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Water Management in Integrated Service Systems: Accounting for Water Flows in Urban Areas

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Abstract This article focuses on studying the natural and artificial water flows of the service sector from an industrial ecology perspective. The purpose is to determine, in the area under study, the water consumption of the service sector and the most water demanding services in global and relative terms, total water consumption per year and liters per user per year (Lpu) respectively, as well as the existing and potential water flow interrelations among service facilities to reduce their water consumption. Finally we propose measures for water consumption minimization, recycling and reusability based on the results of the diagnosis. The analyzed system is Montjuïc Urban Park (Barcelona, Spain), where the economic activity is based on the service sector (about 200 service facilities and no industrial activities). In the individual study of services we found an average consumption of 75 Lpu, with a large range in the water consumption by service types (between 17 and 156 Lpu), and between facilities of the same service type (51 and 155 Lpu). These results indicate a high level and low regulation of water consumption among the service facilities. In the study of the

All amounts of water are expressed in round figures in the text, tables and figures for the sake of simplicity.

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interrelations between the services we found that a high potential for hydrological saving exists in the system (equivalent to 50% of the potable water inflow from the supply network). The results indicate a lack of ecosystemic and synergic vision in the service sector. Interrelations among water flows have to be established, by means of rainwater collection and the reuse of water flows from swimming pools and ornamental fountains. The article proposes the application of industrial ecology methods to improve water management inside Montjuïc Urban Park and, in general, within any system where the service sector is the main economic activity.

Keywords Water flow accounting · Service sector · Urban system · Industrial ecology · Urban ecology

1 Introduction

Human systems require a large amount of material resources for their operation, which implies the generation of flows of solid and liquid waste, and of residual heat. The study of the physical flows of these systems, which allow the maintenance of their complexity, provides information about the metabolism and of the derived environmental costs (Rueda et al. 1998).

The analysis of the system's physical flows is a tool traditionally used in biological ecology for the study of natural ecosystems, and supplies information about the interrelations that are established between organisms and the physical medium in which they live (Tyler-Miller 1999). Analogously, urban ecology and industrial ecology disciplines are focused on the study of physical exchange processes (matter and energy flows between human societies and their natural environment), as well as on the study of the internal flows of matter and energy of human societies (Ayres and Simonis 1994; Fischer-Kowalski 1998).

Information on industrial and urban system metabolism, as well as urban subsystems like the service sector, is essential for understanding the interrelations that take place in their interior (Bettini 1996). The purpose is to improve the sustainability of these systems by means of reducing raw materials and energy use and minimizing waste, simultaneously improving well-being (Newman 1999).

Over the last decades, concern has increased in developed countries in relation to the environmental impacts produced by industrial activity. Nevertheless, there has been a structural change in industrial economies during this period, with service sector growth and the increasing use of technology (where the service sector accounts for between 60% and 70% of the GDP), a type of activity dominating that, a priori, would consume fewer resources. This separation between economic growth and natural resources is called delinking (Carpintero 2003) or decoupling (van der Voet et al. 2005). The OECD (2002) defines decoupling as the break of the link between "environmental bads" and "economic goods". The predominance of the service sector and the new economy, less intensive regarding the use of energy, water and materials, would create the possibility of maintaining the present model of production and consumption without higher environmental costs (Carpintero 2003; van der Voet et al. 2005).

The perception of the low impact of the services on the environment comes from the difficulties in defining the system (Carpintero 2005). Service activities have traditionally been associated with immateriality (Carpintero 2003), although the magnitudes of the metabolic flows of each type of service are not accessible. The availability of these data for each service type would provide interesting elements to discuss the veracity of the dematerialization hypothesis and allow a qualitative comparison of the impacts derived from each service type.

Until now, the study and the reduction of the metabolic flows of service sector activities have analyzed each service separately from the rest of the system, preventing synergies and the exchange of flows among them. Most of these isolated actions have been focused on the reduction of energy flows. Oliver-Solà et al. (2007) and Farreny et al. (2008) carried out studies of two service systems located in the Metropolitan Area of Barcelona (Spain) under an integrative approach. Both studies focused on evaluating the energy performance of the services and on determining their global environmental impact. Results emphasize that the service sector is of paramount importance in global warming policies, as it has a non-negligible energy consumption, which could be reduced by applying synergic strategies between different facilities. However, at the present time there is a generalized lack of knowledge of the magnitude of flows other than energy, such as materials and water, as well as of the possible interrelations between the services of a system to recirculate these flows and optimize consumption of resources.

In order to gain insight into the environmental performance of the service sector, this article focuses on the analysis and diagnosis of the hydrological flows of the service facilities at Montjuïc Urban Park (Barcelona, Spain). This is done by means of water flow accounting, examining the degree of existing dematerialization in water consumption flows as well as the synergies among service facilities from an industrial ecology perspective.

Water management in Barcelona and its surrounding region is an essential concern, as the resource is one of the major limiting factors for economic development in this area and in other semiarid Spanish regions. Increasing competition for fresh water between agricultural, urban and industrial usage, as well as population growth, results in unprecedented pressures on water resources. In Catalonia, uses of water vary according to the hydrographic unit selected. Barcelona is located in the Internal watersheds of Catalonia, where the highest water consuming activity is domestic use (43.7% in household and commercial use), followed by the agricultural sector (35.0% for watering and livestock), and finally the industrial sector (21.3%; ACA 2002). Assessment of future scenarios for the year 2025 indicates that total water consumption in the Internal watersheds of Catalonia will increase slightly due to the population growth in the Metropolitan Area of Barcelona (BMA). On the other hand, water use efficiency will be enhanced, mainly in industrial activities (ACA 2002).

Because water is critical and intimately linked with socio-economic development, it is necessary to move away from sectoral development and management of water resources and to adopt an integrated approach to water management (SEEAW, see http://unstats.un.org/unsd/envaccounting/seeaw.asp). The ongoing regulatory reform in the European Union Water Framework Directive, WFD, which is mandatory in all member states, reflects this water management approach. The WFD promotes the sustainable use of water by means of water saving and reuse. The set of measures necessary for attaining the environmental objectives of the Directive are being drawn up by the authorities responsible in each basin. According to the calendar for application of the WFD, the management measures to be carried out have to be approved by December 2009. To understand how water is used in the service sector, to identify opportunities to reduce its consumption and to determine alternative water resources (like the reuse of gray water) are of great interest, to reduce the pressure on water resources, thereby achieving the objectives stated in the WFD (EC 2000).

