Sustainable Water Treatment Methods to Be Used in Urban Communities

Amal Abdou, Iman Gawad, and Zeina ElZein

Abstract The increasing population and rapid urbanization rates lead to increasing demands on water resources. In an arid country such as Egypt, cities are facing problems of water scarcity and untreated wastewater. Communities consume large amounts of water, leading to higher water demands and an increased wastewater production. Many developing countries can't afford the required infrastructure to cope with the rising demand on water supply and wastewater treatment, leading to a water challenge. The water challenge is studied by researchers in agricultural, infrastructures, and other related fields, while the role of the urban planner/designer is usually not included, though the integration of water management techniques in urban design can provide valuable benefits on water resources, in addition to positive impacts on the social, environmental, and economic aspects of the community and the health of its inhabitants. This chapter introduces the concept of integration of water management in the urban design of communities, from an urban design point of view, providing the link between water management and community design. The chapter focuses on methods that can be applied in Egypt. Examples of communities in similar climatic conditions are examined to provide an understanding of the potential of integration of water management techniques in new urban communities in Egypt.

Keywords Sustainable communities, Urban water, Water-sensitive urban design, Water treatment

Contents

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1 Introduction

Egypt has reached a population of 97,553 thousand in 2017 [1]. "About 95 percent of Egyptians live along the Nile – on less than 5 percent of Egypt's territory" [2]. High population growth has major negative impacts on the urban sustainability. The urbanization rate is rising, adding more pressure on environmental resources and urban infrastructure. In addition, urbanization highly affects the water supply (Fig. 1).

The water supply is still insufficient with water consumption which is higher by 6.3%. Large amounts of untreated wastewater are discharged into the Nile river, lakes, and the Mediterranean Sea [3]. Egypt has passed the water scarcity threshold, which is set to be 1,000 m^3/capita/year, and it is predicted to reach the threshold of absolute scarcity, which is 500 m^3/capita/year [4]. The amount of treated wastewater is only 50% of the total produced wastewater in Egypt, and only fourth of that amount is used in irrigation [5].

The United States Geological Survey has estimated that nearly 30% of our total water use is being directed to landscapes, such as urban green spaces. New water resources such as storm water runoff and treated wastewater should be utilized for irrigation and other non-potable uses, to decrease the need for freshwater supply.

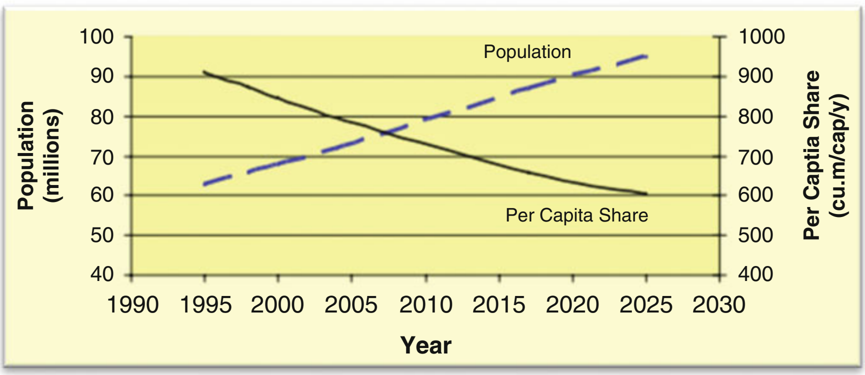

Fig. 1 Projected annual per capita share of renewable water resources in Egypt [6]

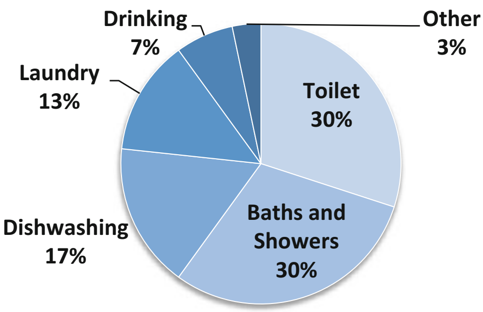

Fig. 2 Average daily water consumption per person in Egypt. By author, adapted from [8]

Thus, it is critical to retrofit existing systems and implement new methods for increasing water use efficiency, wastewater treatment and reuse, and storm water runoff retention [7].

Figure 2 shows the percentage of daily water consumption per person in Egypt, showing that about 70% of the water is considered gray water, which could be treated and reused. Outdoor water use may reach 70% on hot summer days [9].

