L/P/Day, almost doubling the average consumption at home, 160 L/P/Day (Gössling *et al.*, 2012).

Several factors contribute to this higher water demand of tourism facilities, which is expected to keep growing in upcoming years due to increased tourist arrivals, higher hotel standards, and water-intensity of tourism activities (UNWTO, 2008 cited in Gössling *et al.*, 2012). On the one hand, many of the services offered by coastal tourism facilities, such as swimming pools, spas, laundry or irrigated gardens, require substantial allocations of freshwater (Pigram, 2001). Water use is also directly associated with the quality level of the accommodation (Anderson, 2009), and luxury beach resorts, a frequent type of facility on small tropical islands, generally require not only higher direct water use associated with the previous services, but also an increased indirect water demand associated with higher quality food products. On the other hand, the recreational character of the tourism experience may also contribute to greater water consumption, since “holiday makers have a pleasure approach to the shower or bath and generally use more water than they would normally” (Eurostat cited in Gössling *et al.*, 2012).

A literature review by Gössling *et al.* (2012) shows that water consumption, per tourist per day, goes from 84 to 2000 litres. This large variation is due to geographical factors, especially climate, hotel structure, and comfort standard (Gössling *et al.*, 2012). A study in Zanzibar (Gössling, 2001) can be used to illustrate the water footprint of tourism in a tropical destination:



direct use	136L	55 %
swimming pools	0L	0 %
cleaning	12L	5 %
restaurants	37L	15 %
laundry	25L	10 %
irrigation	37L	15 %



direct use	186L	20 %
swimming pools	140L	15 %
cleaning	47L	5 %
restaurants	47L	5 %
laundry	47L	5 %
irrigation	465L	50 %

Fig. 1.7. Average water consumption by use in guesthouses (left) and hotels (right) in Zanzibar. Source: Gössling, 2001.

DESALINATION

The previously described lack of freshwater supply sources makes it necessary to find alternative ways for satisfying the high water demand of tourism facilities. In many cases, expensive and high-energy-demanding technologies, such as desalination, are used (Anderson, 2009; Gössling *et al.*, 2012). For instance, in countries like the Maldives, all the beach resorts and a significant fraction of the local population rely on desalination as the main form of freshwater supply (AQUASTAT, 2012). But it has to be considered that the access to energy sources in SIDS is also challenging, as they mainly rely on imported fossil fuels to provide the required energy supply (United Nations Department of Economic and Social Affairs, 2010). Energy and water management are closely related to each other at tourism facilities in SIDS and technologies like desalination directly contribute to increased greenhouse gas emissions (Gude, Nirmalakhandan, & Deng, 2010).

Desalination is an energy-intensive and expensive technology. As such, it is generally considered appropriate in water scarce regions where the cost of energy is significantly low, such as oil rich countries in the Middle East (Gude *et al.*, 2010). The required energy per cubic meter of desalinated water goes from 3 to 12.5 kWh, depending on factors such as the type of technology used (Gude *et al.*, 2010; Sadhwani & Veza, 2008 cited in Gössling, 2012). Reverse-osmosis, a non-phase changing process, is the fastest growing technology for desalination today (Semiat, 2008). These plants allow the incorporation of energy recovery pumps, which reuse the pressure of the rejected brine in order to save energy (Keeper, Hembree, & Schrack, 1985 cited in Gude *et al.*, 2010). In combination with these energy recovery devices, reverse-osmosis is currently the least energy consuming desalination technique (Semiat, 2008). However, the cost of desalinated water today is still higher than water from most other sources (Wichelns & Nakao, 2007). For example, a case-study in Grenada (Peters, 2006) showed that the cost of desalinated water from the plants built in the last decade was up to nine times higher than the cost of harvested rainwater.

Moreover, the high cost and energy demands of desalination are not the only problems associated with the use of this technology. Local environmental concerns also appear as a consequence of using a desalination plant to produce freshwater. On the one hand, when taking water from the ocean, marine fish and other living organisms can be damaged or even killed. On the other hand, the discharged brine is usually warmer, has a higher salinity and sometimes contains chemicals used in the desalination process, so it can significantly impact the marine ecosystems surrounding the discharge area (Wichelns & Nakao, 2007). While both these problems can be mitigated in different ways, the cost of the devices required to reduce them increases the cost of the desalination process (Wichelns & Nakao, 2007).

SUSTAINABLE TOURISM

In our search, therefore, for more sustainable forms of tourism development, we must find different ways for solving the problem of freshwater supply at remote tourism destinations such as SIDS. The sustainable tourism framework embraces not only environmental issues like these, but also economic or social problems derived from tourism development.

In the context of tourism, then, sustainability refers to "tourism which is developed and maintained in an area in such a manner and at such scale that it remains viable over an indefinite period and does not degrade or alter the environment in which it exists" (Nelson, Butler, & Wall, 1993 cited in Nepal, 1999). Sustainable tourism is thus necessary in order to avoid the so-called "boom and bust" cycles of development in such destinations, leading to a rapid overdevelopment and decline (Forsyth, 1997). The United Nations World Tourism Organization (UNWTO) claims that tourism is "one of the environment's best friends" (UNWTO cited in Gössling, 2000) and defines "sustainable tourism" as follows:

> Tourism that takes full account of its current and future economic, social and environmental impacts, addressing the needs of visitors, the industry, the environment and host communities.
>
> Sustainable tourism should:
>
> 1) Make optimal use of environmental resources that constitute a key element in tourism development, maintaining essential ecological processes and helping to conserve natural heritage and biodiversity.
>
> 2) Respect the socio-cultural authenticity of host communities, conserve their built and living cultural heritage and traditional values, and contribute to inter-cultural understanding and tolerance.
>
> 3) Ensure viable, long-term economic operations, providing socio-economic benefits to all stakeholders that are fairly distributed, including stable employment and income-earning opportunities and social services to host communities, and contributing to poverty alleviation. (UNWTO, 2012a)

Under the 'sustainable tourism' framework, many destinations have increasingly adopted measures to make their projects and operations more sustainable. However, despite the large numbers of hotels and resorts that purport to be eco-friendly or green, realistic sustainable policies are rarely implemented and many questions arise about the real goal of sustainable tourism. Some authors question whether those who claim to provide sustainable tourism actually pursue the alleviation of the problems associated with conventional tourism or is it just "a clever marketing campaign to provide corporations ethically more appealing wrapping paper for the same old toy"? (Lansing & De Vries, 2007, p. 77). Some studies demonstrate that global concerns about environmental issues, such as climate change, have increased dramatically during the last decade and are affecting the way consumers behave (Bergin-Seers & Mair, 2009). This growing consumer awareness about global concerns is one of the main reasons some private sector businesses claim to offer more environmentally friendly products, and while this might be slowly contributing to a more sustainable future (Williams & Ponsford, 2009), their final purposes may be limited to attracting a larger number of environmentally concerned guests. In any case, a higher public demand for environmentally-friendly products may persuade operators to offer more responsible services and consume fewer natural resources (Forsyth, 1997).

ASSESSMENT TOOLS

Tourism owners and operators use sustainability assessment tools as instruments to measure the environmental, social and economic commitment through third-party verification. The availability of these tools for making sustainability concepts and goals more accessible is increasing (Williams & Ponsford, 2009) and their role is very important since, as stated above, the lack of regulation in many tourist destinations leaves the responsibility for promoting sustainable development up to the owners and operators. While many of these benchmarking systems measure the performance of the facilities at different levels, such as resource management and, more specifically, water use, most of these tools assess each level independently, without promoting a holistic approach to sustainability. For instance, energy supply and water supply are assessed separately, even though these two variables, especially in SIDS, as explained above, are closely related to each other, since water is required for energy production and energy is required for water production (UNESCO, 2009 cited in Gössling *et al.*, 2012). Public awareness about issues like climate change or global warming have contributed to the emphasis these benchmarking systems have put on energy supply and carbon emission reduction, while water management is not receiving the attention it should receive in most cases.

Fig. 1.8. GreenGlobe logo. One of the most common benchmarking systems in green building and sustainable tourism.

In this context, a shift in the role of water management in the design of hotels and resorts is crucial for moving toward more sustainable forms of tourism development. This research brings to the table the need to incorporate more ambitious water goals in sustainable tourism development, especially at destinations that lack access to conventional freshwater sources. In order to make tourism more sustainable in the future, design teams and developers need to take a realistic approach to sustainability in small island developing states, one that considers water usage at the outset of the planning and design processes.

1.2 Research Questions

Q1: Is it possible to achieve ambitious water-related design goals, such as net-zero water scenarios, given the isolated conditions of these destinations?

Q2: Which design strategies can be used to reduce the growing water demands of coastal tourism developments at destinations with no access to conventional freshwater sources?

Q3: How must new coastal tourism facilities in small island developing states be designed in order to minimize the impacts associated with their use of water?

Q4: What forms of water supply, other than desalination, can be used at beach resorts in small island developing states within the context of sustainable development?

1.3 Goal and Scope of the Study

The goal of this research is to bring to the table the need to improve water management at tourism facilities of small island developing states, along with tools that could provide solutions. In a water-scarcity situation, the high water-use of beach resorts at these destinations points out the need for new desalination technologies, the current use of which makes it harder to achieve ambitious sustainability-related goals. Water supply and demand need to receive more attention in the context of sustainable tourism development, and for this purpose, the way water-use is assessed in the tourism industry needs to be rethought.

This thesis applies the Corporate Water Accounting framework and the Water Footprint methodology to coastal tourism facilities at small island destinations. This application includes an analysis of possible solutions to the ever more challenging water-related goals of the tourism industry, so that these goals—and the problems associated with the water-use of coastal facilities—become clearer and more comprehensive for all stakeholders. Furthermore, a proposed water accounting method aims to demonstrate that very high reductions in the dependence on desalination can be achieved through the holistic application of a series of water-related design strategies. The results obtained from a case-study in an extreme geographical context such as the Maldives are extrapolated to formulate a new development scenario. This study finally proposes a three-scale (geographical, system, and device scales) process, to be used by design teams at early stages of the design process of new resorts. This process emphasized the need for participation and involvement from all stakeholders, including owners, operators, design teams, governments and tourists, in order to achieve the most ambitious water usage goals.

1.4 Methodology Overview

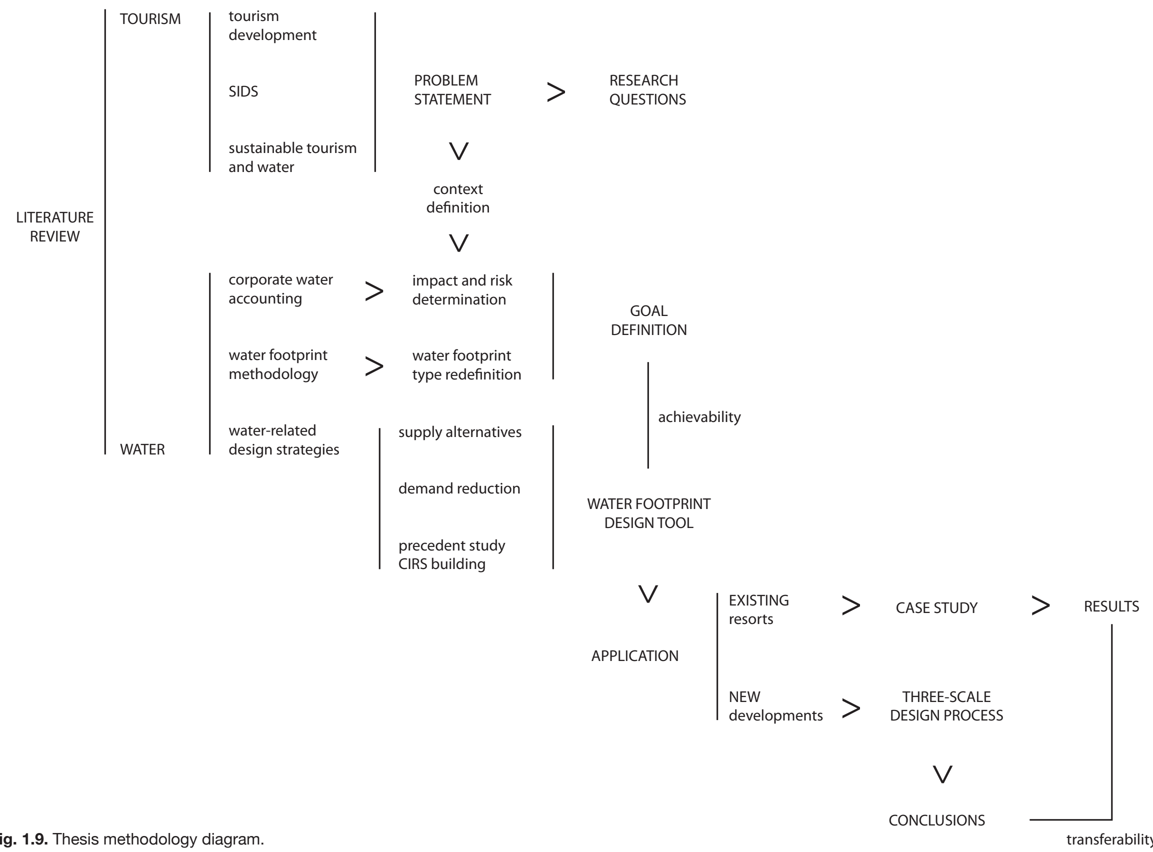


Fig. 1.9. Thesis methodology diagram.

This thesis applies both the 'Corporate Water Accounting framework' and the 'water footprint methodology' to beach resorts in small island developing states and explains how and why this combination is a promising model for water-use assessment in this context. Based on a literature review on different water strategies, using a spreadsheet-based calculator, this research developed the Water Footprint Design Tool and applied it to a case-study in the Maldives. Based on the results from this case-study, this study defines and proposes a three-scale process to be applied by design teams at early stages of design. The thesis is organized into seven chapters, which include the following contents:

Chapter 1, Introduction: The first chapter presents a literature review on sustainable tourism development and water use in small island developing states (SIDS). Based on this literature review, the research questions and goals of the study are defined.

Chapter 2, Redefining Water Goals: The second chapter starts with a review of the Corporate Water Accounting framework defined by the United Nations Environment Programme and explains in detail the Water Footprint methodology. The second part of the chapter discusses the adaptation of this methodology to the built environment and, more specifically, to beach resorts in SIDS. Based on this adaptation, the net-zero water goal is redefined.

Chapter 3, Water-related Design Strategies: This chapter is divided into two sections. The first one contains a literature review on the most common water-related design strategies applied in the context of green building. The second section uses the Centre for Interactive Research on Sustainability at the University of British Columbia in Canada as an exemplary precedent building that illustrates how the most recent and ambitious water strategies can be incorporated into the design of any tourism project.

Chapter 4, Water Footprint Design Tool: Based on the study of the previous strategies, and using a spreadsheet-based calculator, this chapter introduces the Water Footprint Design Tool (the Tool), which calculates the different water footprints of a beach resort and allows us to foresee changes in the water balance of the facility through the application of the previous strategies. A deeper explanation on the methodology used for developing the Tool is provided in chapter 4.

Chapter 5, Case-study: the previous Tool is then applied to a case-study in the Maldives. A general description of the selected beach resort is given and the results obtained through the application of the Tool are provided, both numerically and graphically.

Chapter 6, Designing a Net-Zero Water Resort: Chapter 6 is presented as a concluding chapter, which summarizes the findings presented in all the previous sections of the thesis. This summary is articulated as a three-scale process to be followed by designers in order to achieve the goals defined in chapter 2. Based on the learning from the case-study in chapter 5 and including the Tool and strategies from chapters 3 and 4, this section shows how the process is applicable to other beach resorts in similar geographical contexts and discusses its transferability to other destinations and tourism segments.

Chapter 7, Conclusions: The final chapter includes an overview of the whole thesis, a summary of the conclusions and significance of the project, a discussion on the main limitations found during the research process, and a description of identified further research opportunities.

2 REDEFINING WATER GOALS

CORPORATE WATER ACCOUNTING AND THE WATER FOOTPRINT METHODOLOGY

Corporate Water Accounting is a framework that helps companies evaluate the impacts and risks associated with the direct and indirect water use of their businesses. The Water Footprint concept, which was introduced by Hoekstra in 2001, is one of the proposed accounting methods within this framework. Neither the Corporate Water Accounting framework nor the water footprint methodology have previously been applied to a coastal tourism facility on a water scarce location. This chapter explains both concepts and discusses their application in the context of this study. The different water footprint types (green, blue and grey), widely applied to agricultural products in the last decade, get expanded for covering other potential water supply sources at these destinations, such as desalination and harvested rainwater. Moreover, the impacts and risks associated with each of them are summarized. Based on the water accounting framework and the water footprint methodology, the last section of this chapter redefines the net-zero water goal introduced in the Living Building Challenge. The potential for achieving this goal is tested in the following chapters of this thesis.

2.1 Literature Review

Corporate Water Accounting, as defined by the United Nations Environment Programme (UNEP), is a process that

> allows companies to determine the impacts of their direct and indirect water use and discharges on communities and ecosystems, evaluate material water-related risks, track the effect of changes in their water management practices, and credibly report their trends and impacts to key stakeholders. (Morrison, Schulte, & Schenck, 2010, p. 11)

The process includes a series of steps: accounting, impact determination, risk evaluation, identification of improvement opportunities, and reporting.

ACCOUNTING

The two most relevant methods for water accounting are water footprinting and Life Cycle Assessment (Morrison *et al.*, 2010). This thesis focuses on the water footprint methodology.

The Water Footprint concept introduced by Hoekstra in 2002 (Hoekstra, Chapagain, Aldaya, & Mekonnen, 2009) is defined as a "comprehensive indicator of freshwater resources appropriation" (Hoekstra *et al.*, 2009, p. 8) that goes beyond the classical measure of water withdrawal by including indirect water use. It can be calculated for any individual or community, and also for any product, activity or business. The water footprint of a business, which would be the case of a tourism facility, includes the direct water use necessary for supporting the activity as well as the water used in the business' supply-chain (Hoekstra, 2008). The importance of specifying the geographical and temporal contexts of each component of the water footprint is emphasized, as the potential environmental impacts of each footprint are directly related to the vulnerability of the local water system (Hoekstra *et al.*, 2009).

> A water footprint includes three components: blue, green and grey water footprints:
>
> The blue water footprint refers to the volume of 'blue water' (surface or ground water) that has been evaporated as a result of its appropriation for human purposes. It excludes the part of the water withdrawn from the ground or surface water system that returns to that system directly after use or through leakage before it was used.
>
> The green water footprint refers to the volume of 'green water' (rainwater stored in the soil) that has been evaporated as a result of its appropriation for human purposes.

> The grey water footprint is the volume of polluted water that associates with the production of goods and services. It is calculated as the volume of water that is required to dilute pollutants to such an extent that the quality of the water remains above agreed water quality standards. (Hoekstra, 2008, p. 11)

The distinction between these three types of water footprints is very important because each of them presents substantially different risks and impacts for the surrounding context (Morrison *et al.*, 2010).

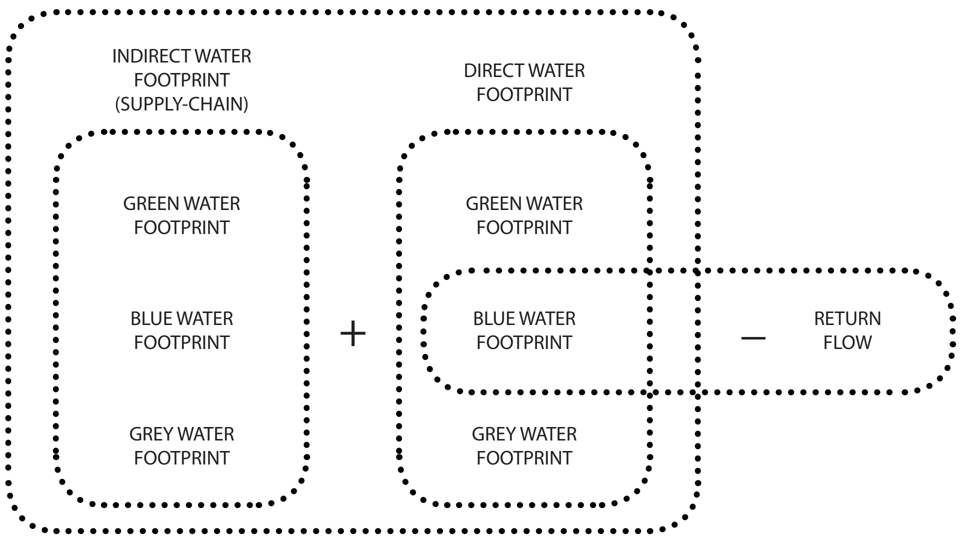


Fig. 2.1. Water footprint components. Adapted from Hoekstra *et al.*, 2009.

IMPACT DETERMINATION

Impacts can be defined as the external implications of water use and discharge from a company for the local context, i.e., both communities and ecosystems, which appear when either the availability or the quality of the water are affected (Morrison *et al.*, 2010). Water-related impacts are highly dependent on the local context the company and its suppliers. Therefore, a volumetric measurement of the company's water use is not sufficient, if not accompanied by local water-related indicators. These indicators should not be restricted to physical water availability but also include factors such as environmental flow needs, local governance, related policy, or access to water from nearby communities (Barton, 2010; Morrison *et al.*, 2010). Impacts can be categorized in different ways. For the purpose of this study, they are classified as environmental or socio-economic. As far as water-related impacts are concerned, an appropriate scope and methodology for assessing them has not been completely developed yet (Morrison *et al.*, 2010).

RISK EVALUATION

Risks refer to the internal implications, generally financial, derived from a business' water use. Water-related risks are usually closely related to impacts but not always in a bidirectional way. While businesses with important associated water impacts generally present equally significant risks, the opposite does not always occur. For instance, while a company may not negatively impact its local water context through its activity, it may be subject to financial risks as a consequence of the impacts caused by external agents (local population, other companies, etc) in the same water context (Morrison *et al.*, 2010).

Risks are generally classified into three interrelated categories: physical, regulatory, and reputational (Morrison *et al.*, 2010). While physical risks refer mainly to water shortage problems that may threaten the continuity of the business' operation, reputational risks relate to potential damage to the company's corporate image, and regulatory risks refer to possible governmental interference and increased regulation that may affect the company's access to water supplies (Barton, 2010; Morrison *et al.*, 2010).

IMPROVEMENT OPPORTUNITIES

A detailed impact assessment and risk determination, based on water accounting, would let the company anticipate the effects that changes to its water management would have. This way, areas for improvement, understood as ways to mitigate impacts or reduce risks, can be identified.

2.2 Application to Tourism in SIDS

The application of the previously defined Corporate Water Accounting framework and the water footprint methodology to coastal tourism facilities in small island developing states requires a series of considerations, which are described below. First, the previous definition of each water footprint type is discussed, as some adaptations are required when applying this methodology to the built environment and, more specifically, to tourism development in SIDS. Second, an overview of the impacts and risks associated with these redefined water footprint components is given.

2.2.1 WATER FOOTPRINT TYPES REDEFINITION

The water footprint methodology has been widely applied to agricultural products or crops, but its application to the built environment has not been completely developed yet. Applying the water footprint methodology to tourism would result in the calculation of both the direct and indirect water footprints related to the business operation. The direct water footprint of a resort would refer to the water use of the facilities, including the water required for drinking, showers, toilet flushing, sinks, kitchens, swimming pools, laundry and irrigation. The indirect water footprint would be calculated as the water footprint of each product in the supply-chain that is required for that resort to function, such as food, energy, furniture, towels, etc. Transportation also plays a crucial role in tourism development and its related water footprint (if considered) would also be included in the indirect component. However, Hoekstra *et al.* do not recommend including the water footprint associated with transportation in the accounting, unless biofuels, or electricity from biomass combustion, or hydropower are used as the main sources of energy, since other forms of fuel do not entail a significant water footprint per unit of energy (2009).

Previous studies have calculated the water footprint of different services and communities. For instance, maintaining a North American diet requires more than 5000 litres per day (Schreier & Pang, 2012). Yang *et al.* (2011) applied the water footprint methodology to a mountain tourism destination in Northwest Yunnan, China. In their study, they differentiated direct water use and indirect water use, the latter focusing only on food supply. The grey water footprint component is also included in the accounting. The results showed that the total water footprint of an average tourist in the Liming Valley was 5207,6 L/tourist/day (Fig. 2.2), from which 144.1 L (2.8%) corresponded to direct water use, 3587.3 L (68.9%) to water required for food production and 1476.6 L (28.3%) to wastewater dilution (Yang *et al.*, 2011). The water footprint associated with the direct water use of this destination is significantly low if compared with the supply-chain or grey water footprints. But it must be remembered that the risks and impacts associated with each type of footprint are different and need to be assessed separately. Moreover, this study did not specify which fractions of the water footprints from direct use or food production corresponded to green or blue water.

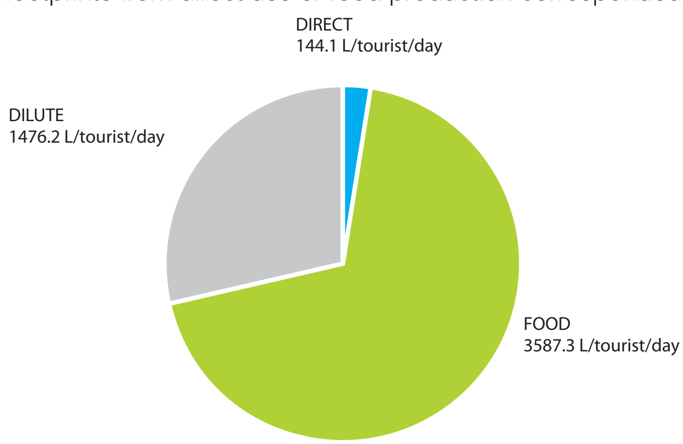


Fig. 2.2. Total water footprint of an average tourist in the Liming Valley, China. Yang *et al.*, 2011.

The direct (operational) water footprint of tourism in this type of destination (SIDS) is very high, as it is required for multiple services and processes, such as bathrooms and toilets, kitchens, spas, swimming pools, and garden irrigation and maintenance. The indirect water footprint is also very important, as water is necessary as an embodied resource in infrastructure development or food production (Chapagain &

Hoekstra, 2003; Chapagain & Hoekstra, 2008; Gössling, 2001). In SIDS, it has to be considered that many of the products offered to tourists come from the mainland. Therefore, this fraction of the total water footprint should be regarded as external or imported virtual water (Hoekstra *et al.*, 2009), the negative impacts of which mainly affect the local area from where it was obtained. For most businesses, the indirect water footprint is larger than the direct water footprint, as the previously cited study in China reveals, but reducing it may be more difficult for business operators due to the lack of direct control over it (Hoekstra *et al.*, 2009). In addition, in most cases, design teams (i.e. architects, landscape architects, engineers) do not have the ability to impact the indirect water footprint of the tourist-related projects they design. Subsequently, this research focuses only on the direct water footprint of beach resorts in SIDS.

Green, blue, and grey water footprint differentiation:

Since the water footprint methodology has largely been used only for agricultural products, some adaptations and clarifications are necessary before it can be applied to a tourism facility on a small island. These adaptations are explained through a sequence of three scenarios (agriculture, built environment and small island resort):

Scenario #1: Agriculture:

Up until recently, researchers have only been applying the water footprint methodology to agricultural products. This scenario allows us to easily understand the difference between the three water footprint types. A specific land area used for crop production that relied only on the rainfall stored in the soil would only present a green water footprint. If, however, this area required irrigation, a blue water footprint component would appear. Finally, if pesticides were used, part of the runoff generated by the rain or irrigation would be polluted, and a grey water footprint would also be considered (Fig. 2.3).

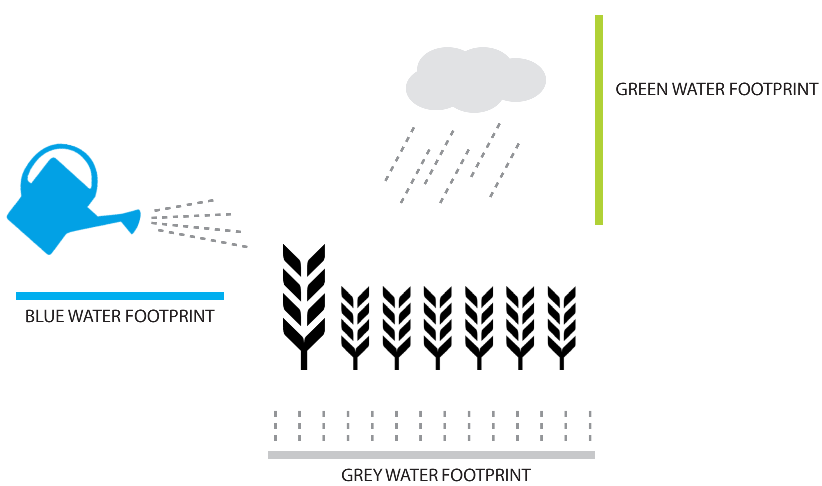


Fig. 2.3. Water footprint types for an agricultural product. Adapted from Sarni, 2011. Wheat icon, by The Noun Project. CC BY 3.0 (http://creativecommons.org/licenses/by/3.0/) via www.iconspedia.com.

Scenario #2: Built environment:

Applying these concepts to any building located in an urban area would require certain adaptations. All the water provided by the municipal supply, which generally comes from surface or groundwater bodies, would represent the blue water footprint of that building. All the wastewater generated by the building would have a grey water footprint associated with the water required for the dilution of its pollutants. However, no green water footprint would appear, at least not related to indoor water use, as buildings do not use rainwater stored in the soil, as crops do. Nevertheless, many buildings worldwide harvest and use rainwater from their rooftops or surrounding areas. How to classify this form of water supply is the main question, as it does not entirely fit any of the previous definitions. On the one hand, it could be considered blue water, as it is water that runs off before being harvested. However, its use does not contribute to the depletion of blue water bodies. On the other hand, it also partially falls into the definition of green water, understood as "the precipitation on land that does not run off or recharge the groundwater" (Hoekstra *et al.*, 2009, p. 21), but it does not get stored as soil moisture either, unless it is used for outdoor purposes. Seen within the Corporate Water Accounting framework, the impacts, risks, and improvement opportunities associated with harvested rainwater are significantly different from those related to either blue or green water use. Applying the water footprint methodology to the built environment therefore requires considering harvested rainwater, when applicable, as an additional water footprint component (Fig. 2.4).

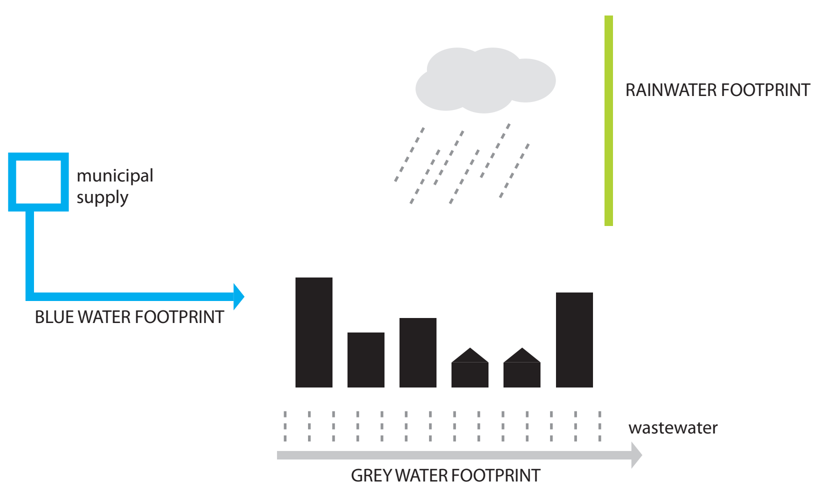


Fig. 2.4. Proposed water footprint types for a building.

Scenario #3: Small island resort:

Just like any another type of development, a tourism facility located in an urban environment would match the previous scenario description, i.e. Scenario #2. However, a large number of resorts located on small islands have no access to blue water sources and thus rely on desalination for satisfying part or all of their direct water demands. The same question must be raised as for harvested rainwater, as desalinated water does not fit into any of the previous definitions. In most cases, desalinated water at these resorts replaces the blue water supply (i.e. bathrooms, laundry, kitchens, etc.). Water obtained from the sea does not contribute to the depletion of any freshwater sources. Nonetheless, desalinating water presents a series of environmental impacts and risks that should not be ignored from a Corporate Water Accounting perspective. Again, an additional water footprint component needs to be included into the accounting process for this scenario. Furthermore, a grey water footprint sub-component associated with the brine produced by desalination plants should also be incorporated (Fig. 2.5). The potential risks and impacts caused by discharging brine into the sea cannot be ignored either, as they are similar to those caused by wastewater discharge into the sea.

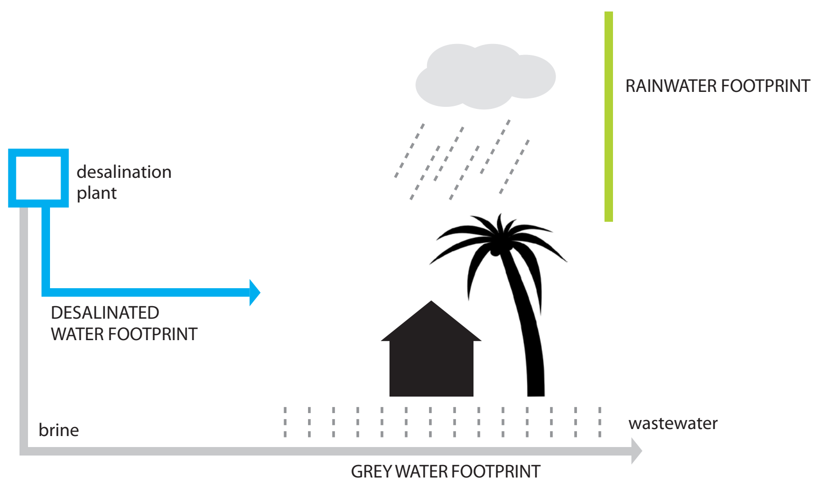


Fig. 2.5. Proposed water footprint types for a beach resort. Palm tree icon by OCAL, via Clker.com.

2.2.2 RISKS AND IMPACTS OVERVIEW

In all the previously described scenarios, anyone conducting an impact and risk assessment needs to consider the specific local conditions of the site (water scarcity, fluctuations throughout the year, etc.). Impacts refer to the external consequences that the water management of a business may produce for the local environment and communities. Risks, on the other hand, focus on the internal implications that may affect the operation of the business itself (Morrison *et al.*, 2010). In many cases, impacts and risks are interrelated and can be better understood if assessed together.

Since this research focuses on destinations with no access to blue water sources, the proposed assessment considered only the impacts associated with the grey, harvested rainwater, and desalinated water footprint. The following tables classify these impacts and risks depending on the type of water footprint they are associated with (Tables 2.1, 2.2).

	IMPACTS	
	ENVIRONMENTAL	SOCIO-ECONOMIC
HARVESTED RAIN WF	Ecosystem water flow-requirements (consequence of land use change) Groundwater recharge reduction	
DESALINATED WF	Marine Ecosystems degradation (water intake) Carbon Emissions, global warming, climate change	Fisheries industry degradation Community Access to Water – Inequitable access to water
GREY WF (INCLUDING BRINE)	Marine Ecosystems degradation (brine) Land Ecosystems degradation (septic tanks) Biodiversity loss (unique habitats, protected species)	Human Health Fisheries industry degradation Surrounding islands degradation – Loss of tourism development potential

Table. 2.1. Summary of impacts associated with the different water footprint types of a beach resort.

Harvested rainwater footprint:

Impacts associated with harvesting rainwater may appear when large amounts of rainfall (relative to the total rainfall on the same water system or watershed) are captured. Excessive precipitation harvesting may reduce the recharge rate of the aquifers relying on that precipitation and interrupt ecological processes that depend on that water. Resorts in SIDS are generally characterized by low density development forms and reduced impervious surface areas around the buildings. Therefore, the groundwater recharge rate and the environmental flow requirements of the surrounding land are considered to be not significantly affected. Other environmental impacts may be related to the infrastructure required for harvesting rainwater, especially storage cisterns. Underground storage systems may be vulnerable to natural disasters such as floods or earthquakes. Also, excessively large cisterns require important land modifications that may impact environmental and ecological processes taking place in the area.

