



## Designing Landscape as Infrastructure Water Sensitive Open Space Design in Cairo

A Thesis submitted in the Partial Fulfillment for the Requirement of the Degree

of Master of Science in Integrated Urbanism and Sustainable Design

by

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### Disclaimer

This dissertation is submitted to Ain Shams University, Faculty of Engineering and University of Stuttgart, Faculty of Architecture and Urban Planning for the degree of Integrated Urbanism and Sustainable Design. The work included in this thesis was carried out by the author in the Year 2013.

The candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of others.

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Lisa Deister

Signature

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#### Abstract

Situated in a desert region, Egypt is a country facing water scarcity. One approach to deal with this situation is to reduce water consumption, especially where it is not urgently needed, e.g. irrigation of green open spaces. This thesis explores opportunities of water sensitive open space design, an approach to reduce water consumption when irrigating green open spaces while increasing their amenity value and maintaining a lush green appearance. The gated community Al Rehab in New Cairo on the desert outskirts of Cairo is chosen as a case study area. Two conceptual design proposals are developed to point out options for interventions in the existing built environment and in the planning stage. Conceptual design proposal I shows how the implementation of different measures can lead to a more attractive landscape design while large amounts of water are conserved. The second design proposal presents ideas on how to substitute potable water as a source for irrigation. The thesis demonstrates that various strategies and measures already exist and can be adapted to achieve water sensitive open space design.

#### **Key words**

water sensitive open space design, water scarcity, decrease of water consumption for irrigation, gated community, Egypt

## **Table of Contents**

	Acknowledgements	
	Abstract in English	
	List of Figures	Ι
	List of Tables	V
	List of Tables (Appendices)	V
	Currency Equivalents	VII
	Area and Volume Equivalents	VII
	Abbreviations	VII
01	Introduction	3
	Egypt – a country facing water scarcity	3
	Theoretical framework: Design paradigm and approach	5
	The necessity of Water Sensitive Open Space Design in Egypt	7
	Research Objective and Questions	11
	Methodology	11
	Structure of the Thesis	13
02	The Case Study Area Al Rehab, New Cairo	17
	New Cairo	17
	Al Rehab	18
	Introduction	18
	Management organization	20
	Landscape design	21
	Water infrastructure and management	27
	Identified potentials and challenges	33
03	Water Sensitive Open Space Design Proposal	39
	The Strategy for Al Rehab	39
	Measures	41
	Description of different measures	42
	Design implementation	53
	Conceptual design proposal I	54
	Conceptual design proposal II	73
04	Conclusion	81
05	References	87
06	Appendices	101
	Abstract in Arabic	

#### List of Figures

Fig. 01 The Nile – Egypt's lifeline	2
Fig. 02 Development of water availability/ capita/ year	3
Fig. 03 Percentage distribution of Egypt's water resources by source 11/20	012 4
Fig. 04 "MIVIDA - The greener place to be"— Advertisement for a gated community in New Cairo, seen in Heliopolis	4
Fig. 05 Components of Water Sensitive Urban Design	6
Fig. 06 Strategies of Water Sensitive Open Space Design	7
Fig. 07 The sharp cut between cultural and desert landscape	7
Fig. 08 Aerial photo of the cultural landscape and the inceasingly cultivated desert	7
Fig. 09 "Landscape Scenery" in Al Rehab	8
Fig. 10 Definition of water demand, water requirement and water consumption	10
Fig. 11 Research methodology	12
Fig. 12 Location of New Cairo and Al Rehab	16
Fig. 13 Districts of Al Rehab and allocation to villa and apartment building areas and services and amenities	18
Fig. 14 Area, population numbers and construction times of Al Rehab	19
Fig. 15 Management organization in Al Rehab	20
Fig. 16 Location of upper part of district 2	21
Fig. 17 Map of the upper part of district 2 illustrating the high amount of green open spaces, marking of sections	21
Fig. 18 Courtyard in apartment building area	22
Fig. 19 Section A/A': Apartment building area	22
Fig. 20 Public green area in villa area	22
Fig. 21 Section B/B': Villa area	22

Fig. 22 Streetscape	23
Fig. 23 Roundabout	23
Fig. 24 Food Court	23
Fig. 25 Section C/C': Streetscape	23
Fig. 26 Section D/D': Food Court	23
Fig. 27 Section E/E': Public park	23
Fig. 28 Courtyard plantation with mixed water demands	24
Fig. 29 Plant nursery in Al Rehab	25
Fig. 30 Sprinkler irrigation	25
Fig. 31 Drip irrigation	25
Fig. 32 Hedges surrounding the courtyard greenery	26
Fig. 33 Kids playing in one of the courtyards	26
Fig. 34 Informal seating opportunities	26
Fig. 35 Location of WTP and WWTP for Al Rehab	28
Fig. 36 Sources of irrigation water starting from summer 2013	29
Fig. 37 Water cycle of Al Rehab	32
Fig. 38 Overview about the strategies and potential measures	41
Fig. 39 Focus areas for the two conceptual design proposals	53
Fig. 40 Green open spaces in the focus area (current situation)	55
Fig. 41 Overlay of different functions, appropriate water sources and relate hydrozones resulting in 15 different types of green open spaces in the focus area	d 58
Fig. 42 Location of green open space type 01	59
Fig. 43 Canna indica	59
Fig. 44 Cyperus papyrus	59
Fig. 45 Locations of green open space type 02	60

Π

Fig. 46 Cynodon dactylon	60
Fig. 47 Ficus microcarpa	60
Fig. 48 Locations of green open space type 03	60
Fig. 49 Agapanthus Headbourne hybrids	60
Fig. 50 Callistemon viminalis	60
Fig. 51 Location of green open space type 04	61
Fig. 52 Strelitzia reginae	61
Fig. 53 Senecio cineraria	61
Fig. 54 Locations of green open space type 05	62
Fig. 55 Pennisetum setaceum	62
Fig. 56 Chorisia speciosa	62
Fig. 57 Locations of green open space type 06	62
Fig. 58 Acalypha	62
Fig. 59 Parkinsonia aculeate	62
Fig. 60 Locations of green open space type 07	63
Fig. 61 Carpobrotus edulis	63
Fig. 62 Azadirachta indica	63
Fig. 63 Locations of green open space type 08	63
Fig. 64 Pandanus veitchii	63
Fig. 65 Nerium oleander	63
Fig. 66 Locations of green open space type 09	64
Fig. 67 Dodonaea viscosa	64
Fig. 68 Tamarix aphylla	64
Fig. 69 Locations of green open space type 10	65
Fig. 70 Portulacaria afra	65

Fig. 71 Yucca aloifolia	65
Fig. 72 Locations of green open space type 11	65
Fig. 73 Delonix regia	65
Fig. 74 Peltophorum africanum	65
Fig. 75 Locations of green open space type 12	66
Fig. 76 Conocarpus erectus	66
Fig. 77 Washingtonia robusta	66
Fig. 78 Locations of green open space type 13	66
Fig. 79 Melia azedarach	66
Fig. 80 Psidium guajava	66
Fig. 81 Locations of green open space types 14	67
Fig. 82 Locations of green open space types 15	67
Fig. 83 Exemplary perspective of courtyard in the apartment building area	68
Fig. 84 Courtyard current situation	68
Fig. 85 Modified water cycle for the focus area (Conceptual design proposal I)	72
Fig. 86 Green open spaces in the focus area (current situation)	74
Fig. 87 Green open spaces in the focus area (proposal)	75
Fig. 88 Modified water cycle for the focus area (Conceptual design proposal II)	77