The huge financial needs for water infrastructure, along with the increasing gap between water demand and consumption, represent one of the most growing issues facing urban communities in Egypt. The water challenge can't be handled by traditional urban design approaches, which rely on large-scale centralized systems, due to their negative impacts on the environment and higher costs.

2 Urban Design and Water Management

Land use and surface management in communities have direct impacts on the water aspects. The design of community affects the water demand, costs, and management. For example, developments with large lots and low density consume more water for irrigation, car washing, and other outdoor uses [10]. Low density developments also require longer transmission lines and piping, leading to increased costs and water leakage. Water supply systems are estimated to lose 6–25% of water due to leakage. Thus, the community layout contributes to water consumption affecting the need for water supply and infrastructure. Landscape design of the community also affects water demands, as using native plants and ground covers decreases the need for irrigation, saving large amounts of freshwater [11].

In recent years, there has been a shift in water resource management to develop new methods that meet the demands of growing populations and incorporate ecological values in water policies. Many cities and countries have responded to this by implementing water principles for better resource efficient land use as a result of major challenges with water contamination, storm water runoff, flood damage liability, and concerns for enough reliable water for current residents [7]. The interest in designing communities that consider water management concepts has gradually increased. Many terms have emerged in the past decades, among them are the sustainable urban drainage systems (SUDS), storm water best management practices (BMPs), green infrastructure (GI), low impact development (LID), and water-sensitive urban design (WSUD) [13]. Although the concept and scope of these approaches are different, they all agree on activating the natural hydrological cycle instead of ignoring it [12]. Water-sensitive urban design differs from traditional urban design as it is integrated in the urban space, reflecting multifunctionality of the urban space.

3 Water-Sensitive Urban Design

"WSUD is an approach to urban planning and design that integrates the management of the total water cycle into the land use and development process." WSUD aims to manage water in the urban environment in a way that minimizes the negative urbanization impacts and maximizes the economic, social, and environmental benefits, providing more livable cities, by adding green spaces, managing flood risks and impacts, reducing urban temperatures and pollutant flow to coastal recreation areas, minimizing the need for expensive infrastructure upgrades, and increasing property values. These allow for the transformation of the negative effects of urbanization into positive effects for the community [13] (Table 1).

WSUD first appeared in Western Australia in the early 1990s, and then it was spread out in the USA, Europe, and other countries. It combines different disciplines, which are environmental, water engineering, and urban and landscape planning and design. A WSUD approach involves using decentralized water systems; providing aesthetic values, adaptation to the surroundings, and local conditions; considering the maintenance and control; providing comparable costs to the traditional systems; fulfilling the demands of all stakeholders; creating multifunctional places whenever possible; and involving different disciplines in the planning process [5].

The concept of WSUD involves water savings, storm water management, alternative water use, reduction of wastewater production, and the quality and

Table 1 Potential benefits of WSUD – table used with permission from the Department of Environment, Water and Natural Resources, South Australia [11]

Economic	Environmental	Social
– Lower capital costs by reducing the need for piping and built infrastructure – Cost savings of water quality and the existing waterways are maintained – Cost savings of drainage – Increased value of real estate – Higher value of sites that are unsuitable for construction	– Maintain hydrological balance by infiltration, storage, and evaporation – Protecting the ecological system from urban developments – Restoration of waterways – Protecting the natural groundwater	– Amendable urban and residential landscapes – Aesthetical values for the community – Better open spaces – Reducing urban heat island effects

quantity of groundwater. WSUD aims to avoid or minimize the negative environmental impacts of urbanization, in terms of water demand and pollution of natural water bodies.

The main components of WSUD are:

– Water supply (demand reduction, potable substitution, local sources)
– Wastewater management (recycling and reuse, public health, environmental health)
– Catchment management (maintain ecological functions, protect sensitive areas, groundwater management)
– Amenity (urban amenity, integration in design, support park and recreation water) [14]

WSUD aims to raise the value of urban water in the urban design and decision-making process, in addition to the process of integration of urban design, with environmental science and other disciplines. Wong and Brown have proposed a three pillar approach for a water-sensitive city, which should be integrated in the urban design. These are:

– Access to diverse water supply options, using centralized and decentralized infrastructure
– Provision of ecosystem services for the built and natural environment
– A sociopolitical capital for sustainability and water-sensitive decision-making and behaviors

Diversity of infrastructure requires the community to rely on centralized and decentralized water systems. A dual distribution system, separating potable and non-potable water, allowing for a fit for purpose water use and preserving water resources. Cities providing ecosystem services require that water management solutions consider the natural environment and don't have a negative impact; instead they add to its value, such as using constructed wetlands, which provide benefits to the environment. Social acceptance and decision-making are also key roles in the implementation of WSUD in communities [15].