As far as risks are concerned, a high dependence on rainwater may entail physical risks for the business, as the supply directly depends on weather conditions. Unpredicted long dry periods may result in a disruption of the supply and therefore interrupt the business operation, unless backup supply sources are provided. Climate change may contribute to the accentuation of this risk, as it is predicted to affect precipitation patterns (Morrison *et al.*, 2010). A reputational risk may also appear as a consequence of this physical risk, as other resorts not relying on a rainwater supply may be seen as more competitive by potential guests traveling to the destination during the dry season. This research has found no significant regulatory risks or socio-economic impacts for local communities related to the harvested rainwater footprint of a beach resort.

	RISKS		
	PHYSICAL	REPUTATIONAL	REGULATORY
HARVESTED RAIN WF	Operational Efficiency for unreliable long-term water supply Climate Change rainfall pattern variations	Competitiveness loss	
DESALINATED WF	Increased energy demand Dependence on fossil fuel market price fluctuations Sea-level Rise threat	Increased carbon footprint Consumer's perception Corporate Social Responsibility	Country's carbon neutrality goal interactions Inequitable water use compared to local population
GREY WF (INCLUDING BRINE)	Groundwater pollution Increased treatment costs	Consumer's perception Decreased brand value Loss of destination attractiveness	Increased wastewater discharge regulations Loss of license to operate Further development restrictions

Table. 2.2. Summary of risks associated with the different water footprint types of a beach resort.

Desalinated water footprint:

Blue water related impacts and risks are generally associated with the depletion of surface and ground water bodies. The over-exploitation of a blue water source by a business may affect the freshwater availability for local communities, especially in developing and water scarce regions. However, impacts and risks for a resort in a SIDS that relies on desalinated seawater to satisfy its water demands are significantly different. Seawater availability is unlimited and therefore depletion problems do not occur. Environmental impacts associated with desalinated water include damage to marine ecosystems during the water intake process or increased carbon emissions derived from a higher energy demand for producing freshwater. Negative socio-economic impacts may also appear if fishing communities on which the local fisheries industry depends are seriously damaged.

Different types of risks are derived from these impacts. Desalination plants require high amounts of energy to operate. The energy supply at resorts located in SIDS is mainly based on diesel generators. Therefore, an interruption of the diesel supply would directly affect freshwater production. Also, price fluctuations for fossil fuels directly affect the cost of desalinated water. Reputational risks associated with the larger carbon footprint of the company derived from its intensive use of these fossil fuels might also appear, affecting the consumer's perception of the business and its Corporate Social Responsibility policies. The reputation of a business may also be affected by the inequitable use of water at the destination. While resorts' water demands are covered by their own desalination plants, allowing them to offer such services as swimming pools or spas to their guests, part of the local population may not have access to safe freshwater sources. Climate change also entails risks associated with the desalinated water footprint, as any rise in sea-levels could damage the associated infrastructure on the shoreline. In addition, further measures affecting energy use and carbon emissions may entail a regulatory risk, given the high-energy-demanding technologies required for desalinating water.

Grey water footprint:

The grey water footprint refers to the polluted water generated by the assessed product or business. In the case of a resort, the grey water footprint would be associated with the wastewater discharged by the resort. The impacts derived from this fraction of the direct water footprint depends on how well the infrastructure of the facility manages wastewater. Brine from desalination plants or wastewater discharged into the sea would threaten marine habitats and could also damage shoreline ecosystems. Wastewater filtrations from septic tanks may also affect the natural processes occurring around them. In addition to these environmental impacts, local communities can also suffer the consequences of the grey water footprint of a resort in different ways. Damaged marine ecosystems may harm the fisheries industry, which is an important economic sector in SIDS. Moreover, polluted groundwater may threaten the health of the local population, if they rely on this supply source for domestic water use. Also, polluted beaches would lose their attractiveness for tourists and affect the resort industry and subsequently the country's economy.

Financial risks of all three types, i.e., physical, reputational, and regulatory, associated with these impacts also appear for resort businesses. Physical risks would refer to the loss of access to certain types of water sources that may be used by the business, such as groundwater. Also, an increased grey water footprint would imply higher wastewater treatment costs. A typical reputational risk related to grey water appears when pollution generated upstream is not compensated for to downstream communities (Hoekstra *et al.*, 2009). In addition, the impacts derived from water pollution could harm public perception and, in the process, degrade the company's brand and social license to operate (Williams, Gill, Marcoux, & Xu, 2012). Regulatory risks are more evident for this type of water footprint too, as increased governmental policy and regulations are likely to appear to counteract the negative impacts that, in more extreme cases, would result in the loss of a license to operate, if pollution is not controlled.

2.3 Net-Zero Water Scenario Definition

Applying the Corporate Water Accounting framework and the water footprint methodology to the built environment and, more specifically, to beach resorts, goes beyond the classical approach to water assessment in green building, which mainly focuses on demand reduction. For instance, LEED™ water-related credits can be obtained if indoor water use is reduced by at least 20% from baselines based on the International Plumbing Code (IPC) and Uniform Plumbing Code (UPC) standards; by reducing potable water use for irrigation by 50% or by treating more than 50% of the generated wastewater on-site (USGBC, 2009). Moreover, EarthCheck™, a tourism-specific benchmarking system, assesses water use based on total water consumption, the amount of captured rain or wastewater, and the use of water saving devices (Earthcheck, 2010). However, these systems do not pay attention to the nature of the supply sources and the impacts and risks associated with each of them and the established baselines do not always respond to different geographical conditions.

This research emphasizes the need for a shift in the way water use is assessed in the context of sustainable development. Benchmarking systems should not only focus on demand reduction opportunities but also include the problems associated with different supply sources in the assessment process. Because the impacts associated with desalinated water use are not the same as those associated with blue water use, reducing the demand on each of them does not have the same consequences. The water footprint methodology allows assessors to incorporate this differentiation, as it separates water-use into the previously described water footprint types. The Corporate Water Accounting framework goes further and emphasizes the need to pay attention to the many different impacts and risks associated with each water footprint type. The local character of these impacts and risks requires that water-use assessment is made in accordance to the conditions of the water context in which the assessed projects are located.

The Corporate Water Accounting framework and the water footprint methodology allow design teams to incorporate more ambitious water-related goals into sustainable design and tourism development. Benchmarks should be based on the previous states of the sites where tourism facilities are developed and not on conventional projects.

New concepts, such as water neutrality or net-zero water, have appeared in the last years as a response to the need for more ambitious water-related goals in sustainable development. The water footprint network introduces the concept of water neutrality, although the authors recognize that this concept still needs further development (Hoekstra, 2008):

> One can say that a good, service, individual consumer, community or business is water neutral when the negative externalities (...) have been reduced and offset. [In order to achieve water neutrality] all that is reasonably possible should have been done to reduce the existing water footprint [and the remaining footprint should be offset] by making a reasonable investment in establishing or supporting projects that aim at the sustainable and equitable use of the water. (Hoekstra, 2008, p. 18)

The water neutrality concept acknowledges the impossibility of reducing the water footprint of a business to zero. A zero water footprint system would be one in which all the used water is recycled without any evaporation occurring, which is an impossible situation. 'Water neutral' can then be defined as the maximum level of reduction (not nullification) of the negative externalities (not the footprint itself) for a specific system (Hoekstra, 2008). However, this maximum level of reduction is not clearly specified. Neither is the idea of offsetting easily applicable because impacts related to water footprint occur in the catchment area, where the business is located. Thus, offsetting measures aiming to mitigate the associated impacts should take place in the same catchment area, which is not always possible (Hoekstra, 2008; Morrison *et al.*, 2010).

The Living Building Challenge, a new certification system embracing some of the most ambitious sustainability-related goals in green building, includes the net-zero water concept as part of the water-related requirement for achieving certification:

> One hundred percent of the project's water needs must be supplied by captured precipitation or other natural closed loop water systems that account for downstream ecosystem impacts, or by re-cycling used project water. Water must be appropriately purified without the use of chemicals. (International Living Future Institute, 2012, p. 19)

The net-zero water goal not only assumes that the whole water supply must come from locally renewable sources, such as rainfall or natural closed loop systems, but it also acknowledges the importance of considering the environmental impacts associated with this water use at the local scale. Additionally, the Living Building Challenge requires all the stormwater and water used at the site to be treated and either recycled for internal building use or returned to the environment in an appropriate way. This thesis combines the water footprint methodology, in association with the Corporate Water Accounting framework, and the net-zero water goal, due to its higher clarity and applicability to the built environment when compared with the water neutral concept. The achievability of this goal for a beach resort in a small island developing state is tested and discussed in the following chapters.

Achieving the net-zero water goal, understood from a water footprint perspective, implies that all the following criteria are met:

1. All the water supply sources used at the resort development site need to be low-impact sources. Impacts, both environmental and socio-economic, need to be assessed at the local water system scale (i.e. Island or watershed). This criterion implies that:

A. The desalinated water footprint, considered as a high-impact supply source, needs to be equal to zero.

B. A blue water footprint could only appear if the local analysis shows that no impacts associated with it exist (e.g. groundwater use without exceeding recharge rates).

C. Supply must therefore depend totally or mainly on rainwater harvested onsite, which means that the entire or, eventually, most of the water footprint of resort developments needs to be a harvested rainwater footprint. Potential impacts associated with the rainwater footprint need to be considered, as well as any limitations associated with rainwater use that may exist.

D. As rainwater supply is limited, either by the impacts discussed above or by climatic conditions, demand reduction strategies, including wastewater recycling or water-conservation measures, need to assure that the entire water demand of the resort can be satisfied by rainfall.

E. The rainwater supply must be able to meet the whole demand during the whole year, including potential dry periods that may occur, depending on local climatic conditions. How seasonal variability affects demand needs to be taken into account.

2. There can be no impacts on the local environment or communities associated with the discharge of water used at the resort. This criterion implies that:

A. The grey water footprint of the resort needs to be equal to zero.

B. All the wastewater produced at the facilities needs to be treated on site and be either reused for demand reduction purposes or be released into the environment without producing any additional impacts.

C. All the processes used to achieve the previous points need to be natural and/or not entail any negative impact on the environment or local communities.

3 WATER-RELATED DESIGN STRATEGIES

TAKING WATER STRATEGIES TO THE NEXT LEVEL

Green strategies for improving water supply and management are currently widely applied worldwide. Rainwater harvesting (RWH) systems, for instance, have been implemented in many areas around the world for thousands of years (Pinfold, Horan, Wirojanagud, & Mara, 1993; Simmons, Hope, Lewis, Whitmore, & Gao, 2001), especially in remote or arid environments where there is no water supply through piped networks (Sazakli *et al.*, 2007). But RWH systems are optimal when implemented as part of a wider water approach that includes other demand management strategies (Handia, Tembo, & Mwiindwa, 2003). Wastewater recycling or efficient water use are some other examples. This chapter describes the most common water-related strategies, which are classified into two different categories: freshwater supply alternatives and demand reduction options. The application of such strategies has allowed design teams to achieve diverse water saving goals, generally in accordance with local standards, regulations, or green building-related benchmarking systems. However, more challenging goals such as achieving a net-zero water level (Living Building Challenge) require further improvements in these two categories. A series of strategies from the Centre for Interactive Research on Sustainability (CIRS) at the University of British Columbia in Canada is presented as an example to illustrate how water-related design strategies can be taken to the next level.

3.1 Freshwater Supply Alternatives

3.1.1 RAINWATER HARVESTING

Rainwater harvesting (RWH) systems are devices that allow people to collect water from rainfall, store it and distribute it for further utilization. Every system is usually conformed by three subsystems depending on their function: harvesting, storage, and distribution (Farreny, Gabarrell, & Rieradevall, 2011). The harvesting subsystem refers to the catchment area, roofs being the most common type of catchment surface used for rainfall harvesting (Farreny, Gabarrell, *et al.*, 2011). Storage systems are commonly called tanks, if located aboveground, or cisterns if underground (Herrmann & Schmida, 2000), and there are different types depending on the material they are made of. Distribution refers to the pumping (if applicable) and piping system that will conduct water from the storage tank to the devices using that water. The following graphic illustrates a typical rainwater harvesting system.

Fig. 3.1. Rainwater harvesting system. Grand Canyon National Park, South Rim visitor center. Arizona, USA.

RWH has been practised for thousands of years in many regions and is essential in arid or remote areas where the provision of water through piped networks does not exist (Peters, 2006; Sazakli *et al.*, 2007). This kind of supply is seen by many authors as an alternative water source in small island developing states, where groundwater resources are increasingly threatened by seawater intrusion as a consequence of climate change (Peters, 2012). In addition, many of these small islands have no surface freshwater systems, such as rivers or lakes, and rainwater thus becomes the main freshwater supply option for a population without access to alternative sources such as desalination (Peters, 2012). But RWH systems are also applied in areas with access to municipal supply or conventional water sources because of their associated economic and environmental benefits (Jones & Hunt, 2010). Design teams play an important role in the implementation of these systems in the context of green building and sustainable development.

In order to optimize a water supply based on RWH and its related benefits, the system needs to be properly designed. While the inaccurate design approach of a single building may not entail significant environmental or economic losses, the cumulative effect may become important as the implementation of these systems increases (Guo & Baetz, 2007).

There are two main groups of considerations when implementing rainwater harvesting systems: first, the amount of water to be collected and used; and second, the quality of that water.

A.QUANTITATIVE ASPECTS

The efficiency of rainwater harvesting systems in terms of quantity of collected water mainly depends on four variables: rainfall intensity and pattern, catchment area, water demand, and storage capacity (Fewkes, 2000; Han & Ki, 2010; Imteaz, Shanableh, Rahman, & Ahsan, 2011). Other factors, such as spillage or leakage are generally included in a runoff coefficient, which represents the amount of rainfall that runs off the surface. This coefficient varies depending on the nature of the catchment surface (Imteaz *et al.*, 2011) and the climatic conditions. The relation between all these parameters is crucial to understanding the potential for rainwater harvesting in a specific location.

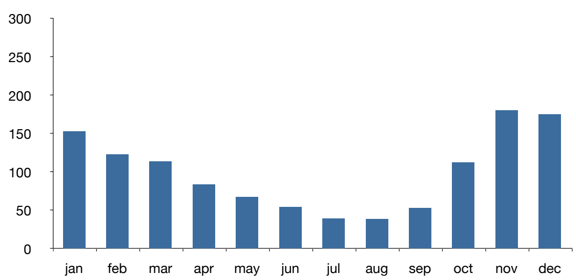


Fig. 3.2. Average monthly rainfall (mm) in Vancouver, BC.

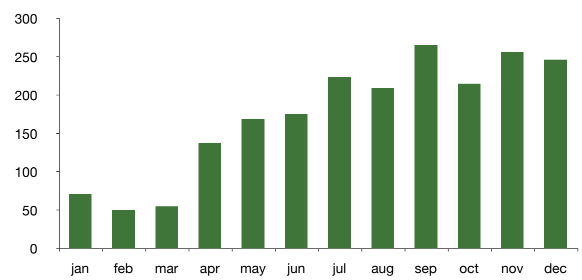


Fig. 3.3. Average monthly rainfall (mm) in Malé, Maldives.

A.1. RAINFALL PATTERN

The precipitation regime is considered the key factor influencing the performance of RWH systems (Palla, Gnecco, Lanza, & La Barbera, 2012; Su, Lin, Chang, Kang, & Lin, 2009). The local precipitation characteristics that affect the performance of RWH systems are the magnitude of rainfall events, their frequency, and the length of the dry periods between events (Guo & Baetz, 2007). It is therefore not sufficient to consider only the mean annual precipitation of a site when designing a RWH system (Kahinda, Lillie, Taigbenu, Taute, & Boroto, 2008). A case-study in Guja-do island in Korea (Han & Ki, 2010) concluded that the rainfall pattern of the location was unfavourable for effective rainwater harvesting systems because of the uneven distribution of rainfall. Other parameters, such as the length of drought periods, can significantly affect the performance of RWH systems. Excessively high storage volumes may be required to provide water during the entire dry season. In addition, long dry periods may result in equally long detention times for the stored rainwater, during which some level of degradation is expected to occur (Palla, Gnecco, & Lanza, 2011). However, the precise duration of these dry periods is hard to predict (Smet & Moriarty, 2001, cited in Peters, 2012). Detailed rainfall data is thus necessary to size these systems appropriately.

A.2. CATCHMENT AREA

The most typical rainwater harvesting systems applied in buildings are those that use roofs as catchment areas (Farreny, Gabarrell, *et al.*, 2011). Other surface types, such as hardscapes, can also be included in some cases. Besides the total plan catchment area, other factors, such as the surface geometry and slope may affect the system's efficiency and cost as well. The roof material can also have implications for the runoff coefficient, since, depending on its nature, there may be temporary depression storage points where water is contained and evaporates before reaching the tank. The following table created by Farrany *et al.* (2011) summarizes the runoff coefficient for the most common roofing materials based on previous articles.

	SLOPING ROOFS	
	Runoff Coefficient	**Reference**
Concrete – Asphalt	0.9	Lancaster (2006)
Metal	0.95	Lancaster (2006)
	0.81-0.84	Liaw & Tsai (2004)
Aluminium	0.7	Ward *et al.* (2010)
	FLAT ROOFS	
Bituminous	0.7	Ward *et al.* (2010)
Gravel	0.8-0.85	Lancaster (2006)
Level Cement	0.81	Liaw & Tsai (2004)

Table. 3.1. Runoff coefficient for the most common roofing materials. Source: Farrany *et al.* 2011.

A combination of both an appropriate roof material and geometry is therefore necessary for optimizing the harvesting potential of these systems. Farreny *et al.* (2011) estimate that sloping smooth roofs can harvest as much as 50% more rainwater than rough flat roofs.

A.3. WATER DEMAND

Demand patterns can also directly affect the performance of these systems (Su *et al.*, 2009). Harvested rainwater is generally not used to cover the whole water demand of a project. On the contrary, it is generally used to supply freshwater for a fraction of the water-use, mainly for services not requiring potable water quality, such as irrigation, laundry or toilet flushing. It is the mission of design teams to decide which fraction of the total water demand is to be provided by harvested rainwater. The nature of this demand can influence the performance of the system, especially if this demand is not constant throughout the year. This demand variability clearly appears in the context of tourism, the higher demand periods corresponding to the high season, which generally coincide with drier periods especially at coastal destinations (Essex, Kent, & Newnham, 2004; Ioannides, Apostolopoulos, & Gayle, 2002 cited in Gill, Williams, & Thompson, 2010). A rainwater harvesting system works if this fraction of the water demand can be satisfied by the collected rainfall throughout the whole year. Therefore, knowing the anticipated demand and its variability is crucial to ensuring the optimization of the system (Jones & Hunt, 2010).

A.4. STORAGE VOLUME

As the most common design parameter of RWH systems (Palla *et al.*, 2011), storage capacity is usually determined based on an analysis of the previous variables. As far as the rainfall pattern is concerned, the frequency of rainfall events is significant for sizing the storage tanks, since long dry periods would need to be managed with stored rainwater. For this reason, extremely long periods without precipitation may result in excessively high storage volumes, which could make the system economically unviable. Concerning the water demand, its relation to the storage size is relevant but not direct. Palla *et al.* (2011) concluded that high demand fractions limit the performance of RWH systems without being significantly influenced by the storage volume. Similarly, low demand fractions guarantee a high efficiency of the system, irrespective of its storage capacity. “Only when the demand fraction is close to unity, can the quantitative performance of rainwater harvesting system[s] be maximized through suitable sizing of the storage tank” (Palla *et al.*, 2011, p. 69). In any case, the performance of a tank is not strictly proportional to its size. A smaller tank would be filled and emptied often while a large tank would be cycled rarely (Helmreich & Horn, 2009). This is an important consideration because, in many cases, the storage tank size will also depend on the available space and affordability by individual households (Aladenola & Adeboye, 2009), and oversizing the tanks does not necessarily imply further advantages. Similarly, an excessively small tank will result in high overflow rates, lowering the potential for a specific area.

B. QUALITATIVE ASPECTS

In addition to these quantitative aspects, qualitative considerations also need to be part of the design of a RWH system. In most cases, RWH systems include quality control mechanisms that vary, depending on the future use of the collected water (Shaffer & Leggett, 2002). Rainwater is considered to be relatively unpolluted water, so the required treatment for non-drinking purposes is generally only limited to filtration (Zhang, Gersberg, Wilhelm, & Voigt, 2009). However, if used for drinking purposes, rainwater needs to be treated and disinfected in order to eliminate all the pollutants and meet the applicable potable water standards (Central City Concern, 2009). While there are different types of treatments available to achieve potable water quality, in many countries it is still not permitted to use harvested rainwater for drinking. In these cases, regulatory changes become necessary for achieving water independence (Central City Concern, 2009). The design of the system may impact the quality of the harvested water and therefore the cost of the future treatment. Since the catchment surface material itself is often the main source of pollutants (Shaffer & Leggett, 2002), its selection is also important for qualitative reasons. Organic roofs (Fig. 3.4), such as reed and palm, are not recommended because they produce a dirty runoff (Ersson, 2006). Similarly, roofs tied with bamboo gutters can generate health hazards (Helmreich & Horn, 2009). Green roofs (Fig. 3.5) are considered a good option since they can even improve the quality of the harvested water through a filtration process. Metal roofs (Fig. 3.6) made of treated steel or aluminium are also viable options, as they have the advantage of being relatively smooth and less prone to dust, leaves, or bird-dropping contamination than other types of roofs. They can also reach high temperatures by solar radiation which could automatically sterilize them (Ersson, 2006). However, zinc and copper roofs, or roofs with metallic paint or coatings, should not be considered because they can lead to high heavy metal concentrations (Helmreich & Horn, 2009). Other than metal roofs, low or non-polluted rainwater can generally be harvested from roofs constructed with clay, ceramic, and/or concrete tiles or slates (Helmreich & Horn, 2009) (Fig. 3.7). Finally, plastic roofs are not recommended because they are neither inexpensive nor durable and roof paints that include bitumen should also be avoided (Ersson, 2006).

Fig. 3.4. Thatched roof in Hungary, detail. By Zyance (Own work). CC-BY-3.0 (http://creativecommons.org/licenses/by/3.0), via Wikimedia Commons.

Fig. 3.5. Norðragøta, Faroe Islands. By Erik Christensen, Porkeri (Contact at the Danish Wikipedia). CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0/), via Wikimedia Commons.

Fig. 3.6. Lakota MS PV array 1. By Architectsea (Own work). CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0), via Wikimedia Commons.

Fig. 3.7. Red tile roof repair. By Downtowngal (Own work). CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0), via Wikimedia Commons.

3.2 Demand Reduction

3.2.1 WASTEWATER RECYCLING

Wastewater recycling is a strategy for water demand management that allows for significant reductions in potable water use. Reusing the greywater and/or the blackwater generated in buildings keeps the water required for their functioning in a closed loop, thereby reducing their dependence on external freshwater sources (Jefferson, Laine, Parsons, Stephenson, & Judd, 2000). Moreover, this strategy reduces the pressure on wastewater treatment infrastructure (Mandal *et al.*, 2011). Seen from a water footprint perspective, greywater recycling can help reduce both the operational blue and grey water footprints of a project at the same time. Moreover, demand variability due to tourism demand fluctuations throughout the year does not affect this strategy either, since higher demand periods will also result in a higher greywater availability.

Fig. 3.8. WasteWater. By Palintest Ltd (Own work). CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0), via Wikimedia Commons.

Even though wastewater recycling in the last decades has mainly focused on greywater, new technologies have recently allowed several buildings to treat and reuse blackwater as well. The International Plumbing Code defines greywater as "waste discharged from lavatories, bathtubs, showers, clothes washers, and laundry trays" (International Code Consortium, 2012, p. 12). On the other hand, blackwater is characterized by higher concentrations of organic material, nutrients and pathogens than greywater (Gallagher & Sharvelle, 2009). Blackwater definitions vary, but it always includes wastewater discharged by urinals and toilets. For this research, wastewater from kitchen sinks and dishwashers is also considered as blackwater. As for RWH systems, both quantitative and qualitative aspects are analyzed and presented here.

A. QUANTITATIVE ASPECTS

The parameters determining the available wastewater to be recycled in a building are not the same as for rainwater harvesting. For instance, the amount of greywater available throughout the year is not linked to climate conditions (Central City Concern, 2009; Zhang *et al.*, 2009), as it mainly depends on the building's water use. Therefore, in the tourism context, given that the water consumption varies throughout the year, wastewater availability will also vary between high and low seasons.

Several studies have measured the amount of greywater generated by buildings hosting different uses (Table 3.2). Stephenson and Judd (1998, cited in Jamrah, Al-futaisi, Prathapar, & Harrasi, 2008) estimated that between 50% and 80% of the total water used in residential buildings can be reused for other purposes. A study in Syria (Mourad, Berndtsson, & Berndtsson, 2011) concluded that a typical Syrian urban area household's greywater production corresponded to 46% of the total water consumption. A study in a residential area in Oman (Jamrah *et al.*, 2008) showed that household greywater production varied between 80% and 83% of total water consumption and was mostly generated from showers.

Source	Study Location	Wastewater Reuse Potential (% of total water consumption)
Stephenson & Judd, 1998	-	50% - 80%
Mourad *et al.*, 2011	Syria	46%
Jamrah *et al.*, 2008	Oman	80% - 83%

Table. 3.2. Wastewater reuse potential observed in different studies.

A similar parameter to the runoff coefficient applied in rainwater harvesting systems also appears in this case, as not all the water used for a specific service can be reused. For instance, it cannot be considered that all the water used for laundry can be recycled, since a significant amount is lost by evaporation (cloth drying). It is estimated that about 10% of the water is evaporated and 5% is reused for backwashing the filters of the washing machine (AquaRecycle™, 2012). Similar considerations would apply to other uses from which grey or blackwater is to be recycled, such as showers, toilets or bathtubs.

The technology and investment costs required for wastewater recycling are higher than for rainwater use (Zhang *et al.*, 2009). However, the higher the volume of treated water, the higher the saving potential (Zhang *et al.*, 2009), which indicates that if applied in a project, all the potentially recyclable water should be included in order to optimize its cost-efficiency.

B. QUALITATIVE ASPECTS

Different treatment options achieve varying water quality levels for recycled wastewater. The choice of the treatment type and also the level of the treatment depend on several factors, including the end use of the recycled water, the grey and blackwater sources, the properties of the pollutants to be removed or the cost and energy demand corresponding to each treatment alternative (Cheremisinoff, 2002).

Similar to harvested rainwater, the level of treatment that wastewater should receive before being reused depends on its end uses (Mourad *et al.*, 2011). As an example, for toilet flushing, water needs to be treated to avoid smell and transport of bacteria and viruses (Mourad *et al.*, 2011), since the presence of organic compounds increases the risk of microbial growth in the distribution system and cisterns (Windward *et al.*, 2008 cited in Mourad *et al.*, 2011).

The treatment type also depends on the nature of the harvested water, as each type of wastewater has different characteristics. Compared to blackwater, greywater contains lower levels of organic contaminants, nutrients and pathogens (Gallagher & Sharvelle, 2009), but some sort of biological treatment is usually necessary to guarantee the absence of risks associated with its reuse (Nolde, 2000, Winward *et al.*, 2007 cited in Zhang *et al.*, 2009). The composition of each type of wastewater depends on several factors, such as the water source, the plumbing system, or the living habits (e.g. laundry or bathing habits, chemical composition of the cleaning products, etc.) (Al-Jayyousi, 2003; Badadoost, 1998; Jamrah *et al.*, 2004 cited in Jamrah *et al.*, 2008). For instance, laundry greywater is characterized as containing less nitrogen and phosphorus and a higher pH than other greywater types (Eriksson *et al.*, 2002 cited in Mourad *et al.*, 2011).

Wastewater purification requires the removal of a series of pollutants in order to meet the established water quality standards. Wastewater can be contaminated by heavy metals, turbidity, organic compounds and pathogens, such as bacteria and viruses (Cheremisinoff, 2002). There are multiple technologies and processes involved in the most modern wastewater treatment schemes (Cheremisinoff, 2002), each of them generally focusing on one or several types of pollutants. The most common methods include biological processes, such as aeration, in some cases using active sludge (Haandel & Lubbe, 2012); physical processes such as filtration, in some cases enhanced by chemical additives; or combined technologies, such as membrane bio-reactors. Plant-based systems, which have been used more frequently in recent years, imitate natural processes for water purification, such as the ones that occur at wetlands.

Treatment types can be classified in different ways, such as conventional vs. more recent technologies or mechanical vs. natural processes. Depending on where the wastewater is treated with respect to its source, it can be classified into either on-site or off-site treatment. Off-site wastewater treatment, also known as centralized wastewater treatment, generally happens at a municipal treatment plant. The capacity of these plants depends on the volume of water to be treated, according to the size of the city or neighbourhood to be served. Remote tourism destinations, on which this thesis is focused, typically do not have access to municipal wastewater treatment plants, and therefore need to treat the wastewater they produce on-site. But on-site treatment is not exclusive to urban development taking place on isolated environments such as small islands. Small or remote urban areas located on the mainland, and also in some rural areas, may not have access to centralized treatment either. Moreover, on-site or decentralized treatments are nowadays being incorporated into buildings that have access to municipal treatment plants, as a means of reducing their own potable water demand, by reusing their own wastewater, as well as for reducing the pressure on the municipal infrastructure.

The cost and energy demands of the treatment process need special attention too, particularly at remote tourism destinations that rely on fossil fuels for their energy supply. Treating grey and blackwater separately generally reduces the cost of the process (Kreysig, 1996 cited in Jamrah *et al.*, 2008), since each type of treatment is selected according to the nature of the water source and the minimum quality requirements for its end use. Therefore, in order to optimize treatment costs, it is recommended to reuse the wastewater containing the higher levels of contaminants for usages requiring lower water quality, such as toilet flushing or irrigation (Central City Concern, 2009; Thomas, 2012). However, while this separation is easily achievable in new buildings, it can be difficult to apply in existing buildings using a centralized water distribution system (Eriksson *et al.*, 2003 cited in Jamrah *et al.*, 2008). Furthermore, newer technologies can also reduce the energy and carbon emissions associated with the recycling process, in some cases achieving an energy positive treatment (Lazarova, Choo, & Cornel, 2012).

3.2.2 IMPROVED EFFICIENCY

Another strategy for reducing the water demand of a project is the incorporation of efficient water devices. Efficient devices include plumbing fixtures, such as toilets or shower heads, efficient appliances, like washing machines or dishwashers, and irrigation systems. The objective of this strategy is to reduce the water needed for each service without interrupting its appropriate functioning, which means using the water in a more efficient way.

The potential for water conservation by replacing old devices with more efficient ones has been tested in several buildings in the past (Table 3.3). A case-study in Teheran (Bidhendi, Nasrabadi, Vaghefi, Hoveidi, & Jafari, 2008) showed a 19% total water use reduction for an apartment complex after retrofitting. A study in Sicily (Roccaro, Falciglia, & Vagliasindi, 2011), Italy, analyzed the water savings for two houses (A and B) after applying efficient plumbing products coupled with educational measures (brochures showing water saving tips), and obtained a 9% average reduction for house A and 19% for house B. The results of a test in Tampa, Florida, USA (Mayer, DeOreo, Towler, Martien, & Lewis, 2004 cited in Willis *et al.*, 2011), showed a reduction potential of almost 50%. Based on similar studies in Australia and the USA, Inman and Jeffrey (2006) concluded that between 35% and 50% indoor water use reduction can be achieved through the application of highly efficient devices.

Source	Study Location	Water saving potential based on efficiency improvement strategies
Bidhendi *et al.*, 2008	Teheran (Iran)	19% for an apartment complex
Roccaro *et al.*, 2011	Sicily (Italy)	9% and 19% for two different houses (includes educational measures)
Mayer *et al.*, 2004	Tampa (USA)	50%
Inman & Jeffrey, 2006	Australia and USA	between 35 and 50%

Table. 3.3. Water saving potential through improved efficiency observed in different studies.

Other studies focus on users' acceptance of these kinds of appliances, showing that the most significant barrier to applying them is the high cost of these devices (Dolnicar & Hurlimann, 2010). Their willingness to apply them is therefore dependent on their capacity to acquire and apply them. However, this is not applicable to the context of tourism, since tourists do not have decision-capacity over the application of these fixtures at the hotels where they stay. It is, on the contrary, the accommodation management's responsibility to implement them.

The different options for water conservation through improved efficiency are classified into the following categories: efficient plumbing fixtures, efficient appliances and efficient landscaping.

EFFICIENT PLUMBING FIXTURES

Efficient plumbing fixtures refer to water-related devices connected to the plumbing system which consume less water than conventional devices offering the same services. These fixtures include toilets, shower heads, aerators for kitchen and lavatory faucets and urinals. WaterSense®, a partnership program sponsored by the United States Environmental Protection Agency (USGBC, 2003), offers an overview of reduced water use levels that can be achieved through the application of these plumbing fixtures. *LEED Reference Guide for New Construction* (USGBC, 2003) measures the performance to be achieved in water conservation by the use of efficient fixtures through a comparison between WaterSense Standards and the UPC (Uniform Plumbing Code) and IPC (International Plumbing Code) Standards (Table 3.4).

Fixture	UPC and IPC Standards	EPA WaterSense Standards
Water closets (gallons per flush, gpf)	1.60	1.28
Urinals (gpf)	1.00	0.5
Shower Heads (gallons per minute, gpm)	2.50	1.5 - 2.0
Public lavatory faucets and aerators (gpm)	0.5	-
Private lavatory faucets and aerators (gpm)	2.2	1.5
Kitchen and janitor sink faucets	2.20	-

Table. 3.4. UPC and IPC standards for plumbing fixture water use. Source: USGBC, 2009.

In the context of tourism, special attention needs to be given to the use of low-flow shower heads, as contrary to other efficient fixtures, such as dual-flush toilets, their use can impact the amenity's performance and therefore produce a negative reaction by tourists. In some cases, standards for new shower heads include comfort ratings in order to guarantee a minimum comfort level for users (Stone, 1996).

EFFICIENT APPLIANCES

In addition to the use of the previously described plumbing fixtures, a significant indoor water use reduction can be obtained by the incorporation of water efficient appliances, such as clothes washers and dishwashers. In tourism, laundry and restaurants consume large amounts of water, therefore the incorporation of these appliances can significantly impact the total water use of the facility.

ENERGY STAR™, an international standard for efficient products, certifies clothes washers that consume 35% less water than conventional ones, 15 gallons per load compared to the 23 gallons used by standard washing machines (ENERGY STAR, 2013a). Similarly, dishwashers using less than 4.25 gallons of water per cycle are also certified (ENERGY STAR, 2013b). The use of efficient appliances like these helps reduce not only water but also energy demands in buildings, which, in the case of remote destinations, is another common goal in the context of sustainable development.

EFFICIENT LANDSCAPING

The presence of gardens at coastal resorts is frequent and in some cases the amount of freshwater required to maintain them is very high. A study of several tourism facilities' water use in Zanzibar (Gössling, 2001) showed that hotels with extensive gardens require an average of up to 50% of the total freshwater consumption. Different landscape design strategies aim to reduce the need for garden irrigation, which can greatly contribute to reducing the whole water demand of resorts.

The previously described strategies, rainwater harvesting and wastewater recycling, present an opportunity to significantly reduce outdoor potable water use. Water reuse for irrigation has been widely applied worldwide in recent decades, as the lower quality requirements when compared with indoor water reuse do not imply complex or expensive treatment processes (Dixon, Butler, & Fewkes, 1999). However, some considerations are always necessary. If wastewater is reused for irrigation, special attention should be given to the presence of sodium because of its environmental damage potential (Misra and Sivongxay, 2009 cited in Mourad *et al.*, 2011). While other metals, microorganisms and complex organic compounds may entail additional environmental risks (Finley, Barrington, & Lyew, 2009), on the contrary, the presence of nutrients can in some cases have a positive impact, both organically and financially, as the need for fertilizers is reduced (Friedler, 2004; WHO, 2006 cited in Mandal *et al.*, 2011). Edible food gardens also require special attention, as the presence of heavy metals or pathogenic microorganisms can generate health risks.

The use of smart irrigation systems is another strategy for reducing outdoor water use. Drip irrigation (Fig. 3.9), providing small amounts of water directly to the root systems of plants, offers an increased yield when compared with other methods, such as sprinkler irrigation (Fig. 3.10) (Bernstein & Francois, 1973). Appropriate irrigation timing is also crucial for increasing the efficiency of the water used for this purpose.

Fig. 3.9. Irrigation dripper. By Fir0002/Flagstaffotos. CC-BY-NC-3.0 (http://creativecommons.org/licenses/by-nc/3.0), via Wikimedia Commons.