#### List of Tables

Table 01 Development of water prices/ m <sup>3</sup> depending on the water as well as the end user	source	28
Table 02 Calculation of the percentage of Al Rehab, which could be irrigated with treated waste water originally produced in A	l Rehab	29
Table 03 Limit values for treated municipal waste water reused in agriculture (mg/L)		31
Table 04 Classification of plants and crops irrigable with treated wa	ste water	31
Table 05 Summary of potentials and challenges		35
Table 06 Calculation of rewards/ gardener/ day in case of 100%, 75 50 % water savings	i% and	71

#### List of Tables (Appendices)

Table A Water demands of frequently used plants species	100
Table B Summary of values of factors contributing to the plant coefficient	108
Table C Approximate application efficiency of various on-farm irrigation systems and methods	108
Table D Definition of factors and resulting plant coefficient	109
Table E Calculation of water demand and water requirement for irrigation of a planting with plant coefficient = 0.6 and ET <sub>o</sub> values in mm/l for Giza Governorate	110
Table F Daily condensate water production during the year	111
Table G Calculation of plant coefficient for plants with low water demand	112
Table H Calculation of water demand and water requirement for irrigation of 141 m <sup>2</sup> planting with plant coefficient= 0.24 and ET <sub>o</sub> values in mm/l for Giza Governorate	112
Table I Calculation of percentage of irrigation requirements which can be covered with condensate water from air conditioning systems for 141 m <sup>2</sup> planting beds at the Food Court	112

Table J Calculation of plant coefficient for plants with high water demand (Hydrozone L)	113
Table K Calculation of water demand and water requirement for irrigation of planting with plant coefficient= 0.96 and ET <sub>o</sub> values in mm/l for Giza Governorate	113
Table L Calculation of plant coefficient for plants with upper moderate water demand (Hydrozone M with lawn)	113
Table M Calculation of water demand and water requirement for irrigation of planting with plant coefficient= 0.72 and ET <sub>o</sub> values in mm/l for Giza Governorate	113
Table N Calculation of plant coefficient for plants with moderate water demand (Hydrozone M)	114
Table O Calculation of water demand and water requirement for irrigation of planting with plant coefficient= 0.6 and ET <sub>o</sub> values in mm/l for Giza Governorate	114
Table P Calculation of plant coefficient for plants with low water demand (Hydrozone L)	114
Table Q Calculation of water demand and water requirement for irrigation of planting with plant coefficient= 0.24 and ET <sub>o</sub> values in mm/l for Giza Governorate	114
Table R Calculation of total water requirement of the focus area	115
Table S Total amount of green open spaces (current situation)	119
Table T Total amount of green open spaces (proposal)	119

#### **Currency Equivalents**

#### **Area and Volume Equivalents**

1 ha = 10 000 m<sup>2</sup>, 1 m<sup>2</sup> = 0.0001 ha 1 feddan = 0.42 ha = 4200 m<sup>2</sup> 1 m<sup>3</sup> = 1000 l, 1 l = 0.001 m<sup>3</sup>

#### Abbreviations

A/C	Air conditioning system
CAPMAS	Central Agency for Public Mobilization and Statistics
GW	Grey water
ILPÖ	Institute of Landscape Planning and Ecology, University of Stuttgart
PTWW	Polished treated waste water
PW	Potable water
TMG	Talaat Moustafa Group
TGW	Treated grey water
TWW	Treated waste water
WSUD	Water Sensitive Urban Design
WSOSD	Water Sensitive Open Space Design
WTP	Water treatment plant
WWTP	Waste water treatment plant

# 01 Introduction



Fig. 01 The Nile – Egypt's lifeline (own 2013, satellite image: NOAA 2013)

## **01** Introduction

#### Egypt – a country facing water scarcity

With more than 90% of its area being arid desert and the Nile supplying 86.2% of its water, Egypt is considered a country facing a critical water situation (El-Nahrawy 2011). The limited access to other water resources and therefore high dependency on the Nile can put the country in a serious situation in case of lower stream flow or other problems resulting in the decrease of available water.

The availability of water per capita has dropped significantly from 2189 m<sup>3</sup>/capita  $\cdot$  year in 1966, to 1035 m<sup>3</sup> in 1990 and below 1000 m<sup>3</sup> in 2011 due to high population growth. Given Egypt's continuous population growth of 1.66% each year, which equals an increase of 1 Million people every nine months, it is predicted to drop to 536 m<sup>3</sup>/capita  $\cdot$  year by 2025 signifying severe water scarcity. (Agrawala et al. 2004: 7, Abdel Wahaat & El-Din Omar 2011: 11)

Besides, increasing temperatures due to climate change resulting in higher evaporation and higher



Fig. 02 Development of water availability/ capita/ year (own, based on Abdel Wahaat & El-Din Omar 2011: 1)



Nile water<br/>(86.2%)Underground water<br/>(11.6%)Sea water desalination<br/>(0.1%)Rain and floods<br/>(1%)Sewage water recycling<br/>(2%)

Fig. 03 Percentage distribution of Egypt's water resources by source 11/2012 (adapted from Ministry of Water Resources & Irrigation, cited in CAPMAS 2012:2) water demands as well as a potential increase of water claims from upstream riparian countries might lead to decreasing water levels and, thus, a greater water stress for more than 80 Million people living in the country (Agrawala et al. 2004).

The potential to draw more water from other resources is limited: groundwater is often too deep and in addition saline, while the average rainfall in Egypt is extremely low (25 mm/m<sup>2</sup>  $\cdot$  year). Sea water desalination appears to have a greater potential at least for population centers near the cost. Within the last years, the technology has become a reasonable option (Bucknall 2006:38). According to Abdel Wahaat, also the reuse of treated waste water (TWW) can be seen as a promising opportunity for Egypt since its potential has not been fully tapped yet. It has been used to substitute potable water for irrigation since 1980. Egypt has a long tradition of recycling effluent water, more precisely the reuse of drainage water to irrigate agricultural land since 1930 (Abdel Wahaat & El-Din Omar 2011: 2).



Fig. 04 "MIVIDA - The greener place to be"– Advertisement for a gated community in New Cairo, seen in Heliopolis (own 2013))

Nevertheless, it is obvious that Egypt is in need to find more solutions to deal with water scarcity. One approach is to reduce water consumption, especially where there is no urgent need – for example the excessive irrigation of green open spaces, often using potable water.

In order to accommodate the continuously growing population so called New Towns are constructed in the desert on the outskirts of Egypt's capital Cairo. Private investors attract Cairenes promising a life in a lush and green oasis far away from the city's stress and pollution. And they keep their promise: beside a few public housing areas, numerous gated communities with low building and population densities, a well connected road network and extensive green open spaces pop up in "New Cairo" and "6th of October City" east and west of Cairo respectively. They offer a calm life to the upper middle and upper class of Egypt's society and expatriates. The exploitation of resources, especially of water, reaches a peak to create these artificial oases in the desert.

