Construction and operation costs of urban water supply systems: conventional versus alternative dual systems

João de Quinhones Levy[a], Francisco Regateiro[a,*], Joaquim Dias[a]

[a]Department of Civil Engineering, Architecture and Georesources
Instituto Superior Técnico, Lisbon University

Abstract

Agenda 21, the plan of action resultant from the "Earth Summit" (Rio Conference on Environment and Development) requested UN states to implement new and alternative water supply sources, including water recycling. Despite the obvious benefits on sustainability and ecological preservation resulting from water recycling, the paradigm in design and construction of water supply systems has not changed. Considering that decision-making related to water supply infrastructures is mostly driven by financial criteria, clarification is needed about the implications of using reclaimed water for the construction and operating costs. Urban water recycling implies the construction of a dual water supply system with two distribution networks – one for primary uses and the other for secondary uses. We investigate the cost implications of reclaiming water to meet the secondary water demand. We contemplate two alternative municipal management models: integrated, and with water purchase. We propose a framework for estimating construction and operation costs of conventional and dual municipal supply systems, and demonstrate through a case study that a dual system may be less costly than a conventional system from a specific number of inhabitants upwards.

Keywords: dual water supply systems; engineering and operating costs; municipal water management; urban water recycling; sustainable development.

1. Introduction

One bad presage interconnects today with the concerns about human living conditions, education, and equity. The possibility that our inertia to change the current path to development makes us miss the path to sustainability (Poff et al., 2010; WWAP, 2012; Haines et al., 2012). Like a paradox of an inexorable human journey towards societies that are irreversibly incompatible with the very ecosystem that is indispensable to human existence and cohabitation – the paradox of “non-recyclable” human societies.

Seawater and freshwater are vital to earth’s health. Safe water and drinking water are vital to human’s health. To get on a path to sustainable development, besides preserving freshwater resources (Moroglu and Yazgan, 2008; Mylopoulos and Kolokytha, 2008), also safe alternative water sources must be achieved (Bakker, 2012; Gleick, 2003; UNESCO, 2010).

In order to face future water challenges, we need to: (1) control and account true costs of freshwater captation and wastewater discharge; (2) preserve and monitor water quality of natural sources (surface and groundwater) and water provided to users; and (3) use efficiently different water qualities according to different purposes, including water recycling (Anderson, 2003; Domènech et al., 2013; Grant et al., 2012; Hermanowicz, 2008; Hochstrat et al., 2008; Ives, 1970; Sala and Serra, 2004).

There is knowledge about pollution and human health risks that supports the benefits of water recycling (Asano et al., 2007; Chen et al., 2012a; Kalavrouziotis and Apostolopoulos, 2007; Li et al., 2009; Miller, 2006; Schäfer et al., 2005; Toze, 2006). Reclaimed water should be regarded as an alternative water source, even where there is presently no shortage of “cheap” freshwater.

In 1958, the United Nations Economic and Social Council proclaimed the use of low quality water for purposes that can tolerate a lower grade in case of scarcity (Okun, 1996). Agenda 21(UN, 1992), one of the outcomes of the “Earth Summit” includes many references to water reuse. Today, the UN reiterate all past commitment sand recognize the necessity of "promoting water efficiency, wastewater treatment and the use of wastewater as a resource, particularly in expanding urban areas." (UN, 2012).

There is a wealth of knowledge from various nations and regions on water recycling. Africa (Lahnsteiner and Lempert, 2007), Brazil (Ghisi and Oliveira, 2007), China (Chang and Ma, 2012; Tang et al., 2006; Yi et al., 2011), European and Mediterranean countries (Angelakis and Bontoux, 2001; Bixioet al., 2006; EEA, 2012), Germany (Nolde, 2005), Japan (Asano et al., 1996), Middle East (Friedler et al., 2006; Mourad et al., 2011), Portugal (APE, 2012; Coutinho, 2009; Levy, 2008; MAOTDR, 2007; Monte and Albuquerque, 2010; Paiva, 2008), and UK (Hills et al., 2002; Memon et al., 2005) are some examples. Specific countries are especially active at the forefront of water recycling. The concept of dual systems to separate high quality and low quality water supply is known in USA for a long time. The first dual system was installed in Grand Canyon Village in 1926, and the oldest standards for water reuse were developed in California, in 1978 (Okun, 1996; Trussell et al., 2012). The US Environmental Protection Agency provides updated documentation about water reuse (EPA, 2012).

Australia is a precursor nation that accumulates a vast experience, strongly motivated by water scarcity (Anderson, 2006; DHGWA, 2011; Lake and Bond, 2007; Mainali et al., 2013; Radcliffe, 2006; Simpson and Stratton, 2011; Willis et al., 2011; WSAA, 2004). In this country, where community acceptance of recycling is high for toilet flushing and gardening, experience shows that use of reclaimed water for toilet flushing and lawn gardening could achieve water savings from 30% to 50% of total household water usage (Muthukumaran et al., 2011). In fact, reclaimed water for toilet flushing, garden watering and car washing is considered as "business as usual" in some research where reclaimed water for household laundry is investigated (Mainali et al., 2013). In Israel, a high proportion of participants in a study revealed concern with "water saving", "minimization of importing water from abroad'', "infrastructure cost saving", and ''environmental improvement", and supported medium contact reuse options, such as sidewalk landscaping (95%), domestic WC flushing (85%) and fire fighting (96%) (Friedler et al., 2006).

Public willingness to use reclaimed water depends on public perception (Haddad et al., 2009; Hartley, 2006). Perception and acceptance is critical for the success of municipal water reclamation projects (Chang and Ma, 2012; Hurlimann et al., 2008; Kandiah et al., 2013; Poet al., 2003). Hurlimann et al.(2008) concluded that reclaimed water retailers, reclaimed water authorities and policy makers should be aware that communities' satisfaction with water recycling depends on increasing trust, perception of fairness, and positive quality perceptions, and on decreasing perception of risk.

Available economic assessments confirm the potential of water reuse (Heinz et al., 2011; Hernández et al., 2006; Listowski et al., 2013). The same occurs with environmental assessments related to wastewater treatment plants (WWTPs) and water supply plans (Chen et al., 2012b; Corominas et al., 2013; Lundie et al., 2004; Meneses et al.,2010; Muñoz et al., 2010). Specifically, life cycle assessments (LCAs) for WWTPs with tertiary treatment (to provide reclaimed water) show that the addition of tertiary treatment in WWTPs increases the environmental impact considerably less than the environmental impact of other water production methods (Chen et al., 2012b; Meneses et al., 2010). Other studies conclude that water recycling has a high potential of offsetting carbon footprint and recognize this alternative as the most environmentally friendly (Mo and Zhang, 2012).

OECD corroborates the arguments for water reuse: "From an environmental perspective, water reuse can reduce demand for freshwater resources, diversify water sources and enhance reliability of access to resource; it can reduce volume of wastewater discharged into the environment. Decentralized systems can reduce energy required to transport water from the point of production to the point of use; and reduce greenhouse gas emissions (due to energy savings)" (Leflaive, 2009). Nowadays, decentralization and satellite water systems are already being considered by a number of national and local authorities (Libralato et al., 2012; Trussell et al., 2012).

According to the previous paragraphs, the traditional concept of water system is to be altered, as WWTPs will start to be seen as "water factories" that supply some of the water for types of use that do not require high quality water (Al-Jayyousi, 2003; Kalavrouziotis and Apostolopoulos, 2007; Rygaard et al., 2011). We should foresee a future where the utilisation of reclaimed water will become generalised.