The specific objectives of this study of water flow accounting in the service sector were: (1) to estimate the volume of water consumed in Montjuïc Park, (2) to quantify the water consumption of each type of service in the study area, (3) to identify the services with greatest demand in terms of consumption per time period (year) and consumption per service unit (liters per user, Lpu), (4) to assess the differences, and possible reasons for these, in the water consumption of the different service facilities, (5) to identify unused water resources and their potential uses, to optimize and reduce consumption and (6) to determine the potential savings of potable water using other endogenous resources of Montjuïc Park.

2 Study Area

The object of the study is Montjuïc Urban Park (Barcelona, Spain). Located in the south of the municipality of Barcelona, it has an approximate surface area of 450 ha (Barcelona City Council, B:SM—Divisió Montjuïc 2003; Fig. 1) and received 14.5 million visitors in 2004 (Barcelona City Council, B:SM—Divisió Montjuïc 2005). The Park was chosen as it is an area where a great number and diversity of services

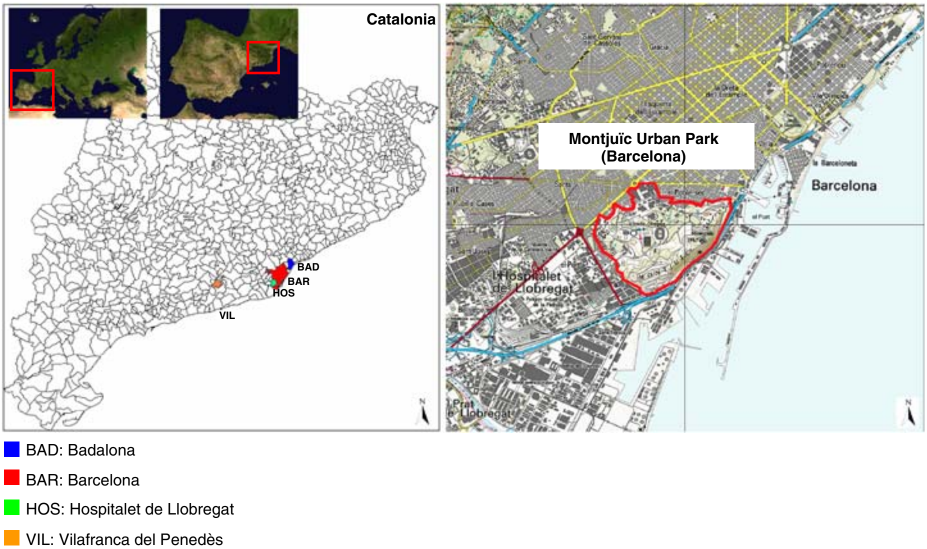


Fig. 1 Geographical location of Montjuïc Urban Park at various scales (Europe, Spain, Catalonia and Barcelona) and of the municipalities used for water consumption comparisons with service activities in Montjuïc. Source: Prepared by the author based on ICC (1995, 2000)

are concentrated (Table 1), forming a highly complex multi-service grouping to study metabolic flows.

Urban and peri-urban parks of similar characteristics exist in other cities around the world, which can also be considered service systems: the Retiro in Madrid, the Central Park in New York, the Djurgarden in Stockholm, and the Bois de Boulogne in Paris. The methodology used to study the water flow of the service facilities at Montjuïc Park can be generalized for these parks or applied in less complex service systems located in municipalities (library areas, bars, cinemas, educational centers, etc.), which tend to become more and more general due to present day city-planning policies.

The great variety of services provided in Montjuïc Park is shown in Table 1, with nearly 200 service facilities.

For the study of water flows the services have been grouped into three subsystems:

Green subsystem: water flows in 222.1 ha of parks, gardens and forests, of which 200 ha are parks and gardens and the remainder forest, dominated by the species *Pinus halepensis*

Table 1 Principal types of services at Montjuïc Urban Park

Services	Number of facilities	Class
Green	17	Parks
		Gardens
		Forests
Ornamental (leisure and enjoyment)	96	Public drinking fountains
		Ornamental fountains
		Ponds
		Surface lagoons
Sport	20	Pools
		Sports complexes
		Riding clubs
		Gyms
		Tennis courts
Culture	14	Museums
		Theatres
Education	16	Nurseries
		Primary, secondary and special education facilities
		Universities
Catering	23	Bars
		Restaurants
Special venues	3	International trade fairs and shows
		Multifunctional center (exhibition, concerts, sports competitions)
		Exhibition centre for artisan and architectural products
Total	189	

Source: Prepared by the author based on Barcelona City Council B:SM—Divisió Montjuïc (2003) and Barcelona City Council, B:SM—Divisió Montjuïc (2005)

Blue subsystem:	water flows of drinking and ornamental fountains and surface lagoons
Gray subsystem:	water flows in 228 ha of conventional services in built-up areas, such as sports and cultural facilities

3 Methodology

Data for water consumption in the study area was based on standardized methods of flow accounting and field work.

3.1 Water Flow Accounting

The methodology followed by the European Environment Agency (EEA 1995) was adapted for the water flow accounting in the service system of Montjuïc Park, as applied in the water flow accounting of Barcelona (Barracó et al. 1999). Since then, the System of Integrated Environmental Economic Accounting has standardized the methodology on water accounting at the international level (SEEAW, http://unstats.un.org/unsd/envaccounting/seeaw.asp).

Figure 2 shows the methodology applied in the study, with two classifications of water flows:

(a) Inflows, consumption flows and outflows:

Inflows:	flows from the environment to the service facilities. Total amount of water available in the system
Consumption flows:	water flows used in the service system, in each subsystem and in the different services
Outflows:	flows from service facilities to the environment

(b) Natural flows and artificial flows:

Natural flows:	inflows from rain and outflows from evapotranspiration and subsoil infiltration in permeable areas (green areas in our study) or from evaporation in impermeable areas (gray areas)
Artificial flows:	water inflows from the supply network (potable water and non-potable water networks in Montjuïc Park), its consumption, outflows through the sewage system (unitary system of residual and pluvial waters) and losses from the supply network and the sewage system

The method differentiates between the consumption of water in the green, blue and gray subsystems (classification of biotopes by Boada and Capdevila 2000), grouping them respectively between water consumption in garden services, services associated with public and ornamental fountains and services offered inside buildings.

The hydrological balance obtained using this methodology gives results on the water inflow and outflow into and from Montjuïc Park, the total consumption, the consumption of each subsystem and that of each service type. From the results it is possible to identify existing and potential synergies between facilities to optimize and to reduce water consumption.