The purpose of this thesis is to reveal measures to lower water demand and consumption of green open spaces and to show how these measures can be integrated into the landscape design, while maintaining a pleasant appearance of those green spaces. The gated community Al Rehab in New Cairo was chosen as a case study area to illustrate opportunities to intervene in an existing built environment as well as in the planning stage.

#### Theoretical framework: Design paradigm and approach

"Designing landscape as infrastructure" is a design paradigm recently discussed amongst architects and urban planners as well as landscape architects.<sup>i</sup> It aims to combine infrastructural, ecological, social and aesthetic aspects within the design of urban landscapes. It adds values, which influence public perception and acceptance of necessary infrastructure facilities by coming from a holistic point of view rather than a solely infrastructural one. In this way, urban landscape shall become productive, offering values for different sectors all at the same time and, thus, increasing its sustainability.

"Water Sensitive Urban Design" (WSUD) is one example on how the paradigm "Designing landscape as infrastructure" finds its application. Hoyer et al. define WSUD as "[...] the interdisciplinary cooperation of water management, urban design, and landscape planning. It considers all parts of the urban water cycle and combines the functionality of water management with principles of urban design. WSUD develops integrative strategies for ecological, social, and cultural sustainability [...]" (Hoyer et al. 2011:14) (see Fig. 05). This approach is mostly discussed in the context of rainwater management in temperate climate zones which have a lot of rainfall (Hoyer et al. 2011: 14). However, a lot of countries around the world face water scarcity and have to deal with weeks, months or sometimes even years of drought. Drastic measures had to be taken in California for example, where 2009 was the third year of drought in a row. Inhabitants were asked to cut down their water consumption by 20%. Also certain regions and cities of Australia such as Perth struggle although the overall water avail-



Fig. 05 Components of Water Sensitive Urban Design (Hoyer et al. 2011:14, modified layout)

ability per capita is sufficient. However, water is not equally distributed. Egypt as well as other countries in the MENA region simply do not have enough water resources to meet the demands of its continuously growing population (Black & King 2009: 22-23). In both cases, WSUD can – and partly already does – play an important role. Research projects, PhD and final theses as well as pilot projects increasingly try to find ways to reduce the consumption of potable water within the urban water cycle. Water sensitive design of green open spaces also called "Water Sensitive Open Space Design" (WSOSD), represents one field of intervention aiming to reduce potable water used for irrigation purposes. A promising alternative to irrigation using potable water is the use of TWW. Other additional water resources such as condensate water gained from air conditioning systems can play a minor, but nevertheless important role. Furthermore, a general reduction of water consumption can be achieved by reducing demand, e.g. with plants which consume less water, and avoiding losses. (See Fig. 06)



Fig. 06 Strategies of Water Sensitive Open Space Design (own 2013)

#### The necessity of Water Sensitive Open Space Design in Egypt

When looking at an aerial image of Egypt it is possible to clearly see the distribution of the aforementioned very high percentage of desert and the narrow strip of fertile land. The cut between these two types of land is a sharp one (Fig. 07). The fertile land consists of the former Nile floodplain, which was regularly inundated until the construction of the High Dam in Aswan in 1971, and its artificial extension by multiple irrigation channels through which the water flows mostly by gravity force. These enabled agriculture to take place and mankind shaped the landscape. In contrast to this cultivated landscape there is the harsh desert environment. Increasingly, Egyptians began settling in this landscape since the 90's due to the continuous population growth and limited space along the river. (Fig. 08)

One result is the development of so-called New Towns on the outskirts of Cairo. As described previously, private investors establish large, lush and green housing areas to attract people to move out of the city of Cairo. Studies and research show that



Fig. 07 The sharp cut between cultural and desert landscape (Google Earth 2013)



Fig. 08 Aerial photo of the cultural landscape (left) and the increasingly cultivated desert (right) (own 2013)



Fig. 09 "Landscape Scenery" in Al Rehab (own 2013)

beside beneficial health effects, green open spaces can help to mitigate extreme heat caused by high solar radiation (SPRINGUEL 2006: 36). According to Cabe, temperature decreased between 1 °C and 4 °C due to the existence of trees and greenery in different areas in Tel Aviv (Cabe 2004 cited in Kafafy 2010:92). Besides, cooling effects can reach out to up to 100 meters (Shashua-Baret et al. 2000, cited in Kafafy 2010:92). Thus, green open spaces can be considered as necessary infrastructure in this kind of settlement suffering from harsh environmental conditions. But still there is a high potential to increase the value of these green open spaces and strengthen the legitimation of their existence. Currently, it is mostly seen as "landscape scenery", a term suggested by Mohammed Refaat, a landscape architect in Cairo (Interviewee: Refaat 2013). These sceneries imitate large parks originally designed for countries with moderate climate. They are designed to look neat but not to be used, as it is not part of Egypt's upper classes to do so. Besides, they do not provide a basis for ecological benefits such as increasing biodiversity or offering habitat to different kinds of species. They rather have a negative impact and contribute to the exploitation of scarce water resources: the already high amount of water being used in order to maintain their lush green appearance is boosted drastically due to broken systems and wasteful irrigation in the daytime. Moreover, high energy consumption and enormous infrastructural facilities such as extensive pipe networks are necessary to pump water from the Nile to where it is required.

The amount of green open spaces in the New Towns is - compared to the inner city districts of Cairo extremely high. According to Dr. Nezar Kafafy, the average amount of green open space per person is about 1.7 m<sup>2</sup> in the capital. However, the numbers vary greatly depending on the district. For instance the district Marg only allows for 0.2 m<sup>2</sup> per inhabitant, whereas Shobra provides 1.37 m<sup>2</sup> and Helwan 2.93 m<sup>2</sup>. Nasr City offers 6.12 m<sup>2</sup> and Heliopolis 10.05 m<sup>2</sup> (Kafafy 2010: 172).. The amount of green space per **person in Al Rehab**, the gated community in New Cairo, which was chosen as a case study area, is about 20 m<sup>2</sup> (Kafafy 2010: 163).

In his PhD thesis, Kafafy drew up a detailed analysis of the amount, the distribution and also the kind of green spaces which can be found in Cairo. He analyzed different neighborhoods, their urban pattern and the resulting green open space facilities. One very interesting finding is that according to Kafafy's estimations, 67% of the green open spaces in Cairo are privately owned, while only 33% are provided by the government. In addition, just 1/3 of those 33% of public green open spaces are free to enter. (Kafafy 2010: 88)