Fig. 3.10. A picture of a sprinkler watering a lawn. By Fir0002. CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0), via Wikimedia Commons.

Timing strategies include watering gardens at an adequate time and frequency, generally avoiding high evaporation rates in the middle of the day, and for the optimum duration (United States Environmental Protection Agency, 2013b). New technologies such as soil moisture sensors or rain sensors, combined with shutoff systems, allow for an automatic interruption of the irrigation process when it is not required (United States Environmental Protection Agency, 2013c).

However, the most efficient way to reduce outdoor water use is an appropriate landscape design. Plant selection, i.e., prioritizing the use of native and drought tolerant plants, limits the need for irrigation in extreme weather condition situations (United States Environmental Protection Agency, 2013a). Furthermore, an adequate landscape design eliminates the need for additional strategies, such as the previous ones (outdoor water reuse or smart irrigation systems), as their saving potential is drastically reduced (Muthukumaran, Baskaran, & Sexton, 2011). This way, harvested rainwater or recycled wastewater can be reused for other indoor purposes, the demand reduction of which cannot be achieved by other strategies, contributing to an improved performance of the whole water system.

3.2.3 IMPROVED BEHAVIOUR

In order to achieve the most ambitious water goals, all the previous strategies need to be incorporated into the design of coastal tourism facilities. However, in many cases, the anticipated performance during the design process of these strategies does not correspond to the actual building use during its operation (Cole, 2010). Since tourists are directly responsible for much of the total water use in tourism facilities, their commitment to sustainability goals is necessary to assure their achievement. Conventional assumptions about tourists, who are generally considered as passive users of the accommodation facilities, need to evolve and embrace recent trends in green building design, in which a new series of responsibilities and commitments are being required of building users (Brown, O'shea, Cole, & Robinson, 2008).

Outside the context of tourism, several studies have analyzed the potential for water conservation based on different measurements that focus on the building user. A study in Sicily (Italy) by Roccaro *et al.* (2011) monitored and compared the effectiveness of structural and non-structural strategies in a series of projects with different uses. All the previous strategies (as described in Section 3.2.2) would correspond to structural measures as their level of performance does not depend on the user's behaviour. Non-structural measures include economic incentives or educational programs. The results showed that the consumption reduction obtained through non-structural strategies were negligible when compared with that obtained by structural measures (Roccaro *et al.*, 2011). This study also showed that the application of structural measures reduces the amount of water wasted by users, which minimizes the potential for further water saving through educational programs (Roccaro *et al.*, 2011). Moreover, other studies have demonstrated that only non-structural measures, i.e., not involving personal sacrifice or comfort reduction, such as water pricing and economic incentives, have the potential to change the behaviour of water users (Gilg & Barr, 2006).

In the tourism context, non-structural measures to reduce guest water consumption have been applied at many hotels worldwide. For instance, it has become common practice to let guests choose whether or not to have their bath towels washed everyday (Fig. 3.11). More recently, some hotels are linking energy and water saving opportunities with economic incentives for guests by rewarding them with a daily small credit to be used at the hotel if they opt out of housekeeping services (Nassauer, 2010). However, the high water consumption by guests observed at some destinations when compared to local residents suggests that more commitment from the individual tourist is necessary to further reduce demand (Yang *et al.*, 2011).

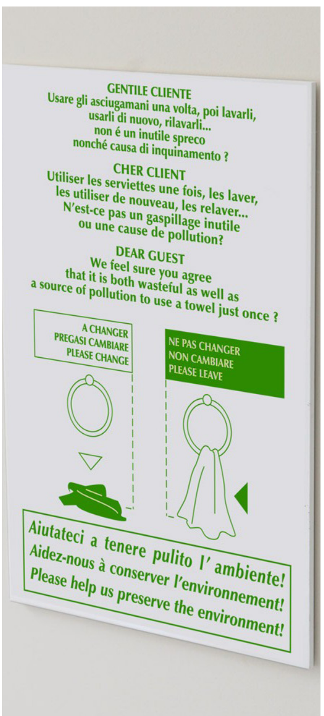


Fig. 3.11. Daily towel-changing card.
Source: www.apir.com

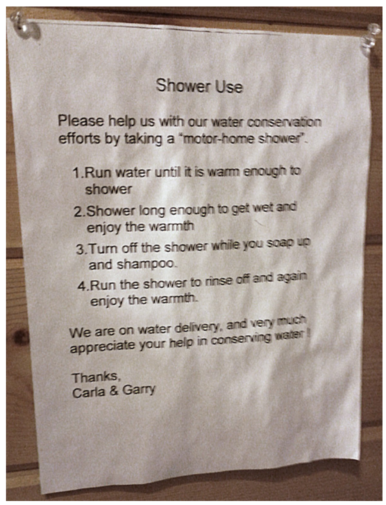


Fig. 3.12. Shower use instructions. Hotsprings Valley Retreat. Yukon, Canada.

Different strategies for guest behaviour improvement are therefore necessary in order to increase their commitment to resource conservation. In their analysis of the relationship between lifestyle, environmental awareness, and water saving in Spanish housing, Mondéjar-Jiménez *et al.* (2011) concluded that a higher awareness leads to an increased disposition to save water. Increased awareness about the water problem is therefore one of the keys to improving behaviour. The design of the tourism facilities is crucial in this sense. The benefits of the water-related strategies could be greater if these technologies and strategies are made more transparent. 'Transparency' is here understood as allowing "something that was previously latent to become visible" (Ockman & Lasansky, 2004, p. 235 cited in Owen, 2007b).

Accordingly, Mitchell (2005) identifies a series of actively instructional green building strategies (interpretive signage, exposed building systems, real-time monitoring, and green building tours) and defines 'triggers' as design solutions that stand out in some way to cause an occupant to pause and reflect on their purpose (Fig. 3.13). In order to be effective, these triggers must be easily noticed, linked to an environmental message, and interact with the occupants of the building (A. Mitchell, 2005).

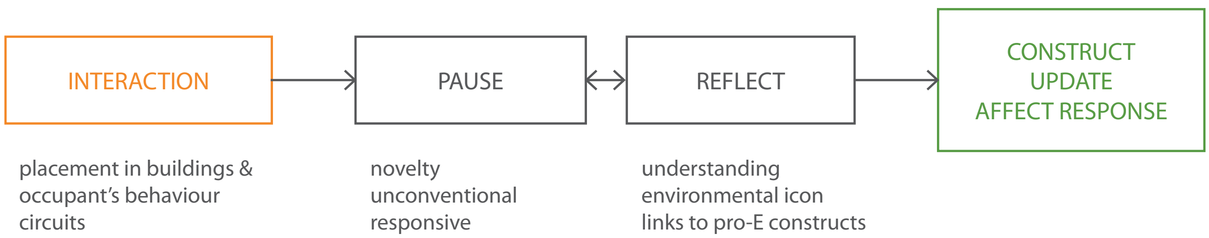


Fig. 3.13. The structure of a trigger. Mitchell, 2005.

But awareness is not the only component leading to improved behaviour. Guests also need to understand the impact that their actions may have on the building's performance. Design strategies need to direct tourists' attention to the problems they resolve, and, through inviting them to participate, help them acquire knowledge, discipline and useful skills that cannot be acquired other than by taking the appropriate action (Orr, 1993).

Also, their involvement must not entail a loss of comfort or harm the recreational experience. It has been observed in some studies that attitudes become actions only when it is easy and not inconvenient for the user to do so (Dolnicar & Hurlimann, 2010). In this sense, providing guests with tools and easy ways of participating should enhance their experience, in accordance to some studies that show that the level of satisfaction at the accommodation is "linked to awareness and involvement in the environmental management practices" (Lee & Moscardo, 2005, p. 563). Through this interaction process, guests would receive a "first-hand experience" of living in a more sustainable way and would be able to verify whether (or not) this new lifestyle implies a major change (Anderson, 2009).

In accordance with these principles, Beyer *et al.* (2005) define a "best practice model for tourism facilities in remote areas" in which "interpretation leading to education" is one of the key "product assessment criteria" leading to the development of low impact facilities. According to this model, sustainable design “must be evident”, and contribute to a “heightened consumer awareness, appreciation and understanding of environmental processes” arguing that “the more personal interpretation leads to a better experience” (Beyer *et al.*, 2005, p. 7). Also, some existing benchmarking systems related to sustainable tourism, such as Green Globe Design and Construct Standard already include this principle implicitly, by identifying the design as one of the key strategies to achieve the goal of enhancing the visitor’s understanding and integration with the environment (Hyde *et al.*, 2004 cited in Owen, 2007b).

As far as the aesthetics are concerned, some anthropologists assume that ecotourists are generally more concerned than other types of tourists about “the physical and aesthetic properties of locations in which they will spend their leisure time” (Peace, 2005 cited in Owen, 2007a). The construction of new facilities should be understood as a contemporary interpretation rather than a reproduction of traditional architecture, in which the integration of rainwater guttering and tanks or other systems would express the self-sufficiency aspirations of the resorts (Howard, Hes, & Owen, 2008). As a consequence, the exposure to these technologies could help to accelerate the process of accepting a new design style (Anderson, 2009). After all, the real objective of sustainable tourism is to mitigate its negative impact, and “the most important thing about an ecolodge is that the ecolodge is not the most important thing” (Ceballos-Lascurain, 1996 cited in Owen, 2007b).

3.3 Precedent Study. CIRS Building

While most of the previously described strategies have already been widely applied in the context of green building and sustainable tourism, some projects have taken some of these ways for improving water management to the next level. The Centre for Interactive Research on Sustainability (CIRS), at the University of British Columbia in Vancouver, is one example (Fig. 3.14). Ten years after conceiving the idea of creating “the greenest building in North America”, CIRS, designed by Perkins+Will, started operating in September 2011 (University of British Columbia, 2013).

Fig. 3.14. CIRS Building, UBC Vancouver campus, Canada. By James Kruk (Own work) [CC0], via Wikimedia Commons.

CIRS not only offers space for multidisciplinary education and research, but also embraces some of the most challenging sustainability goals, aiming to be energy net-positive, water self-sufficient, and net-zero in structural and operational carbon emissions. Moreover, the building has been described as a "living laboratory" that allows research, not only into sustainable building technology but also on the impacts of its inhabitants' actions. User participation and behavioural improvement are also part of the goals of the building. Real-time monitoring of continuous measures of the performance of the building allows researchers to identify areas for optimization. Performance levels in different categories (i.e. energy, carbon, water) are displayed in the atrium in a comprehensive way for users to understand how the building works (University of British Columbia, 2013).

On the energy side, photovoltaic cells located on part of the roof provide electricity. Solar tubes and a heat recovery system are used to pre-heat domestic hot water. Passive design strategies, together with a high-performance envelope, minimize energy loads. And, in order to become energy-positive, the excess heat generated by heat-pumps at CIRS is transferred to the adjacent Earth and Ocean Science building, reducing energy demand on the campus steam system. Additionally, control over personal spaces is provided for building users (University of British Columbia, 2013).

As far as water is concerned, CIRS is 100% dependent on rainwater and all the wastewater generated in the building is treated and recycled for several uses. Two main systems allow these two objectives to be achieved.

Fig. 3.15. Green roof. CIRS Building, UBC Vancouver campus, Canada. Photo: Martin Tessler. Courtesy: Perkins+Will.

RAINWATER HARVESTING SYSTEM

The CIRS harvests rainwater from the rooftops of the two main wings of the building, which make available a 1000 square meter catchment area. Rainwater falling on the living roof over the lecture hall (Fig. 3.15) is not harvested, as the presence of particulate matter from the green roof could damage the treatment system. Located on a site with an average annual rainfall of 1226mm, such a catchment area could provide 1226000 litres per year, enough to cover the building's estimated demand of 2000 litres per day. However, the rainfall pattern in Vancouver presents a drier period between June and September, so enough water needs to be collected throughout the rest of the year to satisfy the water demand during the summer. For that purpose, a 100 cubic meter (100 000 litres) cistern underneath the building serves as water storage, from which 57000 litres need to be continually available for the fire suppression system. It has to be considered, though, that the building water demand is also lower during the summer period, due to a lower presence of students and staff at this time of the year (NovaTec Consultants Inc., 2012). Contrary to the case of tourism, in this case, rainwater availability and demand throughout the year present similar evolution patterns.

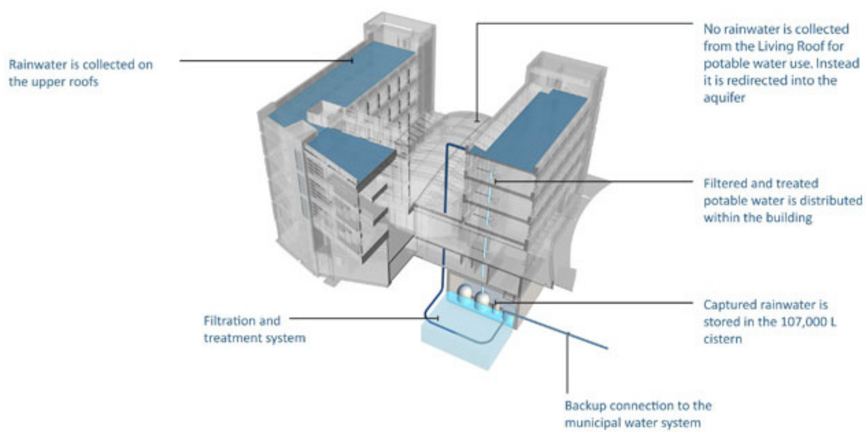


Fig. 3.16. Rainwater harvesting system. CIRS Building, UBC Vancouver campus, Canada. Photo: Perkins+Will.

As described above, the rainwater harvesting system is similar to any other rainwater harvesting system. What makes this system special is that the harvested water is not used for non-potable uses but for potable ones. The services using this water include showers, bathroom and kitchen sinks, and drinking water for the cafe located on the main floor. Treating harvested rainwater for potable use is required for achieving a net-zero water scenario, as otherwise potable water would need to be obtained from the municipal supply. The treatment process is the following:

The collected rainwater is first stored in a water tank before being treated. From this tank, harvested rainwater undergoes a treatment process of several steps, including a slow sand filter, a cartridge filter, and a granular activated carbon filter. At the end of this process, water is disinfected by an ultraviolet unit and chlorination, and pH is adjusted by adding either sodium bicarbonate or sodium hypochlorite, before flowing into the treated rainwater storage tank. A backup municipal supply provides water in case of insufficient rainfall (NovaTec Consultants Inc., 2012).

WASTEWATER RECYCLING SYSTEM

A Solar Aquatics System™ located on the main floor treats all the wastewater generated by the building, including blackwater. In addition, water from the campus sewer system is also incorporated into the treatment process and reused in the building. The Solar Aquatics System was designed by Eco-Tek, Ecological Technology Inc. This system mimics natural processes to produce clean water, which is reused for toilet flushing and irrigation.

Sewage flows by gravity from the building and from the campus sewer into a collection buffer tank, which is the only component of the whole system located underground. From this tank, water flows into an aerated blending tank. Then water overflows by gravity into two aerobic tanks, in which bacteria from the water gets attached to the roots of a group of aquatic and terrestrial plants (Fig. 3.17). Through a conical bottom gravity clarifier, where bacteria is settled, water is then conducted to a sand filter, where particulate matter is removed before water is discharged into the constructed wetland. In this wetland, a number of plants extract the phosphorus and nitrogen from the effluent. Water is then pumped through a series of filters, in which turbidity is controlled. Finally, water passes through an ultraviolet disinfection unit and is stored in the treated-water tanks (EcoTek. Ecological Technologies Inc., 2012).

Fig. 3.17. Aerobic tanks. Solar Aquatics System™. CIRS Building, UBC Vancouver campus, Canada.

Fig. 3.18. Gravity clarifiers. Solar Aquatics SystemTM. CIRS Building, UBC Vancouver campus, Canada.

This wastewater treatment plant allows for the creation of a closed-loop water system, completely nullifying the potential grey water footprint of the CIRS building. But the most interesting aspect of this wastewater treatment system is its transparency. The integration of this living machine into the building design makes of it a perfect learning tool for building users and researchers. The Solar Aquatic System is located in a glass box right at the entrance of the building in order to maximize its visibility. Moreover, guided tours provide the possibility of entering the facility and receiving an explanation about its functioning (Fig. 3.18).

The CIRS building is an example of what taking conventional water-related strategies to the next level means. The achievability of ambitious water goals, such as the net-zero water scenario, is not possible if all the previous strategies are used and applied in a conservative way. Potable water quality is required for many building uses, especially at beach resorts, due to the nature of the hospitality services offered to tourists at these facilities. Rainwater needs to start being considered as a potable water source, as in the CIRS building, in order to move beyond a freshwater supply based on desalination. CIRS also demonstrates that on-site wastewater treatment is possible, not only for greywater but also for blackwater. The implementation of plant-based technologies avoids the use of energy-intense technologies, such as membrane bio-reactors for cleaning and reusing wastewater. The different parameters (water consumption, harvested rainwater, treated wastewater) associated with all these strategies are real-time monitored and displayed at the entrance of the building (Fig. 3.19). Finally, a transparent integration of these technologies into the aesthetics of the building makes them perfect learning tools which, extrapolated to this thesis context, could be used to improve guests' awareness of the water availability problem at remote tourism destinations.

Fig. 3.19. Building entrance. CIRS Building, UBC Vancouver campus, Canada.

4 WATER FOOTPRINT DESIGN TOOL

CALCULATING THE WATER FOOTPRINT OF A BEACH RESORT

Based on the previously described water strategies, this section assesses the potential for achieving the net-zero water scenario defined in chapter 2, for a case-study in the Maldives. In order to do that, a spreadsheet-based calculator, the "Water Footprint Design Tool" (Tool) is proposed. This Tool allows us to estimate the direct water footprint and all its sub-components for the case-study, in this case, an existing beach resort. This quantitative analysis is based on daily metered water-use data provided by the resort and daily rainfall data obtained from the Maldivian Meteorological Agency. In the first stage, the Tool calculates the annual direct water footprint of the assessed project under its current conditions and then allows the designer to foresee the potential impact on the different footprint components of a number of water-related strategies. All the strategies described in chapter 3 are included: rainwater harvesting, wastewater recycling and water conservation. Even though the application of the Tool is illustrated in this thesis through an existing project, the Water Footprint Design Tool is conceived as applicable also to new projects. In these cases, due to the absence of metered water data for the designed project, the water-use pattern introduced in the Tool needs to be based on measurements from projects which are similar in size and program.

4.1 Water Footprint Design Tool Components

The Water Footprint Design Tool (the Tool) developed for this research is a spreadsheet-based calculator that allows design teams to foresee the impacts of a series of water strategies on the different water footprints of a building and its site. The Tool is composed of 2 spreadsheet pages linked to each other. The first page contains all the data and formulas associated with each water strategy and the second page includes the Tool control panel and results.

The first page of the tool is composed of a series of groups of columns differentiated by colour. The first group of columns, "water-use data" (Fig. 4.1), includes the demand pattern of the project, which is introduced by the Tool user. Four additional groups of columns contain the formulas corresponding to each water strategy (see section 4.2 Methodology): "rainwater harvesting" (Fig. 4.2), wastewater recycling ("greywater recycling" and "blackwater recycling") (Fig. 4.5), "efficient fixtures" (Fig. 4.4) and "education" (Fig. 4.3). Finally, a last set of columns, entitled "water footprints", shows the different water footprint components that result from the calculations (Fig. 4.6). This last set of columns is the data source for the graphics, illustrating the results on the second page. All these groups of columns are divided into two sets of rows (Fig. 4.6). The Tool calculates the annual water footprint using a daily time step. On the first row-group, each cell corresponds to one day of the year, for a total of one whole year. The second row-group summarizes the results on a monthly basis. All the cells on this second-row group automatically calculate monthly values based on the daily-step calculations.

TIME	WATER-USE DATA													
	Guest rooms				Employees facilities			Other						
	TOTAL (original data)	Showers +Sinks	Toliets	Swimming Pools	TOTAL (original data)	Showers +Sinks	Toliets	Laundry	Restaurants (1)	Spa	Process Water	Food Gardens	Landscaping	Drinking
		Q1 / GW	Q3 / BW	Q2 / -		Q1 / GW	Q3 / BW	Q2 / GW	Q1 / BW	Q1 / GW	Q2 / -	Q2 / -	Q3 / -	Q1 / -
jan	2823000	2258400	451680	112920	577000	461600	115400	607106	780000	96000	363000	193000	0	41000
feb	2747000	2197600	439520	109880	404000	323200	80800	521783	702000	91000	376000	184000	0	38000
mar	2861000	2288800	457760	114440	468000	374400	93600	585049	840000	114000	400000	250000	0	47000
apr	2769000	2215200	443040	110760	440000	352000	88000	581001	857000	97000	318000	147000	0	48000
may	2509000	2007200	401440	100360	442000	353600	88400	497424	815000	97000	314000	75000	0	42000
jun	2012000	1609600	321920	80480	406000	324800	81200	394456	796000	70000	358000	36000	0	36000
jul	2354000	1883200	376640	94160	448000	358400	89600	483983	822000	79000	461000	23000	0	40000
aug	2538000	2030400	406080	101520	549000	439200	109800	586246	845000	90000	457000	131000	0	40000
sep	2305000	1844000	368800	92200	464000	371200	92800	556565	755000	84000	432000	109000	0	39000
oct	3055000	2444000	488800	122200	672000	537600	134400	641826	889000	112000	446000	206000	0	53000
nov	3142000	2513600	502720	125680	607000	485600	121400	685495	868000	93000	426000	70000	0	45000
dec	3573000	2858400	571680	142920	580000	464000	116000	691355	983000	106000	509000	28000	0	44000
TOTAL	32688000	26150400	5230080	1307520	6057000	4845600	1211400	6832289	9952000	1129000	4860000	1452000	0	513000
average	2724000	2179200	435840	108960	504750	403800	100950	569357	829333	94083	405000	121000	0	42750
jan														
1	97000	77600	15520	3880	15000	12000	3000	16390	26000	2000	11000	0	0	1000
2	96000	76800	15360	3840	16000	12800	3200	32173	34000	4000	17000	1000	0	1000
3	97000	77600	15520	3880	15000	12000	3000	26132	25000	3000	16000	2000	0	2000
4	84000	67200	13440	3360	16000	12800	3200	20401	27000	3000	14000	3000	0	1000
5	106000	84800	16960	4240	17000	13600	3400	23046	27000	3000	14000	4000	0	2000
6	93000	74400	14880	3720	18000	14400	3600	21536	27000	3000	11000	5000	0	1000
7	100000	80000	16000	4000	22000	17600	4400	21386	26000	4000	13000	6000	0	2000
8	125000	100000	20000	5000	20000	16000	4000	21000	25000	4000	14000	5000	0	1000

Fig. 4.1. Water Footprint Design Tool. Page 1: Set of columns for water-use data. The Tool user introduces in these cells the high-resolution demand pattern for the designed project. This set of columns includes all the different water uses included in the program of the building. The estimated daily consumption is introduced in litres for every day of the year.

TIME	RAINFALL	RAINWATER HARVESTING YAS (Yield After Spillage)					
		inflow	demand	stored volume	outflow	main supply	overflow
		Qt	Dt	Vt	Yt	Mt	Ot
	2010			0			
jan	8	97200	2955400	2999514	916505	2038895	0
feb	93	1127520	2723246	4556926	1127520	1595726	0
mar	22	272160	2978534	151456	272160	2706374	0
apr	88	1072845	2898464	1582794	1072845	1825619	0
may	277	3364335	2696096	23420211	2173489	522607	0
jun	236	2868615	2308628	31933119	2308628	0	0
jul	222	2698515	2587792	12236967	2388757	199035	0
aug	178	2157840	2802452	11376645	2454104	348348	0
sep	341	4141935	2514524	21133370	1394561	1119963	0
oct	69	841995	3275292	54506641	3275292	0	0
nov	128	1557630	3252654	3009761	1758403	1494251	0
dec	355	4316895	3624388	37918315	3624388	0	0
TOTAL	2018	24517485	34617470		22766652	11850818	0
average	168	2043124	2884789	17068810	1897221	987568	0
jan							
1	0	0	96452	722853	96452	0	0
2	0	0	105252	617601	105252	0	0
3	0	0	96602	520999	96602	0	0
4	0	0	90550	430449	90550	0	0
5	0	0	105408	325041	105408	0	0
6	0	0	97656	227385	97656	0	0
7	0	0	104912	122473	104912	0	0
8	2.4	29160	118920	32713	118920	0	0

Fig. 4.2. Water Footprint Design Tool. Page 1: Set of columns for rainwater harvesting. The only data to be introduced by the user in this set of cells is the daily precipitation (mm) for the site location throughout a complete year ("rainfall" column). Based on the behavioural model described in section 4.2, the rest of the cells are filled automatically according to the RWH parameters established by the user on the control panel.

TIME	EDUCATION			
	Saved water			
	Guests + Employees			
	Laundry	Showers Sinks	Toilets	TOTAL
jan	25802	115600	28354	169756
feb	22176	107134	26016	155326
mar	24865	113186	27568	165619
apr	24693	109106	26552	160351
may	21141	100334	24492	145967
jun	16764	82212	20156	119132
jul	20569	95268	23312	139149
aug	24915	104958	25794	155667
sep	23654	94146	23080	140880
oct	27278	126718	31160	185156
nov	29134	127466	31206	187806
dec	29383	141202	34384	204969
TOTAL	290372	1317330	322074	1929776
average	24198	109778	26840	160815
jan				
1	697	3808	926	5431
2	1367	3808	928	6103
3	1111	3808	926	5845
4	867	3400	832	5099
5	979	4182	1018	6179
6	915	3774	924	5613
7	909	4148	1020	6077
8	893	4930	1200	7023

Fig. 4.3. Water Footprint Design Tool. Page 1: Set of columns for water conservation through education. The user does not introduce any data in this set of columns. All the cells are filled automatically according to the educational saving parameters established by the user on the control panel.

TIME	EFFICIENT FIXTURES						
	Saved water						
	Landscaping	Laundry	Kitchens	Showers sinks	Toilets	Food Gardens	TOTAL
jan	0	91066	117000	408000	0	0	616066
feb	0	78267	105300	378120	0	0	561687
mar	0	87757	126000	399480	0	0	613237
apr	0	87150	128550	385080	0	0	600780
may	0	74614	122250	354120	0	0	550984
jun	0	59168	119400	290160	0	0	468728
jul	0	72597	123300	336240	0	0	532137
aug	0	87937	126750	370440	0	0	585127
sep	0	83485	113250	332280	0	0	529015
oct	0	96274	133350	447240	0	0	676864
nov	0	102824	130200	449880	0	0	682904
dec	0	103703	147450	498360	0	0	749513
TOTAL	0	1024843	1492800	4649400	0	0	7167043
average	0	85404	124400	387450	0	0	597254
jan							
1	0	2459	3900	13440	0	0	19799
2	0	4826	5100	13440	0	0	23366
3	0	3920	3750	13440	0	0	21110
4	0	3060	4050	12000	0	0	19110
5	0	3457	4050	14760	0	0	22267
6	0	3230	4050	13320	0	0	20600
7	0	3208	3900	14640	0	0	21748
8	0	3150	3750	17400	0	0	24300

Fig. 4.4. Water Footprint Design Tool. Page 1: Set of columns for water conservation through efficient fixtures. The user does not introduce any data in this set of columns. All the cells are filled automatically according to the efficiency-related saving parameters established by the user on the control panel.

TIME	GRAYWATER RECYCLING			BLACKWATER RECYCLING		
	SOURCE	DEMAND	overflow	SOURCE	DEMAND	overflow
			source - demand			source - demand
jan	0	475920	-475920	530400	538726	-8326
feb	0	485880	-485880	477360	494304	-16944
mar	0	514440	-514440	571200	523792	47408
apr	0	428760	-428760	582760	504488	78272
may	0	414360	-414360	554200	465348	88852
jun	0	438480	-438480	541280	382964	158316
jul	0	555160	-555160	558960	442928	116032
aug	0	558520	-558520	574600	490086	84514
sep	0	524200	-524200	513400	438520	74880
oct	0	568200	-568200	604520	592040	12480
nov	0	551680	-551680	590240	592914	-2674
dec	0	651920	-651920	668440	653296	15144
TOTAL	0	6167520	-6167520	6767360	6119406	647954
average	0	513960	-513960	563947	509951	53996
jan						
1	0	14880	-14880	17680	17594	86
2	0	20840	-20840	23120	17632	5488
3	0	19880	-19880	17000	17594	-594
4	0	17360	-17360	18360	15808	2552
5	0	18240	-18240	18360	19342	-982
6	0	14720	-14720	18360	17556	804
7	0	17000	-17000	17680	19380	-1700
8	0	19000	-19000	17000	22800	-5800

Fig. 4.5. Water Footprint Design Tool. Page 1: Set of columns for wastewater recycling. The user does not introduce any data in this set of columns. All the cells are filled automatically according to the wastewater recycling parameters established by the user on the control panel.

TIME	WATER FOOTPRINTS				
	ORIGINAL DESALINATED WF	ORIGINAL GREY WF	DESALINATED WF	RAIN WF	GREY WF
jan	5480106	3816149	3274055	916505	2657091
feb	5063783	3484722	2762120	1127520	2433752
mar	5565049	3802887	3998085	272160	2608602
apr	5257001	3706593	2921061	1072845	2514928
may	4791424	3408051	1458301	2173489	2296291
jun	4108456	2878381	829003	2308628	1866812
jul	4710983	3274258	1209107	2388757	2178269
aug	5236246	3605381	1553788	2454104	2438145
sep	4744565	3257892	2246185	1394561	2208576
oct	6074826	4198101	1384940	3275292	2903965
nov	5936495	4215852	2738740	1758403	2929044
dec	6514355	4632348	1314295	3624388	3200323
TOTAL	63483289	44280615	25689681	22766652	30235799
average	5290274	3690051	2140807	1897221	2519650

MONTHLY SUMMARY

jan					
1	168390	122008	29115	96452	84145
2	201173	142666	48820	105252	95971
3	186132	129802	45576	96602	91238
4	168401	117633	37834	90550	79905
5	196046	137445	43832	105408	96328
6	179536	127053	38110	97656	87722
7	194386	135509	43969	104912	95569
8	215000	152000	47758	118920	109942

DAILY VALUES

(continues until December 31st)

Fig. 4.6. Water Footprint Design Tool. Page 1: Set of columns for water footprints. The user does not introduce any data in this set of columns. All the cells are filled automatically according to the parameters established by the user on the control panel. The obtained monthly values are used to build the charts on Page 2.

On this first page, the Tool user needs to introduce two different sets of data, which are mandatory for the Tool to be applicable: one for the precipitation pattern and the other, the project water demand. The precipitation data is introduced into the rainwater harvesting column group (Fig. 4.2). It must be rainfall data, in mm, metered on a daily basis, and it must come from a reliable source (for this case-study, it was the Maldives Meteorological Agency, Appendix A). The Tool allows us to show the precipitation data for a complete year. However, since precipitation patterns vary inter-annually, the obtained data should cover a number of years, i.e., enough to include long-term precipitation variations from which to estimate best-case, worst-case, and average scenarios (see 4.3 Scenario Definition below).

Second, a high-resolution water-use data package is required for the project in question. This second data package has its own set of columns and refers to the demand pattern of the project (Fig. 4.1). This Tool is proposed to be used by design teams at early stages of the design process of new projects. Consumption data from the assessed project is therefore not available, and this demand pattern needs to be obtained from projects hosting similar programs and therefore similar water demand patterns. The information obtained from these similar projects needs to have been measured on a daily basis for at least one year. If more than one year of data is provided, it is recommended that the Tool user employ the most recent consumption data. If the Tool is applied to an existing project, as for the case-study presented in this thesis, this data should come from the project under assessment. This sub-metered consumption data-set must include a minimum separation between different uses (i.e., laundry, kitchens, toilets, showers, swimming pools, etc.) in order to be able to contemplate the different types of wastewater (greywater, blackwater or none) generated by each service and the required water quality (potable, non-potable) for each service. Based on this separation, the provided demand data is introduced in Litres into the corresponding water-use column for every day of the assessed year. In case the provided data does not include a differentiation between all the different uses, the Tool allows its users to incorporate use percentages for some of these services. For instance, if the sub-metered data for guest rooms does not include a separation between the water required for toilet flushing and showers, the designer can introduce the estimated percentage for each service on the control panel of the Tool, as this separation is necessary for the calculation process of all the strategies. These percentages, if not provided by the operators, must be based on measurements from projects with a similar program.

The second page of the Tool includes the control panel and the results obtained through the formulas on page one. The control panel is again divided into several groups of cells, each of them linked to a water strategy column group on page one. For the rainwater harvesting system, the Tool user must introduce the catchment area (sqm), the runoff coefficient, storage tank size (L), and the services at the site for which the harvested water is to be used. For grey and blackwater recycling, the user selects the wastewater sources to be considered, including an evaporation coefficient for each of them, and specifies their future uses. For efficient devices and improved behaviour, the user introduces the estimated saving percentage for a series of services (Fig. 4.7).

RAINWATER HARVESTING		GRAYWATER			GUEST ROOMS distrib	
		Recycled from:		Evap. coeff	Toilets	16%
roof area (m2)	13500	Laundry	☐	0.80	Showers + Sinks	80%
runoff coef	0.90	Showers/bathroom sinks	☐	0.80	Swimming pools	4%
S=tank volume (l)	4000000	Spa	☐	0.80		
		Greywater used for:				
Rainwater used for:		Q2			EMPLOYEES distrib	
Q1		Food Garden Irrigation	☐		Toilets	20%
Sinks + Showers	☑	Swimming Pools	☑		Showers + Sinks	80%
Spa	☑	Laundry	☐		EFFICIENT FIXTURES	
Kitchens	☑	Process Water	☑		Irrigation	0%
Drinking	☐	Q3			Laundry	15%
Q2		Landscaping	☐		Kitchens	15%
Food Garden Irrigation	☐	Toilet Flushing	☐		Showers + Sinks	15%
Swimming Pools	☐	BLACKWATER			Toilets	0%
Laundry	☐	Recycled from:		Evap. coeff	Food Gardens Irrigation	0%
Process Water	☐	Kitchens	☑	0.80	EDUCATION	
Q3		Toilets	☐	0.80	Laundry	5%
Landscaping	☐	Blackwater reused for:			Guests Showers	5%
Toilet Flushing	☐	Q3			Guests Toilets	5%
		Landscaping	☑		Employees Showers	5%
		Toilet Flushing	☑		Employees Toilets	5%

Fig. 4.7. Water Footprint Design Tool. Page 2: Control panel. In this set of cells, the user establishes the conditions for the calculations made by the Tool on page 1.

The results are displayed both in a numeric and a graphic way and vary depending on the parameters for each water strategy selected on the control panel. The estimated annual desalinated, grey and rainwater footprints are given in litres. The chart shows the monthly distribution of these three components throughout the year, compared to the original (before applying any water strategy) footprints of the project (Fig. 4.8). Combining the control panel and the results on the same page allows the designer to immediately see the impact associated with the application or variation of every water strategy considered in the model.

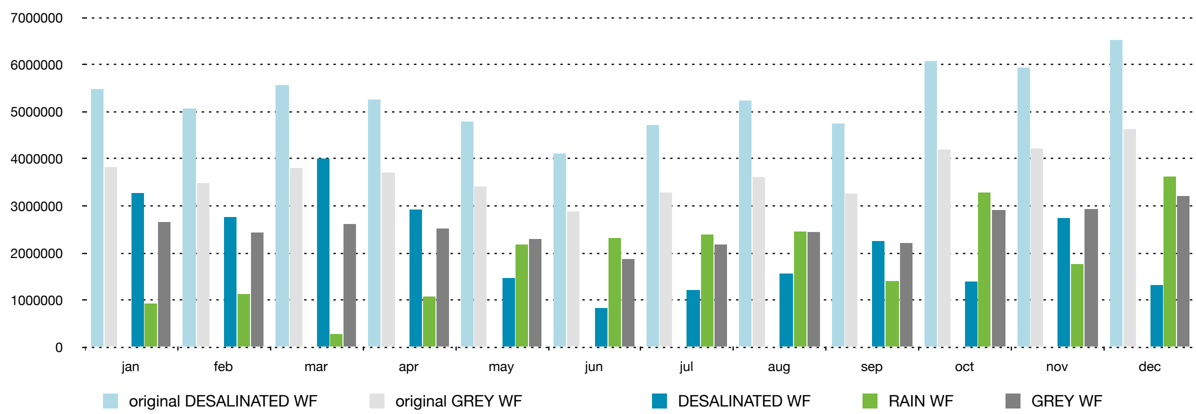


Fig. 4.8. Water Footprint Design Tool. Page 2: Graphic result representation. Monthly water footprint components for the assessed year.