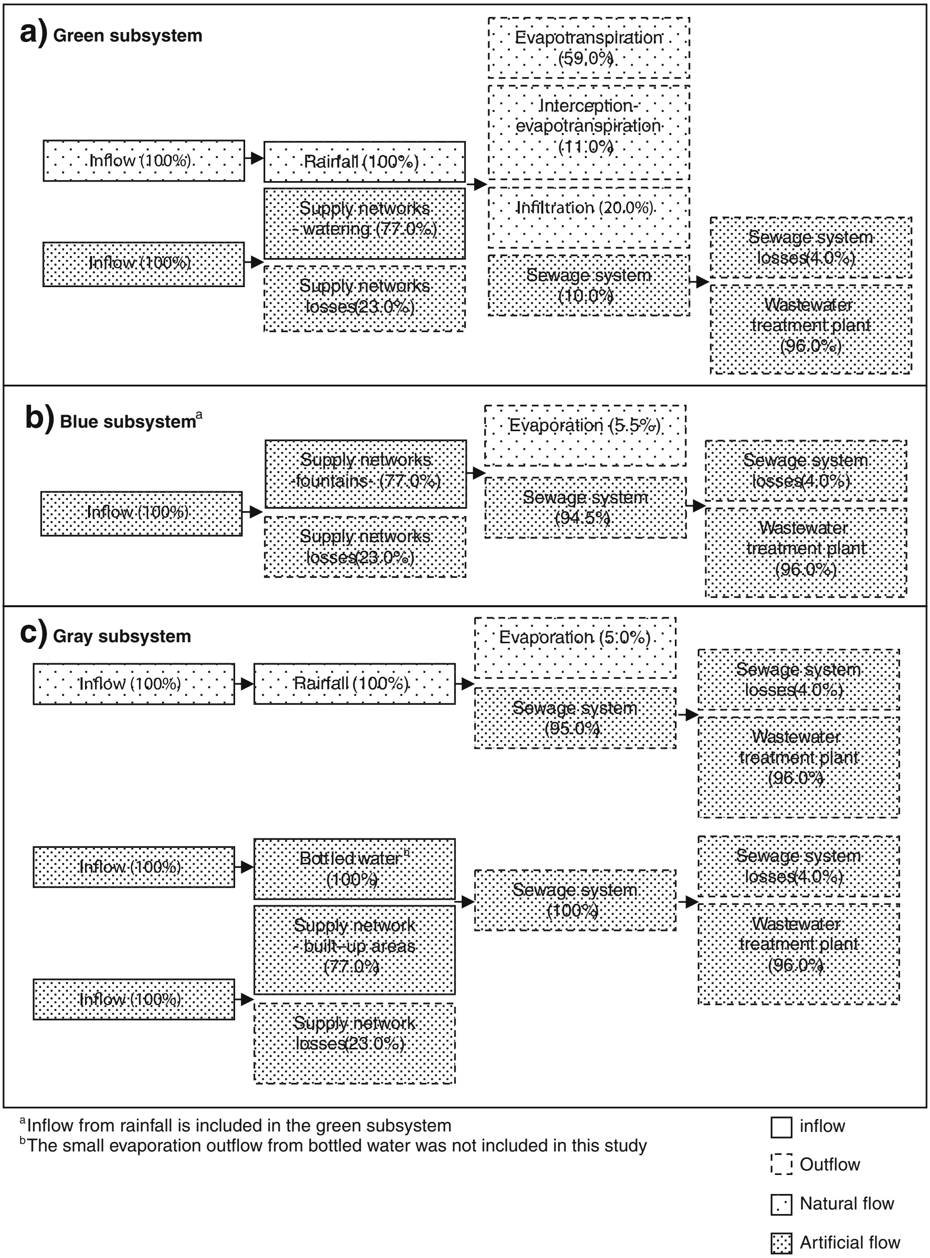


Fig. 2 Applied methodology in water flow accounting at Montjuïc Park. In brackets, the percentages used for calculating each flow. Consumption flows not shown

3.2 Research for Water Flow Data

To obtain local quality data on the hydrological flows of the system, field work was carried out in the year 2004 compiling data from 2003. Data for natural inflows (rainfall) was obtained from local pluviometric records of four climate observatories: Montjuïc Park Observatory (2003), Barcelona Port Observatory (2003), the observatory at Pia School (2003) and The Fabra Observatory (Climate Observatory Fabra 2003; Meteorological Service of Catalonia 2003). Rainfall conditions during 2003 were considered representative with respect to the average of 7 years: the average annual rainwater recorded in the area in the period 1997–2003 was 550 ± 183 L m^{-2} $year^{-1}$, and in 2003 this was 600 L m^{-2} (Climate Observatory Fabra 2003; Meteorological Service of Catalonia 2003). Since 2004, the annual rainfall recorded was around this average, except for the drought years 2005 and 2006, both with precipitation recorded below 500 L m^{-2} (RuralCat 2009).

Quantitative information of the artificial inflows (potable and non-potable water) was obtained from the potable and non-potable water supply companies in the area (AGBAR 2003; BCN Fonts 2004; Municipal Institute of Parks and Gardens 2004). Data for the consumption of bottled water was estimated based on an average consumption in Catalonia of 120 L per inhabitant per year (Barracó et al. 1999). Bottled water consumption includes drinking water needs of the residents in the Park and that of the workers and visitors.

Consumption flow was obtained by compiling the water invoices and audits in each service facility for a base year (2003) and complemented with the information provided by the water supply companies. Taking into account the number and kind of events, water consumption during 2003 was considered a representative annual consumption as the facilities, which have been supplying their services for more than 10 or 15 years, had a stable annual consumption without any special events.

The natural and artificial outflows (evaporation, evapotranspiration, interception–evaporation, infiltration and losses from the distribution networks and the sewage system) were taken from referenced material (e.g. Barracó et al. 1999; Kazim 2003; Lallana 2003), mainly related with Montjuïc Park. The methodology to obtain each of the natural and artificial outflows is described below and in Fig. 2.

In the green subsystem (parks, gardens and forests), rainwater evaporates directly from the plant canopy (interception–evaporation outflow in Fig. 2a) and by evapotranspiration (evapotranspiration outflow in Fig. 2a).

Interception of rainwater depends on the plant canopy, being higher in leafy vegetation, and accounts for 8–15% of the annual rainfall, depending on the rainfall intensity (Barracó et al. 1999). These authors estimated around 8–11% of interception–evaporation losses in Barcelona. Here, the maximum value for Barcelona (11%) was chosen, justified by the wooded areas (22.1 ha), which has an interception capacity higher than the normal urban vegetation of parks and gardens.