The private green open spaces are usually highly maintained. According to Hana'e Ibrahim, infrastructure consultant at Talaat-Imam Consultants, governmental areas are irrigated with 20-30 m<sup>3</sup>/feddan  $\cdot$  day (=4.76 - 7.14 l/  $m^2 \cdot day$ ), whereas in privately owned areas usually 30-50 m<sup>3</sup>/feddan  $\cdot day$  $(7.14 - 11.9 \text{ l/m}^2 \cdot \text{day})$  are used (Interviewee: Ibrahim 2013). These numbers have been confirmed by several engineers working in irrigation in Egypt. Especially the numbers for irrigation of privately owned green open spaces represent an extremely high amount when comparing to the water demand of plants in different arid cities. As an example, in Lima (Peru) the average water requirement of lawn, which is considered to belong to the group of plants with moderate to high demands accounts to approximately 3.40 l/m<sup>2</sup> · day (Ascencios Templo 2013:18). Therefore, it is assumed that these high amounts cover the water demand of plant species in a very arid climate and also include factors such as irrigation efficiency (70-90%, depending on the irrigation system) and soil evaporation losses (10-20% depending on soil wetness, texture, structure and density; defined as water requirement within this thesis). In addition, the high water losses occurring due to broken systems and wasteful irrigation behavior are taken into account and represent about 60% of the total amount (defined as water consumption within this thesis). (See Fig. 10)

The designers of gated communities with lush green open spaces are usually aware of the negative side of their concepts. Nevertheless, the planning of those areas is done "as if they weren't in the desert" according to Ahmed Yousry, an



Fig. 10 Definition of water demand, water requirement and water consumption (own 2013)

urban planner in Cairo involved in designing several gated communities around Cairo (Interviewee: Yousry 2013). A shift towards a more adequate, integrated and thus sustainable planning comes about very slowly only because investors put pressure on to create lush green, well marketable oases in the desert. However, due to the increasing pressure on the already stretched water resources, urgent intervention is needed in all respects in order to conserve water.

#### **Research Objective and Questions**

#### **Research** Objective

This master thesis aims at revealing strategies and measures to develop water sensitive open space design solutions. Their adequacy in the context of Al Rehab, a gated community in New Cairo, is assessed and two conceptual designs will be developed as an example.

#### **Research Questions**

- What are the options to decrease the water demand of green open spaces and the water consumption for irrigation in arid countries?
- Which other water sources exist that can be used for irrigation?
- What can water sensitive open space design proposals look like?

#### Methodology

Fig. 11 shows the research structure underlying this thesis. Based on the general approach of WSUD, this study comprises an examination of WSUD in the context of water scarcity, for the particular case study of Al Rehab, New Cairo. With the help of interviews, site visits in Al Rehab as well as other gated communities, and literature review, the water management side as well as the landscape design are analyzed to be able to identify potentials and challenges. This, in turn, is the starting point to develop water sensitive open space design solutions, tailored to the case of Al Rehab. The WSOSD strategies illustrated in Fig. 06 are adapted, and suitable measures are being derived from interviews, literature and best practice review and are linked to the analysis. Preconditions for the successful implementation of measures are defined. Selected measures are applied within two conceptual design proposals, one showing opportunities to intervene in an existing built environment, while the other one indicates options for interventions in the planning stage.



Fig. 11 Research methodology (own 2013)

#### **Structure of the Thesis**

This thesis is organized into four chapters. Chapter one, *Introduction*, outlines the research context, the chosen design paradigm and approach and its necessity for Egypt. It concludes with the resulting research questions, the research methodology and the structure of the thesis.

Chapter two, *The Case Study Area Al Rehab,New Cairo*, presents an introduction to New Cairo and the development of Al Rehab. Furthermore, the landscape design as well as the water management in Al Rehab is being explained, resulting in the identification of potentials and challenges regarding WSOSD.

Chapter three, *Water Sensitive Open Space Design in Al Rehab*, explains the tailored strategy for the case study area. Potential measures to implement the strategies are described and some are selected to be applied in two conceptual design proposals. After a short overview about the chosen sites for the proposals, the selected measures, their relations and their potential water savings are presented.

To conclude the thesis, chapter four discusses limitations of the study, and provides an outlook.

i There is also a debate whether this discussion is a recent or a refurbished one. For more insights into this discussion see Czechowski, D., Hauck, T., Hausladen, G. (2012) Designing nature as infrastructure. Conference on ,Natur als Infrastruktur entwerfen'. Held 29-30 November 2012 at TUM München. München: TUM Graduate School.

## 02 The Case Study Area Al Rehab, New Cairo



Fig. 12 Location of New Cairo and Al Rehab (own 2013, satellite image: Google Earth 2013)
# 02 The Case Study Area Al Rehab, New Cairo

#### **New Cairo**

New Cairo, a new settlement on the eastern outskirts of Cairo, offers nowadays space for about 2.5 Million inhabitants on a total area of 244 km<sup>2</sup>. About 150 km<sup>2</sup> is built up. The development of land owned by the government evolved in three steps since 1985. Originally, a new settlement was planned for public affordable housing in order to offer alternatives to informal construction for the lower income classes. Between 1995 and 1999 the area was extended. Exclusive and partly gated areas were established by the private sector, only leaving limited space for lower and middle class groups in this area. Further extension started in 1999 and is almost completely realized by the private sector. Most of the building area is being sold to investors for low prices and only a small part is being offered to private land developers.

Planned to be completely finished in 2050, large parts of the new settlement are already constructed and used as residential areas with full infrastructure coverage and various educational facilities such as the German University Cairo and American University Cairo, and amenities (Mayer 2012).



Number of district
Apartment building areas
Villa areas
Services and amenities

Fig. 13 Districts of Al Rehab and allocation to villa and apartment building areas, services and amenities (own 2013, satellite image: Google Earth 2011)

## Al Rehab

#### Introduction

One of the first gated communities in New Cairo was Al Rehab. It is located in the northern part of New Cairo on the Cairo-Suez Road, approximately 27 km east of Cairo. The Talaat Moustafa Group (TMG), one of Egypt's major construction and industry companies, was one of the first to enter the new real estate market and invited tenders for the planning of Al Rehab in the mid 90s (Yousry 2009: 4).

The winning competition entry by Mahmoud Yousry Associates meant to create a self-sustaining city offering a variety of services and amenities in addition to the residential areas. The construction of "Al Rehab I" was scheduled in six phases. Accordingly, the land was split into six districts, covering an area of 6 140 000 m<sup>2</sup> in total. It is supposed to offer home to about 120 000 inhabitants. Construction started in late 1996, and was extended by 3 760 000 m<sup>2</sup> in 2006. Another 80 000 inhabitants are expected to find a place to live in the districts 7-10 (Talaat Moustafa Group 2010). This area is commonly called "Al Rehab II" or "Al Rehab extension".

These ten districts containing villa areas as well as apartment building areas are arranged around the so-called green heart of Al Rehab: the sports club. The services and amenities are located along a ring road running through all the districts. (Interviewee: Yousry 2013) Internal bus lines cover all of Al Rehab and other busses connect Al Rehab to Cairo (Nasr City, Heliopolis, Ma'adi).

Districts number 1 to 6 are planned and executed by several companies. The "Cairo Group", consisting of Mahmoud Yousri Associates, APG and Dr. Assad Said, was in charge of the master plan for the whole area as well as detailed planning for the districts one, two, three and six. Dar El Handesa and Space carried out the planning of districts four and five. Districts number 7 to 10 are also planned by the "Cairo Group" and currently under construction (Interviewee: Yousry 2013).

Al Rehab was the first compound in New Cairo offering apartments and semidetached villas, which are affordable not just for the upper class but also for the upper-middle and middle classes. This was a market-driven decision, as the demand for this kind of housing is higher than for high-end villas (Yousry 2009: 4). According to Farag, 21% of Al Rehab's inhabitants belong to the middle income group, 60.5 % to the upper-middle income group, while only 18.5% have an income level of the upper class (Interviewee: Farag 2013).