4.2 Methodology

The Tool calculates the potential water footprint reduction through the application of several water conservation strategies. The calculation methodology used for each water strategy is the following:

4.2.1 RAINWATER HARVESTING

There are different methodologies for designing rainwater harvesting (RWH) systems: from simplified approaches depending on user-defined relationships (Ward, Memon, & Butler, 2010 cited in Palla *et al.*, 2011) to non-parametric ones, which use probability methods (Basinger, Montalto, & Lall, 2010 cited in Palla *et al.*, 2011), the most common one being the behavioural analysis based on continuous simulation (Palla *et al.*, 2011). Coombes and Barry (2007) concluded that the selection of the length of the time step could have significant influence on the accuracy of the results, the more reliable ones corresponding to the shorter time steps. This study therefore uses a behavioural analysis method with a daily time step, similar to the one used by Palla *et al.* (2011) (Fig. 4.9).

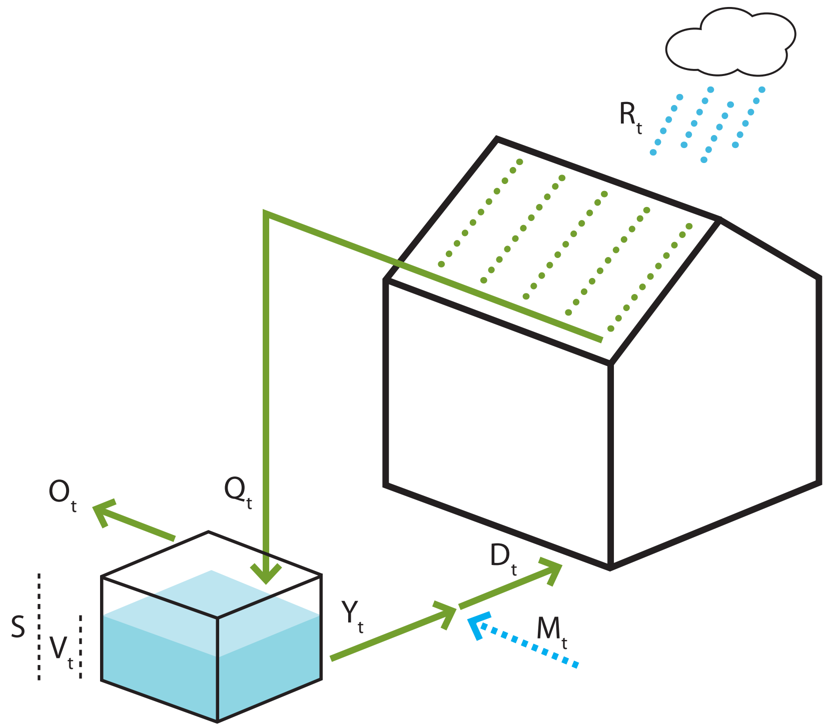


Fig. 4.9. Illustration of the behavioural analysis method for the rainwater harvesting system. Adapted from Palla *et al.*, 2011.

This behavioural model is based on the following equation:

$$V_t = Q_t + V_{t-1} - Y_t - O_t$$

where

V_t = stored volume	V_{t-1} = stored volume on the previous day
Q_t = inflow; $Q_t = R_t \cdot A \cdot \varphi$	R_t = rainfall
A = catchment area	φ = runoff coefficient
Y_t = outflow	O_t = overflow
D_t = rainwater demand	Y_t = rainwater supply
M_t = municipal supply	S = tank capacity

There are two different algorithms that can be used for this model depending on the order of the operations: Yield After Spillage (YAS) and Yield Before Spillage (YBS). In YAS, "the order of operations is: determine yield, inflow, overflow and extract yield" (Roebuck, 2007, p. 386). In YBS, "the order of operations: is inflow, determine yield, extract yield and overflow" (Roebuck, 2007, p. 386). The different operating rules for both approaches are as follows (V. G. Mitchell, 2007):

$$\text{YAS: } Y_t = \min (D_t; V_{t-1}) \qquad V_t = \min (V_{t-1} + Q_t - Y_t; S - Y_t)$$

$$\text{YBS: } Y_t = \min (D_t; V_{t-1}) \qquad V_t = \min (V_{t-1} + Q_t - Y_t; S)$$

While some authors have demonstrated improved effectiveness from the YBS under specific circumstances (Liaw & Tsai, 2004 cited in Palla *et al.*, 2011), the YAS approach is generally recommended for being more conservative (Fewkes, 2000 cited in Palla *et al.*, 2011) and for demonstrating a lower sensitivity to variations in the storage volume or water demand (V. G. Mitchell, 2007 cited in Palla *et al.*, 2011), The proposed tool therefore uses the YAS approach. Also, the model considers an initially empty storage as recommended by Mitchell (2007).

The RWH behavioural model used for this tool considers an initially empty storage. A first series of measurements for the whole year, starting on January 1st, showed very small variations in performance results for increased tank volumes. This is due to the accumulation of the driest months at the beginning of the year, in January, February, and March. Higher storage volumes generally increase the performance of the system, as they allow for the storage of water during the wetter months, which can then be used during the dry season. However, starting the calculations on January 1st with an empty storage did not allow for this phenomenon to be reflected in the results. Therefore, in order to obtain more realistic results, the initial day for the calculation period was set to July 1st.

The performance of these RWH systems can be expressed in different ways, based either on volumetric reliability or time-based reliability (Palla *et al.*, 2011). Time-based reliability refers to the fraction of time during which the RWH system meets the total demand (Palla *et al.*, 2011). Volumetric reliability "is defined as the total volume of rainwater supplied, divided by the total demand during the simulation period" (Palla *et al.*, 2011, p. 65) and this one is usually preferred because it is "less restrictive than the time-based one" (Fewkes, 2000; Liaw & Tsai, 2004; V. G. Mitchell, 2007; Zhang *et al.*, 2009 cited in Palla *et al.*, 2011 p.66). The performance is thus assessed based on volumetric reliability, using the following formula:

$$E_T = \frac{\sum_{t=1}^{T} Y_t}{\sum_{t=1}^{T} D_t}$$

where

E_T = volumetric reliability

D_t = rainwater demand

Y_t = rainwater supply

4.2.2 WASTEWATER RECYCLING

The Tool also calculates the potential water footprint reduction after implementing wastewater recycling strategies. The Tool calculates the potential for water-saving after recycling greywater and blackwater separately, due to water quality differences that affect its potential future reuse. The designer selects the source from which wastewater is to be recycled (e.g. laundry, showers, and bathroom sinks and/or spas for greywater and kitchens and/or toilets for blackwater). Also, the future uses for both recycled greywater and blackwater are selected. The end uses available in this case do not include those requiring potable water quality. The calculation method goes as follows:

$$WW_t = D_t \cdot K$$

where

WW_t = wastewater (to be recycled)

D_t = water consumed by the service

K = evaporation coefficient

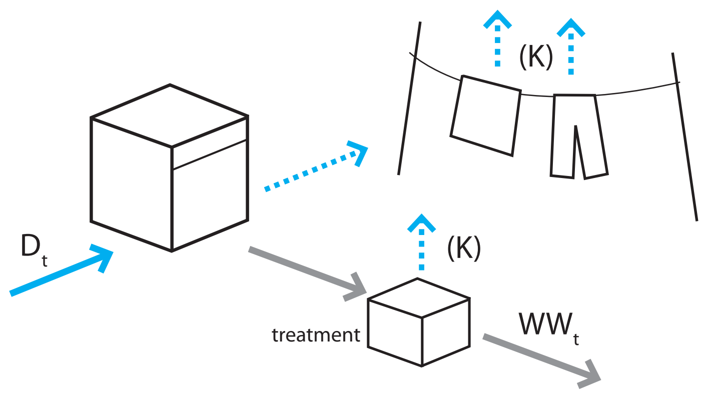


Fig. 4.10. Illustration of the calculation method for wastewater recycling.

An evaporation coefficient was introduced for greywater and blackwater recycling. This evaporation coefficient acknowledges that not all the water consumed by a service can be recycled because part of this water is evaporated while being used and therefore cannot be reclaimed. For instance, part of the water used by laundry machines, about 10% (AquaRecycle™, 2012), stays on the clothes and evaporates during the drying period. An additional fraction of the water also gets evaporated during the recycling process. A 0.8 coefficient (meaning that 20% of the water is evaporated) was applied for all the services from which grey and blackwater was recycled (Fig. 4.10). In all the scenarios, the considered wastewater sources generated a higher water volume than that required for its end uses. Therefore, a reduction of this coefficient would not have affected the performance of the water system.

4.2.3 EFFICIENT DEVICES AND USER BEHAVIOUR IMPROVEMENT

The third block of strategies focuses on water conservation leading to a demand reduction that would contribute to the efficiency of the whole water system. As for wastewater recycling, demand reduction strategies are divided into two sub-groups that correspond to the incorporation of efficient fixtures and educational programs, respectively. The Tool allows the designer to show the estimated water saving potential that could come as a result of the incorporation of both efficient fixtures and educational programs. The considered efficient fixtures include irrigation (both for food gardens and landscaping separately), dual-flush toilets, low flow showers and aerators for guestrooms, aerators and efficient dishwashers for kitchens, and efficient laundry machines. The saving potential, introduced as a percentage, is independent for each of them, since, in many cases, not all of them would be applicable. The saving potential due to improved guest and employee behaviours through educational programs, include potential water conservation in laundry, guestrooms (both for showers and toilets) and employees' facilities; again, the saving potential is introduced as an independent percentage for each use.

Very few studies show water saving percentages attributed to the application of efficient fixtures in hospitality businesses. The Orchard Hotel in San Francisco is the only reference that has been found for this saving potential in the tourism context. This hotel reduced water consumption by 20% after incorporating low-flow toilets, shower heads and flow restrictors (USGBC, 2010). Since the case-study already uses dual-flush toilets, the considered saving potential for its assessment is reduced to 15%. No references referring to the saving potential associated with educational programs involving guests and employees were found. The considered water conservation potential associated with these practices for this research is 5%.

4.3 Scenario Definition

The large number of variables incorporated in the Tool make it possible for designers to work with multiple combinations, depending on the water strategies they select. Three main scenarios are considered for the case-study in this study.

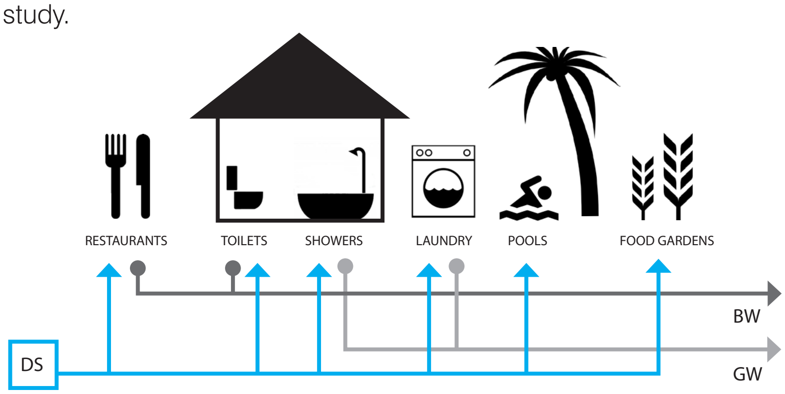


Fig. 4.11. Scenario #0. Current state. Wheat icon, by The Noun Project. CC BY 3.0 (http://creativecommons.org/licenses/by/3.0/) via www.iconspedia.com.

Scenario #0: Current State (Fig. 4.11). The current situation of the case-study project corresponds to 'scenario #0', in which no new water strategies are applied yet. The results obtained for all the remaining scenarios are compared to this scenario in order to assess the water footprint reduction and potential improvement for each situation.

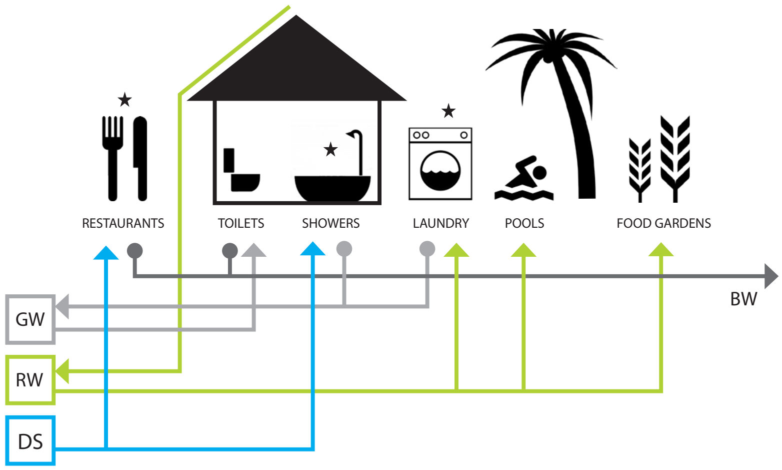


Fig. 4.12. Scenario #1. Conventional strategies. Wheat icon, by The Noun Project. CC BY 3.0 (http://creativecommons.org/licenses/by/3.0/) via www.iconspedia.com.

Scenario #1: Conventional Strategies (Fig. 4.12). This scenario is the one in which a number of water strategies defined as conventional in chapter 3 are applied. These conventional strategies are those which have been widely applied in green building in recent years, including rainwater harvesting for non-potable use, greywater recycling, and water conservation through the use of efficient fixtures.

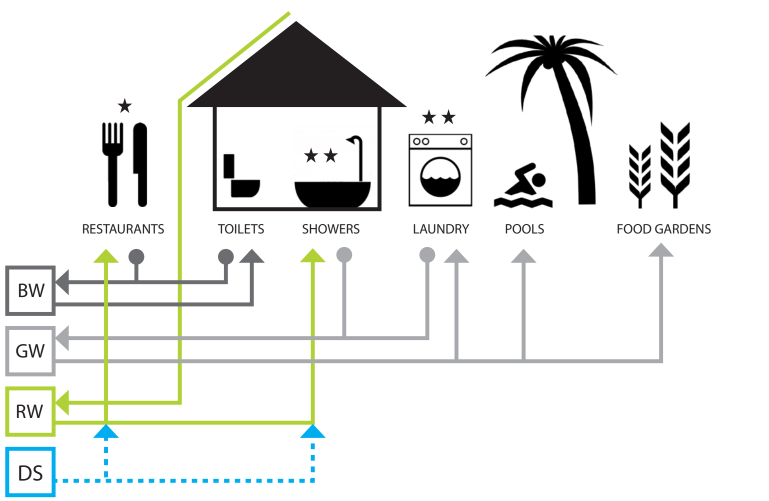


Fig. 4.13. Scenario #2. All strategies. Wheat icon, by The Noun Project. CC BY 3.0 (http://creativecommons.org/licenses/by/3.0/) via www.iconspedia.com.

Scenario #2: All Strategies (Fig. 4.13). This scenario corresponds to the one in which all the considered water strategies in the Tool are applied. These additional strategies include treating harvested rainwater until it reaches potable quality, blackwater recycling, and additional conservation measures through guest and employee education.

Additionally, based on the rainfall data obtained from the Maldives Meteorological Agency, which gives daily rainfall information from 2001 to 2010 in the capital city of Malé, three sub-groups of scenarios are analyzed: (A) best case, (B) worst case and (C) average scenarios. The best and worst cases scenario subgroups correspond to the years with the highest (2006) and lowest (2005) total annual rainfall, respectively. The average scenario corresponds to the year whose total annual rainfall is closer to the yearly average rainfall in the 10 year period, in this case, 2010. There are no sub-scenarios for scenario #0 as rainfall only affects performance of rainwater harvesting systems and the analyzed resort does not harvest rainwater at this time.

	SCENARIO SUMMARY		
	High precipitation (2006)	Low precipitation (2005)	Average precipitation (2010)
Current State	Scenario #0		
Conventional Strategies	Scenario #1A	Scenario #1B	Scenario #1C
All Strategies	Scenario #2A	Scenario #2B	Scenario #2C

Table 4.1. Scenario summary.

For these scenarios, rainwater harvesting system parameters are kept optimum, as follows: runoff coefficient = 0.90; catchment area = current resort's roof area; storage tank volume = 8M litres (total overflow = 0). In the second stage, the volumetric reliability of the rainwater system is assessed for different catchment area vs. storage tank volume relations. Considering that the ultimate goal of this research is to assess whether a net-zero water scenario is achievable for this case-study, this optimization analysis of the RWH system is restricted to scenarios #2A, #2B and #2C, in which all the potential strategies are applied.

4.4 Tool Transferability

This Water Footprint Design Tool has been specifically developed for application in this study's research. Some components of the Tool are directly related to some particularities of the site context. For instance, the major freshwater source at the resort at this moment is desalination. As a consequence, all the current water consumption is identified as part of the so called "desalinated water footprint". As in the case of many similar tourism facilities, a distinction is made between the water consumed for guests and employees, even though this differentiation is not strictly necessary for the calculations associated with each water strategy. Using this Tool for a different beach resort, that also depends on desalination, would be possible only by introducing new precipitation and demand pattern data-sets.

But the Tool, in its currently state, is only applicable to this very specific context. However, all projects, no matter what their location or program, can be assessed based on the Corporate Water Accounting and water footprint frameworks defined in chapter 2. Similar analyses based on the particularities of each of them are possible and the Tool has thus been made flexible to allow its adaptation to different water supply or demand scenarios, if necessary. New column sets can be added on the first spreadsheet page if new water strategies, both on the supply or demand sides, are to be incorporated. As an example, water sources other than desalination or harvested rainwater, such as groundwater, could be available at other locations. Its incorporation into the Tool would be possible by adding the columns and formulas associated with this new water source, and also adjusting the cells on the control panel to allow for the measurement of its availability and use parameters. An additional blue water footprint component would be added, which should also be included in the graphic and numeric results. Similarly, desalination as a potential source could be eliminated for the cases in which it is not to be considered.

Moreover, in this research the Tool is only applied to one existing beach resort. However, it can also be applied to new projects at early stages of design. By introducing water-use data based on measurements from similar tourism facilities, design teams can incorporate challenging water goals at the beginning of the planning and design processes and use the Tool to foresee the potential achievability of these goals.

5 CASE-STUDY

DESTINATION: MALDIVES

In this chapter, the previously defined Water Footprint Design Tool is applied to an existing resort located in a small island developing state (SIDS). The Maldives is a country located in the Indian Ocean right above the equator. Due to its tropical climate, which offers high temperatures throughout the year, and the astonishing beaches located on almost every small island, this country is a perfect destination for coastal tourism. Luxury beach resorts are the most predominant form of accommodation. However, the geographical conditions of the Maldives make freshwater a scarce resource, as it has no surface water streams and any groundwater bodies are vulnerable to seawater intrusion. Thus, desalination has been the only water supply alternative for the major cities and all resort islands. Moreover, the Maldives are one of the countries most threatened by rising sea-levels because of its low elevation (only 2.3 meters above normal sea level). As a consequence, the former President of the Maldives has embraced the objective of becoming the first carbon neutral country in the world by 2019, a goal that seems hardly achievable under the high energy demand circumstances associated with desalination technologies. In this chapter, the potential achievability of the net-zero water goal defined in chapter 2, in which the desalination water footprint is nullified, is tested for the Soneva Resort.

5.1 Recruitment Process

5.1.1 SELECTION CRITERIA

The selection of this case-study was based on the following criteria:

A. The analyzed project needed to be located in a small island developing state.

B. The desired type of tourism accommodation was a beach resort. Beach resorts are one of the most predominant forms of accommodation in SIDS, upon which this research focuses. Additionally, these destinations generally offer a large number of services requiring large amounts of water to operate, such as swimming pools and spas (see chapter 1).

C. A resort with no access to municipal freshwater supply sources was preferred. This disconnection from the grid makes resorts generally dependent on alternative water sources, such as desalination. This circumstance provides the perfect scenario for testing the achievability of the net-zero water goal.

D. The resort should have shown some sort of commitment to sustainable development.

E. The selected resort needed to be able to provide high-resolution water-use data (sub-metered daily water consumption for at least 1 year).

5.1.2 CASE-STUDY SELECTION

Based on the previous criteria, 34 beach resorts located on different small island destinations were identified as potential case-studies for having shown some sort of commitment to environmental sustainability. This commitment was demonstrated by several means: third-party verification programs (e.g. Earthcheck, Green Globe), detailed environmental policy descriptions available on their websites, or sustainability-related online publications. After a first approach via email, 11 of these resorts (32%) gave an answer. 9 of them expressed their commitment to sustainability-related academic research as well as their willingness to participate in the study. On a second approach, these 9 resorts were asked about their ability to meet the last criterion on the previous list by providing high-resolution water-use data packages. Only 2 resorts located in the Maldives were willing to provide the requested information. The remaining 7 resorts were unable to provide the requested data for different reasons (i.e. lack of sub-metered water data, lack of time to gather the requested data, confidentiality, no response). The Soneva Resort in the Maldives' short delay in sending the requested data-package and willingness to answer all the questions associated with this research were the final reasons for its selection as the case-study project for this thesis.

5.2 Maldives Context Definition

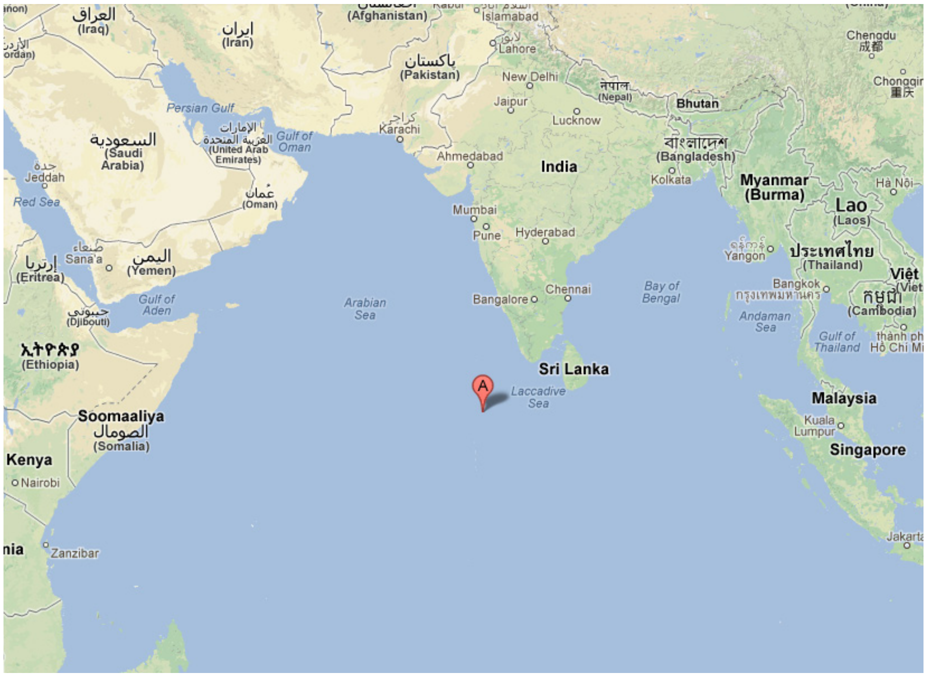


Fig. 5.1. Maldives location. ©2013 SK planet, ZENRIN, Google, mapIT, Tele Atlas.

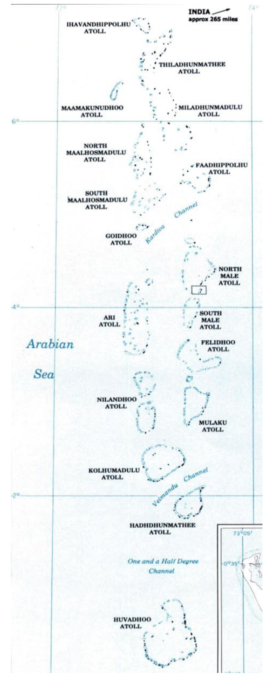


Fig. 5.2. Maldives map. Source: US Central Intelligence Agency. Public domain, via Wikimedia Commons.

GEOGRAPHY

The Maldives is a small island developing state located in the Indian Ocean (Fig. 5.1) composed of about 1200 islands grouped in 26 natural coral atolls that spread out on a north-south axis over 1000 km on both sides of the equator (Fig. 5.2). The total land area of the country is 300 km2 (AQUASTAT, 2012). Most of the islands are very small (less than 1 km2) and have very low elevations, the average elevation above sea-level being 1.5 meters (US Department of State, 2012). The highest natural ground level in the country is only 2.3 meters (Henley, 2008), which makes the Maldives one of the countries most threatened by sea-level rise.

Fig. 5.3. Aerial view of Malé. Source: By Shahee Ilyas. CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0/), via Wikimedia Commons.

Fig. 5.4. Aerial view of Thinadhoo island. ©2013 Microsoft Corporation ©2012 Digital Globe ©2012 Nokia.

The population in 2009 was 312,000 inhabitants (AQUASTAT, 2012), of which almost one third is concentrated in Malé (Fig. 5.3), the capital city (GeoNames.org, 2012). Only 198 islands are inhabited, almost 100 are occupied by resorts and some of the remaining ones are used for agriculture.

CLIMATE

The Maldives' islands have a tropical climate characterized by two monsoons. The southwest monsoon corresponds to the rainy season and appears from May to September. The northeast monsoon brings the dry season, from November to March (AQUASTAT, 2012).

The annual average precipitation is 1972mm, and it is distributed uniformly throughout the year, with the exception of a drier interval from January to April, when dry periods of up to two months are frequent (Ibrahim, Bari, & Miles, 2002) (Fig. 5.6). The annual average temperature is 28°C, with very little variation throughout the year (AQUASTAT, 2012; US Department of State, 2012) (Fig. 5.5). The average relative humidity is 80% and evapotranspiration of open water from vegetation is very high (Ibrahim *et al.*, 2002).

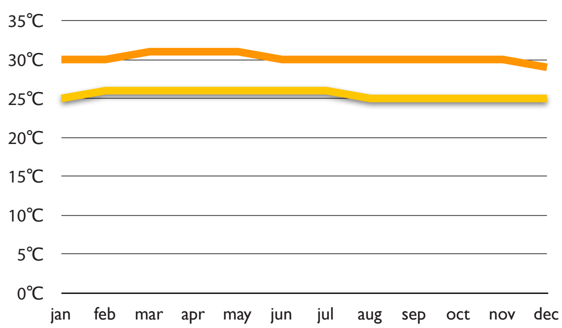


Fig. 5.5. Monthly average maximum and minimum temperatures for Malé, Maldives. Data source: www.weather.com

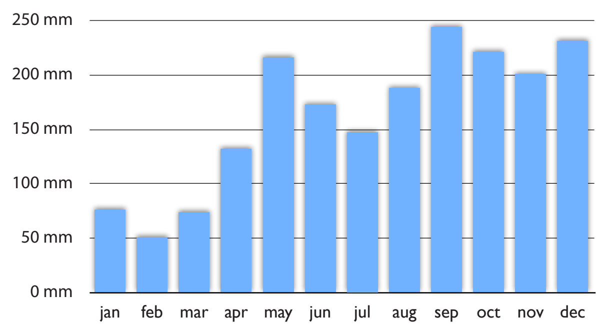


Fig. 5.6. Monthly average precipitation for Malé, Maldives. Data source: www.weather.com

TOURISM

Beach resorts (Fig. 5.8) are the main form of tourist accommodation offered in the Maldives. In 2010, 98 resorts offered more than 21000 beds (83% of the total number of beds available for tourists) (Fig. 5.7). The first resort opened in the Maldives in 1972 and, since then, the country's economy has been increasingly dependent on tourism. In 2010, tourism contributed to 35.7% of the total Gross Domestic Product (GDP). The Government of the Maldives selects the uninhabited islands suitable for tourism development. These areas are publicly tendered for the creation of new tourism facilities and supporting infrastructure. Out of the 98 resorts (2010), 43 are managed by local operators, 37 by foreign operators and 18 by a combination of both. In 2010, the average annual occupancy rate, including both resorts and hotels was 74.2%, with an average stay of 7.6 days. (Maldives Ministry of Tourism, Arts and Culture, 2011).

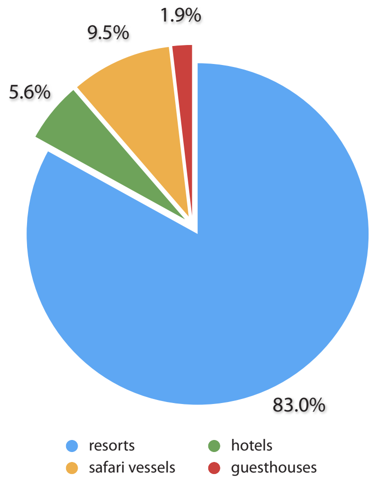


Fig. 5.7. Bed distribution per accommodation type in 2010. Source: Maldives Ministry of Tourism.

Fig. 5.8. Villingili Resort & Spa in Maldives. Source: Shangri-La

WATER SYSTEMS

Freshwater sources in the Maldives are very scarce, mainly because permanent surface water streams do not exist on any of the islands, although small brackish water ponds can be found on some of them (Fig. 5.9). Groundwater is considered the only renewable water resource in the country, with an annual recharge rate of 0.03 km3/year. But many groundwater bodies, especially those located on inhabited islands, have suffered seawater intrusion after heavy extraction or have been contaminated when recharged by polluted rainfall percolating through the soil (AQUASTAT, 2012).

With the exception of the capital city, Male, and Kadholhudhoo, the most densely populated islands, Maldivians rely mainly on rainwater for drinking purposes and groundwater for other household needs (Ibrahim *et al.*, 2002). Rainwater is usually harvested from rooftops and collected in different types of tanks (AQUASTAT, 2012). Today, all the islands have both community and individual rainwater tanks, and the government has recently invested in developing a consistent rainwater supply for all inhabited islands (Ibrahim *et al.*, 2002).

Nevertheless, Male and Kadholhudhoo depend on desalination as the main freshwater source. High population density in both cities has resulted in groundwater pollution and over-extraction, as well as insufficient space for rainwater storage tanks (Ibrahim *et al.*, 2002). The lack of freshwater supply alternatives has made desalination the only option for providing a safe water supply in these cities. The first desalination plant in Male was built in 1988 and today the capital city has a desalination capacity of 5800 m3/day, giving everyone access to desalinated water for domestic use through a piped network (AQUASTAT, 2012).

Desalination is, however, an expensive supply alternative in the Maldives. The estimated monthly cost of desalinated water per household in Male ranges between US$40 and US$60 (Ibrahim *et al.*, 2002).

Resorts started using desalinated water in the 1970s and today each resort island has its own desalination plant. Many of these resorts recommend that guests buy bottled water for drinking and desalinated water is thus mainly used for cooking and bathing (AQUASTAT, 2012; Ibrahim *et al.*, 2002). The cost of desalinated water for resorts is not as significant as for the local population, since it is relatively low when compared with the revenue generated by tourism (Ibrahim *et al.*, 2002). A few resorts harvest rainwater and use it for staff to drink. Other resorts reuse wastewater for irrigation, yet it is not a common practice (Ibrahim *et al.*, 2002).

Fig. 5.9. ©Ilyas Shujau (Ishu). Nolhivaram Kulhi (lake), H.Dh. Nolhivaram, Maldives. Source: http://www.ugo.cn/photo/MV/en/808.htm.

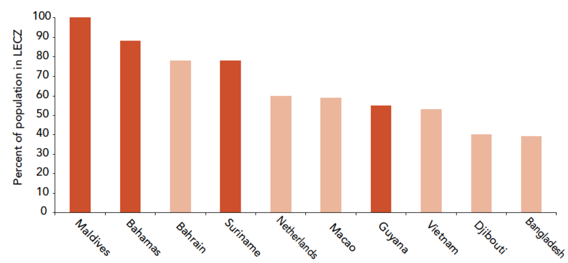


Fig. 5.10. Countries with largest population shares in the low elevation coastal zone. Source: McGranahan, 2006 cited in UN DESA, 2010.

CLIMATE CHANGE

The Intergovernmental Panel on Climate Change (IPCC) projected an average sea-level rise between 19 and 58cm at the end of the 21st century (IPCC, 2007 cited in Becken, Hay, & Espiner, 2011). The low elevation of Maldives makes this country one of the most threatened states from climate change (Fig. 5.10). The potential consequences of the projected sea-level rise include “accelerated shoreline and beach erosion, temporarily reduced water availability, interrupted supply chains, physical damage to property and warmer sea temperatures” (Becken *et al.*, 2011, p. 74). Moreover, the already vulnerable and limited groundwater resources are expected to suffer the consequences of this issue, as the chances of seawater intrusion occurring will increase as well (Ibrahim *et al.*, 2002). This global threat prompted the former President of the Maldives, Mohamed Nasheed, elected in 2008, to announce that part of the tourist revenue would be used to buy a new homeland (Becken *et al.*, 2011). In addition, Nasheed introduced the objective of making the Maldives the first carbon-neutral country in the world by 2019 (Becken *et al.*, 2011). Nonetheless, access to clean energy sources is not abundant in the Maldives, and high-energy demanding technologies, such as desalination, not only increase the country's dependence on fossil fuels, but also produce carbon emissions that contribute to global warming. The use of desalination as the main technology for providing water supply in the Maldives thus seems to stand in contradiction to the country's ability to achieve its carbon neutrality goal in the next decade.

5.3 Soneva Resort

5.3.1 GENERAL INFORMATION

Resort location: Kunfunadhoo Island, Baa Atoll, Maldives

Year of Construction: 1995

Year of Last Major Renovation: 2007

Capacity: 150 guests + 400 employees

Price range (per double room per night): 810 to 13 440 US$

Average Annual Occupancy Rate: 70%

Roof area: 13 500 sqm

Roof type/types (material): Tin 73% + Thatch 27%

Property (island) area: 450 000 sqm

Design author (architect): Soneva

Fig. 5.11. Soneva resort, Kunfunadhoo island aerial view. Source: Soneva

5.3.2 RESORT DESCRIPTION

Sustainability plays a very significant role in the company's policy for the Soneva Resort in the Maldives. Its website offers a great amount of detailed information about the sustainability-related strategies that have been applied in the last few years. The Soneva Resort has the objective of becoming carbon-neutral by 2014. Its environmental performance has been assessed by different benchmarking systems, obtaining, among others, EarthCheck Benchmarked Accommodation certification in 2009. Additionally, the resort has shown a high level of transparency throughout the communication process with the author, always responding to specific questions related to their practices and facilitating all the requested data.

The Soneva Resort started operating on Kunfunadhoo Island (Fig. 5.11), Baa Atoll, in the Maldives in 1995. It offers accommodation for 150 guests in 65 villas and rooms spread along the beachfront (Fig. 5.12) and divided into different categories, depending on their size and the services included. All the villas, except for 15 rooms articulated in groups of two or three, are isolated from each other and have their own swimming pools (Figs. 5.13, 5.14, 5.15). Accommodation sizes go from 182 sqf (Rehendi room) to 1710 sqf (The Jungle Reserve). In addition to all the services included in the rooms, the resort has a private spa, a diving school, and several restaurants and bars distributed across the island. Moreover, about 400 employees live within the resort facilities.

Fig. 5.12. Soneva resort map. Source: Soneva

Fig. 5.13. Soneva resort aerial view (2). Source: Soneva

Fig. 5.14. Soneva resort villa, outdoor view. Source: Soneva

Fig. 5.15. Soneva resort villa, outdoor view (2). Source: Soneva

In order to be the first carbon-neutral resort in the world (Nasheed, 2009), the resort has been implementing a series of strategies since they started operating in 1995, with the objectives of both switching to renewable supply sources and reducing resource demand.