The evapotranspiration rate depends on several climatic parameters—maximum and minimum air temperature, relative humidity, solar radiation and wind speed, and the specific requirements of on-site conditions—and on the type of vegetation. In this study, the evapotranspiration methods of Sachon and Michaeli (suitable for forest vegetation, 22.1 ha of pines, see Eq. 1) and Miller and Poole (for bushes and urban green areas, 200.0 ha of parks and gardens, see Eq. 2) were applied. Both were preferentially selected as, firstly, only rainfall data is needed, which was the only information available for the four climate observatories from which natural inflows were estimated, and secondly, they had already been used in previous water flow accounting studies in Barcelona. Based on the results from Eqs. 1 and 2 (72% evapotranspiration losses from forest vegetation and bushes and 63% from urban green areas) and bearing in mind the rate of interception–evaporation losses to balance outflows to the atmosphere, the evapotranspiration flow was taken as 59% of the overall annual precipitation for the Montjuïc green subsystem, irrespective of the type of vegetation cover in each area.

$$ET_c = 0.19P + 320 \quad (1)$$

$$ET_c = 476 \log P - 942 \quad (2)$$

where ET_c is the evapotranspiration (mm or L m^{-2}) and P is the precipitation (mm or L m^{-2}).

Other outflows from the green subsystem to the environment are infiltration, which accounted for 20% of the rainfall inflow (Barracó et al. 1999), and runoff through the sewage system, which accounted for the remaining 10% of rainfall. Barracó et al. (1999) stated that 4% of the channeled wastewater will be lost by leakage before reaching the wastewater treatment plant. These losses are common in the three subsystems (Fig. 2a–c).

In the green subsystem, precipitation inflow is complemented by artificial water from the supply networks (potable and non-potable) to irrigate vegetation when necessary. As in many cities worldwide, the water infrastructure in Barcelona and in Montjuïc Urban Park is obsolete, causing leakage problems and therefore contributing to the increase in water abstraction to maintain water supply levels. In Spain, average water losses increased from 20.0% to 21.4% between 1996 and 1999 (Lallana 2003). In Barcelona and its surrounding area (BMA) the trend is opposite, and global efficiency of the network has improved from 76.0% to 80.0% between 1998 and 2004 (Peralta 2005). According to Tabesh et al. (2009), two types of what they named non-revenue water can be distinguished: apparent and real losses. Apparent losses are produced by metering, human and management errors, and lead to water consumption without charging, while real losses include wasted water and can be divided into pipe leakage (reported and unreported bursts, and background losses), reservoir leakage and overflow, as well as leakage from valves and pumps. Apparent losses in the distribution network of the study area accounted for 15% of the water inflow into Montjuïc Park (Barracó et al. 1999) and real losses for 8% (AGBAR 2003). Gross water supplied by companies is therefore reduced to 77% of net water, partly used for satisfying service activities in Montjuïc. These rates of losses occur in green, blue and gray subsystems. Apart from supply network losses, other outflows of water used for irrigation are the same as those for precipitation (Fig. 2a).

In the blue subsystem (fountains for drinking, ornamental fountains and surface lagoons), net water from pipe networks (77% of the gross water supplied from the origin by companies) could either evaporate from water surfaces of fountains or leave the system through the wastewater main. Evaporation basically depends on air pressure, temperature and humidity: the higher the temperature and the lower the humidity, the higher the evaporation. Evaporation ratio from water surfaces of fountains was estimated from May to September, inclusive, the hottest months in the study area. Many methods have been reported for the estimation of evaporation losses from free water surfaces (Sivapragasam et al. 2009). We estimated water evaporation over 1 year using the relationship established by Kazim (2003) between air temperature and humidity and the rate of water evaporation, which gave a figure of 5.5% evaporation of the water inflow in Montjuïc Park (Fig. 2b).

In the gray subsystem (built-up areas), evaporation from rainwater is the only natural outflow (Fig. 2c). On asphalted surfaces evaporation is much lower than in planted areas and it is estimated as 5% of the annual rainfall (Barracó et al. 1999). However, as evaporation rate is strongly related to rainfall intensity, this parameter is very variable. As the surface is completely sealed, there is no rainwater infiltration and storm-water not evaporated becomes runoff to the sewage system. The outflows from bottled water and the potable water supply network are also collected in the sewage system.

4 Results and Discussion

The results below, separated into hydrological inflows, consumption flows and outflows, were calculated using the base year 2003. Figure 3 shows the amount of each flow in Montjuïc Urban Park.

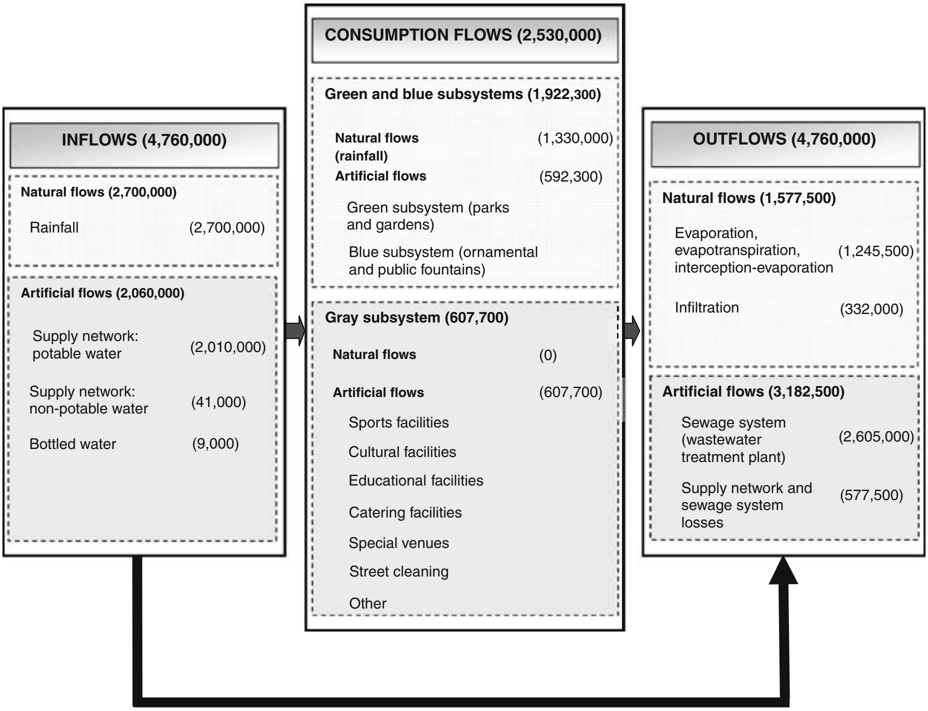


Fig. 3 Inflows, consumption flows and outflows in Montjuïc Urban Park. Units in cubic meter. Statistics for the year 2003

4.1 Water Inflows

The water inflow in the Montjuïc Park service system is 4,760,000 m^3 $year^{-1}$ (for the year 2003), or around 1,060 L m^{-2} $year^{-1}$ (Fig. 3).