Al Rehab is considered to be the most reputable gated community in Cairo. Nonetheless, sales have gone down since the financial crisis in 2008 and the revolution in 2011 (Interviewee: Farag 2013).

Al Rehab	Al Rehab I (districts 1-6)	Al Rehab II (districts 7-10)
<i>Total area</i> 9 900 000 m²	Area 6 140 000m²	<i>Area</i> 3 760 000 m²
<i>Expected population</i> 200 000	<i>Expected population</i> 120 000	<i>Expected population</i> 80 000
	<i>Construction</i> 1996 – 2011 (planned, but not fully accomplished yet: district 6 still under construction)	<i>Construction</i> 2006 – 2017 (projected)

Fig. 14 Area, population numbers and construction times of Al Rehab (TMG 2010)



Fig. 15 Management organization in Al Rehab. Departments, which are engaged in the landscape design and/or the water management are highlighted in black (own 2013, based on interviews with Farag 2013, Marey 2013)

#### Management organization

With the TMG as the private investor, the affiliated company Arab Co. for Urban Development & Projects SAE is in charge of the management of Al Rehab (Mayer 2012). Different tasks are distributed to different departments, which are locally based. Fig. 15 shows the general organization. Departments, which are engaged with or related to the landscape design and water management in some way are highlighted in black. During the research several interviews have been conducted with responsible persons of these different departments.



Fig. 17 Map of the upper part of district 2 illustrating the high amount of green open spaces, marking of sections (own 2013)

#### Landscape design

As previously described the 10 districts are located around the Al Rehab sports club. Each district was planned to include areas with villa and apartment building housing. Because people want to live in lush green areas instead of the existing desert landscape, the gated communities in the new towns are planned "as if they weren't in the desert" (Interviewee: Yousry 2013). In total 40% of the land of Al Rehab is supposed to be green open space (Mayer 2012) (see Fig. 16 and 17). In the following, the green open spaces of a part of district 2 are illustrated to give an impression about the landscape design in Al Rehab. Furthermore, the general realization and maintenance as well as the usage of the green open spaces are described.

#### Green open spaces in different areas

Apartment building areas



Fig. 18 Courtyard in apartment building area (own 2013)

The apartment buildings are arranged in clusters surrounding courtyards. These are interconnected by a pedestrian network bordered by green strips. Groundfloor apartments often have small private garden plots to block views and increase privacy. The planting in the courtyards and gardens consists of extensive lawns with single trees, which are often encircled by perennials, and small groups of shrubs. These green spaces are usually surrounded by hedges, which show man-made gaps to enter the lawn areas. Pergolas can be found in some green areas. Green strips comprise lawns and shrubs, sometimes perennials as groundcover. (Fig. 18 and 19)



Fig. 19 Section A/A': Apartment building area (own 2013)

#### Villa areas



Fig. 20 Public greenery in villa area (own 2013)

Semidetached and detached luxurious villas offer living space in 170 to 320m<sup>2</sup> on plots of 200-800m<sup>2</sup>. Private gardens represent up to 60% of the plot area. Further public greenery with extensive lawns, and a few trees and shrubs loosen up the streetscape in the villa areas (see Fig. 20). Trees on the narrow sidewalks provide shade for the parking cars on the street. (Fig. 21)



Fig. 21 Section B/B': Villa area (own 2013)

#### Public areas

The streetscape in Al Rehab is spacious, offering up to 3 traffic lanes for each driving direction plus parking spots along some parts of the main streets. The lanes for different driving directions are separated by green strips (see Fig. 22). Most streets are accompanied by tree lines and several public parks can be found along the ring road (see Fig. 25 and 27). Roundabouts, which substitute traffic lights, and parks comprise extensive lawns, and some groups of shrubs and single trees (see Fig. 23). In addition, usually two kinds of perennials are planted in roundabouts: one blooming in summer, the other in winter.

Other public areas with services and amenities such as the Food Court offer their clients seating areas surrounded by lawns with single trees, bordered by hedges. The area at the Food Court as well as the one in front of the building of the Sales Department of Al Rehab is further enhanced by water installations (ponds and fountains). (See Fig. 24 and 26)



Fig. 25 Section C/C': Streetscape (own 2013)



Fig. 22 2013) Streetscape (own



Fig. 23 Roundabout (own 2013)



Fig. 24 Food Court (own 2013)



Fig. 26 Section D/D': Food Court (own 2013)



Fig. 27 Section E/E': Public park (own 2013)

#### Realization and maintenance of the green open spaces

In Al Rehab the design of the public green open spaces in the different districts was developed by different (landscape) architecture offices. However, modifications in the design are made during the execution, which is done by the contracted company called Basateen. In most cases the hardscape design (design of paved areas) is followed, but modifications in the softscape (plant selection and arrangement) and the selection of materials are made, if the originally planned plants and materials are difficult to get. Thus, always the same plant and material repertoire are used, once they have been approved by the head of the Technical Department and they have proven to be successful in terms of heat resistance as well as publically accepted aesthetic values (Interviewee: Farag 2013). The plant repertoire mainly comprises non-native plants with high ornamental value. Plants with low, moderate and high water demands can be found next to each other (see Fig. 28). The information about the different water demands is taken from data sheets provided by the landscape architecture office "Nature for landscape architecture and planning", Cairo (Dr. Mohamed Refaat, landscape architect) (see Appendix 01).

A gardening department within the city council is in charge of the maintenance of the public green spaces. Their tasks include irrigation (in general: daily irrigation in summer, twice a week in the winter, but usually it is held flexible depending on the weather), pruning (twice a year), fertilizing (organic in winter and chemical in the summer), mowing, as well as the management of the plant



Fig. 28 Courtyard plantation with mixed water demands (own 2013)

nursery located in the north eastern part of Al Rehab (see Fig. 29). There, plants are grown to replace those which do not meet the standards anymore. For irrigation, about 200 gardeners are currently employed, who earn between LE 30-50 per day depending on their qualification (Interviewee: Farouk 2013).

Lawns and flower beds are irrigated with sprinklers (see Fig. 30); shrubs, trees and palm trees with drip irrigation systems (see Fig. 31). Both systems have quite high application efficiencies (75-90%) (Phocaides 2000: 74). Irrigation often takes place during the day when water losses due to evaporation are estimated to be 20%-30% depending on humidity, wind speed, and temperature (Smith 2008). Especially during the hot summer days in Egypt these water losses are likely to be much higher. Besides, the duration of irrigation is often longer than necessary due to the large area one gardener is responsible for. Lawn for example should be irrigated for 10 minutes in winter and 15 minutes in summer according to the instructions of the irrigation engineer. However, gardeners go to open the next valve in a different area while irrigation takes place in the first area. This often leads to much longer irrigation times (Interviewee: Hazem 2013). Thus, irrigation water often floods planting areas. Beside additional water losses through evaporation from theses puddles, it can also harm the plants. Overwatering can cause soil pests, root-destroying fungi, as well as lack of oxygen for the plants (Moore 1986: 58).