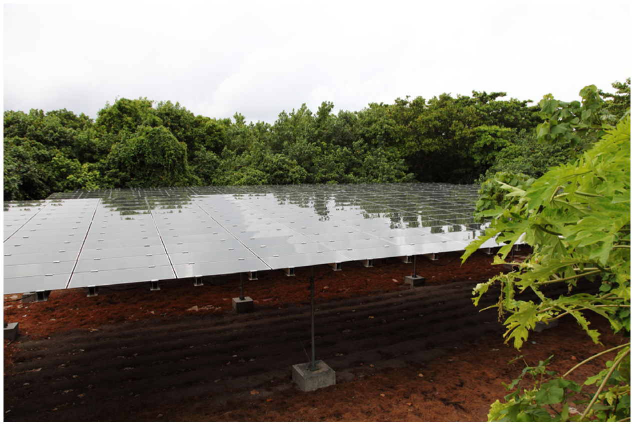


Fig. 5.16. Soneva resort, photovoltaic plant. Source: Soneva

Fig. 5.17. Soneva resort, deep sea water cooling system. Source: Soneva

While many of these strategies have significantly reduced the resort's dependence on fossil fuels (most of the energy is produced by an on-site diesel generator), other strategies have focused on improving water management. On the energy side, a 70kW photovoltaic plant built in 2009 (Fig. 5.16) provides 3% of the total energy demand of the resort. An extension of this plant up to 1MW is expected to start operating in 2013 (Oines, personal communication, March 2013). Moreover, an experimental deep sea water cooling system, aiming to reduce energy demand by an additional 25%, was tested in 2008 (Fig. 5.17). This technology had been incorporated by other hotels at similar locations, such as at the Intercontinental Resort in Tahiti, with very positive results (InterContinental, 2013). However, this system at Soneva Resort was not efficient enough due to the excessively high length of the pipes for reaching sufficiently cold water, and was therefore discarded (Kesterton, personal communication, De2011). On the water side, a reverse-osmosis desalination plant, upgraded in 2007, fulfills the entire freshwater demand of the resort. According to the resort's Decarbonising Department, 9% of the total energy demand is used for desalination. Sub-meters record daily water consumption at different areas of the resort, making it easier to identify leakage problems. Dual-flush toilets are used in guest rooms (EarthCheck, 2010) and daily laundry service is offered as optional in order to contribute to water conservation. Other water strategies, such as rainwater harvesting or wastewater recycling, are not implemented. Their incorporation would contribute positively and directly to the resort's carbon neutrality goal, since the demand for desalinated water, and therefore its associated energy consumption, would be reduced. One of the reasons for not having introduced these technologies is the high cost associated with the creation of a secondary plumbing system, since currently a central distribution scheme from the desalination plant is used (Kesterton, personal communication, December 2011).

The assessment report created by EarthCheck analyzed the performance of the resort in a number of key areas, such as energy and water management, based on a series of indicators. Concerning water, the Soneva Resort presented a consumption of 291,2 litres/guest night, significantly below the best practice level established by EarthCheck at 630 litres/guest night. No points were obtained on the recycled/captured water section, since the percentage of recycled and captured water for 2009 was 0%. Finally, it obtained 67,8/100 points for water saving, between the baseline and best practice levels, for checking for leaks every week, using dual-flush toilets and minimal irrigation landscaping, including the use of sprinklers after dark (EarthCheck, 2010).

The commitment to sustainable development of this resort is demonstrated by EarthCheck certification and by their interest in pioneer technologies, such as the deep water cooling system described above. Also, the dependence of this resort on desalination for its water supply corresponds to the adequate scenario for testing the water footprint improvements that could be achieved by incorporating further water strategies. These reasons, together with the high level of transparency and willingness to collaborate on sustainability-related research projects, make the Soneva Resort a perfect case-study for testing the findings of this research.

5.3.3 WATER-USE PATTERN

The resort provided a high-resolution water consumption data package to be introduced into the previously described water Tool. This package included the daily metered water consumption in different areas of the complex, from July 2009 to March 2011. Since the water Tool calculates the water footprint throughout a complete year, only the data corresponding to the year 2010, from January to December, is used. This data shows the following overall consumption pattern:

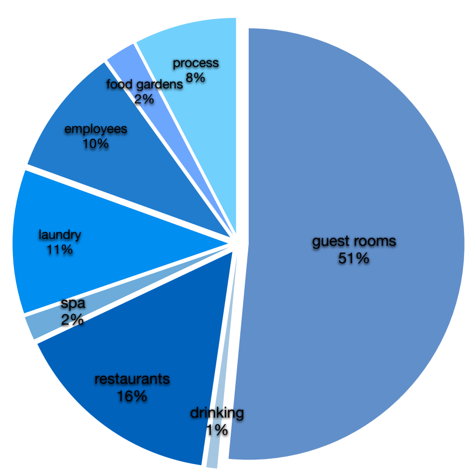


Fig. 5.18. Water-use distribution at Soneva resort in 2010. No water is used for landscaping. Data source: Soneva

The water consumption data obtained from the case-study does not specify how much water consumed at guest rooms is used for toilet flushing, showers, and/or hand basins. This differentiation was crucial, as the quality of the water required for these services is significantly different. Similarly, while toilets generate blackwater, showers and hand basins produce greywater, which would also affect the calculations associated with wastewater recycling. For these reasons, the Tool offers the possibility of assigning a percentage to these two groups of uses, toilet flushing and showers + hand basins, for both guest rooms and employees' water consumption. Ideally, this data should be obtained from sub-metering the water consumption of these two services at the assessed project. However, since this information is not available in the data package provided by the case-study, the percentages introduced into the Tool are based on previous studies conducted by different authors. Seattle Public Utilities presented a study (O'Neill & Siegelbaum, 2002) in which they measured the water consumption at two hotels in the city. For one of the hotels, the water use distribution in guest rooms was 35% for toilets and 65% for showers and lavatories. For the other hotel, the distribution was 26% for toilets and 74% for showers and lavatories. A similar report made in Perth, Western Australia (Saunders, 2011), calculated the room water distribution for a series of hotels, including a resort. In this case, the obtained percentages were the following:

HOTEL	Toilets	Showers + Baths + Basins	Kitchens
N (4 stars)	10%	90%	-
J (4.5 stars)	21%	79%	-
H (resort, 5 stars)	6%	84%	10%
D (5 stars)	17%	83%	-
E (4.5 stars)	16%	75%	-

Table 5.1. Room water-use distribution for 5 hotels in Perth, Australia. Souce: Saunders, A. HFM Asset Management, 2011.

Considering all these measurements, the average percentages (both Seattle and Perth) were 19% for toilets and 81% for showers, baths and basins. Three of the hotels in the Australian study (Saunders, 2011) also show the percentage of the total water use required for swimming pools (3%, 3% and 1% respectively). Relative to the room water consumption (as in the case-study used for this research, since many villas have their own swimming pools and therefore their water consumption is included in the guest rooms' consumption values), these percentages would be 1,2%, 4.1% and 4.3%, respectively. Based on these reports, the percentages used for this research were 80% for showers and basins / 16% for toilets / 4% for swimming pools in the case of guest rooms; and 80% for showers and basins / 20% for toilets, in the case of employees' facilities. Based on these coefficients, the demand pattern for 2010 resulted as follows:

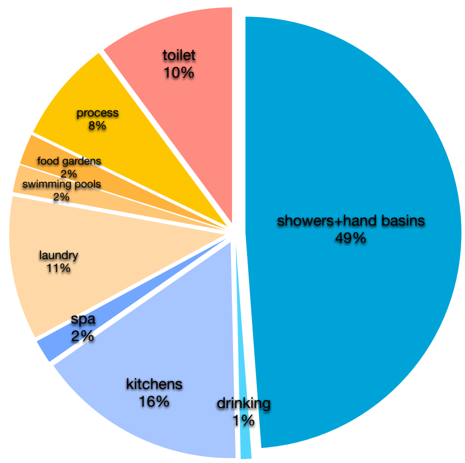


Fig. 5.19. Water-use distribution at Soneva resort in 2010 after applying the room water-use distribution coefficients.

5.3.4 RESULTS

The following table offers an overview of the results obtained for this case-study (Appendix B):

	WATER FOOTPRINTS				
	Desalinated WF reduction	Remaining Desalinated WF	Grey WF reduction	Remaining Grey WF	Rain WF
Scenario #0	-	63.48M litres	-	44.28M litres	-
Scenario #1A	42.6%	36.45M litres	73.1%	11.92M litres	13.43M litres
Scenario #1B	42.1%	36.76M litres	73.1%	11.92M litres	13.11M litres
Scenario #1C	42.6%	36.45M litres	73.1%	11.92M litres	13.43M litres
Scenario #2A	95.5%	2.87M litres	100,00%	0.00M litres	32.26M litres
Scenario #2B	75.5%	15.56M litres	100,00%	0.00M litres	19.57M litres
Scenario #2C	80.6%	12.30M litres	100,00%	0.00M litres	22.83M litres

Table 5.2. Summary of the results obtained for the case-study after applying the Water Footprint Design Tool.

The initial desalinated water footprint (WF) and grey WF for the Soneva Resort are 63.48M litres and 44.28M litres, respectively. The results for scenarios #1A, 1B and 1C, in which harvested rainwater is used for laundry, swimming pools, food garden irrigation, and process water, while greywater is reused only for toilet flushing (this resort does not use water for landscaping according to their data), present very little variation among them. Note that the difference between these three scenarios lies in the different precipitation patterns of the three considered periods (2005, 2006 and 2010). Therefore, the performance of the rainwater harvesting system is the only variable affected by moving among these three scenarios. The total harvested rainwater demand for these scenarios, 13.43M litres, can be fully covered by scenarios #1A and #1C (Fig. 5.20) and almost fully covered by scenario #1B (Fig. 5.21).

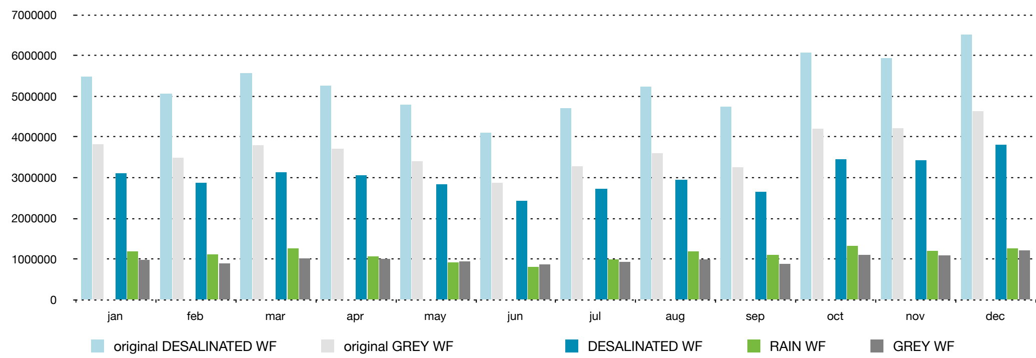


Fig. 5.20. Water Footprint Design Tool results for scenarios #1A (Conventional strategies + high precipitation) and #1C (Conventional strategies + average precipitation). The results obtained for both scenarios are exactly the same due to the relatively small rain water demand, which can be covered by the available precipitation at the two considered years, 2006 and 2010.

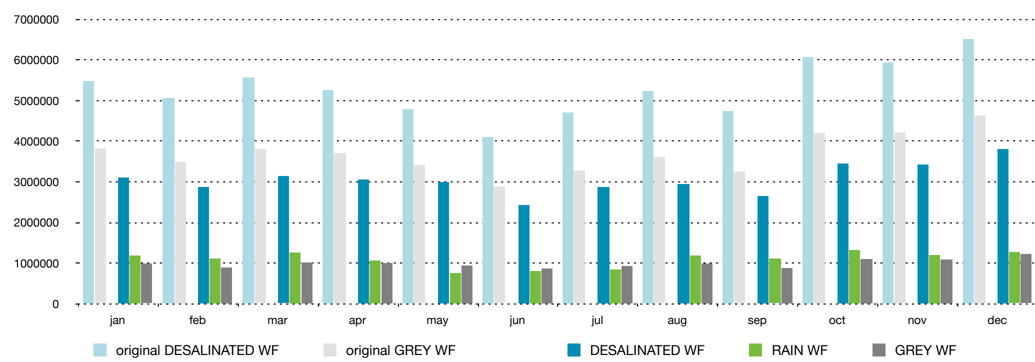


Fig. 5.21. Water Footprint Design Tool results for scenario #1B (Conventional strategies + low precipitation). The results obtained for this scenario are slightly different from the previous ones, as the entire rainwater demand was not met by the precipitation in 2005..

In scenarios #2A, 2B and 2C, at which rainwater demand is increased (35.13M litres), as it is used for all the services requiring potable water quality (drinking water, kitchens, showers, hand basins, and spa), the results show a higher variation among them. Even though further strategies aimed at reducing water demand are incorporated, compared to scenarios #1A, 1B, and 1C, such as blackwater recycling or educational measures, the harvested rainwater demand at 2A, B, &C is higher than for the previous scenarios and, therefore, the amount of available rainfall between the three considered periods has a higher impact on the performance of the whole water system. This way, while the potential desalinated water footprint (WF) reductvaries only 0.5% between the years with the highest and lowest precipitations, when only conventional strategies are applied (scenarios #1A and #1B), this variation reaches 20% when all the strategies are considered (between scenarios #2A and #2B). The water demand associated with the rainwater harvesting system is thus a key variable impacting the performance of the whole system.

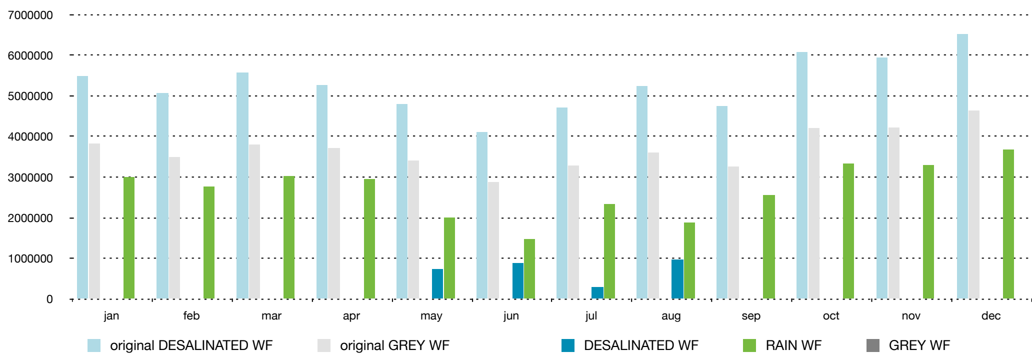


Fig. 5.22. Water Footprint Design Tool results for scenario #2A (All strategies + high precipitation). This is the scenario in which the best results, understood as the desalinated water footprint reduction potential, are achieved. As this chart shows, desalinated water would only be required between May and August, as the available rainfall during the rest of the year 2006 is estimated to be suficient to cover the total rain water demand between September and April.

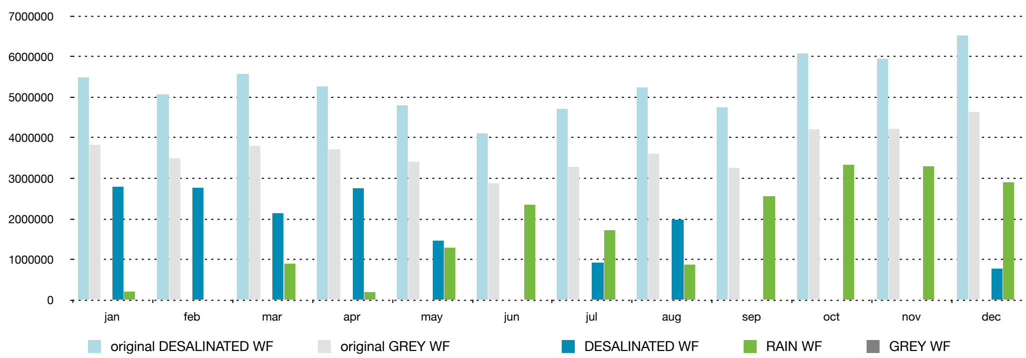


Fig. 5.23. Water Footprint Design Tool results for scenario #2B (All strategies + low precipitation). The lower precipitation values for the year 2005 prevented the achievement of results as good as those for Scenario #2A. In this case, desalination still appears to be necessary for 8 months of the year, while the rainwater for the remaining 4 months appears sufficient. In this case, the highest demand for desalinated water appears at the beginning of the year, between January and April.

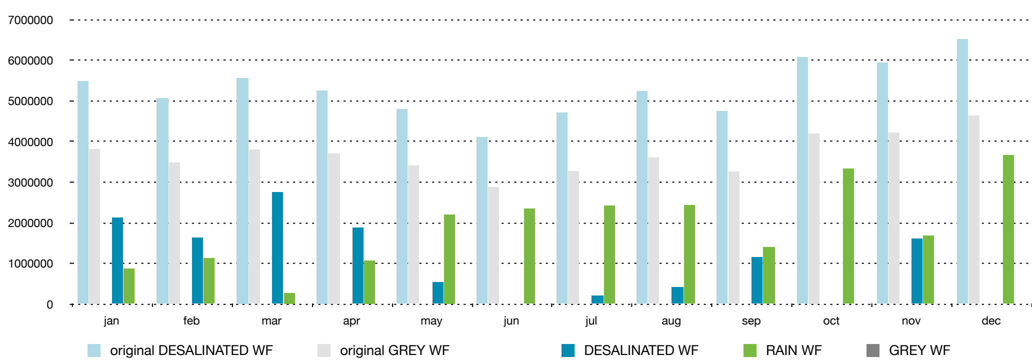


Fig. 5.24. Water Footprint Design Tool results for scenario #2C (All strategies + average precipitation). The performance of the water system at this scenario is slightly higher than for scenario #2B. This chart shows that desalinated water is necessary to cover the potable water demand of the resort during 9 months of the year. Even though this period is longer than for scenario #2B (8 months in total), the estimated volume of desalinated water required to cover the total demand of the resort is lower, therefore the desalinated water footprint reduction is higher.

5.4 Achievability of the Net-Zero Water Scenario

The results obtained from the Tool for the case-study indicate that significant reductions in the desalinated WF of this resort can be achieved when all the water strategies are applied. However, not even in the best-case scenario in terms of precipitation (scenario #2A) can the desalinated WF be completely nullified. The following paragraphs discuss the potential achievability of the net-zero water goal by either increasing the rainwater supply or further reducing the demand.

The volumetric reliability of the RWH system, as defined in section 4.1.1, tells us what percentage of the total demand for rainwater can be satisfied by the RWH system.

$$E_T = \frac{\sum_{t=1}^{T} Y_t}{\sum_{t=1}^{T} D_t}$$

This equation can be used as an indicator to assess the achievability of the net-zero water goal, as the fraction of the water demand not being covered by the RWH system is fully satisfied by the reused wastewater. The volumetric reliability values of the RWH system for scenarios #2A, 2B and 2C are 91.83%, 55.71%, and 65.77%, respectively (Table 5.3).

Scenario	Applied Strategies	Precipitation (Year)	Volumetric Reliability
#2A	All	High (2006)	91.83%
#2B	All	Low (2005)	55.71%
#2C	All	Average (2010)	65.77%

Table 5.3. Volumetric reliability for scenarios #2A, #2B and #2C.

The net-zero water goal would only be achieved if a 100% volumetric reliability is achieved at all these scenarios. Based on the equation, three groups of measures could be implemented in order to move toward the net-zero water goal: a rainwater supply increase, a further rainwater demand reduction, or a combination of both.

On the supply side, some of the parameters used for the RWH system in the previous calculations were already at their maximum level, so that further optimization of them is not possible. The considered runoff coefficient, 0.90, was already very high, especially considering that 27% of the catchment area corresponds to thatched roofs. Further improvements of the runoff coefficient are therefore not possible, as the previous one already assumed that thatch roofs could be replaced by other types of roof. Similarly, in order to simplify the calculations and maximize the RWH system potential, an infinite storage volume (overflow=0) was considered, so there is no room for improvement regarding this variable either. The only variable affecting the inflow volume of the RWH system that could be improved is thus the catchment area. Since the previous calculations assumed that rainwater was harvested from the total roof area of the resort, further increase of this variable would imply considering not only the rooftops but also the hardscape areas of the resort as potential catchment surfaces. In addition to the ones already considered in the previous Tool calculations (i.e. Wastewater recycling, efficient devices, and education), further demand reduction measures could also lead to the achievement of the goal. These measures would need to focus specifically on reducing the demand of the services requiring potable water quality, as these are the ones using rainwater as a source. The volume of wastewater produced by the resort largely exceeds the demand corresponding to the services that reuse the treated wastewater. Therefore, further demand reduction options could make use of this remaining wastewater in different ways. For instance, depending on the condition of the aquifer of the island, this remaining treated wastewater volume could be used to refill the aquifer in a way that allows groundwater use as an additional potable source in a sustainable way. Other demand reduction measures could rely on more ambitious water conservation programs, based on an improvement in guest and employee behaviour, as the previous calculations assumed that only 5% of the demand of certain services could be achieved by educational programs.

All these potential measures for further increasing the rainwater supply or reducing the rainwater demand cannot yet be quantified, as the required information for that purpose is not available from this case-study. However, the Tool allows us to calculate how much the catchment area would need to be increased in order to achieve the net-zero water goal under different demand reduction hypotheses. The following graphics (Figs. 5.25, 5.26, 5.27) show the minimum conditions of the RWH system (catchment area and storage volume) for achieving the net-zero water goal under different demand reduction hypotheses.

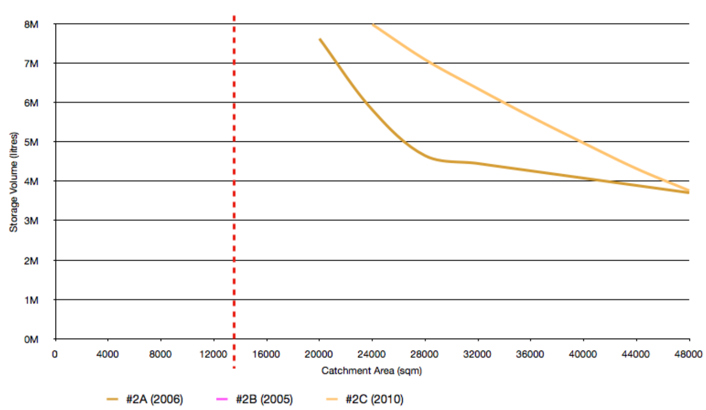


Fig. 5.25. Net-zero water achievability study with no additional rainwater demand reduction for scenarios #2A, #2B and #2C. The graphic shows the minimum catchment area in sqm together with its associated storage volume in litres for achieving a 99% volumetric reliability.

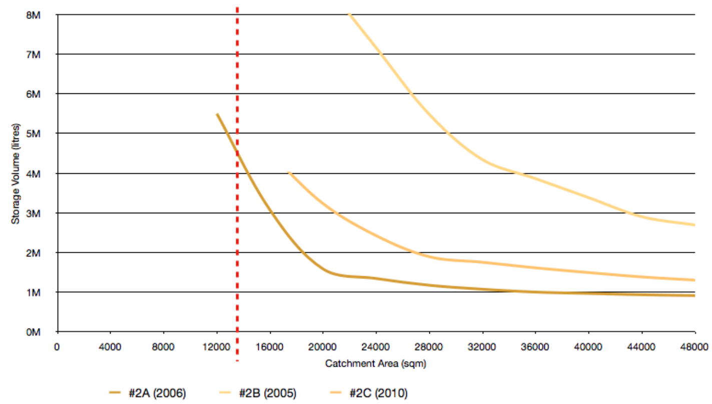


Fig. 5.26. Net-zero water achievability study considering an additional rainwater demand reduction of 20% for scenarios #2A, #2B and #2C. The graphic shows the minimum catchment area in sqm together with its associated storage volume in litres for achieving a 99% volumetric reliability.

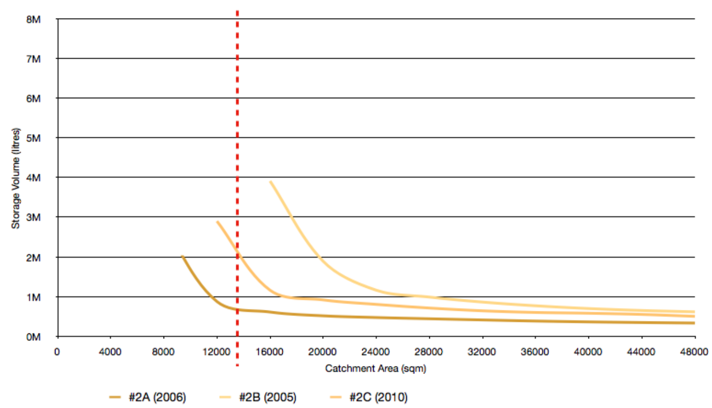


Fig. 5.27. Net-zero water achievability study considering an additional rainwater demand reduction of 40% for scenarios #2A, #2B and #2C. The graphic shows the minimum catchment area in sqm together with its associated storage volume in litres for achieving a 99% volumetric reliability.

The first graphic (Fig. 5.25) shows the minimum catchment area and its corresponding minimum storage volume, if no further demand reduction measures are applied. It can be observed that the worst-case rainfall scenario (2005) does not even appear within the limits of the graphic. Furthermore, the required catchment area increase, even for the year with the highest precipitation (2006), is very high and so are the minimum storage volume values. The second graphic (Fig. 5.26) assumes that the demand for rainwater has been reduced by 20%, in which case the worst-case scenario already appears. For the best-case precipitation scenario (year 2006), even withno further catchment area increase (the red line indicates the current roof area of the resort), 100% volumetric reliability can be achieved with a storage volume of 4.5ML. However, for the average and worst-case scenarios (years 2010 and 2005 respectively), an increase in the catchment area is always necessary, and the required storage volumes would still have to be considerably high. The last graphic (Fig. 5.27) shows an hypothesis in which the rainwater demand has been reduced by 40% and, in this case, even for the average year, the goal can be achieved without increasing the catchment area. Also, the required storage volume significantly decreases for higher catchment areas, stabilizing under 1ML for all scenarios. A combination of both a catchment area increase and further demand reduction measures appears thus as the best hypothesis for achieving a net-zero water goal for this resort.

As explained above, the first calculations assumed an infinite water storage volume. However, this is one of the most important values to be considered when designing a rainwater harvesting system. These graphics offer an idea of what the required storage volumes would be for different catchment areas. It should be noted that these two variables are directly dependent on each other. Storage volume needs to receive special attention for several reasons. On the one hand, it has a major impact on the cost of the RWH system. The potential variation between differently dimensioned RWH systems depends uniquely on the cost variation of the storage tank (material, size) as the rest of the costs are fixed independently of the size of the storage (Oliveira Ilha & Siqueira Campos, 2011). On the other hand, enough space for tanks and cisterns needs to be available, as suitable places for water storage are not always easy to find on small islands (Pigram, 2001). Moreover, environmental impacts associated with the construction of tanks may also appear. These potential impacts and the availability of space for storage may result in further limitations associated with the rainwater footprint component. Based on these considerations, it must be assumed that the RWH systems need to be optimized and a site analysis assessing potential impacts needs to be included as part of their design process.

This case-study allows us to illustrate the problem of water supply and demand in the context of this thesis and serves as a perfect scenario at which to apply the developed Tool. The analyzed resort is a good representative of most other resorts in the Maldives, and also in other SIDS with similar climates, as identical supply conditions (major dependence on desalination, lack of blue water sources, and similar precipitation patterns) can be expected. In terms of water demand, it is harder to determine how representative the resort is, as detailed consumption patterns from other facilities could not be obtained. The importance of how representative the case-study is in terms of water demand is however relative. This thesis aims to assess the potential achievability of a net-zero water goal at this type of destination and one case-study is enough for this purpose. This case-study demonstrates that very significant reductions can be achieved through the implementation of various water strategies and indicates that the net-zero water goal could be achieved if further measures were applied. The set of measures included in the final hypotheses go beyond the implementation of a series of water saving technologies and imply, in many cases, measures that could be more easily introduced during the design process of the resort. Under these specific supply conditions, for which this case-study is representative, ambitious water goals appear thus as achievable for new beach resorts.

6 DESIGNING A NET-ZERO WATER RESORT

ACHIEVING AMBITIOUS WATER GOALS AT NEW RESORT DEVELOPMENTS

The previous case-study is an example of how challenging it is to move toward a more sustainable water model in the context of tourism in SIDS. The rainwater supply becomes a key piece of the system, as it is the only water source whose environmental and social impacts do not impede the achievability of the goal. Other locations, either in the Maldives or in any other small island developing state, would present similar water supply access restrictions. The highest reliability on the rainwater supply system thus needs to be assured. Moreover, the high water demand shown by the beach resort, which is characteristic of this type of tourism facility, makes the net-zero water goal unachievable, even under favourable precipitation conditions. However, the desalinated water footprint reduction achieved at the simulation (higher than 75% at the worst case scenario) is very significant, even though the analyzed resort was not initially conceived for achieving such a challenging goal. The net-zero water goal may therefore be achievable if incorporated at early stages of the design process of a new resort. In this case, since design teams would have more control over the supply system and demand patterns, their optimization would thus be easier to achieve than for an existing project. This chapter explains how the previously described framework should be applied to a new development scenario in order to facilitate the achievement of the net-zero water goal.

6.1 Net-Zero Water Goal Review

The achievability of the net-zero water goal has been defined by the following equation:

$$\frac{\text{SUPPLY from sources meeting the established criteria (see chapter 2)}}{\text{DEMAND relying on these supply sources}} = 100\%$$

This case-study demonstrates how important it is to consider the water system as a whole for achieving challenging results, including the net-zero water goal. Both sides of the previous equation thus need to be carefully regarded (Fig. 6.1).

On the supply side, given the isolation condition of the case-study, rainwater is identified as the only freshwater source meeting the established criteria. As defined in chapter 2, the goal is not achieved by a complete reduction of all the water footprint components, but by nullifying all the environmental and social impacts associated with each water footprint component. Other supply alternatives for the island, such as desalination, groundwater or imported water are discarded in the previous example, given their associated impacts. However, additional supply sources not existing in the Maldives, due to the very small size of most islands, may appear at other destinations. Larger islands in other SIDS may have surface water bodies or aquifers less vulnerable to sea water intrusion. Rainwater is therefore not necessarily the only alternative in all geographical contexts. The potential incorporation of additional water supply sources into the net-zero water scenario needs to be assessed, based on the specific analysis of each geographical context.

On the demand side, the potential reduction achieved through wastewater recycling and conservation measures, such as educational programs or efficient fixtures, is highly dependent on the demand pattern of the assessed project. The case-study, a luxury beach resort, has a very particular demand pattern due to the amount of water intense services offered to guests and for the recreational character of this form of tourist activity. The consumption data offered by the resort showed that the highest water consumption occurs in guest rooms. Based on previous studies, it is considered that showers consume most of the water in these rooms, this service requiring almost 50% of the case-study's total water consumption. Different tourism facility types (non beach resorts) would present a different consumption pattern. Different tourist capacities (from guesthouses to large scale resort cities), facility typologies (low versus high density), and types of services (swimming pools, golf courses, spas) would determine the new demand pattern. The potential savings obtained through the implementation of the same strategies may vary significantly.

These two variables, supply and demand, correspond to the two sets of data introduced in the Tool for assessing the potential footprint reduction of an existing beach resort. The same tool can be used to assess the achievability of the net-zero water goal for new tourism projects. In these cases, as explained above, new sets of data corresponding to the new supply and demand conditions would be introduced. Each set of data, supply and demand, depend on different factors.

On the one hand, the water supply conditions depend exclusively on the project location. The impacts related to the water footprint of the new development will be local, so every project requires an independent analysis of its water context. When rainwater is considered as one of the potential supply sources, the rainfall data to be introduced in the Tool needs to be specific to the project location. Similarly, if other sources are considered, their supply parameters and limitations need to be determined in the initial analysis of the local context as well.

On the other hand, the water consumption pattern of the new resort will depend on the specific program of the new project. As no real consumption data will be available for new developments that are still not operating at the moment of the assessment, the introduced demand pattern needs to be based on existing projects hosting programs as similar as possible to the new one. Beach resorts that are similar in size, accommodation type and number of water-related services offered, will generally present similar demand patterns. However, different tourism segments are characterized by very different facility types and services. For instance, urban hotels or ski resorts are very different from the case-study in terms of programming. Applying this framework to other facility types would therefore require the introduction of the specific demand estimations based on projects corresponding to the same tourism segment.

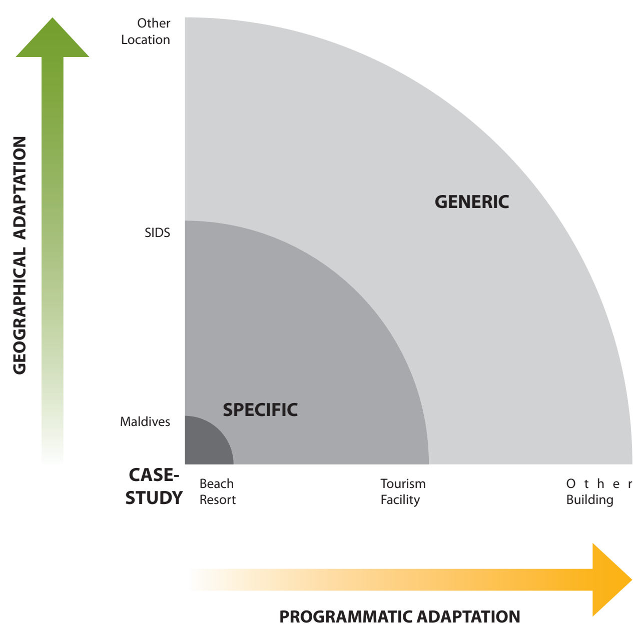


Fig. 6.1. Adaptability diagram.

Finally, the results of the case-study also showed that the efficiency of all the considered strategies, and therefore the potential for improving the performance of the whole system, depended on a number of different variables. For this reason, the appropriate design of all these strategies, associated with both the supply and the demand, is crucial for achieving the established goal. All the design parameters that affect the performance of each strategy will therefore have to be optimized in order to obtain the best results.

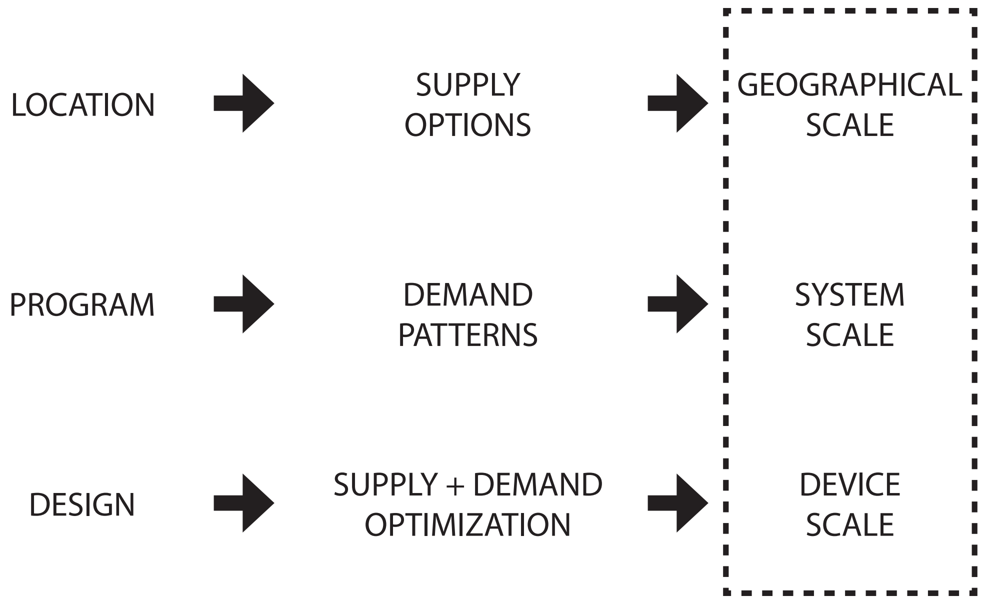


Fig. 6.2. Three-step design process diagram.

These three main components, supply, demand, and their optimization, correspond to three different scales: geographical, system, and device scales (Fig. 6.2). For a new project, the process for achieving the net-zero water goal needs to cover all these three scales, from selecting an appropriate site to defining the finest detail of each water strategy.

6.2 Design Process for Achieving the Net-Zero Water Goal at New Resort Developments

The application of the proposed framework to a new beach resort is thus presented as a three-scale process covering all the requirements for achieving a net-zero water goal (Fig. 6.3). The geographical scale focuses on the supply sources to which the potential site may have access and the specific assessment of each of them in order to understand their impacts. The system scale determines the conditions for the program definition based on the previously identified supply sources. This program definition is based on a scenario in which all the water strategies considered in the Tool are applied. Finally, at the device scale, a series of design variables corresponding to each previous strategy is identified and controlled in order to optimize the efficiency and transparency of all these strategies.