The major inflow is the endogenous local resource derived from precipitation (2,700,000 m^3, 57%), seldom distributed equally between the combined green and blue subsystems (222.1 ha) and the gray subsystem (228.0 ha).

The other important inflow is the gross potable water supplied by the distribution network (2,010,000 m^3, 42% without deducting losses). Smaller inflows (50,000 m^3, 1%) are the canalized non-potable groundwater pumped from the Barcelona aquifer (Arandes 2001), and the other bottled water.

4.2 Water Outflows

The relationship between artificial outflows (return to the environment through the sewage system network and through losses from the sewage system and supply networks) and natural ones (evaporation, interception–evapotranspiration, evapotranspiration and infiltration) is 2:1, with 3,182,500 m^3 $year^{-1}$ and 1,577,000 m^3 $year^{-1}$ respectively (Fig. 3), demonstrating the importance of artificial flows in this urban system.

The main water exit flow is through the sewage system network, where nearly 2,605,000 m^3 $year^{-1}$ of water is piped to the wastewater plant. This is 55% of the total outflow, not including the sewage system losses, as they are accounted for separately. The sewage system is unitary, serving for both residual and pluvial water, the latter accounting for 1,434,500 m^3 in the year of study (without deducting sewage system losses). The mixture of water qualities in the sewage outflow prevents the reuse of rainwater and other potential hydrological resources. The lack of tanks for collecting and storing rainwater from land surfaces in Montjuïc means it enters directly into the sewage system without previous use, even though rainwater is suitable for irrigation, fountains or cleaning the Park facilities.

It is estimated that in the study area approximately 577,500 m^3 $year^{-1}$ of water are lost from the distribution network (23% of the gross water supplied by water companies, Section 3.2) and from the sewage system (4% of the water channeled to the sewage plant, Section 3.2).

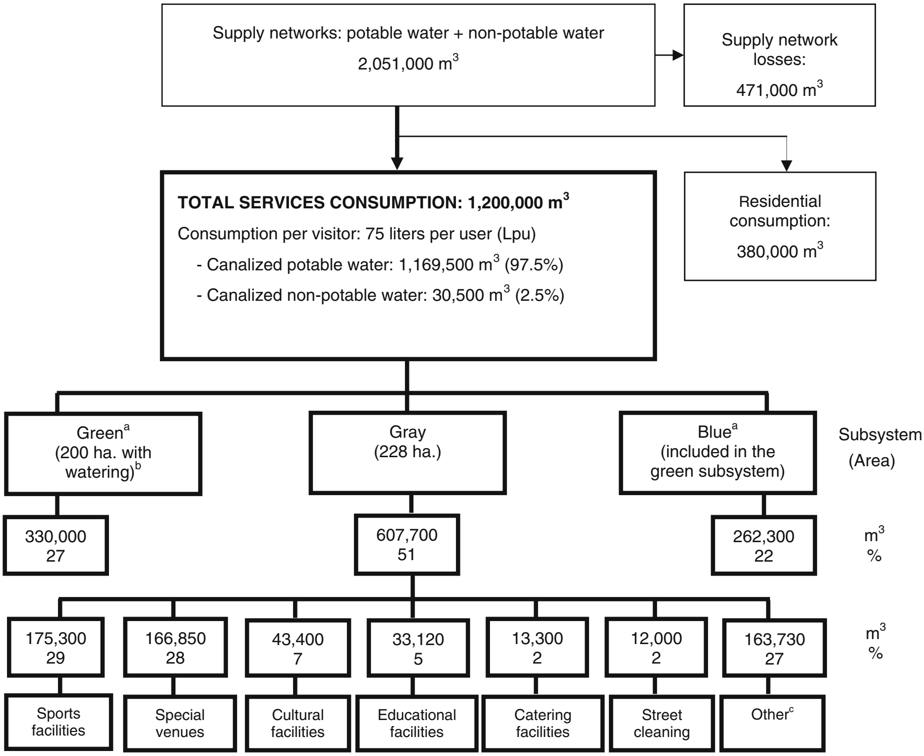
4.3 Flows in the Services

Total water consumption in the three service subsystems is 2,530,000 m^3 $year^{-1}$, representing 53% of the water inflows to the service facilities (Fig. 3). The green and blue subsystems are responsible for 76% of this consumption (1,922,300 m^3 $year^{-1}$) and the gray subsystem consumes the remaining 607,700 m^3 $year^{-1}$. The high consumption for gardens and fountains is explained because of the rainfall in these areas (1,330,000 m^3 $year^{-1}$, equivalent to 600 L m^{-2} $year^{-1}$). This rainwater avoids the use of supplementary potable water which can therefore be used to satisfy other purposes. In contrast to the blue and green subsystems, rainwater in the gray subsystem becomes unused runoff, even though it is potentially suitable where water of high quality is not required. Rainwater in the gray subsystem represents 29% of the total water inflow from the environment to Montjuïc Park, 1,370,000 m^3 $year^{-1}$. Non-evaporated rainwater, 1,301,500 m^3 $year^{-1}$ is collected together with the wastewater in the sewage system.

4.4 Artificial Water Consumption in the Services

Figure 4 shows the artificial water consumption from the potable and non-potable supply networks for the Montjuïc Park services and the distribution in water consumption in the three subsystems. Consumption of bottled water has not been included as it represents less than 0.5% of this water consumption, whereas 99.5% is from the two supply networks. These results highlight the importance of the supply infrastructures to satisfy water needs in this service system.