Dual water supply systems provide higher and lower quality water separately (Grigg et al., 2013; Tang et al., 2007; Trussell et al., 2012; WSAA, 2004). Many dual systems are operating (Okun, 2000, 1996).Since most of the water supplied to residences is used for activities other than human ingestion or direct contact, dual systems should be increasingly adopted in urban water scenarios (Grayman et al., 2012; Rygaard et al., 2011). In the scope of this paper, a dual system is a municipal water distribution system that provides drinking water and reclaimed water for urban purposes (

Figure **1 – Water recycling for domestic secondary uses.**

). It comprises the construction of two distribution networks – one for primary uses and the other for secondary uses. The reclaimed water corresponds to treated grey water; therefore, the WWTP must be equipped with tertiary treatment processes adequate for the planned secondary uses.

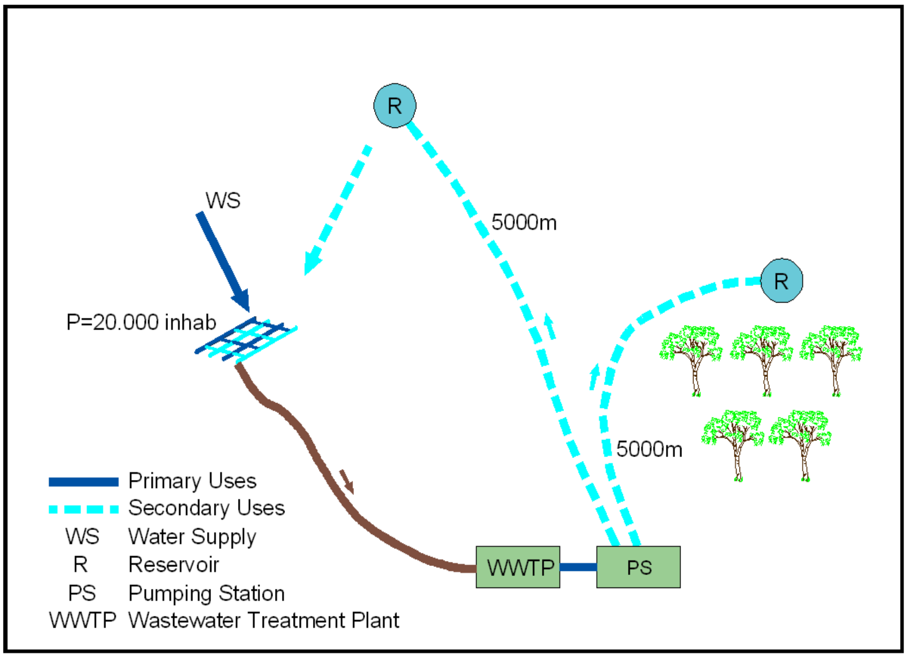

Figure 1 – Water recycling for domestic secondary uses.

According to Almeida et al. (2006), 75% of non-lost urban water supplied in Portugal is consumed in domestic uses. The remaining percentage, excluding the industrial component, corresponds to public (10%) and commercial uses (15%). In the same study, the analysis of how domestic consumptions are distributed showed that 28% of Portuguese domestic water is used for toilet flushes and 10% for outside watering. In other words, 38% of domestic water uses do not require drinking water. Additionally, some of the uses in commercial and public categories also do not require high quality water, such as street cleaning or public gardens watering. As an underestimating value, we will assume in this work that one third of the urban water demand is associated with secondary uses, which consequently may be supplied by low quality water.

In Portugal, there are two prevalent management models. The first corresponds to the existence of a unique management entity, which is responsible for the whole process – from captation of freshwater to discharge of effluents. In the second model, the entity that distributes the water to clients and treats the wastewater, acquires the freshwater from a supplier, to whom it pays a tariff T_p. The average value of T_p in Portugal is 0.55 $€\, m^{-3}$(ERSAR, 2012).

A frequent argument against reclaimed water concerns the costs of required infrastructures (Hochstrat et al., 2008), which correspond to a second water distribution network in the urban context plus the extension of the wastewater treatment processes, pumping, storing and pipe systems (Levy, 2008; Paiva, 2008). However, the idea that recycling water and, consequently, that a dual system is more expensive than a conventional system needs to be analysed because the reduction in the cost of acquisition, or captation, and treatment of freshwater to supply secondary demand may offset the cost of the second network.

Financing and managing are critical issues in the development of municipal water reclamation projects (Schäfer et al., 2005). Leflaive (2009) considers that alternative systems may be cost effective, even in cases where central infrastructure is already in place, and states that investment and operating costs constitute an important issue when discussion alternative systems. Moreover, Leflaive asserts that a combination of centrally provided and alternative water systems might be the most practical approach to fit all the different functions of urban water services; and asks for further development on technical, regulatory, economic and financial aspects for incorporating alternative water systems.

Our goal is to propose a basis to estimate construction and operation costs of dual and conventional systems for both management models. Within this framework, we want to be able to compare costs between conventional and dual systems. Concerning the organization of the rest of this text, section 2 contains our characterizations of conventional water supply system and dual water supply system. In section 3, we formulate the framework for the cost assessment within both management models. In section 4, we use this framework to assess conventional and dual systems' costs for a realistic implementation scenario; and we discuss the costs' comparison. Section 5 includes the conclusions and final remarks.

2. Water Supply Systems

Figure 1 and

Figure 2depict the configuration of a conventional water system and of a dual water system, respectively. It is included in both the freshwater captation. However, the element related to captation is not mandatory because freshwater may be purchased.

A conventional system is typically composed by (Figure 1): water treatment plant (WTP), captation element, two reservoirs, pipe system (represented by a dashed line), pumping station, and distribution network.

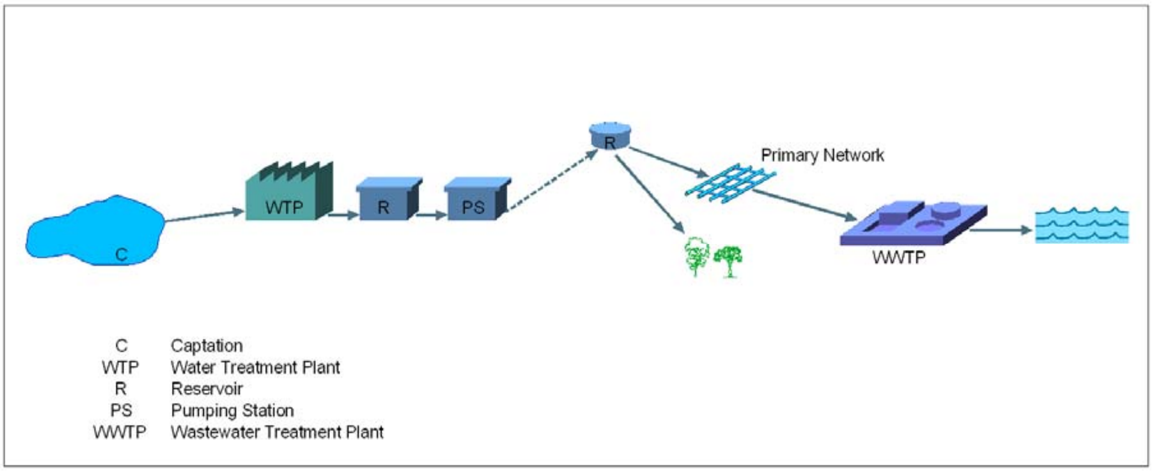

Figure 1 – Conventional water supply system.

A dual system typically includes all the elements that are present in a conventional system, which provide the primary water demand. Additionally, it includes five more elements that provide the secondary water demand (

Figure 2): reservoir, pipe system (represented by a dashed line), pumping station, distribution network and tertiary treatment element inside the water treatment plant (WWTP).