WSUD is based on both structural systems (such as constructed wetlands, green roofs, rain gardens, and bioswales) and nonstructural tools such as policies and regulations [17] (Fig. 3).

Fig. 3 Water-sensitive solutions in Montmorency, Victoria, to the left, and in Auckland, New Zealand, to the right [16]

4 Examples of WSUD Application

Examples of communities using WSUD solutions are chosen from arid and semi-arid regions to study the implementation of WSUD in similar climatic conditions to Egypt. Finally an example located in Egypt is studied to examine its applicability.

4.1 *Taylor Mall, Phoenix, Arizona*

Phoenix is located in the Sonoran Desert; its climatic classification according to Koppen is BWh, which is the same as Egypt. The city provides some examples for coping with climate change in a desert climate.

The project lies at the heart of the Arizona State University (ASU). A three-block landscaped pedestrian walkway unifies the university campus by creating a pedestrian walkway along Taylor Street from Central Avenue to Third Street [18] (Fig. 4).

The project involves redesigning a three-block segment of Taylor Street to function as an outdoor classroom for students to learn about green building techniques. A planted canal harvests storm water and air conditioner condensate; in addition, this canal recalls the historic canals of Phoenix. Permeable surfaces and natural local materials provide water management and reduce urban heat island effect. The system allows new streetscapes to be watered by the storm water and harvested air conditioning water [19]. The project also uses recycled air conditioner condensate (stored in a cistern) to provide water surfaces as a landscape element (Fig. 5).

The existing street from second street to third street was replaced with a narrower road. It used permeable pavement and curb cuts to collect storm water. A bioswale treated the storm water and provided green areas and shade, resulting in decreased heat island effect. The street between Central Avenue and 1st Street was converted to a pedestrian street, except for emergencies. Pervious pavement and a bioswale were also used to collect and distribute storm water to be used in the landscape.

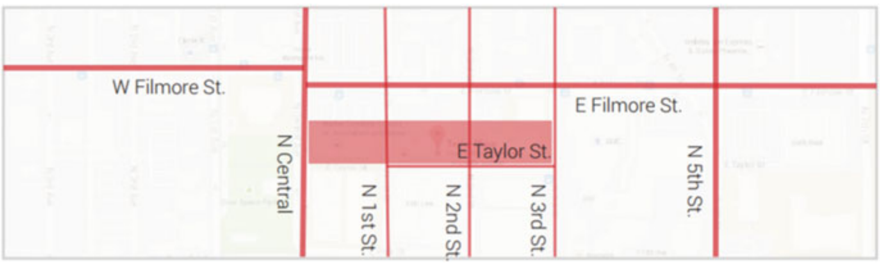

Fig. 4 Taylor Street location [20]

Fig. 5 (**a**) Water features can harvest rainfall, making water visible and celebrating its importance in an arid climate. (**b**) Grated curb cuts convey storm water from pavement into planting areas. (**c**) Porous pavers and permeable pavement at the pedestrian walkway allow infiltration and reduce off-site runoff. (**d**) Standard curb cuts open up planting areas to receive storm water flow [20]

Fig. 6 Taylor Mall: Central Avenue to 3rd Street – ASU Downtown Campus [19]

The storm water runoff was reduced by approximately 50%. Other social and economic benefits included the addition of student housing, classrooms, and addition of a pedestrian corridor that links students and visitors to the central park and entertainment avenues [20] (Fig. 6).

4.2 Pete V. Domenici US Courthouse, Albuquerque, New Mexico

Albuquerque is characterized by a semiarid climate. The project lies in the heavily urbanized downtown Albuquerque district. The area extensively uses asphalt and concrete, while spaces available for landscape plantings are limited.

The project is a retrofit of the existing design. The aim was to convert a water-intensive landscape into an environmentally friendly landscape that suits the court operations. Rainwater harvesting, storm water management, energy-efficient lighting, on-site solar panels, native and drought-tolerant plants, and the use of repurposed materials have transformed the place into a model for the Government Services Administration (GSA) demonstrating how a municipal site can more efficiently use public and natural resources (Fig. 7).