The majority of the water consumed comes from the potable water network (97.5%), with just 2.5% from the non-potable water network. The results shown in Fig. 4 also demonstrate that consumption from the supply networks by the



ha: hectares
[a] Consumption from the potable and non-potable water network
[b] Forests are not included as they are not irrigated from the water supply network
[c] Combined consumption of the facilities without data on individual consumption. It includes: 9 sports centers (without swimming pools), 5 cultural centers, 2 educational centers, 6 catering locations, and small facilities of other service categories not included in the study

Fig. 4 Water consumption from the supply networks (in cubic meter per year and percent) for the service sector in Montjuïc Park, according to service type. Statistics for the year 2003 service sector facilities of the three different subsystems is 76% of the total water consumption in Montjuïc Park (1,200,000 m^3 for the year 2003). The remaining 24% is for domestic consumption (380,000 m^3 $year^{-1}$). There is no agriculture or industry in Montjuïc Park.

Finally, in relative terms, each visitor to Montjuïc Park consumes nearly 75 L of water from the supply networks, based on the year 2003, when there were 16,155,635 visitors (Barcelona City Council, B:SM—Divisió Montjuïc 2005) and the service water consumption was 1,200,000 m^3. This means that each visitor may be responsible for the consumption of 75 L of piped water, independently of the service used (gray, green and blue subsystems) and the time spent in the Park. This data is useful for making comparisons with other service systems, as well as being an indicator of the trend in water consumption efficiency by visitors to the Park. It may also be used as a visitor awareness tool, informing the public of the water consumed in each service unit.

4.4.1 Comparison of Consumption in the Blue, Green and Gray Subsystems

If natural flows are not taken into account, service activities in the gray subsystem have the highest consumption, 51% of canalized water (607,700 m^3 $year^{-1}$). This comes entirely from the potable distribution network, whereas the remaining 49% consumed in the green and blue subsystems (592,300 m^3 $year^{-1}$) comes from both the potable (561,800 m^3 $year^{-1}$) and the non-potable (30,500 m^3 $year^{-1}$) water distribution networks.

The services of the gray subsystem (sports, cultural, educational and catering facilities, special venues and street cleaning) consume an average of 266 L m^{-2} $year^{-1}$, and those of the green subsystem (irrigation of parks and gardens) 165 L m^{-2} $year^{-1}$, which means the network water consumption of the gray subsystem services is 64% higher.

In the blue subsystem, water consumption for ornamental fountains is about 20 m^3 per fountain per day, which is a greater unitary consumption than for drinking water fountains.

4.4.2 Consumption in the Green Subsystem

Network water consumption for the irrigation of gardens (165 L m^{-2} $year^{-1}$) shows that parks and gardens on Montjuïc, with Mediterranean plant species and grass, are efficient in water use when compared to other green parks and public gardens in Barcelona, where the average annual consumption is 470 L m^{-2} $year^{-1}$ (Municipal Institute of Parks and Gardens 2002). Private gardens in the Metropolitan Region of Barcelona dominated by Mediterranean climate shrubs (in 34.9% of the vegetation) have an average consumption of 380 L m^{-2} $year^{-1}$, and in those with a predominance of grass (in 49.6% of the vegetation) the consumption is 1,600 L m^{-2} $year^{-1}$ (Domene et al. 2005). It is important to bear in mind that water consumption from the distribution network for watering gardens on Montjuïc (165 L m^{-2} $year^{-1}$) is complemented by rainfall (600 L m^{-2} $year^{-1}$), resulting in a total water consumption of 765 L m^{-2} $year^{-1}$.

Water consumption from the supply networks could be reduced and made more efficient in the green subsystem by changing the irrigation system, which is predominantly manual (75%; 150 ha), considered the least efficient method (60–80%) for water use (Fuentes Yagüe 1998).

The other irrigation systems employed are automatic sprinkling—hand-activated sprinklers—(18%; 36 ha) and programmed sprinkling—sprinklers activated and controlled by a centralized computer system, with irrigation adapted to the climate and to the water needs of each species (7%; 14 ha). The efficiency of water use is between 65% and 85%, superior to that of hose irrigation (Fuentes Yagüe 1998).

4.4.3 Consumption in the Blue Subsystem

The network water consumption in the blue subsystem is 262,300 m^3 $year^{-1}$. It has been observed that the most effective water saving in this subsystem is that 86% of the ornamental fountains have closed circuits for the recirculation of water, with water being replaced in function of the capacity of the fountain. The remaining ornamental fountains (14%) do not have closed circuits, which means that network water is continuously being replaced (BCN Fonts 2004). In both cases, the water replaced is poured into the unitary sewage system network.

4.4.4 Consumption in the Gray Subsystem

Annual consumption Table 2 shows the relationship between water consumption and different service facilities. The services with the highest annual consumption in the gray subsystem are the sports facilities and the special venues, which are responsible for practically 60% of the water consumption (342,150 m^3), while those services with the least consumption are catering and street cleaning, with 4% of the total consumption (25,300 m^3).

The ranges of annual consumption between the facilities of the same service category are: 1–3 (special venues), 1–15 (catering), 1–35 (educational), 1–145 (cultural) and 1–250 (sports). Data from the field work indicate that the principal factors that determine this variation are the architectural characteristics of the building, the number of users, consumption per user and the efficiency of the technology installed at the water consumption points (restrooms, showers and piping). The variability of consumption in the cultural service is due to one facility, consuming 43% of the total for the sub-sector. The facility responsible for this high water consumption (18,600 m^3) is a museum, the one with the second highest number of visits in Montjuïc Park in the year of study (512,000 visitors) and the highest in surface area. It has a high number of water consumption points, mainly bathrooms, with variable efficiency. This highlights the differences in water consumption among facilities that offer the same or very similar services, as water consumption in this museum is two to three times higher than in other Park museums with similar architectural characteristics and number of annual visitors.

The sports facilities have the greatest annual consumption compared to other service categories in the gray system, especially those with a pool or large irrigated sports areas, representing 73% (127,650 m^3 $year^{-1}$) of the sport services consumption. These sports facilities have an annual consumption range of 1–8, with the highest consumption corresponding to the largest and most used facilities. In the four facilities with pool, the average consumption is close to 22,000 m^3 $year^{-1}$, mainly the result of a legal obligation requiring the daily renewal of 5% of the volume of water in the swimming pools, as well as the renewal of the total volume once a year.