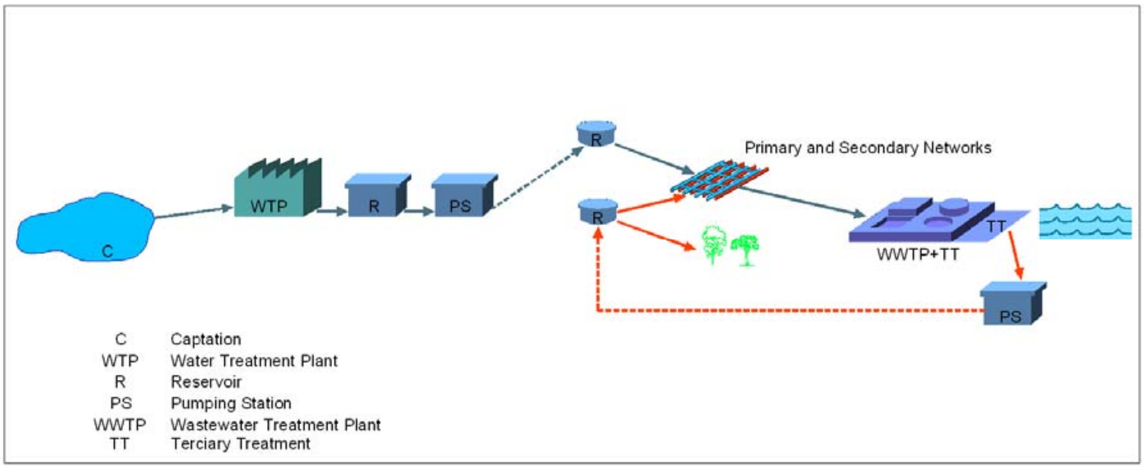

Figure 2 – Dual water supply system.

Each row in

Element type	Construction cost I_0 (€ inhab^{-1})	Annual operating cost C_{op} (%)	Amortisation period A_p (years)
Water treatment plant (WTP)	$392.927\ P^{-0.188}$	10	20
Captation system	$235.986\ P^{-0.388}\ h^{0.287}$	9	20
Reservoir	$31.624\ P^{-0.006}$	4	20
Pipe system	$0.838\ P^{-0.488}\ L$	4	40
Pumping station	$117.993\ P^{-0.388}\ h^{0.287}$	9	10
Distribution network	$1010.385\ P^{-0.239}$	5	40
Tertiary treatment component	$949.476\ P^{-0.370}$	10	20

Table 1 corresponds to a distinct type of infrastructural element that is present in water supply systems. The element type of the last row – tertiary treatment (TT) – is the only that is present exclusively in dual systems. We separate the TT from its container element type – the wastewater treatment plant (WWTP) – because the cost of WWTP without TT is equivalent in both types of system and, consequently, WWTP is omitted in

Element type	Construction cost I_0 (€ inhab^{-1})	Annual operating cost C_{op} (%)	Amortisation period A_P (years)
Water treatment plant (WTP)	$392.927\ P^{-0.188}$	10	20
Captation system	$235.986\ P^{-0.388}\ h^{0.287}$	9	20
Reservoir	$31.624\ P^{-0.006}$	4	20
Pipe system	$0.838\ P^{-0.488}\ l$	4	40
Pumping station	$117.993\ P^{-0.388}\ h^{0.287}$	9	10
Distribution network	$1010.385\ P^{-0.339}$	5	40
Tertiary treatment component	$949.476\ P^{-0.370}$	10	20

Table 1.

Each element type has a *per capita* construction cost (or initial investment) I_0, which depends on the size of the population (or number of inhabitants) P (Lencastre, 1995; Levy, 2008; Paiva, 2008). The I_0 of some elements depends on a particular quantitative parameter, such as a pipe length l, or a pumping height (or depth) h. The expressions for calculating I_0 are present in the second column of

Element type	Construction cost I_0 (€ inhab^{-1})	Annual operating cost C_{op} (%)	Amortisation period A_P (years)
Water treatment plant (WTP)	$392.927\ P^{-0.188}$	10	20
Captation system	$235.986\ P^{-0.388}\ h^{0.287}$	9	20
Reservoir	$31.624\ P^{-0.006}$	4	20
Pipe system	$0.838\ P^{-0.488}\ l$	4	40
Pumping station	$117.993\ P^{-0.388}\ h^{0.287}$	9	10
Distribution network	$1010.385\ P^{-0.339}$	5	40
Tertiary treatment component	$949.476\ P^{-0.370}$	10	20

Table 1. We may see from the expressions that the value of I_0 decreases when the population P increases.

The third column of

Element type	Construction cost I_0 (€ inhab^{-1})	Annual operating cost C_{op} (%)	Amortisation period A_p (years)
Water treatment plant (WTP)	$392.927\ P^{-0.188}$	10	20
Captation system	$235.986\ P^{-0.388}\ h^{0.287}$	9	20
Reservoir	$31.624\ P^{-0.006}$	4	20
Pipe system	$0.838\ P^{-0.488}\ L$	4	40
Pumping station	$117.993\ P^{-0.388}\ h^{0.287}$	9	10
Distribution network	$1010.385\ P^{-0.339}$	5	40
Tertiary treatment component	$949.476\ P^{-0.570}$	10	20

Table 1 contains the annual operating cost C_{op} of each element type, which is presented in the form of a percentage of I_0. The fourth column contains the number of years in the amortization period A_p of each element type.

Element type	Construction cost I_0 (€ inhab^{-1})	Annual operating cost C_{op} (%)	Amortisation period A_p (years)
Water treatment plant (WTP)	$392.927\ P^{-0.188}$	10	20
Captation system	$235.986\ P^{-0.388}\ h^{0.287}$	9	20
Reservoir	$31.624\ P^{-0.006}$	4	20
Pipe system	$0.838\ P^{-0.488}\ L$	4	40
Pumping station	$117.993\ P^{-0.388}\ h^{0.287}$	9	10
Distribution network	$1010.385\ P^{-0.339}$	5	40
Tertiary treatment component	$949.476\ P^{-0.570}$	10	20

Table 1 – Costs per element type.

In the case of a dual system, we have to confirm that the available reclaimed water is sufficient to fulfil the secondary water needs. To answer that, we have to compare the final WWTP effluent E with the secondary consumption demand S, such that $E \geq S$. E is calculated according to (1), taking into account the affluence coefficient to the sewage network c and the consumption of water by the WWTP itself p. S is calculated according to (2).

$$E = P\,Q_I c\,(1 - p) \tag{1}$$

$$S = S_s\,P\,Q_I \tag{2}$$

where

E = Final WWTP effluent, $\mathrm{L\,days^{-1}}$;

P = Number of inhabitants

Q_I = Individual water consumption, $\mathrm{L\ inhab^{-1} days^{-1}}$;

c = Affluence coefficient to the network ($c \in [0, 1]$);

p = Percentage of use of the affluent in the WWTP ($p \in [0, 1]$);

S_s = Secondary consumption share ($S_s \in [0, 1]$).

Substituting E with (1) and S with (2) in $E \geq S$, and eliminating $P\,Q_I$ from both sides of the resulting inequality, we get the constraint in (3).

$$c\,(1 - p) \geq S_s \tag{3}$$

We know that the affluence coefficient c varies between 0.6 and 0.8, and that the value of water consumed in the WWTP p does not exceed 20% of the affluent flow. Considering the most unfavourable scenario, where $c = 0.6$ and $p = 0.2$, we use (3) to conclude that there will be sufficient supply if $S_s \leq 0.48$. This is true because we assume that the secondary consumption share S_s corresponds to one third of total demand. Based on this assumption, we conclude that the reclaimed water provided by the WWTP is sufficient to supply the secondary demand.

3. Cost Assessment Method

We detail here two economic models: (1) model that includes the captation of water (integrated model), where the management entity is responsible for the whole supply process, and (2) model with water purchase, where the management entity acquires the water and pays the correspondent tariff. Comparing between the two, on one hand, since a system in the second model has less elements, it will have a lower construction cost than an equivalent system in the first model; on the other hand, it will have an adding cost corresponding to primary water buying, which does not exist in the first model.