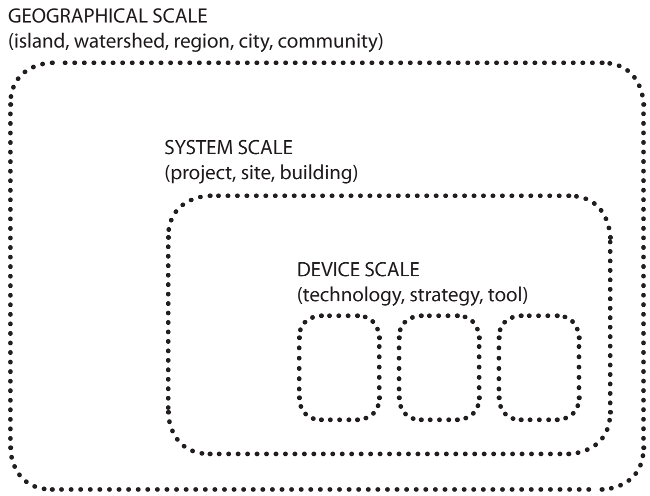


Fig. 6.3. Three-scale process. Units of analysis.

6.2.1 GEOGRAPHICAL SCALE

The first step of the application of the proposed framework for achieving a net-zero water goal is an analysis of the geographical context in which the actual or potential site is located. This analysis will determine if there are freshwater sources whose impacts do not impede the achievement of the goal and also their capacity for supplying the required water demand associated with the new program. The ultimate goal of this first step is the determination of the capacity of the existing sources to provide a water supply adequate to the achievement of the goal. This capacity determination process will be based on a complete and detailed analysis of the local water context.

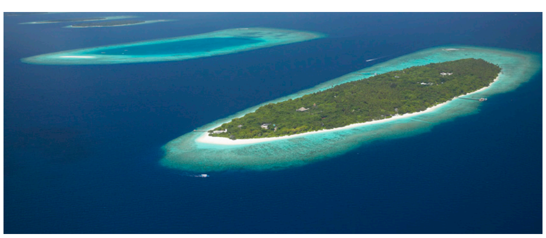


Fig. 6.4. Soneva resort, Kunfunadhoo island aerial view. Source: Soneva.

Fig. 6.5. Manu Island, Fiji. By Heinz Albers,Heinz Albers (Own work). CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0/), via Wikimedia Commons.

Fig. 6.6. English Bay, Vancouver, BC. By No real name given. CC-BY-2.0 (http://creativecommons.org/licenses/by/2.0)], via Wikimedia Commons.

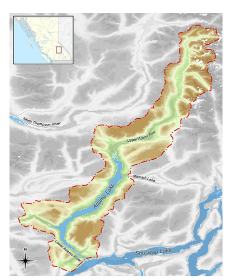


Fig. 6.7. Adams River watershed map. By Obsidian Soul (Own work) [CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons.

The impacts associated with the water footprint of a beach resort are always local, so an analysis on the specific water context of each project is required. The geographical unit to be analyzed at this first scale depends on the site conditions. For the case-study, the geographical unit was the very small island on which the resort is located (Fig. 6.4). Other tourism destinations offering similar programs could be located on larger islands (Fig. 6.5), on which additional supply sources, such as surface or larger groundwater bodies could be available. Even though this thesis focuses on small island developing states, beach resorts are also found on mainland coastlines at very different latitudes, in which case the unit of analysis would correspond to the whole watershed in which the site is located (Fig. 6.7). Resorts can also be part of a city and have access to the municipal water supply. In these cases, the city as a system would be the unit of analysis at the geographical scale (Fig. 6.6).

Once the geographical unit has been defined, the next step is to identify all the potential water supply sources to be used at the projected site. For the case-study, the available sources on the island were desalination (offered by the existing plant at the resort), rainwater, and groundwater (these two not being used for operating the resort at the moment). Different sites may not have some of these sources. For instance, desalination is typical at locations where there is no access to more conventional blue water sources. Similarly, freshwater supply from surface water bodies, such as rivers or lakes, nonexistent in this case-study, may be an alternative at other locations.

For all the identified supply options, an analysis based on the water accounting framework adapted to the built environment needs to be performed. This analysis includes the classification of each water supply source according to the redefined water footprint types, as well as the identification of the impacts and risks associated with each of them. The assessment of each water source is different, since the indicators used for determining their impacts and risks are different (Table 6.1). Furthermore, this impact and risk determination needs to consider the grey water footprint of the new project, even though this footprint is not directly associated with the freshwater supply.

The analysis of each potential freshwater source needs to be detailed enough to provide a complete understanding of the potential consequences of its use. Also, the indicators should allow the design team to determine the freshwater capacity of the site throughout a certain time period. The parameters determining the availability of water from each potential source are not always constant. Variations may appear, not only between different seasons but also from one year to the next. For instance, as far as harvested rainwater is concerned, knowing the total annual precipitation for a specific site is not enough to determine its capacity to satisfy the rainwater demand during the peak season. As explained in chapter

INDICATORS FOR WATER SUPPLY SOURCE ASSESSMENT		
WATER SUPPLY SOURCE	INDICATOR SAMPLES	UNIT OF MEASUREMENT
Desalination	Type (Desalination Technology)	e.g. Reverse Osmosis
	Capacity	Litres/day Litres/year
	Delivery Cost	$/Litre
	Environmental Cost (impacts)	e.g. CO_2 emissions, brine conditions
	Social Cost (impacts)	e.g. community access restrictions
	Initial investment + maintenance cost	$ $/year
	Payback period	Years
Groundwater	Type (Aquifer type and vulnerability)	Confined / Unconfined
	Capacity (Renewable Recharge Rate)	Litres/day Litres/year
	Delivery Cost	$/Litre
	Environmental Cost (impacts)	e.g. ecosystem damage
	Social Cost (impacts)	e.g. community access restrictions
	Initial investment + maintenance cost	$ $/year
	Payback period	Years
Rainwater	Type (RWH system type)	e.g. rooftop RWH system
	Capacity (precipitation pattern, runoff coef, dry periods)	Litres/day Litres/year Variability
	Storage system (type + volume)	e.g. underground cistern Litres
	Delivery Cost	$/Litre
	Environmental Cost (impacts)	e.g. aquifer recharge interruption
	Social Cost (impacts)	e.g. community access restrictions
	Initial investment + maintenance cost	$ $/year
	Payback period	Years
Surface Water	Type (RWH system type)	e.g. Stream, lake, wetland
	Capacity (precipitation pattern, runoff coef, dry periods)	Litres/day Litres/year Variability
	Delivery Cost	$/Litre
	Environmental Cost (impacts)	e.g. ecosystem damage
	Social Cost (impacts)	e.g. community access restrictions
	Initial investment + maintenance cost	$ $/year
	Payback period	Years
Municipal Water	Original Source (+ complete analysis of its indicators)	e.g. Groundwater, surface water
	Delivery Cost	$/Litre
Imported Water	Original Source (+ complete analysis of its indicators)	e.g. Groundwater, surface water
	Delivery Cost	$/Litre

Table 6.1. List of indicators for the assessment of different potential water supply sources.

4, a daily step is required for assuring reliable results in the calculation process. Daily precipitation values allow the design team to consider seasonal variability and dry periods, which play a significant role in designing a rainwater harvesting system. Furthermore, rainfall patterns are not constant every year. The previous parameters, total annual precipitation or the length of dry periods, also vary inter-annually. The obtained daily rainfall data should therefore not be limited only to a specific year but include a number of consecutive years, allowing for an understanding of the long term variability of the precipitation patterns. From this data, the designers can then determine the best, average, and worst case scenario years, as the ones established for the case-study, and use them to assess the availability and/or limitations of that source. These temporary variations are not only applicable to harvested rainwater, as seasonal and inter-annual variations also apply to other freshwater supply options, such as groundwater or surface water. The level of detail of their indicators should thus be equally high.

Based on an exhaustive analysis of each potential freshwater source, the impacts and risks associated with each of them could be identified. This way, design teams will be able to determine which source/sources should be considered for a net-zero water scenario. Moreover, the indicators above will allow them to establish the supply limitations for each source. For instance, the rainfall pattern would indicate how much rainwater could be harvested and used at the tourism facility at different times of the year. The recharge rate of an aquifer would indicate how much groundwater could be used without depleting the source. The availability limitations associated with each source will form the basis for defining the program at the next step.

6.2.2 SYSTEM SCALE

The second step of the process corresponds to what was previously called the system scale. At this scale, developers and design teams should define the program based on the assessment of the previous geographical conditions. The limitations shown by the indicators associated with each freshwater supply source will serve as references for determining the water capacity of the new project (Fig. 6.8).

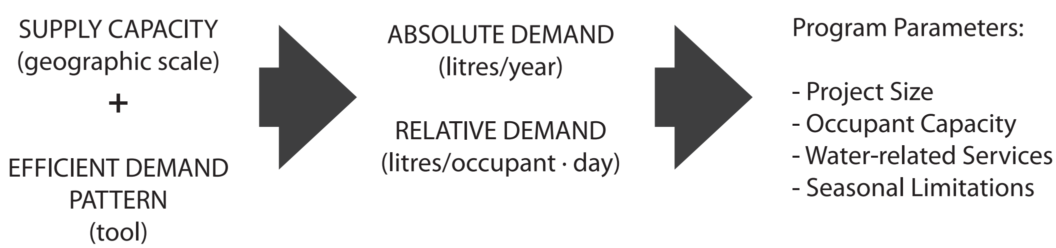


Fig. 6.8. Program definition diagram.

At this second scale, the unit of analysis is reduced to the project site. In the case-study, this system unit was exactly the same as the geographical unit, the island (Fig. 6.9). This is a very particular situation that does not occur in many development scenarios. On larger islands, the resort site would only occupy part of it. Other resorts or accommodation types located in different geographical contexts will have similar sites, smaller than the geographical unit considered at the previous step (Figs. 6.10, 6.11). In any case, the site is the intermediate scale at which the water system of the project needs to be considered as a whole, instead of as a group of isolated strategies.

Fig. 6.9. Soneva resort, Kunfunadhoo island, aerial view. Source: Soneva.

Fig. 6.10. Bahia Principe Resort in Jamaica. By Jasonbook99 (Own work) [CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0), via Wikimedia Commons.

Fig. 6.11. Bellagio in Las Vegas. By Kris Ziel (Own work). CC-BY-3.0 (http://creativecommons.org/licenses/by/3.0), via Wikimedia Commons.

The first step at this second scale is to determine the demand pattern of the new project. Contrary to the case-study, new projects are being considered in this chapter, so no metered water data for the assessed project will be available. This demand pattern must therefore be based on measurements taken at projects that host similar programs. As in the case-study, in order to increase the reliability of the calculations made with the Tool, this data needs to be of high resolution, metered on a daily basis, and differentiate the main uses. Through this differentiation, the Tool will allow us to determine how much the originally estimated demand can be reduced through the application of a closed-loop water system (Fig. 6.12). This reduced demand pattern will finally be used to determine the maximum water capacity of the new project, according to the limitations established by the geographical scale analysis. Based on the water capacity, the design team and developers will be able to define different program variables, such as the size of the operation, the number of occupants it can accommodate, and the number of services that rely on freshwater included in the new project.

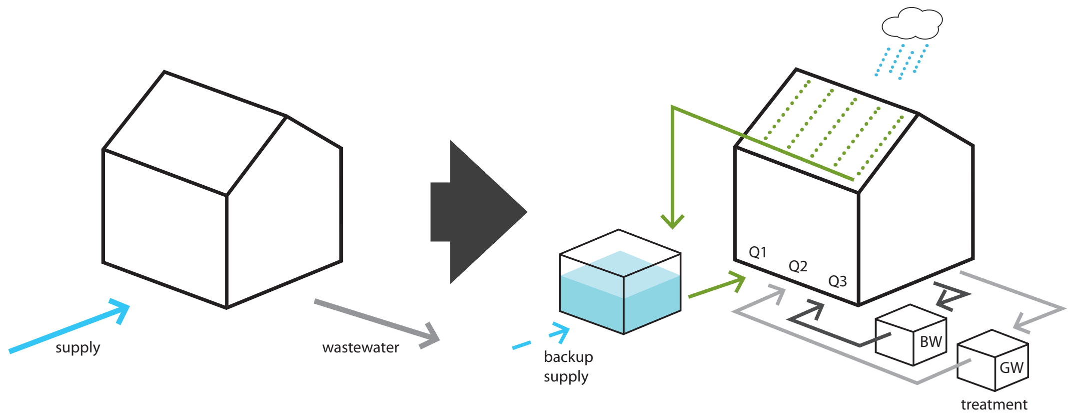


Fig. 6.12. From conventional to closed-loop water systems.

6.2.3 DEVICE SCALE

The case-study showed that, even after incorporating all the water strategies considered in the Tool, the net-zero water goal was not achievable. Based on the two previous scales, the reasons for not achieving the goal could be either an insufficient supply, an excessive demand, or a combination of both. On the one hand, it could be considered that the local rainfall pattern is not adequate to cover the whole demand of a tourism facility of this type. In fact, significant variations were observed between different years, having different amounts of total annual rainfall and diverse distribution patterns throughout the year. On the other hand, it could be assumed that, even though the amount of rainfall available is considerably higher when compared with other climatic zones, the size of the resort and the number of water intense services offered to tourists make the goal unachievable. As a consequence, design teams are responsible for optimizing the strategies that correspond to each of the two previous scales (i.e., the geographical and system scales). Their role in maximizing the benefits from every water strategy is crucial. The key to achieving the goal lies not only in how many water strategies are applied but also on how these strategies are implemented. At this third step, which corresponds to the device scale, we present a list of design parameters to be considered by teams in this optimization process.

There are many variables affecting the performance of the water system that can be controlled by design teams from the early stages of the design process. Achieving a net-zero water goal requires the designers to exert strong control over these variables. The way the different water-related strategies are incorporated into the building or its surrounding landscape determines their efficiency and, in some cases, can generate additional benefits. Design integration, increased transparency, and showing occupants how building users' interact with these technologies can improve their awareness, thus helping them to become active participants in achieving the net-zero water goal.

Each strategy (e.g. a rainwater harvesting system, greywater recycling, efficient fixtures) has a different level of flexibility in terms of design. While some of them, such as RWH depend on many different variables that can be controlled by designers (catchment area, tank type and location, and roof materials), other strategies, such as the use of efficient plumbing fixtures, do not leave much room for designers to improve their water saving potential. Therefore, this third scale focuses on those strategies whose performance mostly depends on their design: rainwater harvesting systems for water supply and wastewater recycling for demand reduction.

The improvement of these strategies through design will focus on two main aspects (Fig. 6.13). On the one hand, designers will examine their efficiency, which will be optimized based on the quantitative and qualitative variables associated with each of them. On the other hand, they will look at their transparency, which is also to be increased in order to maximize their potential use as learning tools and therefore contribute indirectly to further water conservation by improved occupant behaviour.

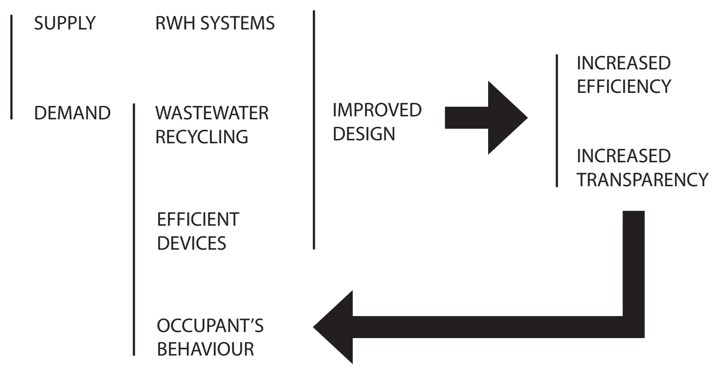


Fig. 6.13. Water strategies. Optimization diagram.

EFFICIENCY

The different variables to be controlled by design teams for optimizing the efficiency of the two main considered strategies are the following:

Rainwater Harvesting Systems:

A rainwater harvesting system is composed of many different elements, all of them described in chapter 3: catchment surfaces, storage tanks, distribution system, and treatment devices. The two components identified as having a higher flexibility in terms of design are the catchment area and the storage system (Table 6.2). The decisions made regarding these two sets of variables have a direct impact on the efficiency and cost of the system. They also affect the input data introduced in the Tool for the rainwater harvesting system and will therefore have an important influence on the results of the simulation.

DESIGN VARIABLES FOR RAINWATER HARVESTING SYSTEMS				
DESIGN VARIABLE		OPTIONS	DIRECT IMPACT ON	TOOL CELL AFFECTED
Catchment Area	Surface Type	Rooftops Hardscapes Both	Water Quality Runoff Coefficient Potential Area	Runoff Coefficient Area Future Uses
	Size (Area)	Multiple	Inflow Volume	Area
	Geometry	Slopped Flat	Runoff Coefficient	Runoff Coefficient
	Material	Multiple	Water Quality Runoff Coefficient	Runoff Coefficient Future Uses
Storage	Type	Open Closed On-site Prefabricated	Water Quality Potential Reuse Loss through Evaporation Potential Volume	Future Uses
	Size	Multiple	Storage Volume	Storage Volume
	Location	Aboveground Underground In-Between	Water Quality Design Integration Potential	Future Uses

Table 6.2. Design variables affecting the rainwater harvesting system.

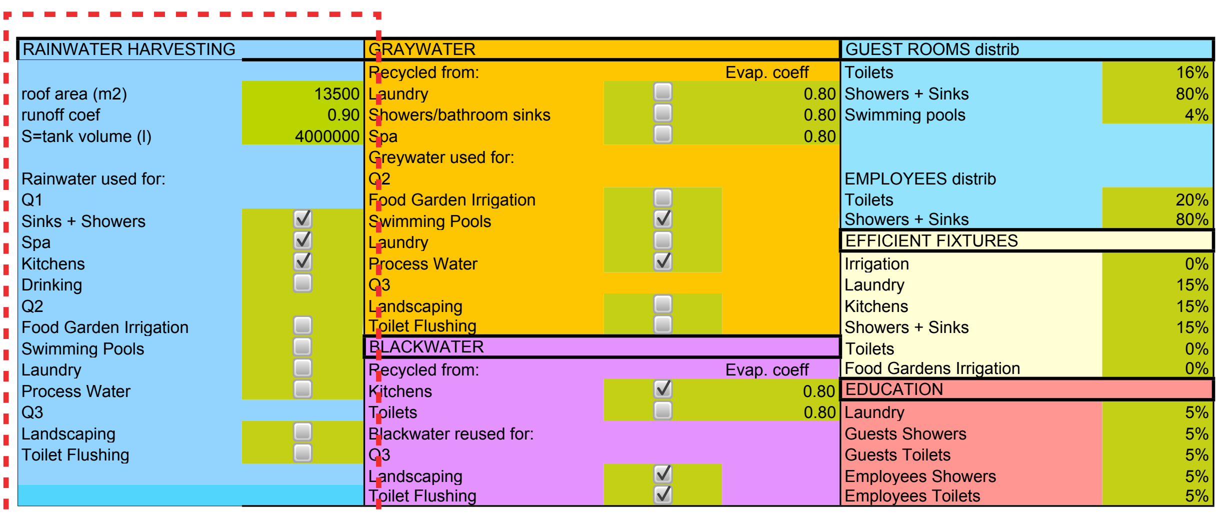


Fig. 6.14. Water Footprint Design Tool. Page 2: Control panel.

A. Catchment Area: Not only the size but also the nature of the catchment area can significantly impact both the quantity and the quality of the harvested water. The following variables associated with the catchment area are to be optimized for increasing the water inflow into the RWH system, as well as its quality:

A.1. Surface type: two different types of catchment surfaces are generally identified: rooftops and hardscapes (Fig. 6.15). While rooftops are more commonly used for harvesting rainwater and are generally more protected against pollution from human use than hardscapes, floor surfaces need to be incorporated in some cases in order to increase the rainwater inflow into the system. The type of surface considered as catchment area will have a direct impact on the quality of the harvested rainwater and also on the runoff coefficient.

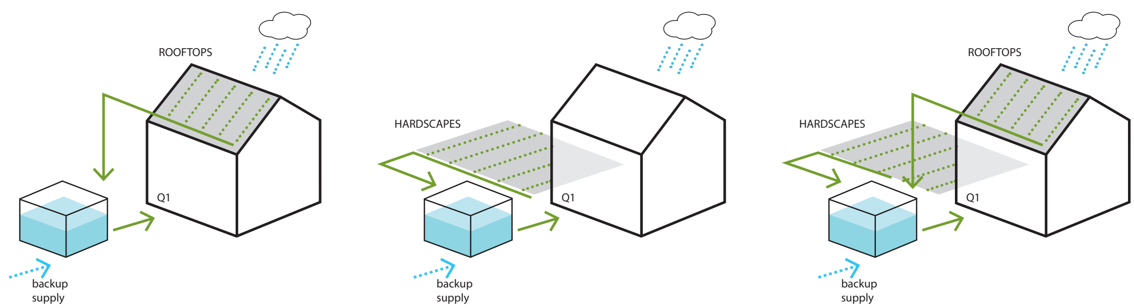


Fig. 6.15. Surface types for catchment areas of rainwater harvesting systems.

A.2. Size: The size of the catchment area is also to be determined by designers (Fig. 6.16). While in some cases, as explained above, rooftops may not be sufficient to cover a high rainwater demand, some programs may not require the use of the whole roof or hardscape area of the specific project. For instance, the CIRS building at UBC harvests rainwater for potable use only from the rooftops of the two higher wings of the building. The rooftop of the auditorium is covered by a green roof aimed to improve stormwater management, but rainwater is not harvested from it. The optimum size of the catchment area will depend on other parameters, such as the rainwater demand and the storage volume of the RWH system.

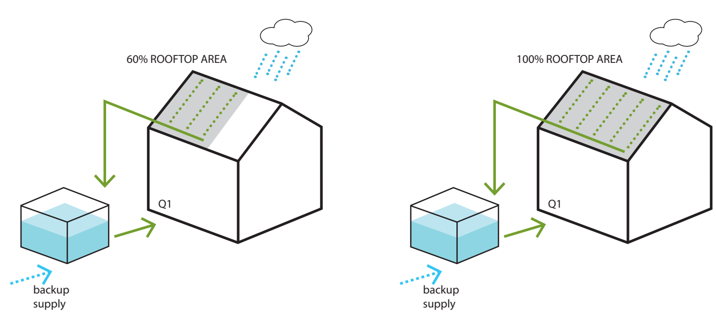


Fig. 6.16. Catchment area variations for rainwater harvesting systems.

A.3. Geometry: The geometry of the catchment surface can also impact the runoff coefficient of the system (Fig. 6.17). As seen in chapter 3, flat roofs generally present a lower runoff coefficient than sloped roofs using the same material.

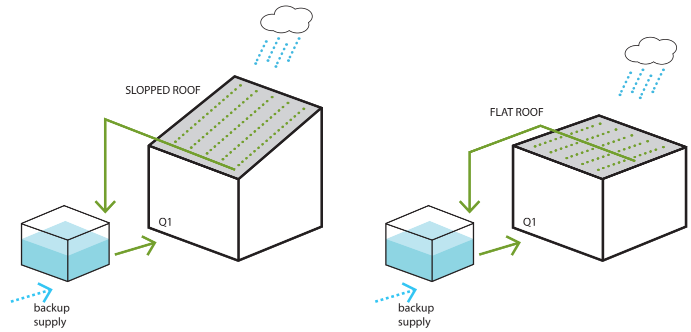


Fig. 6.17. Roof geometry variations for rainwater harvesting systems.

A.4. Material: Finally, the selection of the material used for the catchment area will impact very significantly the runoff coefficient and therefore the inflow volume of the RWH system (Table 6.3). Climate conditions also impact this coefficient directly, as warmer temperatures generally result in higher evaporation rates. Some materials may also impact the quality of the harvested water. The following table shows the different runoff coefficients for a series of materials typically used for roofs.

	SLOPING ROOFS	
	Runoff Coefficient	**Reference**
Concrete – Asphalt	0.9	Lancaster (2006)
Metal	0.95	Lancaster (2006)
	0.81-0.84	Liaw & Tsai (2004)
Aluminium	0.7	Ward *et al.* (2010)
	FLAT ROOFS	
Bituminous	0.7	Ward *et al.* (2010)
Gravel	0.8-0.85	Lancaster (2006)
Level Cement	0.81	Liaw & Tsai (2004)

Table. 6.3. Runoff coefficient for the most common roofing materials. Source: Farrany *et al.* 2011.

B. Storage tank: As for the catchment area, the dimensions and nature of the water storage system are defined by design teams. Different tank types can impact the potential size and quality of the harvested water. These are the identified design variables related to the storage system:

B.1. Type: Generally, two types of storage options appear: open and closed storage systems (Fig. 6.18). Open storage systems, generally natural or artificial basins, require much more space than closed storage tanks. The lack of available land area is a typical problem of small island resort development, so this solution may not be an option in many cases. These large tanks are also more vulnerable to external agents that can reduce the quality of the stored water. Extreme climatic conditions, implying high evaporation rates, may also impact the efficiency of open systems. Closed systems, on the contrary, require less space, no evaporation occurs and the quality of the stored water can be controlled more easily. Tanks can be built on site (usually made of concrete or masonry), or be prefabricated (generally metal or plastic barrels).

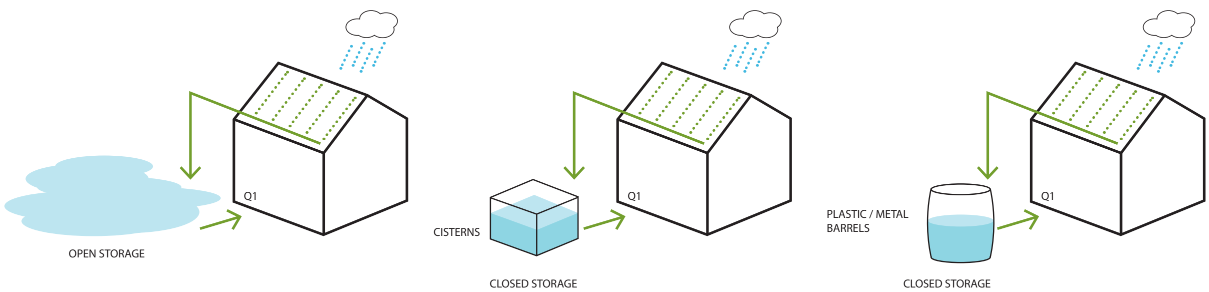


Fig. 6.18. Types of storage tanks for rainwater harvesting systems.

B.2. Size: Similar to the catchment area, the size of the storage tank has a high impact on the quantitative performance of the RWH system (Fig. 6.19). The appropriate size of the tank needs to be determined based on the water demand and the catchment area.

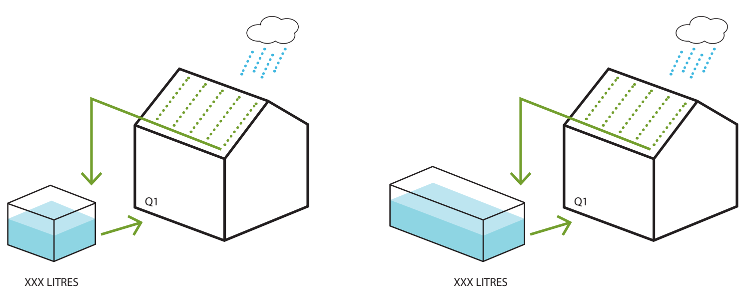


Fig. 6.19. Storage volume variations for rainwater harvesting systems.

B.3. Location: Closed tanks can be located underground, aboveground (even on the rooftops) or in between (Fig. 6.20). While underground tanks may require higher construction costs, they are better protected against temperature changes that might affect the quality of the water. The location of the storage system is to be determined based on its size or the climatic conditions of the site. The selected location, as well as the tank type, will also impact the maintenance conditions and cost of the RWH system.

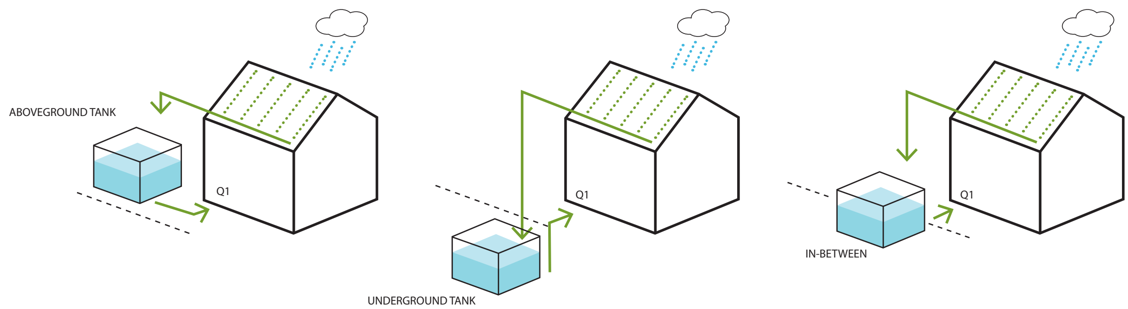


Fig. 6.20. Storage tank location variations for rainwater harvesting systems.

Wastewater recycling:

The types and variables affecting the grey and blackwater recycling systems are multiple, and their choice can significantly impact the efficiency of this strategy (Table 6.4). The three variables having a greater impact on the performance of wastewater recycling systems are the treatment plant location, the treatment type and the capacity of the treatment system.

DESIGN VARIABLES FOR WASTEWATER RECYCLING SYSTEMS			
DESIGN VARIABLE	**OPTIONS**	**DIRECT IMPACT ON**	**TOOL CELL AFFECTED**
Location	On-Site Off-Site	System Capacity Design Integration Potential Potential Reuse	Wastewater Sources Future Uses
Treatment Type	Extensive Intensive Mechanical Natural	Treatment Cost Design Integration Potential Potential Reuse Efficiency	Evaporation Coefficient Wastewater Sources Future Uses
Capacity	Independent Reclaiming	Treatment Cost Efficiency	Future Uses

Table. 6.4. Design variables affecting the wastewater recycling system..

A. Location: Wastewater treatment and recycling can be done at the project site or at a municipal facility (Fig. 6.21). When performed off-site, the wastewater generated by the building is treated together with wastewater from other developments. In some cases, the treated water is available as reclaimed water to be reused by the same or different projects. On-site systems have a smaller size and are designed as part of the project, so their variables are controlled by design teams.

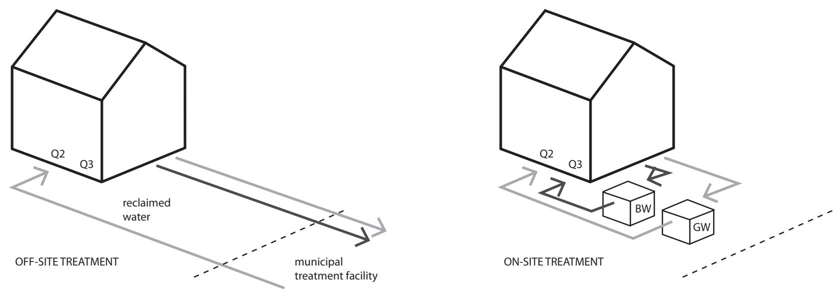


Fig. 6.21. On-site vs. off-site wastewater recycling systems.

B. Treatment type: Chapter 3 offers an overview on different treatment types for grey and blackwater recycling. As open rainwater storage systems, artificial wetlands require larger areas and are more vulnerable against climatic conditions or external pollutants (Fig. 6.22). Smaller scale systems can be classified according to the treatment process. Systems imitating natural processes, such as the one used at the CIRS building, are preferred, as the energy and treatment costs associated with them are lower.

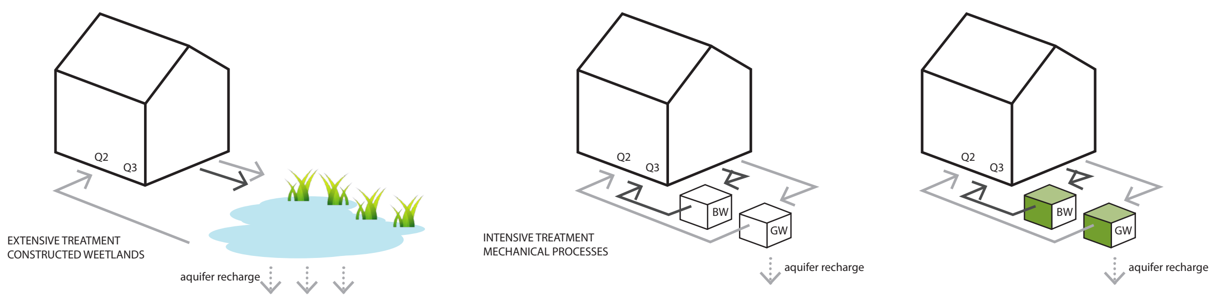


Fig. 6.22. Extensive vs. intensive wastewater treatment.

C. Size: Again, the system size will depend on the amount of water to be treated. In some cases, the system can be conceived for treating wastewater not only from the given site but also from those of neighbours (Fig. 6.23), as the CIRS building does, contributing to the grey WF reduction of the whole neighbourhood.

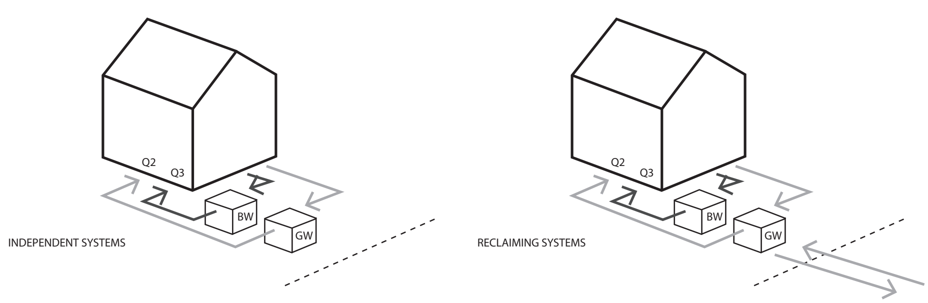


Fig. 6.23. Independent vs. reclaiming wastewater recycling systems.

TRANSPARENCY

Chapter 3 explains how building occupants are starting to be considered as key participants in achieving the challenging goals of green building. In the case of tourism facilities, guests are responsible for a great fraction of the demand pattern of an accommodation facility. The high-resolution water consumption data from the case-study showed that 51% of the total water used at the resort was consumed in guest rooms. Tourists' commitments to reduce water consumption are therefore crucial for keeping the demand below the supply limitations and achieving a net-zero water scenario.

Different ways of “triggering” the reactions of building users, namely, tourists, have been previously described, from interpretive signage to economic incentives, including water pricing policies. This section focuses on the designers’ integration of the water strategies, as explained in chapter 3 of this thesis, in order to contribute to the awareness of the resort users and therefore to their behaviour improvement. As previously mentioned, enhancing the visibility of (and accessibility to) these strategies, along with increased opportunities for user involvement would contribute to a higher perception and understanding of the water resource problem, and will therefore generate a positive reaction from employees and guests (Fig. 6.24).

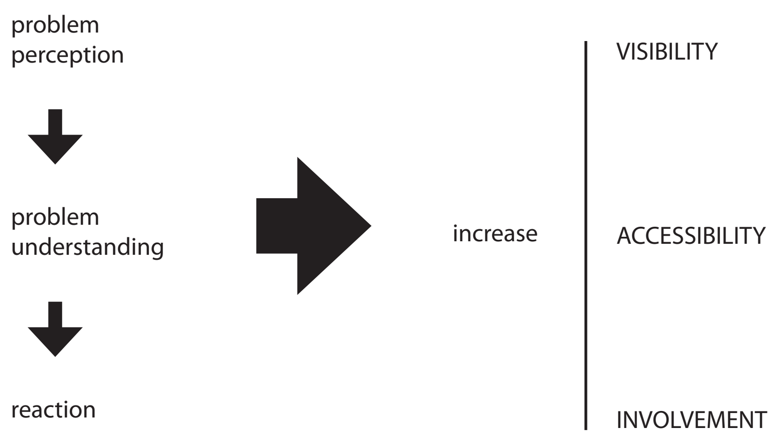


Fig. 6.24. Design variables affecting the transparency of the different water-related strategies.

Different ways of increasing these three parameters, i.e., visibility, accessibility and involvement potential, are illustrated by recent projects as follows:

Visibility: Enhancing visibility of the devices aimed to improve water management in a project is an efficient way to increase occupants ‘perceptions of the problem. There are different ways of making these devices or some of their elements visible, and, in some cases, a great integration into the design of the building or the landscape can be achieved.