Table 2 Water efficiency in the gray subsystem services in Montjuïc Park

	Number of visitors per year[a]	Annual consumption (m^3)		Consumption per user per year (Lpu)		
		Max.	Min.	Max.	Min.	Average
Sports facilities[b]						103.41
With pool and large areas that require irrigation ($N = 5$)	2,496,825	54,590	6,504	5,816.43	37.60	51.13
Without pool ($N = 6$)	308,131	25,890	216	1,115.77	6.59	155.70
Educational facilities[c]						36.64
Nurseries, primary, secondary and special education centers ($N = 11$)	2,089[d]	6,699	191	79.48	2.43	36.64
Cultural facilities						16.00
Museums ($N = 7$)	2,380,519	18,600	130	209.44	8.17	17.27
Theaters ($N = 3$)	155,353	918	642	28.75	12.00	14.73
Special venues						31.18
International trade fairs and shows ($N = 1$)	2,938,360	–	90,000	–	30.63	30.63
Multifunction center ($N = 1$)	1,065,586	–	29,650	–	27.83	27.83
Exhibition centre for artisan and architectural products ($N = 1$)	1,345,261	–	47,200	–	35.09	35.09
Catering facilities[e]						21.50
Bars, restaurants ($N = 17$)	619,814	2,236	157	–	21.50	21.50

[a] Statistics for the year 2003 (Barcelona City Council, B:SM—Divisió Montjuïc 2005)

[b] Including physical education at the university

[c] Consumption per student per day (liter per student and day)

[d] Without data for students in two educational centers

[e] Considering an average consumption per visitor of 21.50 L (including bathrooms; Badia et al. 2003)

The results show that water consumption of the service sector is heterogeneous at two levels, both for service types, and between facilities of the same service.

Consumption per user per year Water consumption per user varies greatly between the different services and facilities of the same service (Table 2). The greatest consumption per user is at the sport facilities, with a large intrinsic variation: pool facilities or large irrigated areas consume an average of 51 L per user per year while, paradoxically, those without a pool consume three times that (156 Lpu). The difference in consumption is due to the greater number of users at facilities with gardens and pools, reducing consumption per user even though the total annual consumption is higher.

Similarly, while close to 30% of the total water per year of the gray subsystem is consumed at special venues, the high number of visitors (close to three million annually), places the consumption per user at 31 Lpu, lower than the average in this subsystem (42 Lpu).

The variation in consumption between facilities of a service type can be associated with insufficient legal regulation of environmental impact by the service sector, as well as the absence of best available technologies protocols, in contrast to the industrial sector, where amounts of water and other resources used and the emission of contaminants for the production of any single unit are legally regulated and limited, for example, in the European Union, the Directive 96/61/CE on integrated pollution prevention and control (IPPC) and the Best Available Technologies (BAT document) for each industrial sector. These reduce the range of consumption of resources among industries with the same activity.

The differences in water consumption between services were expected, and are due to the different water requirements of each one, but the large difference between facilities that offer similar services is a relevant finding. These intrasectorial differences are not attributable to user attitudes or habits, but to two other factors:

1. Infrastructural differences between facilities: The number of pools or shower facilities greatly increases water consumption.
2. Number of visitors that use the facility: In relative terms, if a facility receives a low number of visitors, the unitary consumption can still be higher compared to another facility that consumes more water in absolute terms but also receives a larger number of visitors.

4.4.5 Water Consumption in Services Compared with Other Systems

In Table 3 the water consumption from the supply networks in Montjuïc Park is compared with the water consumption in Catalan towns with a number of inhabitants similar to the number of visitors in Montjuïc and the consumption in Catalonia as a whole.

Table 3 Water consumption from the supply network in Montjuïc Park compared with other systems within Catalonia

	Inhabitants or visitors	Consumption of the service sector ($m^3/year^{-1}$)	Consumption of the service sector (m^3/inhabitant or visitor)	Proportional service water consumption in Catalonia (%)	Total system consumption ($m^3/year^{-1}$)
Catalonia[a]	6,704,146	40,978,000	6.11	100	618,368,000
Barcelona[b]	1,582,738	7,848,243	4.96	19.15	114,530,984
Hospitalet de Llobregat[c]	250,493	1,598,489	6.38	3.90	13,574,678
Montjuïc Park[d]	16,155,635/year (44,264/day)	1,200,000	27.11[e]	2.92	1,580,000
Badalona[c]	214,440	675,457	3.15	1.65	11,706,419
Vilafranca del Penedès[c]	33,381	27,655	0.83	0.07	2,893,140

Statistics for the year 2003

[a] IDESCAT (Institut d'Estadística de Catalunya): http://www.idescat.net

[b] Barcelona City Council: http://www.bcn.es

[c] Diputació de Barcelona, Xarxa de Ciutats i Pobles cap a la Sostenibilitat: http://diba.es. Data for Hospitalet de Llobregat corresponds to the year 1998

[d] Barcelona City Council, B:SM—Divisió Montjuïc (2005)

[e] Calculation based on daily visitors, comparable with village inhabitants

Although these comparisons have to be interpreted with caution, as the systems are on different geographical scales and do not have the same functions (Montjuïc is a service system with only service and residential uses and the others are towns with additional industrial and agricultural uses), it is useful to establish the importance of water consumption by the service sector in Montjuïc. Comparisons between similar systems could not be carried out as there are no other detailed studies of water consumption in service systems.

Taking a visitor to the service facilities of Montjuïc Park as equivalent to a town inhabitant, as can be seen in Table 3, water consumption of Montjuïc services is approximately equivalent to the consumption of a town of 250,000 inhabitants. The water consumption in the Montjuïc Park service facilities is about 3% of the overall Catalonia service water consumption and 15% of Barcelona's service facilities. These data show the high degree of specialization in the service activities of Montjuïc Park and indicate the order of water consumption in similar service systems.

On the same basis of considering the number of daily visitors as town inhabitants, the results show that the water consumption needed to satisfy the use of services per person in Montjuïc Park is 27 m^3, which is 4.5–5.5 times more than the average in the service sector per person in Catalonia, Barcelona or Hospitalet de Llobregat. This value is very high because there is a very small difference (24%) between water consumption in the service sector and the total system consumption in Montjuïc Park because, excluding a reduced number of residential buildings, the service sector is the only one existing in Monjtuïc.

4.5 Improvement Proposals for Hydrological Flow Optimization in the Services

As a result of the field work, it was observed that there was no hydrological flows optimization among services to reduce their water consumption. We have established 11 measures to improve efficiency in water use, quantifying the potential savings of four of them (Table 4). The proposed strategies are the result of a careful analysis of alternatives. The values shown in Table 4 have been calculated from the annual water consumption of each type of service. Measures for each facility from an isolated point of view, where there are no interrelations of water flows among subsystems or facilities, and integrated actions, where water flow synergies are established, are differentiated. The distinction between isolated and integrated measures is based on a systemic approach, as usually applied in industrial ecology.