Investments in infrastructures are typically financed with external funds that are amortised annually during an amortization period. In fact, this will also be valid for the next model, however considering then a smaller set of elements. Therefore, for each element, we start with the interest rate r and the amortization period A_p of the loan, and we calculate the annual amortisation factor f using (4).

$$f = \frac{r\,(1+r)^{A_p}}{(1+r)^{A_p} - 1} \tag{4}$$

The multiplication of the annual amortisation factor f by the construction cost I_0 gives the annual construction cost of an element, i.e., the annual cost of the amortization of the investment. Since we consider in

Element type	Construction cost I_0 (€ inhab[-1])	Annual operating cost C_{op} (%)	Amortisation period A_p (years)
Water treatment plant (WTP)	$392.927\ P^{-0.188}$	10	20
Captation system	$235.986\ P^{-0.388}\ h^{0.287}$	9	20
Reservoir	$31.624\ P^{-0.006}$	4	20
Pipe system	$0.838\ P^{-0.488}\ L$	4	40
Pumping station	$117.993\ P^{-0.388}\ h^{0.287}$	9	10
Distribution network	$1010.385\ P^{-0.339}$	5	40
Tertiary treatment component	$949.476\ P^{-0.370}$	10	20

Table 1 the annual operating cost C_{op} as a percentage of the construction cost I_0, the actual value is obtained through the multiplication of C_{op} by I_0.

3.1. Integrated Model

In the integrated model, the management entity is responsible for the whole water supply process, from captation of water until discharge of effluents into the receiving environment. Therefore, the annual cost of a system corresponds to the sum of the annual construction costs of its elements with the annual operating costs of its elements, according to (5).

$$C_A = \sum_{n=1}^{N} f_n I_{0_n} + \sum_{n=1}^{N} C_{op_n} I_{0_n} \tag{5}$$

where

C_A = Annual cost, € years^{-1};

f = Amortisation factor, %;

I_0 = Initial investment, €;

C_{op} = Annual operating cost, %;

n= Element index.

In fact, we will calculate the annual cost using (5) only when we consider a conventional system. In the case of a dual system, we formulate its annual cost $C_{A_{DS}}$ according to (6), where we separate two parcels that are, per si, calculated using (5). C_{A_P} corresponds to the cost of elements for the primary supply and C_{A_S} corresponds to the cost of elements for the secondary supply. This separation allows us to use different populations for calculating C_{A_P} and C_{A_S}, according to the respective consumption shares.

$$C_{A_{DS}} = C_{A_P} + C_{A_S} \tag{6}$$

3.2. Water Purchasing Model

The model that includes purchasing water reflects the situation where the management entity purchases water from a water seller entity. This water supplier is responsible for water captation, treatment, and channelling into the tanks/reservoirs of the first management entity, typically a municipality, which then distributes it to the population.

The management entity pays an amount calculated as a tariff T_p to the seller entity. The question that should arise with this model is whether it is financially advantageous for the management entity to have a dual system in order to acquire less water. Will the reduction in the cost of acquiring freshwater in a dual system offset the cost of the secondary system? We will analyse that in sections 4.3 and 5.

To calculate the annual cost of a conventional system within this model, we have just to introduce in (5) a new parcel related to the tariff T_p. As shown in (7), we multiply T_p by the number of days in a year and the daily consumption of primary water Q_p . Q_p is calculated, as shown in (8), using the population P and the daily consumption per inhabitant Q_I. Because there is no water captation involved in this model, the number of elements is reduced when compared to the integrated model.

$$C_A^t = \sum_{n=1}^{N} f_n I_{0_n} + \sum_{n=1}^{N} C_{op_n} I_{0_n} + 365\, T_p Q_p \tag{7}$$

$$Q_p = \frac{Q_I P}{1000} \tag{8}$$

where

C_A = Annual cost, € years^{-1};

f = Amortisation factor, %;

I_0 = Initial investment, €;

C_{op} = Annual operating cost, %;

T_p = Primary water acquisition tariff, € m^{-3};

Q_p = Water consumption, m^{3}days^{-1};

Q_I = Individual water consumption, L inhab^{-1}days^{-1};

P = Number of inhabitants;

n= Element index.

Finally, we use (6) to calculate the annual cost of a dual system with purchase of water, however using (7) to calculate the first parcel, i.e., the primary supply cost. We use (9) to clarify this consideration about the reuse of (6), denoting the cost related to primary supply by $C_{A_P}^{i}$, which is calculated using (7), and the cost related to secondary supply by C_{A_S}, which is calculated using (5).

$$C_{A_{DS}}^{i} = C_{A_P}^{i} + C_{A_S} \tag{9}$$

4. Costs Assessment and Comparison

In the scope of each of the two management models that we presented in sections 3.1 and 3.2, we first evaluate the cost of a conventional system and of a dual system. Afterwards, we analyse the difference between these costs for different population's sizes. For these calculi, we assume that the interest rate r for any loan is 5%, and that the water consumed daily by person each day Q_I is 200 litres.

4.1. Integrated Model

Starting with the assessment of a conventional system with primary water captation, we present in Table 2 its elements and the respective dimensioning values. We set the following values: captation depth for the captation element, length of pipe for the pipe system, and pumping height for the pumping station.

Element	Dimensioning value (m)
Water Treatment Plant (WTP)	-
Captation Element	170
Reservoir 1	-
Reservoir 2	-
Pipe System	7 000
Pumping Station	60

Distribution Network	-

Table 2 – Dimensioned elements for a conventional system with water captation.

After applying the formula (5), Table 3 shows in the last column the resulting annual costs of a conventional system with water captation for a population value ranging from 5000 to 300000.

Population	Average daily flow (m^3)	Annual amortization cost (€)	Annual operation cost (€)	Total annual cost (€)
5 000	1 000	153 652	136 834	290 486
10 000	2 000	260 962	232 378	493 340
20 000	4 000	448 301	398 126	846 428
30 000	6 000	618 395	547 654	1 166 049
40 000	8 000	778 675	687 864	1 466 538
50 000	10 000	932 261	821 680	1 753 941
100 000	20 000	1 641 898	1 434 636	3 076 534
150 000	30 000	2 296 873	1 994 521	4 291 393
200 000	40 000	2 920 377	2 523 599	5 443 976
250 000	50 000	3 522 258	3 031 398	6 553 656
300 000	60 000	4 107 897	3 523 152	7 631 049

Table 3 – Annual costs per population of a conventional system with water captation.

Moving next to the assessment of a dual system, we present in Table 4 the system's elements and the respective dimensioning values. We now set the following values: captation depth for the captation element, length of pipe for the two pipe systems, and pumping heights for the two pumping stations.

Primary supply		Secondary supply	
Element	Dimensioning value (m)	Element	Dimensioning value (m)
Water Treatment Plant (WTP)	-	Reservoir	-
Captation Element	170	Pipe System 2	5 000
Reservoir 1	-	Pumping Station 2	30
Reservoir 2	-	Distribution Network 2	-
Pipe System 1	7 000	Tertiary treatment	-

Pumping Station 1	60
Distribution Network 1	-

Table 4 – Dimensioned elements for a dual system with water captation.

After using (6), considering 70% share for primary uses and 30% share for secondary uses, Table 5 contains in the last column the annual cost for the considered dual system in a water captation scenario. The different rows correspond to different population ranging from 5000 to 300000.