A bio-infiltration method, using soil and vegetation, is used to treat large amounts of storm water that falls on site. Large amounts of concrete pavements were removed to allow water infiltration to the ground. Rainwater is directed into terraced rain gardens that start from the site entrance up to the building. The rain gardens are planted with native plants. Drought-tolerant plants are located at the upper edge, while more water-tolerate are located down the slope.

The parking lot on the other side features vegetated bioswales to slow water flow, allowing sediments to settle out. A rock garden also allows water to percolate

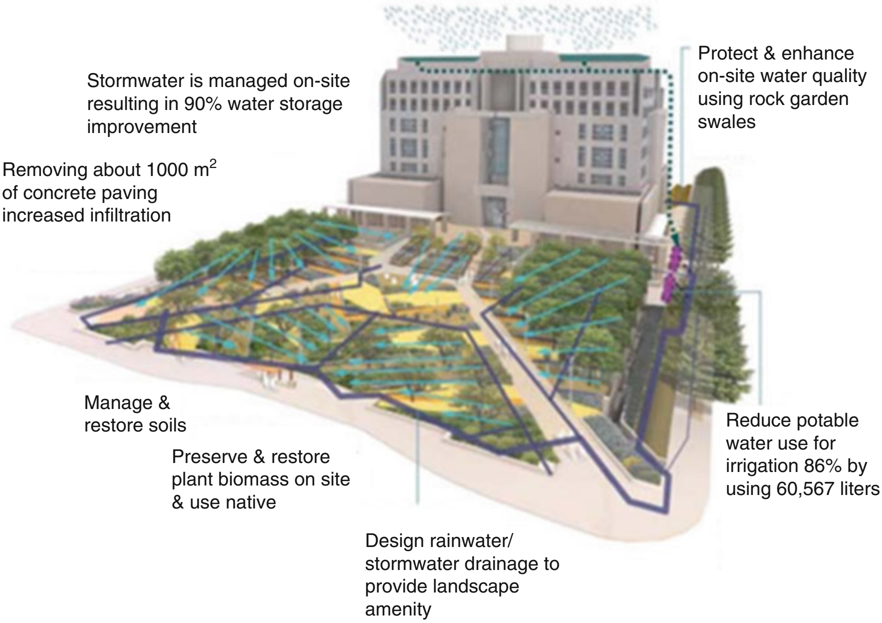

Fig. 7 Illustration of WSUD solutions used in Pete V. Domenici US Courthouse [22]

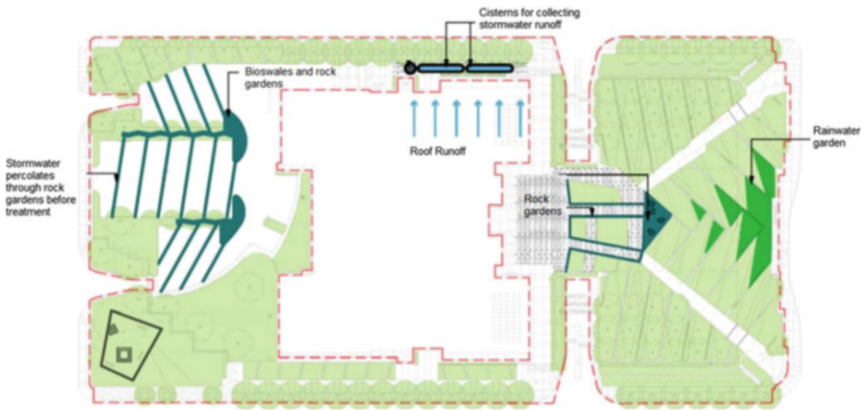

Fig. 8 Water treatment diagram in the Pete V. Domenici US Courthouse [21]

through rocks before moving to the municipal storm water system. Also rainwater falling on the roof is treated and stored in cisterns. Ninety-five percent of the total site storm water is treated to remove pollutants of concern (Fig. 8).

The resulting design reduces potable water use for irrigation by 86%, compared to an established baseline, through the use of a low-water plant palette and rainwater harvesting. The simplified landscape requires less maintenance and irrigation [21].

4.3 Ecological Water Treatment Park, Lima, Peru

Lima is the second largest city located in a desert, after Cairo in Egypt. The Rimac River catchment is the most densely populated region in the country. The city is also characterized by a BWh climate, similar to Egypt [23].

The project is located on an old agricultural land that is shaped by the Chillon River and a network of channels. New settlements are replacing agricultural areas in the land. The new buildings lack basic infrastructure; thus, they discharge wastewater into the channels that are used for irrigation of agricultural lands and green open areas. The discharge leads to health threats on the inhabitants. Also, the channels are converting into concrete irrigation channels, preventing infiltration into groundwater. Some channels have been closed, which has led to the desertification of green areas, leading to social conflicts. New solutions were needed to restore the channels and manage the water cycle.