The theoretical water savings through the reuse and interrelation of flows is 1,000,000 m^3 $year^{-1}$, about 50% of the potable water inflow from the supply network (2,010,000 m^3 $year^{-1}$, see Fig. 3). This saving could be achieved by means of the reuse of outflows from pools (88,000 m^3 $year^{-1}$) and from ornamental fountains (262,300 m^3 $year^{-1}$) and the collection of rainwater from roofs of the gray subsystem services (665,190 m^3 $year^{-1}$ of rainwater, with 5% natural loss by evaporation already discounted). This water should be preferably used for non-drinking purposes after pretreatment (Herrmann and Schmida 2000; van Roon 2007), providing water of sufficient quality to be used for indoor and outdoor cleaning, watering of planted and refilling of ornamental fountains, ponds and surface lagoons, as well as for toilet flushing and fire hydrants, the latter being non-existent in the Park.

Table 4 Isolated and integrated improvement measures for the optimization of service water flows in Montjuïc Park

Measure	System vision		Potential savings	
	Isolated[a]	Integrated[b]	m^3 per year	Percentage saving of potable water from the supply network (%)
Reuse of swimming pool outflow			88,000	4.4
Reuse of ornamental fountains outflow			262,300	13.0
Rainwater collection in all of the gray subsystem services (long term, high economic and technologic investments)			665,190	33.0
Rainwater collection of three services in the gray subsystem (short term, minor economic and technologic investments)			87,300	4.3
Creation of surface lagoons in the green subsystem, filled with water from the non- potable water distribution network				
Substitution of hose pipe with sprinkler irrigation and directional operation during low sunlight hours				
Substitution of lawns with native species				
Installation of water recirculation systems in ornamental fountains				
Installation of fire hydrants for fire extinguishing and street cleaning				
Replacement of inefficient water use devices				
Edition and distribution of guides for water saving techniques, adapted to each service type				

[a]Without interrelation of water flows between different systems or service facilities

[b]With interrelation of water flows between different systems or service facilities

It has been found viable over the short term to collect rainwater from the roofs of the three service facilities with the largest area in the Park (a total of 15 ha), representing savings of 87,300 m^3 $year^{-1}$ of potable water. The captured rainwater is sufficient to reduce, by 15%, the annual consumption in irrigation activities, ornamental fountains and street cleaning, or can be applied in the maintenance and creation of new lagoons and ponds in green spaces, increasing biological diversity and the recreational service areas of the Park (Ole Åstebøl et al. 2004).

This type of water flow optimization in the study area is feasible given the underused distribution network for non-potable groundwater. Increasing its storage capacity and constructing connections for outflows from fountains, pools and for rainwater from roofs would be a good strategy for enhancing the use of this existing network. The suitable storage capacity of the non-potable water main tanks should be calculated according to the amount of outflows, which can vary greatly from 1 year to the next, especially in the case of rainfall, with its annual and seasonal variability in the Mediterranean area. Provided that rainfall variability and uncertainty over one or different years do not reduce the environmental and economic efficiency of the collection system, the tanks capacity should be sufficient.

5 Conclusions

The conclusions are divided into those related to the Montjuïc Park service system and others related to water accounting of the service sector.

5.1 The Montjuïc Park Service System

The results demonstrate that the Montjuïc Park service sector requires a large amount of water from the potable supply network, more than three quarters of the total consumption, 1,200,000 m^3 $year^{-1}$, with household use representing the other quarter.

Water inflow from the supply network is similar to rainwater inflow in the Park, but 27% of the total water inflow (1,301,500 m^3 $year^{-1}$, non evaporated rainfall from the gray subsystem) are unused hydrological resources, potentially apt for uses that do not require high quality potable water.

In relative terms, the average water consumption from the supply networks per user in the services has been recorded at 75 L per user per year (Lpu).

The consumption of water for each service type is variable. In general terms, the services with the greatest consumption of water from the distribution network are those in the gray subsystem, 266 L m^{-2} $year^{-1}$, 64% higher than the 165 L m^{-2} $year^{-1}$ consumed in the green subsystem. In this subsystem, water from the distribution networks is complimented by precipitation (600 L m^{-2} $year^{-1}$), resulting in a total water consumption of 765 L m^{-2} $year^{-1}$.

There is a non-existent application of industrial ecology actions, where low quality water flows are interrelated between services of one subsystem or between subsystems. Actions introduced until now have been individual and from an isolated view of each facility, centered on the installation of saving devices in the consumption points of the gray subsystem facilities (restrooms, showers and piping). The establishment of synergies would save a million cubic meters annually (equivalent to 50% of the inflow of potable water from the supply network) assuming the reuse of water from pools (88,000 m^3), ornamental fountains (262,300 m^3) and rainwater from all the gray subsystem facilities (665,190 m^3), where no rainwater collection or storage infrastructure exists at present.

5.2 Water Flow Accounting of the Service Sector

The water consumption of the service sector is heterogeneous at two levels. There is a wide range in the water consumption by service types (between 17 and 156 Lpu), and between facilities of the same service type (51 and 155 Lpu). These results indicate a high level of water consumption, and low regulation, between the service facilities.

The range of water consumption detected is due to the influence of three factors: architectural characteristics of the facilities, number of users and the efficiency of the technologies installed in the water consumption points (restrooms, showers and piping).

The potential factors that influence this large range of values are: the inexistence of a law that regulates the environmental impact of the service sector, in contrast to the highly regulated industrial sector, the lack of water audits and the inefficiency of the technologies installed in the water consumption points (restrooms, showers and piping). This may well be caused by the perception that services have a reduced environmental impact, which means administration and facility managers do not prioritize the introduction of measures for improving water consumption efficiency. Therefore, economic, environmental and social costs can be avoided.

An ecosystem view of the service systems has not yet been taken. Synergies of water flows between facilities to optimize their use do not exist and have only been applied in individual actions for isolated savings, focused on the change of technologies in consumption points.

6 Further Research

Currently, the concept of industrial parks is extending to the service sector, locating together in a protected area, in large numbers and varying facilities, caused by the local urban planning policies. This happens with services of one type (businesses, education, restrooms, etc.) or of different types (businesses and restaurants, green services in parks and gardens and cultural facilities, etc.). For this reason it is necessary to continue studying the metabolic flows of the service sector activities, with the goal of identifying impacts and defining appropriate strategies for their environmental improvement.

The incorporation of ecosystem ideas and interrelations between flows in the service systems, which characterize industrial ecology, will produce environmental, economic and social benefits. As demonstrated here, water consumption in the service sector is not negligible at all.

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