#### **Usage of the Green Open Spaces**

Different statements were given regarding the permission of usage of the green open spaces. According to Yousry, urban planner who contributed to the winning competition entry for Al Rehab, and Farag,



Fig. 29 Plant nursery in Al Rehab (own 2013)



Fig. 30 Sprinkler irrigation (own 2013)



Fig. 31 Drip irrigation (own 2013)



Fig. 32 Hedges surrounding the courtyard greenery (own 2013)



Fig. 33 Kids playing in one of the courtyards (own 2013)



Fig. 34 'Informal' seating opportunities (own 2013)

architect at the Technical Department of Al Rehab, green areas were designed to be used by the inhabitants of Al Rehab. In contrast to their statement, the general manager of the execution company Al Basateen, Yasser Mahmoud Shaker Ibrahim, stated that the usage of green open spaces is not allowed. (Interviewees: Yousry 2013, Farag 2013, Ibrahim, Y. 2013) This statement is underlined by the lack of seating opportunities and the existence of barriers around the lawns in form of hedges or fences (see Fig. 32).

During site visits it was observed that the courtyards and gardens in the areas with apartment buildings are used by kids (see Fig. 33). A few adults bring their own chairs to sit and keep an eye on them (Fig. 34). Some adolescents meet in there as well and find other seating opportunities such as small walls. However, the intensity of usage of the extensive lawns is rather low, especially seen in relation to available space which could be used. Public gardens along the ring road are almost exclusively used by small groups of workers, who sit down on the lawn during lunch breaks. Green open spaces in the villa areas are not used at all. According to Yousry and Farag the reason for this underusage of green open spaces is explained as not being part of the culture of Egyptians of the upper income groups (Interviewees: Farag 2013, Yousry 2013).

To sum up, it can be said that the design of green open spaces offers low variation and is not based on functions. Design and plant selection almost solely fall back on extensive lawns as groundcover with groups of repeatedly used shrub species and single trees for all kinds of public green spaces. The only significant variation can be found in the quality: roundabouts and green open spaces in the public areas with services and amenities such as the Food Court seem to experience more intensive maintenance, while the green strips to separate the traffic lanes for example fall dry. Especially the extensive lawns seem to be inappropriate in most locations given the low/ non- usage and the fact that lawn is a walk-on-able groundcover, which requires high maintenance as well as a lot of water to meet the aesthetic requirements.

#### Water Infrastructure and Management

After having introduced Al Rehab from the landscape design perspective, now the water management side is examined. The general situation in terms of existing water infrastructure, water sources and processing are described. Water sources and water consumption for green open spaces are explained in more detail.

The Site Supervision Department is in charge of the planning, operation and maintenance of the water infrastructure system. According to Engineer Abdel Mohsen, the Infrastructure Manager at this department, water from two sources is available in Al Rehab from summer 2013 onwards: potable water coming from the water treatment plant (WTP) in Abur city, which is treating water from the Ismaïlia Canal, and treated waste water coming back from the waste water treatment plant (WWTP) at Ain El Sokhna road (see Fig. 35). Groundwater is found in a depth of 350 m under Al Rehab and is highly saline (5000 ppm). For this reason, it is currently not an option to extract and use this water. Stormwater from occasional rainfalls infiltrates into the ground or is fed into the sewage system (Interviewee: Abdel Mohsen 2013a).

The WWTP for New Cairo is located south of New Cairo at the Ain El Sokhna road and lies on a hill, approximately 400 m above sea level and 50-150 m above New Cairo. This makes various pump stations necessary to lead the waste water to the treatment plant (Interviewee: Ibrahim 2013). Originally it was designed to treat the waste water in two treatment stages, but later on it was decided to extend the treatment plant by a third treatment step, which is still under construction. Currently, the WWTP has a capacity of 250 000 m<sup>3</sup>/day, which is not exhausted. Just 100 000 m<sup>3</sup> of waste water coming from New Cairo (approx. 10 000 m<sup>3</sup> from Al Rehab) are treated daily. The construction of the entire WWTP is planned in three phases, from which only the first part has already been finished. After the accomplishment of the third phase the plant will have a capacity of 1 002 050 m<sup>3</sup>/ day.



Fig. 35 Location of WTP and WWTP for Al Rehab (own 2013, based on interview with Ibrahim 2013, satellite image: Google Earth 2012)

At the moment just 60% of the TWW is led back to New Cairo. The rest of the water is used for the irrigation of the green belt around New Cairo and for green spaces on military premises. Additionaly, a part of it gets stolen by Bedouins. Al Rehab receives 6 000 m<sup>3</sup> TWW per day, which are used for irrigation of green open spaces. This amount will be increased in summer 2013 and substitutes the primary treated Nile water, which was formerly used for irrigation. This decision was based on the drastic increase of water prices during the last months (see Table 01).

	Original price	Interim price (until spring 2013)	Current price (June 2013)
Potable water for citizens (also used for irrigation)	LE 0.85	LE 1.20	LE 1.40
Nile water for irriga- tion	LE 0.275	LE 0.275	LE 6.40
Treated waste water for irrigation	LE 0.50	LE 0.50	LE 0.50
Potable water for use in the Al Rehab Club	LE 2.02	LE 4.03	LE 8.65
Potable water for construction sites	LE 5.00	LE 5.00	LE 9.35

Table 01 Development of water prices/  $\rm m^3$  depending on the water source as well as the end user (Interviewee: Abdel Mohsen 2013b)



Potable water Treated waste water

Fig. 36 Sources of irrigation water starting from summer 2013 (own 2013, based on interview with Abdel Mohsen 2013a and 2013b, satellite image: Google Earth 2011)

However, not all green open spaces are being irrigated with TWW, but also with potable water. This is due to two reasons: firstly, not enough TWW is available to cover the water requirement of all green open spaces (see Table 02 for calculations); secondly, there are health-related concerns to provide villa areas with TWW for irrigation: villa owners could easily connect the pipes for potable water with the ones for irrigation water to increase the water pressure of potable

Total population of Al Rehab (expected)	200 000
Water share per capita and day	0.275 m <sup>3</sup>
Approximate water consumption per capita and day if unaccounted water losses are about 34%	0.182 m <sup>3</sup>
Produced waste water	0.182 m <sup>3</sup>
Produced waste water in Al Rehab	36 400 m <sup>3</sup>
Treated waste water available for reuse per day (60% of produced waste water)	21 840 m <sup>3</sup>
Total water need for irrigation (if green open space=40 000 000 $m^2$ (=40% of total area) and irrigation is done with an average of 9.52 $l/m^2 \cdot day$ )	38 080 m <sup>3</sup>
Percentage of Al Rehab, which could be irri- gated with treated waste water	58%

Table 02 Calculation of the percentage of Al Rehab, which could be irrigated with treated waste water originally produced in Al Rehab. The figures of water share and water consumption per capita and day as well as the one for unaccounted water losses are based on the source Cabinet Information and Decision Support Center, cited in Abdel-Gawad 2008. water, which is usually too low. If the delivered irrigation water were TWW, this could lead to health hazards. (Interviewee: Abdel Mohsen 2013a)

The "Egyptian Code for the Use of Treated Wastewater in Agriculture" prescribes a quality of Grade A for the usage of TWW for irrigation of green open spaces. This is reached through tertiary treatment (Abdel Wahaat & El-Din Omar 2011: 17) (see Table 03 and 04). Thus, it is generally questionable, if the current quality of TWW in Al Rehab is good enough to allow the usage for irrigation. Besides, temporary fluctuations in its quality contribute to unreliability.