Population	Average primary daily flow (m^3)	Average secondary daily flow (m^3)	Annual amortization cost (€)	Annual operation cost (€)	Total annual cost (€)
5 000	700	300	167 026	149 651	316 677
10 000	1 400	600	277 587	248 367	525 954
20 000	2 800	1 200	466 565	415 896	882 461
30 000	4 200	1 800	635 487	564 601	1 200 088
40 000	5 600	2 400	793 117	702 633	1 495 749
50 000	7 000	3 000	943 100	833 408	1 776 508
100 000	14 000	6 000	1 627 078	1 424 344	3 051 422
150 000	21 000	9 000	2 249 908	1 956 558	4 206 466
200 000	28 000	12 000	2 837 936	2 455 149	5 293 084
250 000	35 000	15 000	3 402 236	2 930 726	6 332 962
300 000	42 000	18 000	3 948 818	3 389 071	7 337 889

Table 5 – Annual cost per population of a dual system with water captation.

The graph in

Figure 3 shows in the ordinate the relative difference of total annual cost between conventional and dual, given by $(trad\_cost - dual\_cost) / trad\_cost \times 100$, according to the population in the abscissa. This difference is positive from near 76000 upwards, i.e., the dual system becomes financially advantageous above 76000 inhabitants.

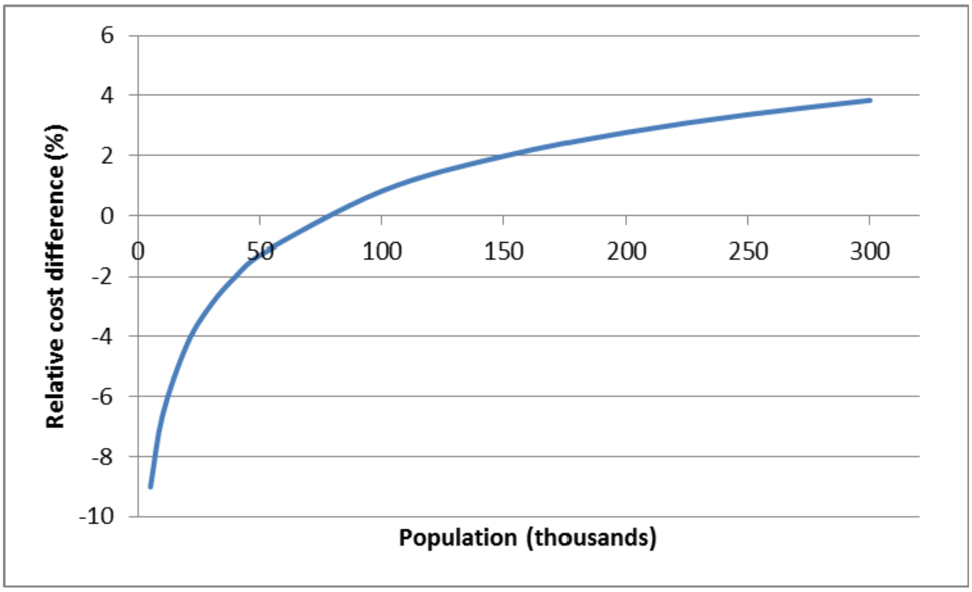

Figure 3 – Relative cost difference between conventional and dual system with water captation.

4.2. Water Purchasing Model

We now consider a system where the freshwater is purchased with a tariff T_p of 0.55(€ m^{-3}). Considering a conventional system, this will have two elements: reservoir and distribution network. We calculate the annual cost of this system using (8). The last column of Table 6 presents the annual cost..

Population	Annual amortization cost (€)	Annual operation cost (€)	Purchase cost (€)	Total annual cost (€)
5 000	50 507	38 999	200 750	290 256
10 000	89 173	67 875	401 500	558 549
20 000	124 645	94 024	602 250	820 919
30 000	158 251	118 581	803 000	1 079 833
40 000	221 904	164 660	1 204 500	1 591 064
50 000	340 678	249 544	2 007 500	2 597 721
100 000	612 653	440 499	4 015 000	5 068 152
150 000	866 049	615 647	6 022 500	7 504 196
200 000	1 108 586	781 564	8 030 000	9 920 149
250 000	1 343 597	941 088	10 037 500	12 322 185
300 000	1 572 923	1 095 786	12 045 000	14 713 709

Table 6 – Annual costs per population of a conventional system with water purchase.

Table 7 contains the composing elements and the respective dimensioning values if we consider a dual system. We set the length of pipe for the pipe system and the pumping height for the pumping station.

Primary supply		Secondary supply	
Element	Dimensioning value (m)	Element	Dimensioning value (m)
Reservoir 1	-	Reservoir 2	-
Distribution Network 1	-	Pipe System	5 000
		Pumping Station	30
		Distribution Network 2	-
		Tertiary treatment	-

Table 7 – Dimensioned elements for a dual system with primary water purchase.

Finally, we use (9) to determine the cost of a dual system, considering a 70% (30%) share for primary (secondary) consumption.

Population	Annual amortization cost (€)	Annual operation cost (€)	Purchase cost (€)	Total annual cost (€)
5 000	87 268	74 450	140 525	302 243
10 000	145 686	122 632	281 050	549 368
20 000	197 433	164 722	421 575	783 730
30 000	245 416	203 378	562 100	1 010 894
40 000	334 391	274 313	843 150	1 451 854
50 000	496 049	401 334	1 405 250	2 302 633
100 000	854 212	677 037	2 810 500	4 341 749
150 000	1 179 267	922 660	4 215 750	6 317 677
200 000	1 485 482	1 151 192	5 621 000	8 257 675
250 000	1 778 861	1 368 097	7 026 250	10 173 208
300 000	2 062 665	1 576 335	8 431 500	12 070 501

Table 8 contains in the last column the resulting annual cost, where the rows correspond to different population ranging from 5000 to 300000.

Population	Annual amortization cost (€)	Annual operation cost (€)	Purchase cost (€)	Total annual cost (€)
5 000	87 268	74 450	140 525	302 243
10 000	145 686	122 632	281 050	549 368
20 000	197 433	164 722	421 575	783 730
30 000	245 416	203 378	562 100	1 010 894
40 000	334 391	274 313	843 150	1 451 854
50 000	496 049	401 334	1 405 250	2 302 633
100 000	854 212	677 037	2 810 500	4 341 749
150 000	1 179 267	922 660	4 215 750	6 317 677
200 000	1 485 482	1 151 192	5 621 000	8 257 675
250 000	1 778 861	1 368 097	7 026 250	10 173 208
300 000	2 062 665	1 576 335	8 431 500	12 070 501

Table 8 – Annual cost per population of a dual system with primary water purchase.

As the graph in

Figure 3 showed for the previous situation with water captation, the graph in Figure 4 shows the relative difference between total annual cost off conventional system and dual system when the water is purchased. This value is positive from near 8000 inhabitants upwards, i.e., the dual system becomes financially advantageous starting from that threshold.

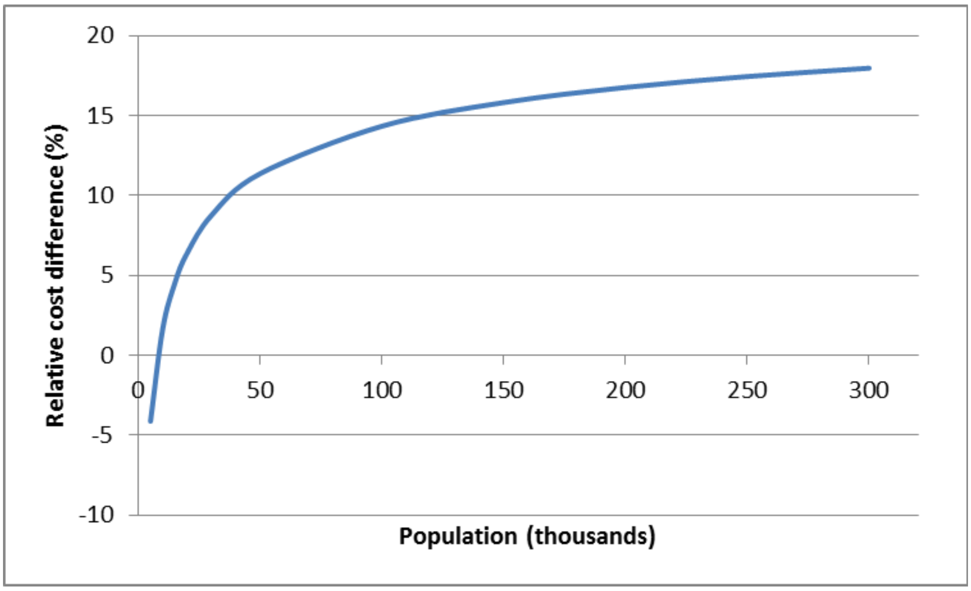

Figure 4 – Relative cost difference between conventional and dual system with water purchase.