The Swenson Civil Engineering Building (Fig. 6.25) in Duluth, Minnesota, designed by Ross-Barney Architects and opened in 2010, is a good example of a high level of design integration of water strategies. Besides incorporating additional strategies aimed at reducing resource consumption, the building is characterized by its storm water management system. The oversized wooden scuppers collecting the runoff from the rooftop appear as one of the main design components of the whole project, participating not only as a water feature but also as an aesthetic element, visible from both outside and inside the building. The runoff from these scuppers falls into several corten steel drums, which become as well part of the landscape design (Fig. 6.26). This building has received great recognition for becoming a learning tool in itself, incorporating systems which are also part of the civil engineering core curriculum (Mays, 2011).

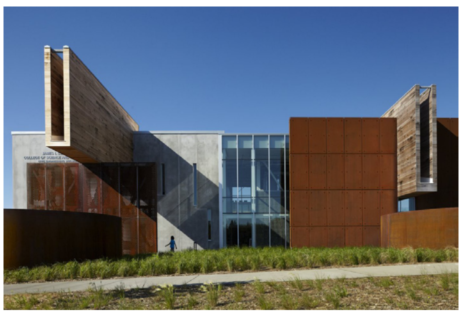


Fig. 6.25. © Kate Joyce/Chicago 2011. James I. Swenson Civil Engineering Building, Duluth. Ross Barney Architects

Fig. 6.26. Photo: Andrea Schokker. James I. Swenson Civil Engineering Building, Duluth. Ross Barney Architects.

Fig. 6.27. Omega Center for Sustainable Living in Rhinebeck, New York. BNIM Architects. Photo by Andy Milford from Dahlonega, GA (OCSL Uploaded by Ekabhishek) [CC-BY-2.0], via Wikimedia Commons.

Wastewater treatment systems, especially extensive ones (wetlands) can also be easily integrated into the landscape design of a project. The Omega Center for Sustainable Living (Fig. 6.27), in Rhinebeck, New York, was designed by BNIM Architects and opened in 2010. As an example of regenerative design (Omega Center for Sustainable Living, 2013), the heart of the Omega Center is an Eco Machine which collects wastewater from the whole campus and treats it by mimicking natural processes before sending it back to the aquifer (Fig. 6.28). At the end of the treatment process, the water is retained in several dispersal fields, from which the purified water slowly flows back into the aquifer. These dispersal fields become a central component of the landscape design.

Accessibility: Besides contributing to a higher perception of the problem through an enhanced visibility, water devices can also be used as learning tools that allows building users to understand the issue and its potential solutions. Guided tours are an efficient way of introducing tourists to these technologies, and both previous projects are good examples of how these devices can be made accessible. The CIRS building on the UBC campus in Vancouver, used as a precedent in chapter 3, also illustrates how water processing technologies, generally hidden and inaccessible by the public, can be placed in such a way that everyone can access and learn from them. The Adam Joseph Lewis Center (Fig. 6.29) at Oberlin

College in Ohio also has a living machine for processing wastewater that is accessible to building users. Guided tours through these facilities, accompanied by professionals and experts, would help improve tourists' understandings of the efforts hotels committed to addressing challenging water-saving goals are making in order to achieve them.

Fig. 6.28. Omega Center Eco Machine in Rhinebeck, New York. BNIM Architects. Photograph by John Todd Ecological Design.

Fig. 6.29. Adam Joseph Lewis Center at Oberlin College in Ohio. Photograph courtesy of Barney Taxel, © Barney Taxel, Cleveland, Ohio.

Fig. 6.30. Real-time water consumption monitoring device. Source:

Involvement: Finally, guests need to understand how their own behaviour can impact the performance of the water system. Besides showing them the problem and helping them to understand it, they should be made capable of measuring the effects of their behaviour. Smart metering, which allows operators to measure the amount of water consumed by each service on a daily basis, is generally not revealed to building users. Real-time monitoring devices based on these metering strategies can help guests to understand the importance of the fraction of water consumed by them and trigger a reaction aimed to improve water conservation (Fig. 6.30).

6.3 Design Process Summary

This three-scale process shows that achieving a net-zero water goal is a continuous decision-making process that involves multiple variables at every step. Selecting the site where a new resort is to be opened and defining its specific program are two of the earliest stages of the operation, which involve not only design teams but also other stakeholders. Also, most of the described strategies are much easier to incorporate at new developments, as their integration into the architectural and landscape design should be considered in the early stages of the design. Therefore, achieving a challenging water goal, such as the net-zero water scenario, is much easier when this goal is incorporated at the very beginning of the development process.

The multiple steps needed to shape the whole process involve professionals from disciplines which are not always included in conventional design teams (Fig. 6.31). While architects and landscape architects are generally the coordinators of the whole team for a development project, experts in other fields are required at all three scales of the previously described process. Urban planners play a significant role at the geographical scale, as their decisions may determine the availability of sites for new tourism facilities. Biologists and geologists also play a fundamental role, especially in assessing the environmental impacts associated with each water footprint component. Their expertise is further required for establishing the capacity and optimizing the efficiency of all the natural processes incorporated for water treatment. Similarly, the participation of sociologists might be necessary to deal with the possible negative social impacts associated with the intensive use of a specific water source. Economists are also necessary for the budget estimation, both at the program definition stage and at the device optimization step.

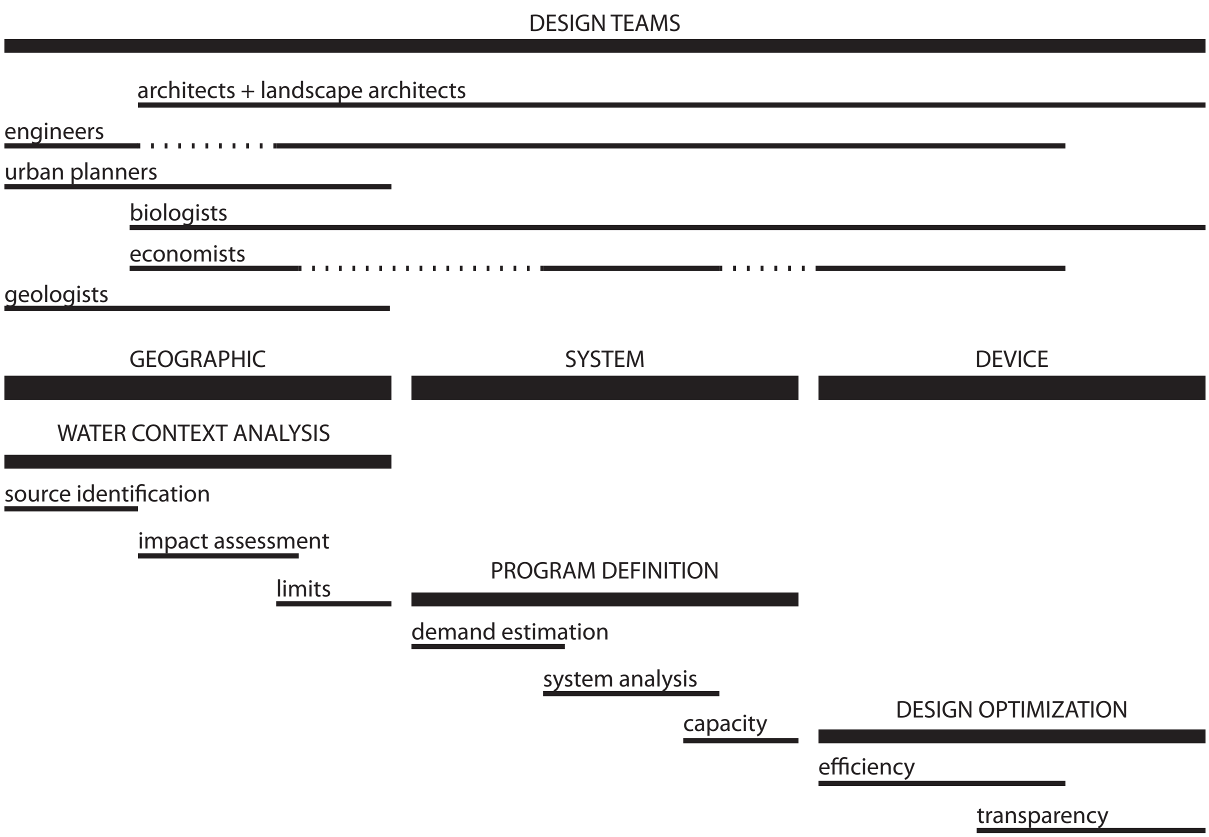


Fig. 6.31. Multidisciplinary process diagram. In order to achieve water ambitious goals, design teams need to incorporate professionals from many different fields. While traditional design team members, such as architects, landscape architects and engineers participate across the entire three-scale process, the responsibility of other professionals focuses on specific phases of design.

Besides the complexity of design teams involved in challenging water goals, the participation of other stakeholders is also crucial for their achievement. Owners and operators are a key piece of the puzzle. Up until recently water has not generally been considered a critical factor when choosing the location and the scale of tourism development operations (Pigram, 2001). Their commitment is thus fundamental for selecting appropriate sites and defining realistic programs, according to the site's water context limitations. Also, their initial investment for all the required technologies and processes is necessary. Moreover, many of the mentioned strategies, such as wastewater recycling or rainwater harvesting, especially for potable use, require regulation modifications in many countries. These regulation changes involve governments directly, so their participation in the achievement of the goal is also significant. Finally, since tourists are responsible for a large fraction of the total water consumption, achieving the goal will never be possible if they do not commit to water conservation.

All stakeholders, business owners and operators, tourists and regulatory agencies play a very significant role in making tourism, and more specifically, water management, more sustainable (Fig. 6.32). While business owners and operators are in the strongest position to lead the change (Williams & Ponsford, 2009), tourists, local communities, and regulatory agencies can also contribute significantly to a more sustainable tourism practice. In order to foster the involvement of all stakeholders in more sustainable tourism development, green designers should show them all the potential benefits for everyone concerned.

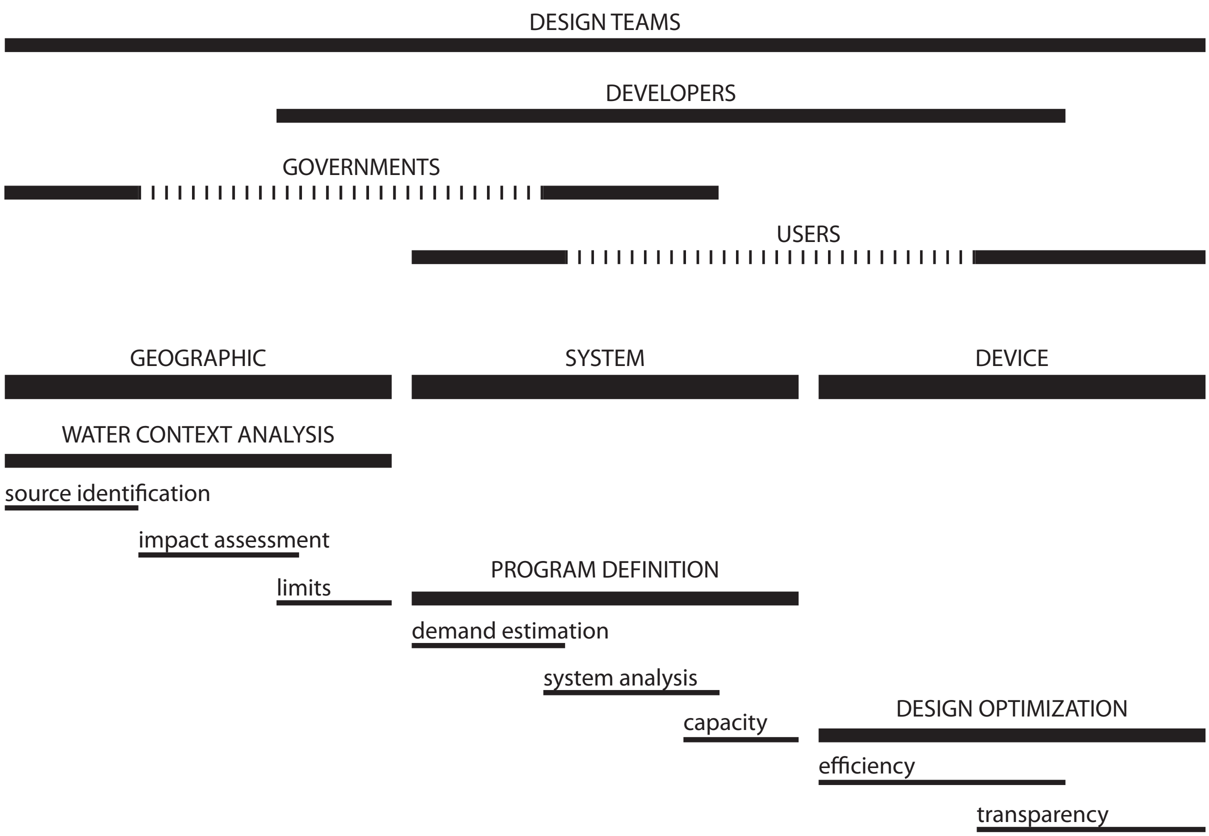


Fig. 6.32. Multi-stakeholder process diagram. In addition to the multi-disciplinary teams described above, additional stakeholders such as developers, governments and users are crucial for achieving ambitious water goals. This graphic explains the impact of each of these stakeholders on every scale of design.

7 CONCLUSIONS

7.1 Thesis Overview

This research brings to the table the need for a shift in the way water management is considered in the design of tourism facilities in small island developing states. The high contrast between the scarce available freshwater resources and the heavy demand for water of luxury beach resorts at these destinations makes it necessary to use high-energy-demanding technologies such as desalination. In a context in which most of the energy is produced by generators depending on imported fossil fuels, a freshwater supply based on desalinated water leads us in the opposite direction of a more sustainable future in tourism development. More challenging water-related goals, such as the net-zero water scenario included in the Living Building Challenge, need to be embraced by resort owners and operators in small islands if they are truly committed to sustainability. The water footprint methodology, understood within the Corporate Water Accounting context, offers developers and designers the necessary framework to introduce such ambitious goals. It is possible to achieve a scenario in which the impacts and risks associated with the water footprint of beach resorts are minimized. However, it is required that conventional water strategies, already widely applied in the context of green building, are taken to the next level. Beach resorts on small islands should not rely on desalination procedures for providing the freshwater that they require for operating. Instead, tourism facilities at remote destinations must obtain water from renewable sources available on their sites, for instance, by means of harvesting rainwater. Moreover, the water demand of these facilities needs to be reduced as much as possible by treating and recycling all the wastewater they generate, and also by implementing conservation policies involving resort employees and users. The proposed Water Footprint Design Tool allows design teams to implement and assess the potential reduction to be achieved by all these strategies. Its application to the case-study in the Maldives shows that high reductions to the desalinated water footprint of the assessed resort can be achieved. The results from this case-study indicate that, given the rainfall conditions of the Maldives, a net-zero water scenario could be achieved if implemented at early stages of the design. An exhaustive analysis of the water context involving professionals from multiple disciplines and performed at the beginning of the design process would allow designers to establish the freshwater availability limitations that should guide the program definition process. Nevertheless, the commitment of all stakeholders participating in the conception of a new tourism facility in such a context is necessary. Regulation changes from the government, strict environmental policies from owners and operators, water-strategy optimization from design teams, and serious involvement from employees and tourists are mandatory. All these components are equally crucial in the incorporation of a new water model for remote tourism facilities that would contribute to a more sustainable future of tourism development.

7.2 Overall Significance

The increased water scarcity problem that the world is expected to suffer in the following decades is perfectly illustrated by the two extreme conditions of the context of this thesis: on the one hand, the lack of access to renewable supply sources of small islands; on the other hand, the excessively high water demand typical of luxury beach resorts.

This research underlines the importance of considering water at the outset of the design process of tourism developments. A detailed analysis of the local water context at the very beginning of the conception of a new resort is crucial for determining some of the design parameters that will assure the achievability of an ambitious water-related goal. These parameters include the resort's size, capacity, and program or morphology, among others. Furthermore, since the cost of implementing water-related strategies increases when they are applied to existing projects, their early implementation is desired in order to increase their cost-efficiency and reduce payback periods.

The most common green building and sustainable tourism assessment tools (i.e. LEED, EarthCheck, GreenGlobe), include different water-related benchmarks and objectives in their certification processes. Water-use assessment is generally based on demand reduction goals, without considering the specific conditions of local water contexts. Subsequently, at destinations like SIDS, with no access to conventional water sources, these forms of assessment appear as insufficient. A revolution in the way water-use is benchmarked in remote tourism developments is necessary for moving toward a more sustainable future.

This research pioneers the application of the Corporate Water Accounting framework, previously tested in other business segments, to the tourism industry. This framework enables a better understanding of the requirements for achieving a net-zero water scenario. The analysis of the local water context of every single new project is necessary to determine the environmental and socio-economic impacts associated with the development of new tourism facilities. This analysis is the basis for the achievement of the net-zero water goal, as it determines the available water sources on which new developments can rely, in a sustainable way, at a specific site.

Within Corporate Water Accounting, the water footprint methodology provides a framework in which more ambitious goals, in accordance with the previously mentioned extreme conditions, can be incorporated. This research applies for the first time the water footprint methodology, introduced in 2002, to a tourism facility in a water-scarce region. While initially conceived as applicable to any person, community, product or business, until today, this methodology had been mostly applied to agricultural products. Applying it to the built environment, and specifically to tourism development in small islands, requires an adaptation process. Such adaptation is presented in this thesis and includes the redefinition of the different water footprint types (blue, green, grey) and the incorporation of new ones (rainwater, desalinated water) which were not covered by the original definitions.

The results from the analysis of the local water context may indicate that zero-impact freshwater sources are not achievable at some destinations. As a consequence, the net-zero water goal, understood as the one in which the impacts of each water footprint type of tourism development are nullified, is not always achievable. Therefore, it has become clear that it is not only design teams that need to take part into the achievement of these goals, but also developers, urban planners and governments, as the selection of the site at which development is to occur is fundamental. Sustainable tourism development is not only about *how* facilities are built but also about *where* they are built and howthey are used by consumers.

7.3 Limitations

The strict criteria established for the selection of potential case-studies determined the decision of applying the proposed framework and the Tool to only one beach resort located in the Maldives. The Tool, as described in chapter 4, requires the introduction of a high-resolution water-demand pattern, whose availability became the hardest criterion to meet during the case-study selection process. A number of beach resorts located in various small island developing states were identified as potential case-studies for having shown some sort of commitment to environmental sustainability. This commitment was demonstrated by several means: third-party verification programs (e.g. Earthcheck, Green Globe), detailed environmental policy descriptions available on their websites, and sustainability-related online publications. On a first approach, while several resorts expressed their willingness to participate in the study, only two declared themselves able to provide the requested data. The reasons given by the remaining potential participants were various nonexistent sub-metered water-use records and confidentiality being the most common ones. Their readiness to provide the required information was the final criterion for the case-study selection.

Focusing on only one case-study did not offer a complete understanding of the demand patterns of beach resorts in SIDS. However, a single case-study on an existing resort was sufficient for the purpose of this research, the aim of which was to assess the achievability of a net-zero water scenario for new coastal tourism developments in SIDS. The case-study in the Maldives allowed us to illustrate the problem of water supply and demand in the context of this thesis and served as a perfect example upon which to apply the research findings and the developed Tool. In terms of water supply, the analyzed resort is a good representative of most of other resorts in the Maldives and at other SIDS destinations, as desalination is frequently the only freshwater source at many of them and climatic conditions are similar. It is more difficult, though, to determine how representative this resort is in terms of water demand since, as explained above, no access to detailed consumption patterns from other resorts was available. Together with an increased transparency from resort operators, a higher implementation of sub-metering and smart-metering devices were found to be crucial for improving research opportunities in the future. However, the importance of how representative the case-study is, in terms of water demand, is relative. The goal of this research was to demonstrate that the achievement of the net-zero water goal is possible at destinations like the Maldives, and the case-study demonstrates that very significant reductions could be achieved through the implementation of several water strategies. One case-study is enough for this purpose. If a resort built in 1995 can achieve more than 75% desalinated water footprint reduction for the worst-case rainfall scenario, new resorts ought to be capable of achieving the net-zero water goal at similar locations.

7.4 Future Research Opportunities

Enhancing the importance of water management in the context of sustainable tourism development opens the door to numerous further research needs and opportunities:

DATA AVAILABILITY

One of these future research opportunities arises from the limited availability of water-use data from coastal tourism facilities. Water-use at resorts and other tourism facilities needs to become more transparent. More studies need to focus on specific tourism facilities in order to highlight the importance of a detailed water-use assessment. Applying the proposed framework to new tourism projects depends on the availability of reliable water-use ratios from similar facilities. There is therefore a need for resorts to make more demand patterns available to researchers and designers through metered studies similar to the one in this thesis. Water sub-metering needs to be detailed enough to provide an accurate understanding of water-use distribution by service. This way, the accuracy of the estimations made during the design process of new resorts and hotels would increase.

Similarly, detailed rainfall patterns are necessary to perform accurate simulations. These rainfall patterns need to cover a minimum number of years, in order to include inter-annual precipitation variations. The impact of climate change on these precipitation regimes must also be considered.

ADDITIONAL METHODS

This research applies for the first time the water footprint methodology and the Corporate Water Accounting framework to coastal tourism facilities. Numerous research opportunities can be derived from this application. First, further research into the impacts and risks associated with each water supply option available at a site is needed. While this thesis focuses on the environmental impacts and assesses the different sources through a quantitative analysis, a complete analysis should include other parameters as well. On the one hand, more detailed studies on the socio-economic impacts on local communities of water-use in tourism development would be useful. On the other hand, from a business owner perspective, a local cost-analysis associated not only with each supply alternative but also with all the proposed water strategies is necessary. Also, this research focuses on the direct waterfootprint of tourism facilities. However, previous studies on different business segments have shown the importance of the consequences of their indirect water footprints. Further analyses focusing on the water-use associated with the supply-chain of tourism facilities would bring to light additional problems that need to be addressed and incorporated into the sustainable tourism development framework.

CASE-STUDIES

Finally, the potential for reducing the water footprint of the built environment by applying innovative water strategies, such as the ones described in chapter 3, also requires further insight. More case-studies on projects that have applied advanced water-saving strategies, such as blackwater recycling or rainwater harvesting for potable use, would provide a better understanding of how much water can be saved from these strategies. Based on these case-studies, new projects would therefore be able to incorporate reliable percentages of water footprint reduction through the implementation of these strategies in their estimations.

Similarly, recent strategies focusing on the improvement of building users' attitudes and behaviours with regard to water conservation also need more research. Since the tourism industry directly consumes a large fraction of the total water used at resorts (and by the general population in their vicinity), the user has been identified as a key agent in the achievement of the goals proposed in this thesis. Further post-occupancy studies evaluating the impact of the educational and transparency-related strategies in the context of tourism would also allow us to better understand their potential for water demand reduction.

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Appendix A: Precipitation data for Malé, Maldives

Year-Month	Day 01	Day 02	Day 03	Day 04	Day 05	Day 06	Day 07	Day 08	Day 09	Day 10	Day 11	Day 12	Day 13	Day 14
2001-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	1.5	0.0	0.0	0.9	0.0
2001-02	0.5	0.0	0.6	13.7	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2001-03	0.0	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2001-04	0.0	0.0	0.0	0.0	0.0	7.4	0.6	0.0	10.8	0.4	48.2	3.1	40.1	0.0
2001-05	35.7	0.1	3.3	0.4	0.0	0.2	0.0	7.2	10.0	1.4	0.0	0.0	0.0	0.0
2001-06	0.0	4.6	0.2	0.0	0.3	1.8	4.4	3.5	5.9	16.7	7.5	3.8	0.0	0.0
2001-07	16.9	0.0	29.0	10.5	0.9	0.0	0.0	0.0	40.6	7.5	0.0	0.0	2.0	0.0
2001-08	12.5	1.5	4.9	0.0	0.0	0.0	0.0	2.0	7.9	1.4	0.0	1.8	0.0	0.0
2001-09	17.9	11.1	5.8	1.4	6.4	10.5	27.0	0.2	6.9	5.1	0.0	6.8	20.5	4.3
2001-10	0.0	3.2	13.9	15.1	0.0	0.0	8.9	0.1	4.0	110.2	0.1	0.2	2.7	0.2
2001-11	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.1	8.3	17.9	0.0	0.0	0.0	0.0
2001-12	0.0	17.4	5.3	5.9	2.0	1.4	24.6	26.5	0.0	0.0	0.0	0.2	0.0	0.0
2002-01	2.3	0.0	0.0	0.0	0.4	0.4	20.6	0.0	0.0	0.0	11.4	0.0	0.0	0.0
2002-02	0.0	0.0	0.0	1.6	0.0	0.0	14.7	13.2	0.0	33.7	11.3	0.5	0.0	2.7
2002-03	7.7	0.1	0.0	0.0	0.0	0.0	0.0	16.3	4.5	0.0	0.0	0.0	0.0	0.0
2002-04	2.0	0.0	0.0	0.1	32.3	0.0	0.0	1.4	0.0	0.0	0.0	9.2	5.5	0.0
2002-05	0.2	58.0	19.1	5.7	3.7	14.2	0.2	3.8	0.0	0.0	0.0	0.0	0.0	0.1
2002-06	2.0	29.2	4.6	0.2	42.4	19.3	0.0	0.7	0.2	0.7	34.0	5.9	1.6	2.6
2002-07	0.7	0.0	0.0	0.0	6.0	8.2	49.4	2.0	0.0	0.0	2.2	1.3	2.3	0.3
2002-08	20.7	1.6	0.8	4.6	10.1	10.1	1.5	0.0	0.0	9.9	0.4	0.0	0.0	0.0
2002-09	0.0	0.0	0.0	0.0	6.5	2.0	0.0	0.0	0.0	0.0	0.0	8.9	0.0	0.0
2002-10	0.8	5.6	5.9	44.2	6.8	20.3	17.4	14.5	8.9	1.0	1.1	0.0	0.3	0.8
2002-11	2.1	14.7	0.0	0.0	0.0	0.0	2.0	21.0	25.6	13.0	4.2	2.4	15.8	0.0
2002-12	0.1	0.0	0.0	31.8	10.8	3.3	22.0	0.6	65.3	2.3	4.6	3.3	54.0	0.3
2003-01	0.0	0.0	0.0	0.0	0.0	25.3	0.1	3.4	0.1	0.0	0.3	0.5	0.0	0.0
2003-02	0.0	0.0	0.0	0.0	0.0	6.5	0.1	0.0	0.0	0.0	1.4	85.6	0.0	0.0
2003-03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0
2003-04	0.0	0.0	0.0	0.0	0.0	7.7	0.0	0.0	0.0	1.2	0.0	0.1	0.0	10.0
2003-05	3.7	4.2	0.0	0.2	0.0	20.7	0.0	2.6	0.0	36.9	0.0	0.0	0.0	0.0
2003-06	0.0	13.2	66.5	6.1	15.9	1.2	1.4	0.1	1.2	8.4	0.6	1.3	9.7	0.0
2003-07	0.0	0.0	0.0	27.6	76.6	0.0	0.0	0.0	0.0	0.0	19.5	6.5	0.0	0.0
2003-08	0.0	0.8	0.2	116.7	13.1	0.0	2.2	0.1	0.6	0.5	0.0	0.0	0.0	0.0
2003-09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2003-10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2003-11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2003-12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2004-01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2004-02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2004-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2004-04	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2004-05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2004-06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2004-07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2004-08	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2004-09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2004-10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2004-11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2004-12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2005-01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2005-02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2005-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2005-04	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2005-05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2005-06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2005-07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2005-08	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2005-09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2005-10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2005-11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2005-12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2006-01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2006-02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2006-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2006-04	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2006-05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2006-06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2006-07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2006-08	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2006-09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2006-10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2006-11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2006-12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2007-01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2007-02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2007-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2007-04	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2007-05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2007-06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2007-07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2007-08	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2007-09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2007-10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2007-11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2007-12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2008-01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2008-02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2008-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2008-04	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2008-05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2008-06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2008-07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2008-08	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2008-09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2008-10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2008-11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2008-12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2009-01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2009-02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2009-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2009-04	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2009-05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2009-06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2009-07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2009-08	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2009-09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2009-10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2009-11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2009-12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2010-01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2010-02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2010-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2010-04	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2010-05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2010-06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2010-07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2010-08	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2010-09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2010-10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2010-11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2010-12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Year-Month	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20	Day 21	Day 22	Day 23	Day 24	Day 25	Day 26	Day 27	Day 28	Day 29	Day 30	Day 31
2001-01	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2001-02	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2001-03	0.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2001-04	0.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2001-05	0.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2001-06	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2001-07	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2001-08	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2001-09	14.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2001-10	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2001-11	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2001-12	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2002-01	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2002-02	82.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2002-03	2.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2002-04	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2002-05	10.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2002-06	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2002-07	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2002-08	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2002-09	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2002-10	7.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2002-11	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2002-12	55.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2003-01	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2003-02	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2003-03	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2003-04	0.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2003-05	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2003-06	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2003-07	32.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2003-08	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2003-09	37.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2003-10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2003-11	99.1	5.0	0.3	0.0	18.2	0.0	0.0	0.0	49.6	0.2	22.4	9.4	9.2	0.0	0.0	0.0	
2003-12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.3	0.0	0.0
2004-01	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.8	17.3	0.0	0.0	0.0	0.0	0.0		
2004-03	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0
2004-04	0.0	0.0	0.0	2.6	7.0	0.2	10.2	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.5	0.0	
2004-05	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.6	1.1	0.7	1.5	0.2	0.0	0.0	0.0	0.2
2004-06	0.0	0.0	0.0	5.6	6.1	0.0	0.0	0.0	0.0	0.5	0.3	0.8	5.3	0.2	0.2	24.9	
2004-07	0.0	0.0	43.0	41.2	6.8	0.2	3.4	0.2	7.9	0.0	0.0	23.3	10.5	8.4	7.8	0.0	0.0
2004-08	11.1	1.1	0.2	0.0	20.7	13.3	0.0	0.0	0.4	0.0	13.2	27.1	21.5	1.9	5.3	5.8	2.3
2004-09	9.0	28.2	6.3	2.9	14.2	2.4	60.1	21.5	0.6	49.2	13.3	32.2	0.6	0.0	0.0	0.0	
2004-10	0.0	6.1	0.0	0.0	0.0	1.9	0.0	0.0	36.8	3.8	0.0	9.3	50.0	18.1	7.0	23.0	95.1
2004-11	2.8	1.3	5.9	0.0	0.0	0.0	20.4	2.6	7.0	10.7	23.9	26.6	3.2	50.4	36.0	0.0	
2004-12	97.4	6.3	0.0	0.0	0.0	4.1	0.0	0.0	0.0	0.0	2.2	0.0	26.5	7.2	0.0	0.3	72.8
2005-01	0.0	0.0	0.0	0.0	0.0	0.0	5.5	0.0	0.0	2.3	0.0	4.1	4.5	0.0	0.0	0.0	0.0
2005-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
2005-03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005-04	0.0	0.0	0.0	0.0	9.6	2.5	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
2005-05	14.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	18.1	0.0	5.3	1.9	17.5	32.3	29.3	3.3
2005-06	25.5	16.9	1.4	0.5	0.0	0.5	0.0	13.5	2.2	0.0	0.0	0.0	0.0	0.8	0.0	0.0	
2005-07	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	11.2	4.6	20.5	9.2
2005-08	1.2	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.4	21.1	16.4	52.1	12.0	0.5	0.9
2005-09	0.0	0.0	0.0	0.0	0.5	4.7	2.8	0.0	52.7	17.4	0.5	0.0	0.0	10.0	20.7	0.0	
2005-10	0.8	46.2	1.2	170.0	12.5	15.8	1.1	2.3	0.0	6.7	2.6	0.4	1.9	10.9	0.0	0.0	0.3
2005-11	9.8	0.0	4.2	8.9	0.0	0.0	0.0	0.5	2.7	0.0	0.0	0.0	0.0	5.2	0.4	3.2	
2005-12	14.2	1.4	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	2.3	0.9
2006-01	0.0	4.2	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	101.1	0.0	0.0
2006-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
2006-03	2.7	28.1	6.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0
2006-04	0.0	37.9	35.8	0.0	0.0	0.0	0.2	23.8	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	
2006-05	0.0	0.9	25.5	0.2	0.0	29.6	2.7	1.4	2.5	0.7	0.8	0.0	0.0	0.0	1.3	0.0	0.0
2006-06	1.8	28.7	0.0	12.9	36.7	3.3	38.1	23.3	2.0	0.0	0.0	0.0	0.9	5.1	1.5	0.0	
2006-07	41.8	16.3	0.0	5.6	0.0	0.0	15.8	1.7	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2006-08	15.8	0.0	14.9	26.7	0.0	14.5	8.8	31.8	8.8	3.1	0.0	0.0	0.0	70.5	0.0	17.6	6.4
2006-09	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.8	10.7	0.0	8.9	37.4	9.6	15.0	0.0	
2006-10	0.0	11.7	0.0	0.0	0.0	11.2	0.0	1.5	20.0	60.1	4.2	0.0	23.6	31.6	0.6	0.0	4.6
2006-11	31.7	5.4	113.2	1.3	0.0	24.5	2.7	15.8	1.0	0.0	25.9	36.6	32.5	0.5	126.4	4.3	
2006-12	0.0	25.8	63.5	2.8	1.2	0.0	28.6	24.1	2.7	50.9	0.0	0.0	4.7	4.1	2.3	0.0	0.0
2007-01	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
2007-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
2007-03	12.1	0.0	0.0	7.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2007-04	2.1	0.3	0.0	0.0	0.0	0.0	41.5	4.4	0.0	0.0	8.9	13.4	13.2	7.4	47.2	0.0	
2007-05	3.9	9.4	19.5	3.1	0.0	0.0	0.0	2.0	0.0	0.0	9.7	26.5	39.1	0.0	0.0	0.3	0.0
2007-06	4.7	5.7	37.2	0.0	0.0	11.8	16.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	7.0	0.0	
2007-07	2.2	10.4	22.6	9.1	15.2	3.6	3.4	0.2	35.5	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2007-08	0.0	0.2	0.0	3.8	0.0	0.0	1.2	0.0	1.6	0.0	9.9	27.4	2.3	1.4	61.5	22.6	0.0
2007-09	0.0	0.0	2.0	1.7	26.0	15.8	41.2	3.7	3.3	0.3	0.0	0.0	3.8	7.1	0.0	3.0	
2007-10	0.0	46.8	9.7	1.9	0.0	0.0	0.0	27.0	34.4	6.1	7.9	6.7	7.4	3.0	2.6	0.2	2.3
2007-11	0.0	0.0	0.0	0.0	0.0	0.0	17.9	1.0	0.0	0.0	3.5	0.8	0.5	0.0	0.0	16.5	
2007-12	0.4	0.5	39.3	0.4	18.4	0.3	48.1	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008-01	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008-02	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	0.0	0.0		
2008-03	1.4	0.0	20.7	18.8	4.7	3.8	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1
2008-04	5.3	4.1	0.0	0.3	3.2	0.0	0.0	0.0	0.0	0.0	0.0	21.3	24.0	20.1	4.3	0.0	
2008-05	59.8	0.0	4.2	34.8	2.8	4.5	0.0	0.0	0.0	0.0	0.0	0.5	3.8	0.9	38.9	15.9	3.9
2008-06	0.0	0.0	27.4	0.1	0.0	3.0	21.4	68.0	5.2	1.8	0.0	0.5	0.0	0.0	0.0	12.5	
2008-07	0.3	16.0	14.9	3.2	0.0	20.0	24.1	0.0	7.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3
2008-08	0.0	0.0	0.0	0.0	26.0	62.3	15.3	8.8	16.6	37.8	4.7	6.9	0.6	0.0	31.4	38.4	10.2
2008-09	0.0	0.0	0.1	0.0	0.0	0.0	0.0	6.6	4.7	4.6	2.0	0.2	0.0	0.0	0.0	0.0	
2008-10	3.7	14.2	0.7	0.0	0.0	0.0	8.4	46.4	0.0	0.0	0.0	6.2	29.1	0.0	0.0	0.0	0.0
2008-11	0.0	3.9	0.0	0.0	0.0	30.4	31.9	3.6	29.8	0.8	0.4	4.2	1.8	1.7	0.0	0.0	
2008-12	0.0	0.0	7.0	14.1	72.2	12.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009-01	2.8	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009-02	0.0	0.0	0.0	0.0	0.0	2.1	8.8	0.0	0.0	1.9	0.0	0.0	0.0	0.0			
2009-03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.5	0.0	0.0	0.0	13.7	0.0
2009-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.0	
2009-05	2.8	0.0	20.9	8.0	21.2	11.7	24.2	25.0	30.8	1.8	0.0	9.5	0.5	0.7	0.0	0.0	0.0
2009-06	0.0	21.0	7.2	32.4	2.3	19.6	0.0	4.5	46.8	36.4	0.0	0.0	0.0	0.0	0.0	6.0	
2009-07	18.1	27.3	33.3	0.8	10.1	0.9	0.5	6.9	8.9	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009-08	38.2	31.2	3.5	44.6	0.7	7.3	7.1	4.8	0.0	0.0	0.1	31.8	37.2	15.4	0.0	5.7	0.0
2009-09	0.6	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	27.8	5.5	0.0	2.2	
2009-10	0.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8	0.0	10.4	1.0	39.5
2009-11	0.0	0.0	0.0	0.0	0.0	0.0	2.3	30.2	0.6	0.0	0.0	12.0	0.0	0.2	4.5	0.0	
2009-12	0.7	0.0	0.0	0.0	0.0	41.7	15.6	8.6	0.3	21.7	15.3	15.1	7.8	5.2	30.4	15.3	0.0
2010-01	0.0	0.0	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010-02	0.0	0.0	32.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
2010-03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010-04	0.0	3.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	45.5	0.0	0.0	0.0	0.0	0.0	1.0	
2010-05	21.1	2.6	37.1	11.0	42.5	22.8	16.4	5.1	19.4	2.2	0.6	0.0	0.0	5.4	0.0	4.9	0.0
2010-06	0.0	0.0	0.0	0.0	0.0	3.1	13.1	1.7	2.0	2.6	6.9	8.2	14.4	46.7	9.2	29.9	
2010-07	0.0	0.0	3.1	0.5	10.7	0.0	0.0	1.6	3.7	0.0	0.0	10.9	20.2	22.6	3.0	0.0	0.0
2010-08	2.4	6.5	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	6.3	0.0	12.2	1.7	0.0
2010-09	3.1	12.7	30.1	29.2	14.3	10.0	13.3	28.1	38.2	43.4	14.9	10.3	22.4	16.3	26.8	27.0	
2010-10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.7	0.0	0.0	0.0	15.5
2010-11	0.0	0.9	0.2	0.0	0.0	11.2	0.4	6.9	0.0	0.0	1.2	0.0	0.0	6.2	2.1	19.8	
2010-12	0.0	0.0	0.0	0.0	2.2	0.0	0.0	73.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	30.1

Table A.1. Daily precipitation (mm) for Hulhule (Malé) in Maldives between 2001 and 2010. Source: Maldives Meteorological Agency.

	average		min	year	max	year
jan	70.94		2.7	2004	184.1	2003
feb	50.62		0	2005 2006	174.7	2002
mar	54.93		4.5	2004	176.7	2008
apr	138.18		15.7	2005	215	2001
may	168.66		87.4	2006	276.9	2010
jun	175.07		66.5	2004	239.2	2008
jul	223.31		157.1	2008	398.5	2003
aug	208.99		84	2001	416.4	2009
sep	265.02		40.4	2008	432	2006
oct	215		62.4	2003	388.1	2005
nov	255.89		41.6	2007	568.9	2006
dec	246.25		65.6	2003	410.8	2002
year	2072.86		1649.2	2005	2711.2	2006
	máx day					
	170.0	18/10/05				

Table A.2. Monthly average, maximum and minimum precipitation values (mm) for Hulhule (Malé) in Maldives between 2001 and 2010. Source: Maldives Meteorological Agency.