In some areas the intensive irrigation of courtyards caused damages to the fundaments of the apartment buildings. For this reason, a geomembrane has been installed in some meter depth. Water that is not used by the plants but infiltrates into the ground, is led into a pipe connected to the sewerage system (Interviewee: Hazem 2013). The entire water cycle of Al Rehab is illustrated in Fig. 37.

According to estimations of Abdel Mohsen, Al Rehab has currently about 500 feddan (210 ha) green open spaces (counting Al Rehab I and the state of construction of Al Rehab II in March 2013). Green open spaces in Al Rehab are irrigated with 30-50 m<sup>3</sup>/ feddan  $\cdot$  day (= 7.14 – 11.90 l/ m<sup>2</sup>  $\cdot$  day). Calculated with an average water consumption of 40 m<sup>3</sup>/feddan/day (9.52 l/ m<sup>2</sup>  $\cdot$  day) this results in a total daily irrigation water consumption of about 20 000 m<sup>3</sup> per day, which is apparently the double of the water consumption for domestic purposes (approx. 10 000 m<sup>3</sup>) (Interviewee: Abdel Mohsen 2013a). As explained in the chapter *The necessity of Water Sensitive Open Space Design in Egypt*, it is assumed that these amounts of irrigation water already include the large losses due to wasteful irrigation behavior, accounting approximately 60%. This assumption is based on calculations, which were done to be able to put the large amounts of water consumption for irrigation into a context.

In this thesis the Landscape Coefficient Method is used to estimate the water demand and water requirement of the landscape plantings. A more detailed explanation of the Landscape Coefficient Method and calculations, which verify the assumption that the water amounts used for irrigation already include water losses due to wasteful irrigation behavior, can be found in the appendices (Appendices 02 and 03).

#### AL REHAB\_WATER INFRASTRUCTURE AND MANAGEMENT

Treatment Grad Requirements	le	Α	В	С
Effluent limit	BOD <sub>5</sub>	<20	<60	<400
and Suspended Solids (SS)	SS	<20	<50	<250
Effluent limit value for fecal coliform and nematode cells or eggs (per liter)	Fecal coliform count (2) in 100 cm <sup>3</sup>	<1,000	<5,000	Unspecified

Table 03 Limit values for treated municipal waste water reused in agriculture (mg/l) (Excerpted from: "Egyptian Code for the Use of Treated Wastewater in Agriculture," February 2005, cited in Abdel Wahaat & El-Din Omar 2011: 17)

Grade	Agricultural Group	
A	G1-1: Plants and trees grown for greenery at touristic vil- lages and hotels.	Palm, Saint Augustin grass, cactaceous plants, ornamental palm trees, climbing plants, fencing bushes and trees, wood trees and shade trees.
	G1-2: Plants and trees grown for greenery inside residential areas at the new cities.	Palm, Saint Augustin grass, cactaceous plants, ornamental palm trees, climbing plants, fencing bushes and trees, wood trees and shade trees.
В	G2-1: Fodder/ Feed Crops	Sorghum sp
	G2-2: Trees producing fruits with epicarp.	On condition that they are produced for processing pur- poses such as lemon, mango, date palm and almonds.
	G2-3: Trees used for green belts around cities and affor- estation of high ways or roads	Casuarina, camphor, athel tamarix (salt tree), oleander, fruit-producing trees, date palm and olive trees.
	G2-4: Nursery Plants	Nursery plants of wood trees, ornamental plants and fruit trees
	G2-5: Roses & Cut Flowers	Local rose, eagle rose, onions (e.g. gladiolus)
	G2-6: Fiber Crops	Flax, jute, hibiscus, sisal
	G2-7: Mulberry for the pro- duction of silk	Japanese mulberry
С	G3-1: Industrial Oil Crops	Jojoba and Jatropha
	G3-2: Wood Trees	Caya, camphor and other wood trees.

Table 04 Classification of plants and crops irrigable with treated waste water (Excerpted from: "Egyptian Code for the Use of Treated Wastewater in Agriculture," February 2005, cited in Abdel Wahaat & El-Din Omar 2011: 17)



Fig. 37 Water cycle of Al Rehab (own 2013)

# Identified potentials and challenges in the Landscape Design and Water Management

With the help of various site visits, observations and interviews, several challenges have been identified. They contribute directly or indirectly to an increased consumption of water for irrigation and high cost. Besides, deficits in the landscape design have been identified, which lead to high maintenance and water requirements. However, potentials to be able to conserve more water in the future exist. Identified potentials and challenges are summarized and first conclusions are drawn below.

A very fundamental, but nevertheless powerful potential is that in parts of Al Rehab I and in the future also Al Rehab II the infrastructure to use TWW for irrigation exists. After completion, 40% of Al Rehab will use this advanced way of irrigation. Generally, if TWW is used for irrigation the most important is to ensure a high quality to avoid health hazards and environmental impacts. Currently, the quality of TWW is not reliable and ways to change this have to be found. One reason not to use TWW for irrigation in the villa areas due to lack of awareness on the inhabitants side. The other reason is that not enough TWW is available to cover the amounts currently consumed. However, these amounts ( $30-50 \text{ m}^3$ / feddan  $\cdot$  day) are not reasonable. In a country facing water scarcity water losses of about 60% due to wasteful irrigation behavior are not acceptable and their reduction has to be of primary importance.

In Al Rehab the green open spaces are irrigated with pressurized systems such as sprinkles and drip irrigation. Their efficiency lies around 75% for the low to medium pressure sprinkler systems and 80 to 90% for drip irrigation, which is quite high compared to other surface irrigation methods (usually 40 - 75% application efficiency) (Phocaides 2000: 74). However, not only the irrigation system, but also the actual operation and maintenance play an important role and, as pointed out previously, this is not done appropriately in Al Rehab.

After just two decades since the first developments, expectations of a certain kind of greenery in the desert compounds are permanently fixed in the people's minds: lush green oases have to be created in order to attract new inhabitants. Green open spaces can also be seen as a necessary infrastructure to attenuate the hot climate in these settlements. However, there is a great potential to preserve the climatic benefits while increasing the quality of green open spaces

and decreasing the maintenance costs. Appropriate landscape design should be based on the function and usage of the different green spaces. Accordingly, different types can be created, which also serve as identifying features and can create diverse atmospheres in the space. The functions can be reflected in an appropriate plant selection, which allows at the same time the creation of zones with different maintenance demands. Areas with solely ornamental function for example do not require maintenance-intensive lawns as groundcover. Besides, different water demands of the plants can be reflected in zones. This also contributes to lower water requirements and facilitates the irrigation process for gardeners.