4.3. **Discussion**

Considering the graphs in

Figure 3 and Figure 4, we conclude that, within the scope of the created implementation scenario, a dual system becomes cheaper than a conventional system when the population exceeds a certain threshold. As far as our realistic scenario may represent, we obtain evidences that dual systems are financially competitive. Besides the cost reduction, a dual system is eco-friendlier. Considering a population with 100000 inhabitants, the 30% of water saving represents 6000 m^3 of freshwater not removed from the natural environment. This saving will be of utmost importance when there is water scarcity or water captation difficulties.

The graph in Figure 5 allows us to confirm, in a purchasing water scenario, when the dual system starts to compensate financially over the conventional system for different tariffs and populations. The threshold line contains the points where the elimination of the cost relative to water acquisition for secondary uses (in the dual system) offsets the cost of the secondary infrastructure, i.e., above the line, a dual system will be financially advantageous over a conventional system.

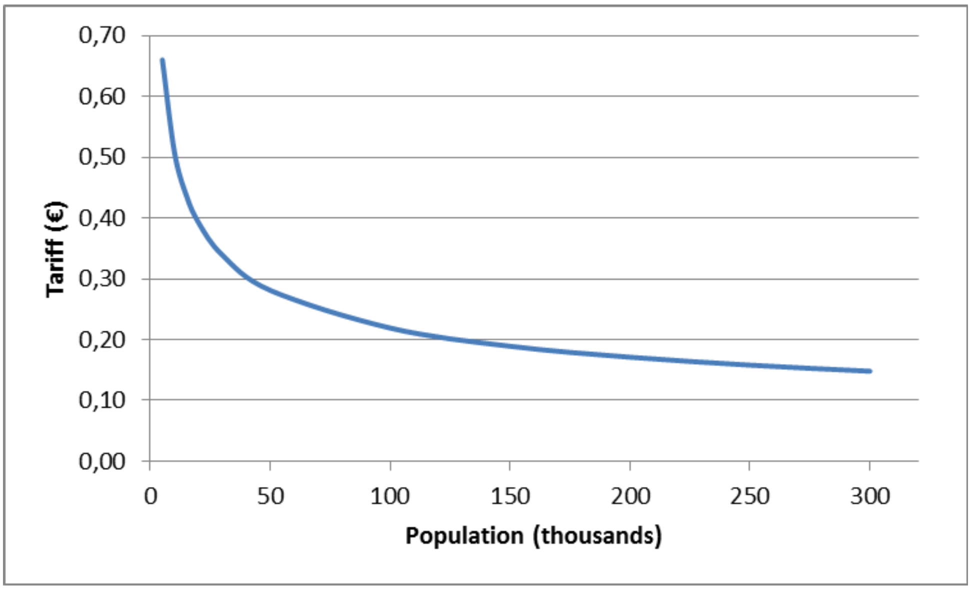

Figure 5 - Cost reduction threshold between conventional and dual system.

5. Conclusion

There are obvious benefits related to the preservation (in quantity and quality) of freshwater resources resulting from water recycling. Recycling is an adequate option to put into practice the UN recommendation to implement new alternative water supply sources. We considered here a dual system as a water supply system that provides two distribution networks, one for drinking water and the other for safe reclaimed water. The widespread implementation of dual systems in urban context will have a very positive impact on the environment because consumption of water from traditional sources will be reduced by around one-third.

The construction of two distribution networks and the extension of the WWTP with a tertiary treatment entail additional construction and operating costs. With the purpose of elucidating about the financial viability of dual systems, we formulated a cost assessment framework. Using this framework, we were able to confirm the financial potential of dual systems over conventional systems. Two management models were taken into consideration: one where the management entity is responsible for water captation and another where it acquires the water from a supplier.

We concluded that, when water is purchased at the considered tariff, cost reduction due to implementing a dual system starts from a population of approximately 8000 upwards. With water captation, this population threshold is approximately 80000 inhabitants. Moreover, the maximum potential gain, represented as a percentage of the cost of a conventional system, is approximately 18%, with water captation, and approximately 4% if water is purchased at the considered tariff.

As a final note, it should be pointed out that in order to implement a dual system it will be necessary, not only to take into account the construction of a second municipal distribution network, but also to lead the companies that promote real estate, tourism, and industrial ventures to build secondary networks within buildings. Without them, the municipal secondary consumption will be below the expected 30%. To achieve this, the tariff for secondary water has to be fixed at an alluring price (Molinos-Senante et al., 2013), well below the tariff for primary water.

6. References

Al-Jayyousi, O. R. (2003). Greywater reuse: towards sustainable water management. *Desalination*, *156*(1–3), 181–192. doi:10.1016/S0011-9164(03)00340-0

Almeida, M. do C., Vieira, P., Ribeiro, R. (2006). *Uso eficiente da água no sector urbano*. Lisboa, Portugal: Instituto Regulador de Águas e Resíduos (IRAR), Instituto da Água (INAG), Laboratório Nacional de Engenharia Civil (LNEC).

Anderson, J. (2003). The environmental benefits of water recycling and reuse. *Water Supply*, *3*(4), 1–10.

Anderson, J. (2006). Integrating recycled water into urban water supply solutions. *Desalination*, *187*(1–3), 1–9. doi:10.1016/j.desal.2005.04.062

Angelakis, A. N., Bontoux, L. (2001). Wastewater reclamation and reuse in Eureau countries. *WaterPolicy*, *3*(1), 47–59. doi:10.1016/S1366-7017(00)00028-3

APE. (2012). *PNUEA: Programa Nacional para o Uso Eficiente da Água. Implementação 2012-2020*. Portugal: Agência Portuguesa do Ambiente, Ministério do Ambiente, do ordenamento Território e do Desenvolvimento Regional.

Asano, T., Burton, F., Leverenz, H., Tsuchihashi, R., Tchobanoglous, G. (2007).*Water reuse: issues, technologies, and applications*. Metcalf & Eddy, McGraw-Hill, USA.

Asano, T., Maeda, M., Takaki, M. (1996). Wastewater reclamation and reuse in Japan: Overview and implementation examples. *Water Science and Technology*, *34*(11), 219–226. doi:10.1016/S0273-1223(96)00841-4

Bakker, K. (2012). Water Security: Research Challenges and Opportunities.*Science*, *337*(6097), 914–915. doi:10.1126/science.1226337

Bixio, D., Thoeye, C., De Koning, J., Joksimovic, D., Savic, D., Wintgens, T., Melin, T. (2006). Wastewater reuse in Europe. *Desalination*, *187*(1–3), 89–101. doi:10.1016/j.desal.2005.04.070

Chang, D., Ma, Z. (2012). Wastewater reclamation and reuse in Beijing: Influence factors and policy implications. *Desalination*, *297*(0), 72–78. doi:10.1016/j.desal.2012.04.019

Chen, Z., Ngo, H. H., Guo, W. (2012a). A Critical Review on the End Uses of Recycled Water. *Critical Reviews in Environmental Science and Technology*, *43*(14), 1446–1516. doi:10.1080/10643389.2011.647788

Chen, Z., Ngo, H. H., Guo, W. (2012b). A critical review on sustainability assessment of recycled water schemes.*Science of The Total Environment*, *426*(0), 13–31. doi:10.1016/j.scitotenv.2012.03.055

Corominas, L., Foley, J., Guest, J. S., Hospido, A., Larsen, H. F., Morera, S., Shaw, A. (2013). Life Cycle Assessment Applied to Wastewater Treatment: state of the art. *Water Research*, (In Press). doi:10.1016/j.watres.2013.06.049

Coutinho, A. C. (2009). *Reutilização de Água: Utilização de águas cinzentas in situ*. Universidade de Trás-os-Montes e Alto Douro, Vila Real, Portugal.