Maldives	Precip..>= 0.2 mm	Precip.>=5 mm	Precip.>=1 0 mm	Precip.>=2 5 mm	Vancouver	Precip..>= 0.2 mm	Precip.>=5 mm	Precip.>=1 0 mm	Precip.>=2 5 mm
jan	6.2	2.3	1.5	0.7	jan	19	10	6	0
feb	3.4	1.9	1.4	0.5	feb	16	8	4	0
mar	5.3	2.3	1.7	0.6	mar	16	7	4	0
apr	11.4	6.4	4.1	1.9	apr	13	5	2	0
may	16.8	7.6	5.5	2.2	may	12	4	2	0
jun	16.8	8.4	5.7	2.2	jun	10	3	1	0
jul	16.3	9.7	6.5	2.9	jul	7	2	1	0
aug	14.4	8.4	5.9	2.6	aug	7	3	1	0
sep	17.7	11.4	7.4	3.8	sep	9	4	2	0
oct	15.6	9	6	2.4	oct	15	7	4	0
nov	16.3	9.7	6.9	3.9	nov	19	10	6	1
dec	15.3	8.6	6.5	3.5	dec	21	11	7	1
TOTAL	155.5	85.7	59.1	27.2	TOTAL	164	74	40	2

Table A.3. Average number of days with different minimum precipitation values for Hulhule (Malé) in Maldives and Vancouver, BC. Source: Maldives Meteorological Agency and theweathernetwork.com.

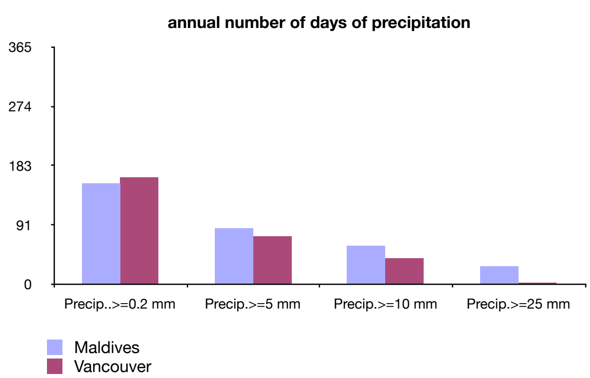

Fig. A.1. Comparison of annual number of days with different minimum precipitation values between Hulhule (Malé) in Maldives and Vancouver, BC. Source: Maldives Meteorological Agency and theweathernetwork.com.

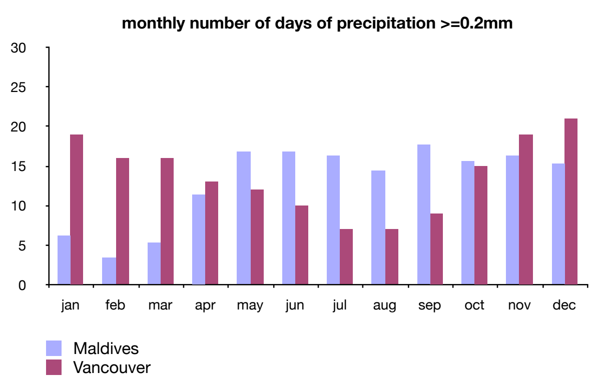

Fig. A.2. Comparison of monthly number of days with precipitation between Hulhule (Malé) in Maldives and Vancouver, BC. Source: Maldives Meteorological Agency and theweathernetwork.com.

Appendix B: Water Footprint Design Tool Results for Case-study

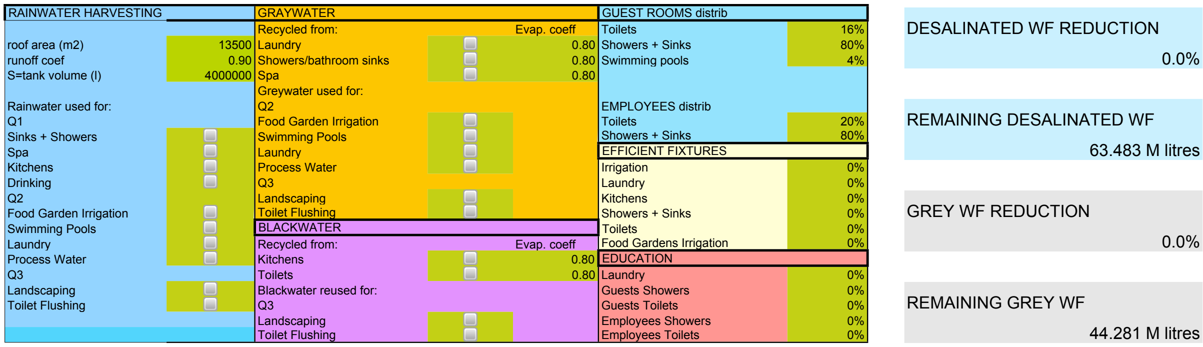

Fig. B.1. Control panel configuration for scenario #0 (current state).

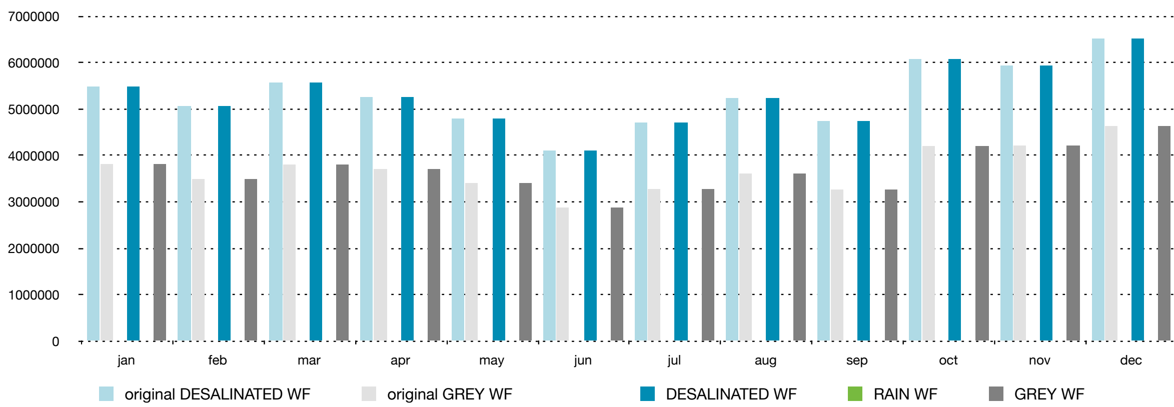

Fig. B.2. Monthly water footprint components for scenario #0 (current state).

	original DESALINATED WF	original GREY WF		DESALINATED WF	RAIN WF	GREY WF	remaining grey + black water
jan	5480106	3816149	0	5480106	0	3816149	0
feb	5063783	3484722	0	5063783	0	3484722	0
mar	5565049	3802887	0	5565049	0	3802887	0
apr	5257001	3706593	0	5257001	0	3706593	0
may	4791424	3408051	0	4791424	0	3408051	0
jun	4108456	2878381	0	4108456	0	2878381	0
jul	4710983	3274258	0	4710983	0	3274258	0
aug	5236246	3605381	0	5236246	0	3605381	0
sep	4744565	3257892	0	4744565	0	3257892	0
oct	6074826	4198101	0	6074826	0	4198101	0
nov	5936495	4215852	0	5936495	0	4215852	0
dec	6514355	4632348	0	6514355	0	4632348	0
TOTAL	63483289	44280615	0	63483289	0	44280615	0
average	5290274	3690051	0	5290274	0	3690051	0

Table B.1. Monthly water footprint components for scenario #0 (current state).

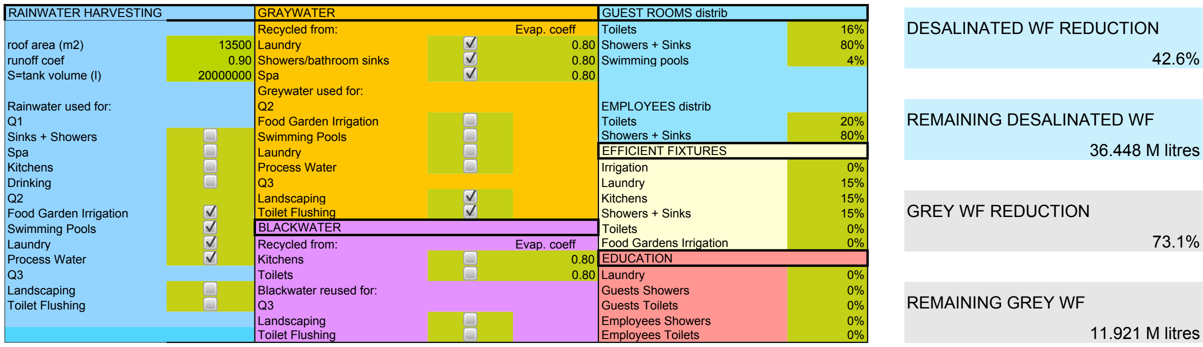

Fig. B.3. Control panel configuration for scenario #1A (conventional strategies, high precipition year 2006).

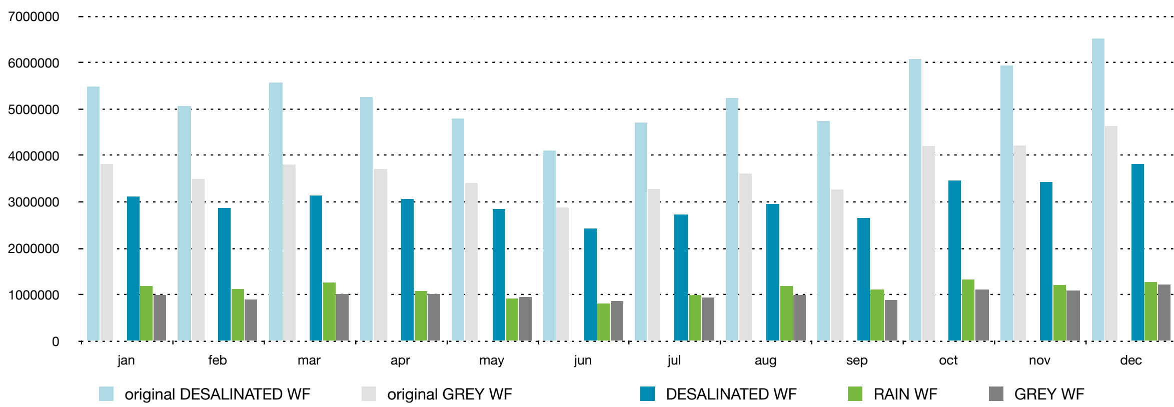

Fig. B.4. Monthly water footprint components for scenario #1A (conventional strategies, high precipition year 2006).

	original DESALINATED WF	original GREY WF		DESALINATED WF	RAIN WF	GREY WF	remaining grey + black water
jan	5480106	3816149	0	3112000	1184960	984064	1772152
feb	5063783	3484722	0	2868380	1113396	893616	1621436
mar	5565049	3802887	0	3138720	1261732	1012288	1748649
apr	5257001	3706593	0	3055570	1069611	1007592	1687337
may	4791424	3408051	0	2838430	912170	946072	1531352
jun	4108456	2878381	0	2426840	809768	863776	1236502
jul	4710983	3274258	0	2723060	989546	931952	1450356
aug	5236246	3605381	0	2947410	1187829	987304	1634095
sep	4744565	3257892	0	2647670	1106280	882680	1490400
oct	6074826	4198101	0	3455010	1319752	1103080	1930330
nov	5936495	4215852	0	3425120	1204351	1089536	1955873
dec	6514355	4632348	0	3809590	1267572	1218584	2126473
TOTAL	63483289	44280615	0	36447800	13426966	11920544	20184957
average	5290274	3690051	0	3037317	1118914	993379	1682080

Table B.2. Monthly water footprint components for scenario #1A (conventional strategies, high precipition year 2006).

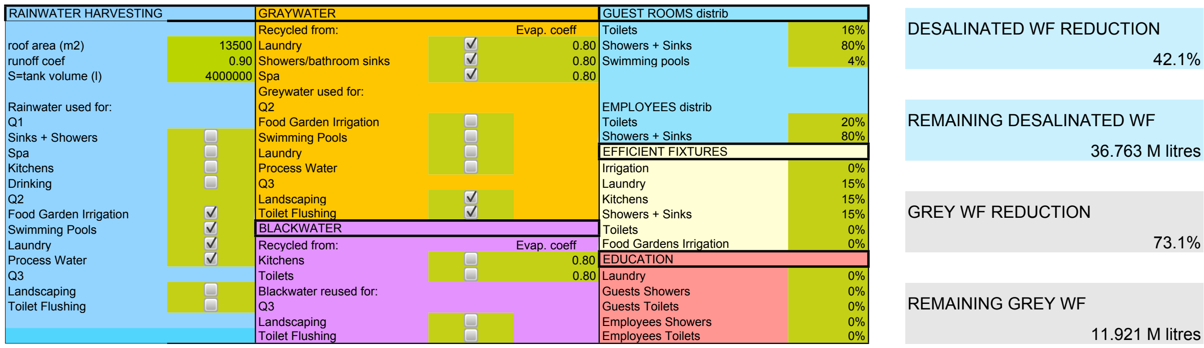

Fig. B.5. Control panel configuration for scenario #1B (conventional strategies, low precipition year 2005).

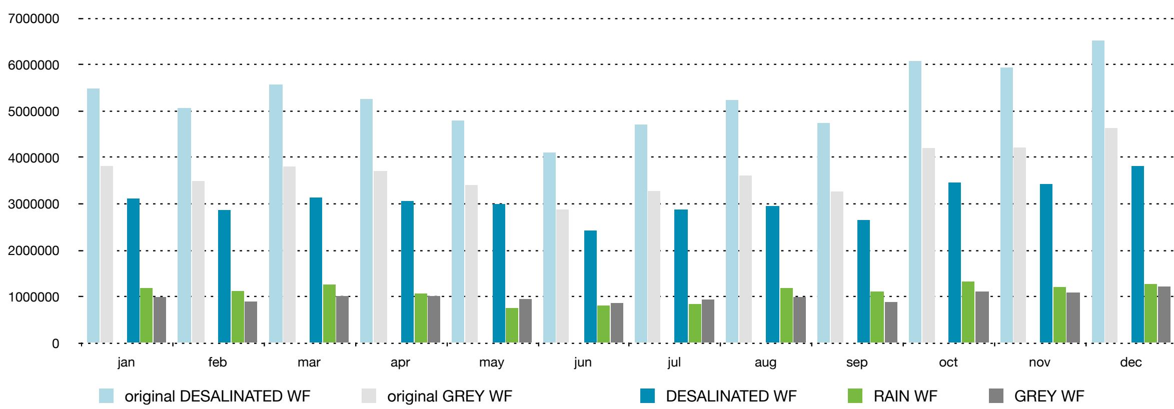

Fig. B.6. Monthly water footprint components for scenario #1B (conventional strategies, low precipition year 2005).

	original DESALINATED WF	original GREY WF		DESALINATED WF	RAIN WF	GREY WF	remaining grey + black water
jan	5480106	3816149	0	3112000	1184960	984064	1772152
feb	5063783	3484722	0	2868380	1113396	893616	1621436
mar	5565049	3802887	0	3138720	1261732	1012288	1748649
apr	5257001	3706593	0	3061939	1063242	1007592	1687337
may	4791424	3408051	0	2998594	752006	946072	1531352
jun	4108456	2878381	0	2426840	809768	863776	1236502
jul	4710983	3274258	0	2871601	841004	931952	1450356
aug	5236246	3605381	0	2947410	1187829	987304	1634095
sep	4744565	3257892	0	2647670	1106280	882680	1490400
oct	6074826	4198101	0	3455010	1319752	1103080	1930330
nov	5936495	4215852	0	3425120	1204351	1089536	1955873
dec	6514355	4632348	0	3809590	1267572	1218584	2126473
TOTAL	63483289	44280615	0	36762874	13111891	11920544	20184957
average	5290274	3690051	0	3063573	1092658	993379	1682080

Table B.3. Monthly water footprint components for scenario #1B (conventional strategies, low precipition year 2005).

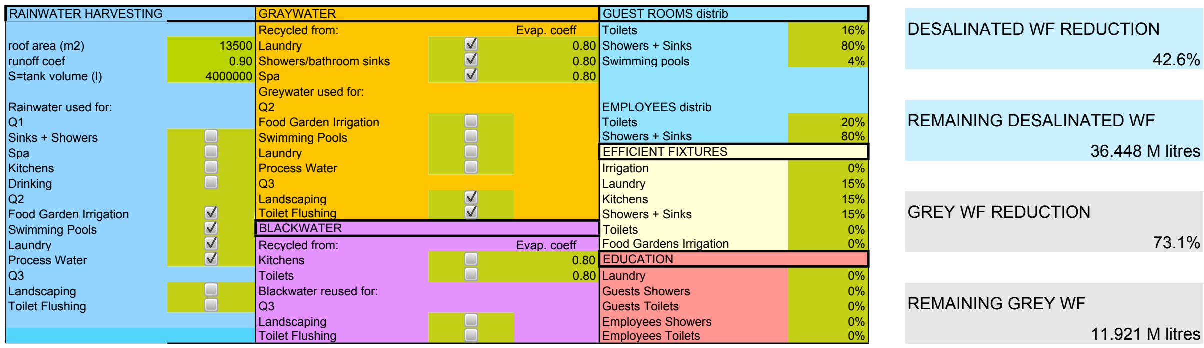

Fig. B.7. Control panel configuration for scenario #1C (conventional strategies, average precipition year 2010).

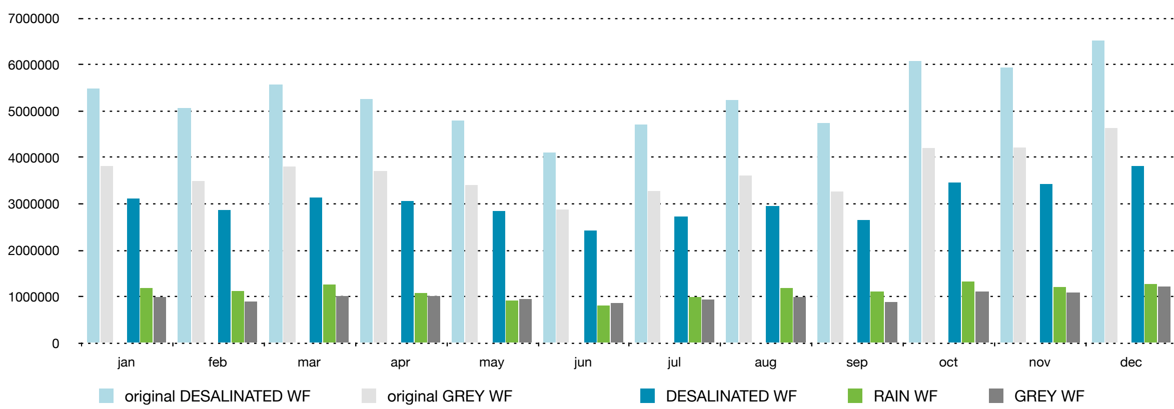

Fig. B.8. Monthly water footprint components for scenario #1C (conventional strategies, average precipition year 2010).

	original DESALINATED WF	original GREY WF		DESALINATED WF	RAIN WF	GREY WF	remaining grey + black water
jan	5480106	3816149	0	3112000	1184960	984064	1772152
feb	5063783	3484722	0	2868380	1113396	893616	1621436
mar	5565049	3802887	0	3138720	1261732	1012288	1748649
apr	5257001	3706593	0	3055570	1069611	1007592	1687337
may	4791424	3408051	0	2838430	912170	946072	1531352
jun	4108456	2878381	0	2426840	809768	863776	1236502
jul	4710983	3274258	0	2723060	989546	931952	1450356
aug	5236246	3605381	0	2947410	1187829	987304	1634095
sep	4744565	3257892	0	2647670	1106280	882680	1490400
oct	6074826	4198101	0	3455010	1319752	1103080	1930330
nov	5936495	4215852	0	3425120	1204351	1089536	1955873
dec	6514355	4632348	0	3809590	1267572	1218584	2126473
TOTAL	63483289	44280615	0	36447800	13426966	11920544	20184957
average	5290274	3690051	0	3037317	1118914	993379	1682080

Table B.4. Monthly water footprint components for scenario #1C (conventional strategies, average precipition year 2010).

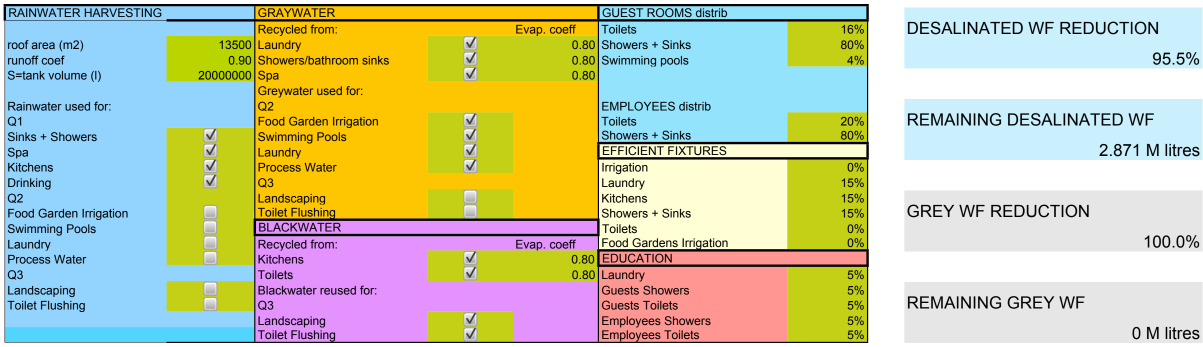

Fig. B.9. Control panel configuration for scenario #2A (all strategies, high precipition year 2006).

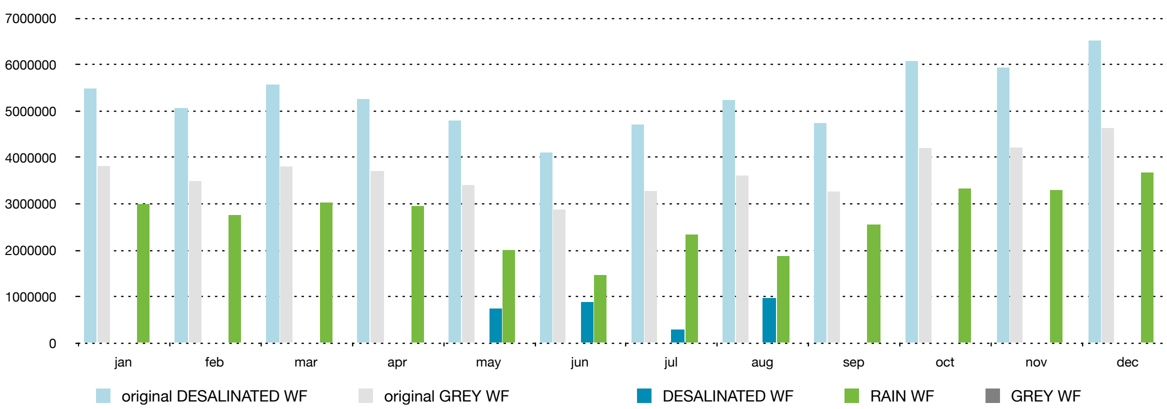

Fig. B.10. Monthly water footprint components for scenario #2A (all strategies, high precipition year 2006).

	original DESALINATED WF	original GREY WF		DESALINATED WF	RAIN WF	GREY WF	remaining grey + black water
jan	5480106	3816149	0	-0	2996400	0	1489607
feb	5063783	3484722	0	-0	2761246	0	1325588
mar	5565049	3802887	0	0	3025534	0	1419143
apr	5257001	3706593	0	0	2946464	0	1548282
may	4791424	3408051	0	737919	2000177	0	1494113
jun	4108456	2878381	0	876698	1467930	0	1232125
jul	4710983	3274258	0	288917	2338875	0	1325325
aug	5236246	3605381	0	967261	1875191	0	1359746
sep	4744565	3257892	0	0	2553524	0	1200830
oct	6074826	4198101	0	0	3328292	-0	1623971
nov	5936495	4215852	0	-0	3297654	0	1751153
dec	6514355	4632348	0	0	3668388	-0	1977277
TOTAL	63483289	44280615	0	2870795	32259675	0	17747160
average	5290274	3690051	0	239233	2688306	0	1478930

Table B.5. Monthly water footprint components for scenario #2A (all strategies, high precipition year 2006).

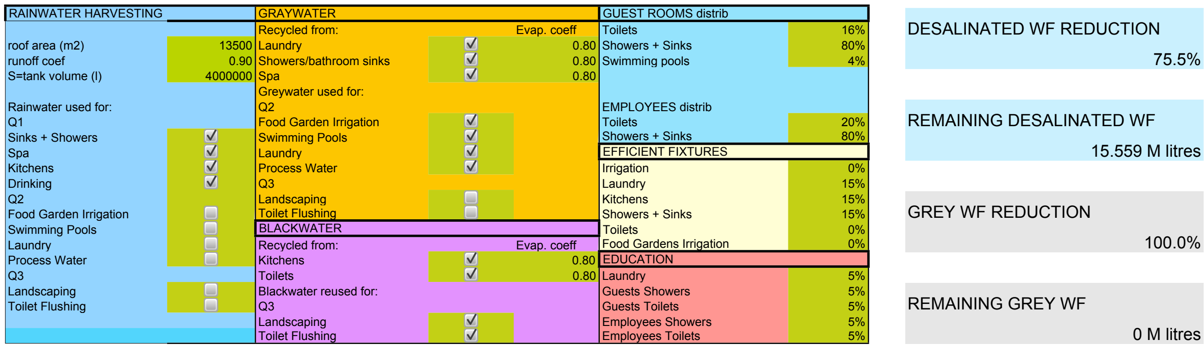

Fig. B.11. Control panel configuration for scenario #2B (all strategies, low precipition year 2005).

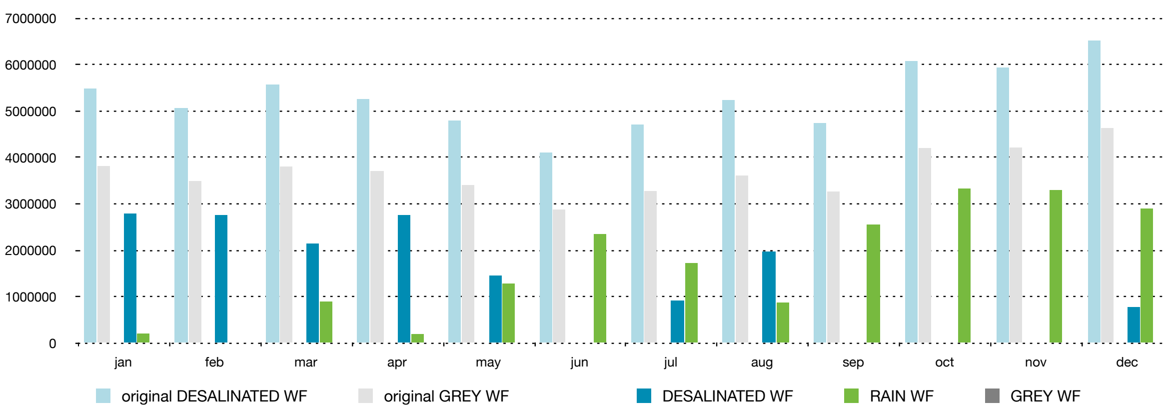

Fig. B.12. Monthly water footprint components for scenario #2B (all strategies, low precipition year 2005).

	original DESALINATED WF	original GREY WF		DESALINATED WF	RAIN WF	GREY WF	remaining grey + black water
jan	5480106	3816149	0	2793495	202905	0	1489607
feb	5063783	3484722	0	2761246	0	0	1325588
mar	5565049	3802887	0	2138584	886950	0	1419143
apr	5257001	3706593	0	2755709	190755	0	1548282
may	4791424	3408051	0	1454184	1283912	0	1494113
jun	4108456	2878381	0	-0	2344628	0	1232125
jul	4710983	3274258	0	911451	1716341	0	1325325
aug	5236246	3605381	0	1971871	870581	0	1359746
sep	4744565	3257892	0	0	2553524	0	1200830
oct	6074826	4198101	0	0	3328292	-0	1623971
nov	5936495	4215852	0	-0	3297654	0	1751153
dec	6514355	4632348	0	772877	2895511	-0	1977277
TOTAL	63483289	44280615	0	15559417	19571053	0	17747160
average	5290274	3690051	0	1296618	1630921	0	1478930

Table B.6. Monthly water footprint components for scenario #2B (all strategies, low precipition year 2005).

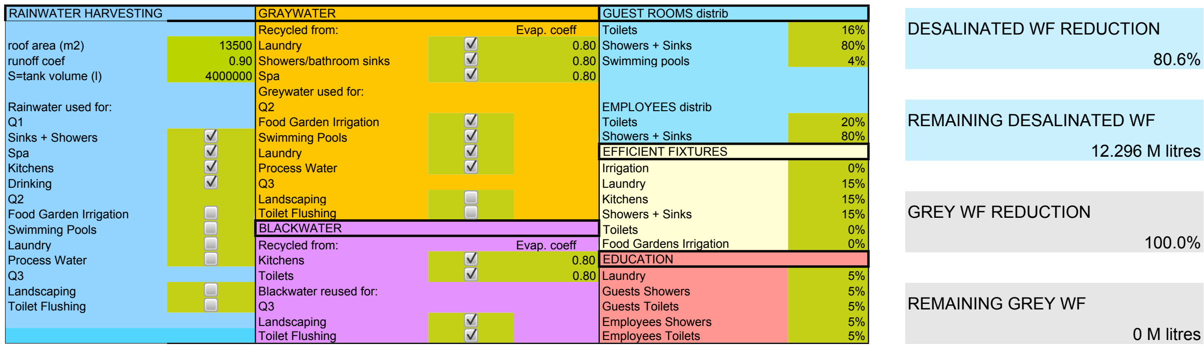

Fig. B.13. Control panel configuration for scenario #2C (all strategies, average precipition year 2010).

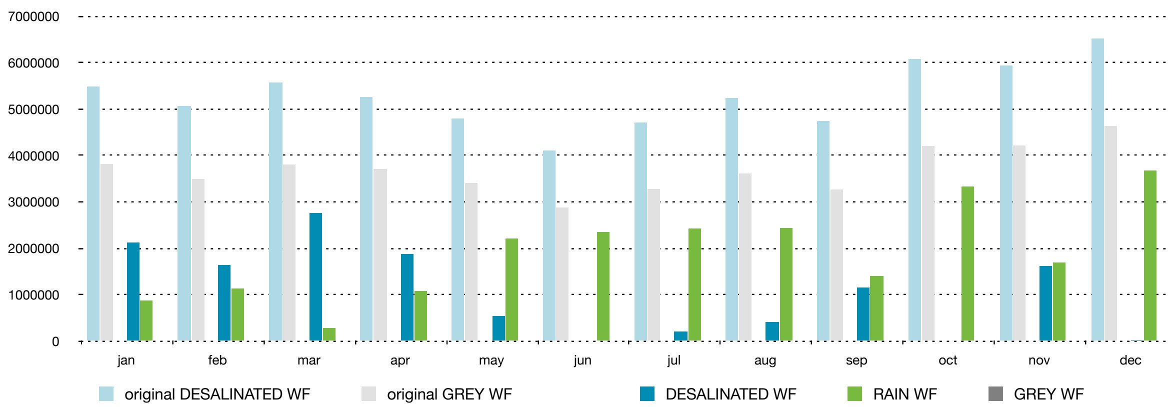

Fig. B.14. Monthly water footprint components for scenario #2C (all strategies, average precipition year 2010).

	original DESALINATED WF	original GREY WF		DESALINATED WF	RAIN WF	GREY WF	remaining grey + black water
jan	5480106	3816149	0	2123809	872591	0	1489607
feb	5063783	3484722	0	1633726	1127520	0	1325588
mar	5565049	3802887	0	2753374	272160	0	1419143
apr	5257001	3706593	0	1873619	1072845	0	1548282
may	4791424	3408051	0	532607	2205489	0	1494113
jun	4108456	2878381	0	-0	2344628	0	1232125
jul	4710983	3274258	0	204035	2423757	0	1325325
aug	5236246	3605381	0	409854	2432598	0	1359746
sep	4744565	3257892	0	1151457	1402067	0	1200830
oct	6074826	4198101	0	0	3328292	-0	1623971
nov	5936495	4215852	0	1612251	1685403	0	1751153
dec	6514355	4632348	0	1086	3667302	-0	1977277
TOTAL	63483289	44280615	0	12295818	22834652	0	17747160
average	5290274	3690051	0	1024652	1902888	0	1478930

Table B.7. Monthly water footprint components for scenario #2C (all strategies, average precipition year 2010).