A project was held in a park in a new residential settlement. The park is directly close to an irrigation channel. The settlement lacks any water supply or sewage services; thus water is expensive and scarce. The project used a WSUD solution by creating a wastewater treatment park that treats water from the irrigation channel, creating a healthy green urban area that is both recreational and educational, in

Fig. 9 Overview of the Children Park project [24]

Fig. 10 Interdisciplinary process for designing of water-sensitive solutions [25]

addition to social benefits. The wastewater treatment system is integrated with recreational activities to create the Children Park (Fig. 9).

The park consists of three main parts: (a) wastewater treatment area, along with seating and interactive educational panel about the treatment system and water resources, (b) grass recreational area with fruit trees, and (c) play area, with playground facilities made from recycled materials. The park is surrounded by a bamboo fence and xerophytic plants.

Polluted water from the irrigation channel is treated in a subsurface vertical flow constructed wetland (VFCW). The treated water is stored in a reservoir to be used for irrigation of the Children Park and another large park in the area. The project succeeded to convert the polluted channels into a main water source for the area [24] (Fig. 10).

4.4 *SEKEM Farm, Egypt*

The SEKEM farm is located in Bilbeis area at the east of Sharqia Governorate. A constructed wetland was set for the treatment of wastewater resulting from a nearby school, training workshops, offices, and some houses. The system aimed to increase

Fig. 11 Raw wastewater to the left and the treated wastewater to the right. The comparison shows improvement in the clarity of the water [27]

the available water for agriculture and solve the problem of uncontrolled wastewater disposal in the area. The treatment method was selected for its low cost, energy, and simple technology. It consists of a three-chamber pretreatment septic tank, a pumping well, a divisor, a horizontal constructed wetlands, an outlet well, and a storage pond. Primary treatment of wastewater is carried out by a septic tank, and then the effluent is directed to the constructed wetland for secondary treatment. Treated wastewater is then stored to be used for irrigation of forest trees [26] (Fig. 11).

Efficiency of treatment and percentage of removal were studied and calculated. The flow rate was measured regularly. Figure 12 shows the net present value of the system over its lifetime. As time passes, the net present value of the system increases [28]. The implementation of the treatment system has improved the quality of the wastewater. No problems with odor or insects occurred; in addition, the physical quality of the sandy soil has improved. The treatment system has a positive impact on the environment and the groundwater. The quality of the treated wastewater is within the permissible limits of the Egyptian standards [27]. About 10 m^3/day of freshwater was saved for irrigating the agricultural area by using the efficiently treated wastewater [29].

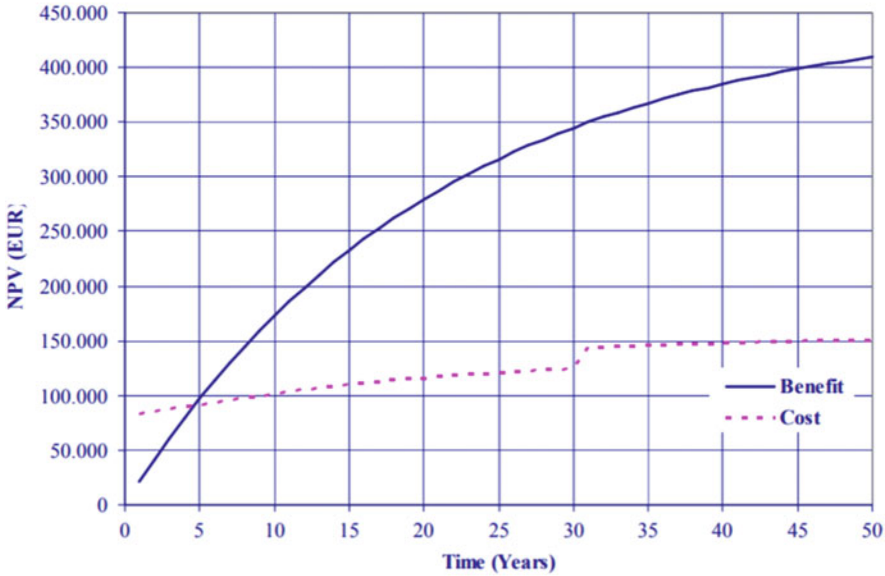

Fig. 12 Net present value of the wastewater treatment system over the lifetime, breakeven after 4 years [28]

5 Discussion

After studying the previous examples, it is noticed that WSUD can provide a sustainable solution for water management in communities. The first case study, Taylor Mall, being a street for the public has achieved both environmental and social benefits, as it provided WSUD solutions integrated in the landscape, in addition to using the collected storm water for the streetscape. The case also achieved aesthetic values as the solutions were specifically designed for the street scale and are convenient for the surrounding buildings. Economic value of the area has also increased.