DHGWA.(2011). *Guidelines for the Non-potable Uses of Recycled Water in Western Australia*.Department of Health, Government of Western Australia.

Domènech, L., March, H., Saurí, D. (2013). Degrowth initiatives in the urban water sector?A social multi-criteria evaluation of non-conventional water alternatives in Metropolitan Barcelona.*Degrowth: From Theory to Practice*, *38*(0), 44–55. doi:10.1016/j.jclepro.2011.09.020

EEA. (2012). *Towards efficient use of water resources in Europe* (No. 1/2012). European Environment Agency.

EPA. (2012). *Guidelines for Water Reuse* (No. EPA/600/R-12/618). U.S. Environmental Protection Agency.

ERSAR. (2012). *RASARP 2012: Relatório anual dos serviços de águas e resíduos em Portugal*. Entidade Reguladora dos Serviços de Águas e Resíduos.

Friedler, E., Lahav, O., Jizhaki, H., Lahav, T. (2006). Study of urban population attitudes towards various wastewater reuse options: Israel as a case study. *Journal of Environmental Management*, *81*(4), 360–370. doi:10.1016/j.jenvman.2005.11.013

Ghisi, E., Oliveira, S. M. de. (2007). Potential for potable water savings by combining the use of rainwater and greywater in houses in southern Brazil.*Building and Environment*, *42*(4), 1731–1742. doi:10.1016/j.buildenv.2006.02.001

Gleick, P. H. (2003). Global Freshwater Resources: Soft-Path Solutions for the 21st Century. *Science*, *302*(5650), 1524–1528. doi:10.1126/science.1089967

Grant, S. B., Saphores, J.-D., Feldman, D. L., Hamilton, A. J., Fletcher, T. D., Cook, P. L. M., Marusic, I. (2012). Taking the “Waste” Out of “Wastewater” for Human Water Security and Ecosystem Sustainability.*Science*, *337*(6095), 681–686. doi:10.1126/science.1216852

Grayman, W., LeChevallier, M., Walski, T. (2012).Water Distribution Systems in 2050.In *Toward a Sustainable Water Future* (Vols. 1-0, pp. 243–252).American Society of Civil Engineers. Retrieved from http://dx.doi.org/10.1061/9780784412077.ch26

Grigg, N., Rogers, P., Edmiston, S. (2013).*Dual Water Systems: Characterization and Performance for Distribution of Reclaimed Water*.Water Research Foundation.

Haddad, B., Rozin, P., Nemeroff, C., Slovic, P. (2009). *The Psychology of Water Reclamation and Reuse: Survey Findings and Research Road Map*. Alexandria, USA: WateReuse Foundation.

Haines, A., Alleyne, G., Kickbusch, I., Dora, C. (2012). From the Earth Summit to Rio+20: integration of health and sustainable development. *The Lancet*, *379*(9832), 2189–2197. doi:10.1016/S0140-6736(12)60779-X

Hartley, T. W. (2006). Public perception and participation in water reuse. *Desalination*, *187*(1–3), 115–126. doi:10.1016/j.desal.2005.04.072

Heinz, I., Salgot, M., Mateo-Sagasta Dávila, J. (2011). Evaluating the costs and benefits of water reuse and exchange projects involving cities and farmers. *Water International*, *36*(4), 455–466. doi:10.1080/02508060.2011.594984

Hermanowicz, S. (2008).Sustainability in water resources management: changes in meaning and perception.*SustainabilityScience*, *3*(2), 181–188. doi:10.1007/s11625-008-0055-z

Hernández, F., Urkiaga, A., De las Fuentes, L., Bis, B., Chiru, E., Balazs, B., Wintgens, T. (2006). Feasibility studies for water reuse projects: an economical approach. *Desalination*, *187*(1–3), 253–261. doi:10.1016/j.desal.2005.04.084

Hills, S., Birks, R., McKenzie, B. (2002). The Millennium Dome“ Watercycle” experiment: to evaluate water efficiency and customer perception at a recycling scheme for 6 million visitors. *Water Science & Technology*, *46*(6), 233–240.

Hochstrat, R., Wintgens, T., Melin, T. (2008).Development of integrated water reuse strategies. *Desalination*, *218*(1–3), 208–217. doi:10.1016/j.desal.2006.08.029

Hurlimann, A., Hemphill, E., McKay, J., Geursen, G. (2008). Establishing components of community satisfaction with recycled water use through a structural equation model.*Journal of Environmental Management*, *88*(4), 1221–1232. doi:10.1016/j.jenvman.2007.06.002

Ives, K. J. (1970). Man’s control of water quality.*Pure and Applied Chemistry*, *21*(3), 389–402.

Kalavrouziotis, I. K., Apostolopoulos, C. A. (2007). An integrated environmental plan for the reuse of treated wastewater effluents from WWTP in urban areas.*Building and Environment*, *42*(4), 1862–1868. doi:10.1016/j.buildenv.2006.07.016

Kandiah, V., Zechman, E., Binder, A. (2013).An Agent-based Modeling Approach to Simulate the Influence of Consumer Behavior on Infrastructure Performance for Urban Water Reclamation Management. In *World Environmental and Water Resources Congress 2013* (pp. 2299–2306). Retrieved from http://ascelibrary.org/doi/abs/10.1061/9780784412947.226

Lahnsteiner, J., Lempert, G. (2007). Water management in Windhoek, Namibia.*Water Science & Technology*, *55*(1), 441–445.

Lake, P. S., Bond, N. R. (2007). Australian futures: Freshwater ecosystems and human water usage.*Re-imagining Australia’s Futures*, *39*(2–3), 288–305. doi:10.1016/j.futures.2006.01.010

Leflaive, X. (2009).*Alternative Ways of Providing Water Emerging Options and Their Policy Implications*.Paris, France: OECD.

Lencastre, A. C. de. (1995). *Custos de construção e exploração*. Lisboa, Portugal: Laboratório Nacional de Engenharia Civil (LNEC).

Levy, J. de Q. (2008). *Novas fontes de abastecimento de água - reutilização e dessalinização*. Lisboa, Portugal: Ecoserviços.

Li, F., Wichmann, K., Otterpohl, R. (2009). Review of the technological approaches for grey water treatment and reuses. *Science of The Total Environment*, *407*(11), 3439–3449. doi:10.1016/j.scitotenv.2009.02.004

Libralato, G., VolpiGhirardini, A., Avezzù, F. (2012).To centralise or to decentralise: An overview of the most recent trends in wastewater treatment management. *Journal of Environmental Management*, *94*(1), 61–68. doi:10.1016/j.jenvman.2011.07.010

Listowski, A., Ngo, H. H., Guo, W. S. (2013). Establishment of an economic evaluation model for urban recycled water.*Resources, Conservation and Recycling*, *72*(0), 67–75. doi:10.1016/j.resconrec.2012.12.011

Lundie, S., Peters, G. M., Beavis, P. C. (2004).Life Cycle Assessment for Sustainable Metropolitan Water Systems Planning.*Environmental Science & Technology*, *38*(13), 3465–3473. doi:10.1021/es034206m

Mainali, B., Pham, T. T. N., Ngo, H. H., Guo, W., Miechel, C., O'Halloran, K., Listowski, A. (2013). Vision and perception of community on the use of recycled water for household laundry: A case study in Australia. *ScienceofThe Total Environment*, *463–464*(0), 657–666. doi:10.1016/j.scitotenv.2013.06.008

MAOTDR. (2007). *PEAASAR II: Plano Estratégico de Abastecimento de Água e Saneamento de Águas Residuais 2007-2013*. Portugal: Ministério do Ambiente, do ordenamento Território e do Desenvolvimento Regional.

Memon, F. A., Butler, D., Han, W., Liu, S., Makropoulos, C., Avery, L. M., Pidou, M. (2005).Economic assessment tool for greywater recycling systems.*Proceedings of the ICE-Engineering Sustainability*, *158*(3), 155–161.

Meneses, M., Pasqualino, J. C., Castells, F. (2010). Environmental assessment of urban wastewater reuse: Treatment alternatives and applications. *Chemosphere*, *81*(2), 266–272. doi:10.1016/j.chemosphere.2010.05.053

Miller, G. W. (2006). Integrated concepts in water reuse: managing global water needs. *Desalination*, *187*(1–3), 65–75. doi:10.1016/j.desal.2005.04.068

Mo, W., Zhang, Q. (2012). Can municipal wastewater treatment systems be carbon neutral? *Journal of Environmental Management*, *112*(0), 360–367. doi:10.1016/j.jenvman.2012.08.014

Molinos-Senante, M., Hernandez-Sancho, F., Sala-Garrido, R. (2013). Tariffs and Cost Recovery in Water Reuse. *Water Resources Management*, *27*(6), 1797–1808. doi:10.1007/s11269-012-0111-4

Monte, H., Albuquerque, A. (2010). *Reutilização de Águas Residuais*. Portugal: Entidade Reguladora dos Serviços de Águas e Resíduos, Instituto Superior de Engenharia de Lisboa.

Moroglu, M., Yazgan, M. S. (2008).Implementation of EU Water Framework Directive in Turkey. *Desalination*, *226*(1–3), 271–278. doi:10.1016/j.desal.2007.01.245

Mourad, K. A., Berndtsson, J. C., Berndtsson, R. (2011). Potential fresh water saving using greywater in toilet flushing in Syria.*Journal of Environmental Management*, *92*(10), 2447–2453. doi:10.1016/j.jenvman.2011.05.004

Muñoz, I., Milà-i-Canals, L., Fernández-Alba, A. R. (2010). Life Cycle Assessment of Water Supply Plans in Mediterranean Spain. *Journal of Industrial Ecology*, *14*(6), 902–918. doi:10.1111/j.1530-9290.2010.00271.x

Muthukumaran, S., Baskaran, K., Sexton, N. (2011).Quantification of potable water savings by residential water conservation and reuse – A case study.*Resources, Conservation and Recycling*, *55*(11), 945–952. doi:10.1016/j.resconrec.2011.04.013

Mylopoulos, Y. A., Kolokytha, E. G. (2008). Integrated water management in shared water resources: The EU Water Framework Directive implementation in Greece. *Physics and Chemistry of the Earth*, *33*(5), 347–353. doi:10.1016/j.pce.2008.02.031

Nolde, E. (2005). Greywater recycling systems in Germany results, experiences and guidelines. *Water Science & Technology*, *51*(10), 203–210.

Okun, D. A. (1996). Water reclamation and nonpotable reuse: an option for meeting urban water supply needs. *Desalination*, *106*(1–3), 205–212. doi:10.1016/S0011-9164(96)00110-5

Okun, D. A. (2000).Water Reclamation and Unrestricted Nonpotable Reuse: A New Tool in Urban Water Management.*Annual Review of Public Health*, *21*(1), 223–245.

Paiva, J. N. S. de. (2008). *Avaliação Técnica e Económica de Sistemas Duais de Abastecimento de Água*. Instituto Superior Técnico, Universidade Técnica de Lisboa, Lisboa, Portugal.

Po, M., Kaercher, J. D., Nancarrow, B. E. (2003). *Literature Review of Factors Influencing Public Perceptions of Water Reuse* (No. 54/03). Perth: CSIRO Land and Water. Retrieved from http://www.clw.csiro.au/publications/technical2003/tr54-03.pdf

Poff, N. L., Richter, B. D., Arthington, A. H., Bunn, S. E., Naiman, R. J., Kendy, E., Warner, A. (2010). The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards. *Freshwater Biology*, *55*(1), 147–170. doi:10.1111/j.1365-2427.2009.02204.x

Radcliffe, J. C. (2006). Future directions for water recycling in Australia. *Desalination*, *187*(1–3), 77–87. doi:10.1016/j.desal.2005.04.069

Rygaard, M., Binning, P. J., Albrechtsen, H.-J. (2011). Increasing urban water self-sufficiency: New era, new challenges. *Journal of Environmental Management*, *92*(1), 185–194. doi:10.1016/j.jenvman.2010.09.009

Sala, L., Serra, M. (2004).Towards sustainability in water recycling. *Water Science & Technology*, *50*(2), 1–7.

Schäfer, A. I., Ravazzini, A., Aharoni, A., Savic, D., Thoeye, C. (2005). Municipal wastewater reclamation: Where do we stand? An overview of treatment technology and management practice.*Water Science and Technology: Water Supply*, *5*(1), 77–85.

Simpson, J., Stratton, H. (2011). *Talking about water: words and images that enhance understanding*.Canberra, Australia: National Water Commission.

Tang, S. L., Yue, D. P., Ku, D. C. (2007). *Engineering and costs of dual water supply systems*. IWA Publishing.

Tang, S. L., Yue, D. P. T., Li, X. Z. (2006). Comparison of engineering costs of raw freshwater, reclaimed water and seawater for toilet flushing in Hong Kong. *Water and Environment Journal*, *20*(4), 240–247. doi:10.1111/j.1747-6593.2006.00036.x

Toze, S. (2006). Water reuse and health risks — real vs. perceived. *Desalination*, *187*(1–3), 41–51. doi:10.1016/j.desal.2005.04.066

Trussell, R. R., Anderson, H. A., Archuleta, E. G., Crook, J., Drewes, J. E., Fort, D. D., Jiang, S. (2012). *Water reuse: potential for expanding the nation’s water supply through reuse of municipal wastewater*. The National Academies Press, Washington, DC.

UN. (1992). Outcome document of “Earth Summit” - UN Conference on Environment & Development: Agenda 21. United Nations.

UN. (2012). The zero draft of the outcome document of “RIO+20” - UN Conference on Sustainable Development: The Future We Want. United Nations.

UNESCO. (2010). *Engineering: Issues Challenges and Opportunities for Development*. Paris: UNESCO.

Willis, R. M., Stewart, R. A., Williams, P. R., Hacker, C. H., Emmonds, S. C., Capati, G. (2011). Residential potable and recycled water end uses in a dual reticulated supply system. *Desalination*, *272*(1–3), 201–211. doi:10.1016/j.desal.2011.01.022

WSAA.(2004). *Dual Water Supply System Supplement to the Water Supply Code of Australia WSA 03-2002* (No.First Edition Version 1.1 A).Water Services Association of Australia Inc.

WWAP. (2012). *The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk*. Paris: UNESCO.

Yi, L., Jiao, W., Chen, X., Chen, W. (2011). An overview of reclaimed water reuse in China. *Journal of Environmental Sciences*, *23*(10), 1585–1593. doi:10.1016/S1001-0742(10)60627-4