In the second example, the courthouse, a building scale WSUD solution, has achieved environmental benefits by successfully managing storm water, reducing water consumption, and increasing the on-site infiltration. It also provided an aesthetic value as the landscape was designed to suit the building use, besides the water management function. The solutions were tailored for the site setting, the building, and the water management goals. Usability in the form of providing another function for the space was not fully achieved as public usage wasn't allowed for the site, but it is still acceptable as the solutions provided the required landscape for the building.

The third example, the Children Park, has achieved the environmental, aesthetic, and social benefits, in addition to the usability as it not only used the space for water treatment purposes but it worked as a children education and recreation park. It also achieved the public acceptance as the community was allowed to participate in decision-making, and workshops were held to gather the opinions of the inhabitants. Table 2 provides a comparison between the three examples in terms of achieving economic, environmental, and social benefits for the community. The SEKEM farm example wasn't included in the comparison, due to its different settings as it was not designed with the concern of integration with the urban design.

In the SEKEM farm, in Egypt, the treatment method wasn't integrated in the area from the beginning, but the economic benefits it achieved are considerable. The project succeeded in protecting the public health, as in the Children Park in Peru. It also provided treated wastewater for reuse in irrigation. The treatment method doesn't provide a multifunctional space for the community, but it can be considered an educational area for nearby students to learn about the environment and the water cycle. The example can be applied in new communities by integration in the design to provide more benefits for the community.

Table 2 Constructed wetlands as a sustainable wastewater treatment method in the previously studied examples (by author)

		Examples		
Aspect	Criteria	Taylor Mall, Phoenix, Arizona	Pete V. Domenici US Courthouse, Albuquerque, New Mexico	Ecological Water Treatment Park, Lima, Peru
Economic	Capital cost savings	○	○	○
	Reduced drainage costs	●	●	●
	Higher real state value	●	○	○
	Operation and maintenance	○	●	●
Environmental	Environmental protection	●	●	●
	Resource conservation	●	●	●
	Water reuse	●	●	●
	Hydrological balance	●	●	●
Social	Public health protection	○	●	●
	Functional open spaces	●	**O**	●
	Providing community landscapes	●	●	●

● fulfilled, **O** nearly fulfilled, ○ unknown

6 Conclusion

Water scarcity is facing the development of Egypt, as new communities require large amounts of water. The poor planning and lack of integration of water management in the design of communities lead to higher water demands and large amounts of wastewater, which require additional infrastructures of high costs, besides their negative environmental impacts. New concepts of urban design have appeared involving water management, such as water-sensitive urban design. WSUD provides water management techniques that are integrated in the urban design of communities, in addition to social, environmental, and economic benefits.

Examples in similar climates to Egypt show that the application of WSUD techniques is successful when integrated with the design, providing positive impacts on water resources, along with the community and its inhabitants. The example in Egypt was successful in the treatment of wastewater. Application of WSUD in new communities in Egypt can provide better living conditions for their inhabitants, besides saving freshwater resources by reusing treated wastewater. WSUD can be implemented in the building scale as in Pete V. Domenici US Courthouse, in the urban design scale such as the Taylor Mall example, or in public parks such as the Children Park.

7 Recommendations

Water management authorities and urban designers should join in decision-making, regarding the establishment of new communities and their design, to allow for the application of WSUD in these communities for the benefit of our country. A new organization including urban designers/planners and water managers would be of a great value for designing communities that are water sensitive, thus saving water resources and promoting an efficient water use. Constructed wetlands, along with other water management methods, should be used in new communities as part of the urban design of the community, to guarantee the lowest capital costs and the highest efficiency. Educational campaigns should be held in these communities to spread the awareness of the water scarcity challenge and the mechanism of the water treatment systems and their benefits on the inhabitant. The water treatment systems should be designed to add an aesthetical value to the community and eliminate any health risks resulting from wastewater. Further research concerning the social acceptance of alternative water treatment methods in Egypt is needed to ensure their applicability and decide on the required information campaigns for the public.

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