As common in Egypt for larger projects including green open spaces, also Al Rehab has its own nursery for growing the plants which are planned in the green open spaces and to replace those that do not meet the requirements anymore. Beside the benefit of lower transportation costs and having plants available all the time, which are adapted to the local climate and soil conditions, it also offers the great potential of growing exactly the plants desired for the design. The current plant repertoire comprises mainly exotic plants, which are not native to Egypt. According to Springuel "[...] there is a great variety of indigenous trees and shrubs in Egypt with a high economic potential, which can grow in diverse habitats and consume little water while being cultivated; some plants can also grow on the water edge and survive long inundation periods" (Springuel 2006: xiii). Epstein even states that "[n]ative tree species such as Prosopis, Tamarix, Acacia and Zizyphus will need to be irrigated only once or twice after planting (and only if no rain falls for one week after planting). There will be no need for irrigation the following summer. Non-indigenous species such as Eucalyptus, Casuarina and Schinus will require permanent irrigation for the first five years after planting" (Epstein 1978: 45). Beside the potential decrease of irrigation demands, the extension of the plant repertoire with native plants can also help in restructuring the landscape and creation of new and adapted types of green open spaces. In addition, the biodiversity will increase.

Although it does not happen very often, once in a while strong rains also occur in Cairo. According to Al Rehab website, the infrastructure is calculated to be able to manage also large amounts of stormwater. According to inhabitants of Al Rehab this is not the case and streets are often flooded after these rain events. This calls for a flexible stormwater management, which could be integrated into the open space design. In this manner, flooding can be avoided and the stormwater can be used in an economical and environmental friendly way.

Table 05 summarizes the information described above.

Potentials	Challenges
Infrastructure for reuse of TWW exists in large parts of Al Rehab.	The quality of the TWW is not reliable.
	The available TWW is not enough to irrigate whole Al Rehab.
	Health concerns exist to provide TWW for ir- rigation in the villa areas.
Irrigation is done with highly efficient irriga- tion systems.	High water losses occur due to wasteful irriga- tion behavior.
	Plantations with mixed water demands require the irrigation with high amounts to cover the needs of the most consuming plant.
Green open spaces are used to attenuate the harsh desert climate (in particular the heat).	The low variation in types of green open spaces results in equally high maintenance and water demands all over Al Rehab.
A plant nursery on site decreases transporta- tions costs and increases successful plant- ings due to the plant's adaptation to the local conditions.	The relatively small plant repertoire compris- ing mainly exotic plants with mostly moderate to high water demand.
Occasional rainfall exists.	Stormwater floods the street due to lack of capacity of the sewerage system.

Table 05 Summary of potentials and challenges

# 03 Water Sensitive Open Space Design Proposal

# 03 Water Sensitive Open Space Design Proposal

## The Strategy for Al Rehab

Based on these identified potentials and challenges in the landscape design and the water management, strategies and measures for appropriate water sensitive open space design have to be tailored to the case of Al Rehab.

The main critic regarding the landscape design in Al Rehab is the lack of functionality and repeatedly used plants leading to a very homogenous appearance of all green open spaces with equally high maintenance demands. This calls for a restructuring of green open spaces. Also from a water management point of view this strategy can help to decrease the water consumption, if plants with similar water demands are grouped in certain areas. So called hydrozones can be created. Like this, irrigation can take place more precisely to fulfill the plants' different needs. Furthermore, it can facilitate the work of the gardeners, if areas with clearly distinguishable maintenance and water needs are established. Bringing together these crucial aspects, the restructuring of the green open spaces according to functions as well as hydrozones is suggested as the main strategy for Al Rehab.

Further strategies to minimize the use of potable water for irrigation, which have been mentioned in chapter *Theoretical framework: Design paradigm and approach* (see Fig. 06), can support the realization of the main strategy.

Based on the fact that TWW is already used for irrigation, but its availability is not enough to irrigate all green open spaces in Al Rehab, the focus is shifted towards "Add other water sources" and "Reduce water consumption". If consumption of TWW is reduced with the help of decreased demands and decreased losses, the surplus water can be used for irrigation in other areas where currently potable water is used. If the water consumption in these areas is also reduced, the area irrigated with TWW can be further extended. If additional water sources can be found, which are suitable for irrigation purposes, the area irrigated with potable water can be further decreased.

Depending on the suggested function of the area, an appropriate water source can be chosen. Irrigation water for areas, which are supposed to be used by the people for example, needs to have a specific quality to avoid health hazards. Certain water sources can be excluded for these areas. In other green open spaces the water quality plays a secondary role. According to the availability of the chosen water source, the hydrozone can be defined. If water from this source is rarely available, plants with low water demands have to be chosen. Also if water is sufficiently available, but large areas have to be irrigated from this source, the hydrozone "low demand" should be selected. Finally, small green open spaces with variable water quality demand shall be chosen to comprise plants with higher water demands to enhance the plant diversity.

To ensure the successful and safe implementation of these strategies two preconditions are defined:

#### Precondition I:

In order to use TWW for irrigation and substitute potable water, its quality has to be ensured to avoid health hazards.

#### Precondition II:

Measures have to be taken to improve the irrigation behavior of gardeners. All technical measures will be unsuccessful if large amounts of water are wasted due to inappropriate irrigation.

#### Measures

Different measures can be used to implement the strategies and preconditions and achieve water sensitive open spaces design. Based on literature and best practice example review, some are gathered and described briefly on the following pages. Preconditions for their implementation are defined and their potential for Al Rehab is delineated. An overview is given in Fig. 38.



Fig. 38 Overview about the strategies and potential measures (own 2013)

## Description of different measures

## Precondition I: Ensure quality of TWW

<i>Measure A</i> <i>Implementation of quality control at WWTP</i>
Preconditions
Intervention at WWTP level
Examples
n/a
Applicability in Al Rehab
This measure has to be implemented on another level of planning.

#### Measure B

TWW polishing on site

An additional treatment step can be added on site before the water is used for irrigation. Constructed wetlands and treatment reservoirs present options, which can be integrated into the green open space design.

#### **Preconditions**

- Availability of space for constructed wetlands or treatment reservoirs (min. 1 ha)
- Professional maintenance and supervision to ensure quality of water

#### **Examples**

- Campus of the American University Cairo, New Cairo (Interviewee: Ibrahim 2013)
- Waste water polishing park proposal within the Research project "Sustainable Water And Wastewater Management In Urban Growth Centres Coping With Climate Change - Concepts for Metropolitan Lima (Perú)" (Eisenberg et al. 2013: 180 ff)

Applicability in Al Rehab

Applicable. Green open spaces, which currently just serve as landscape scenery can be transformed into constructed wetland or treatment reservoir parks.

#### **Precondition II: Improve irrigation behavior**

Measure A Development of efficient management plan for and with the gardene	ers
Preconditions	
No special preconditions are required.	
Examples	
n/a	
Applicability in Al Rehab	
Applicable.	

#### Measure B

Creation of incentives program for the gardeners

An incentives program can be set up in order to give the gardeners a motivation to improve their work. If they manage to reduce the water consumption while maintaining the quality of the green open spaces they receive a part of the saved costs as a reward.

#### **Preconditions**

 Installation of water meter to measure the water consumption for irrigation

**Examples** 

n/a

Applicability in Al Rehab

Applicable.

#### Add other water sources

#### Measure A

Reuse of condensate water from air conditioning systems

#### **Preconditions**

- Existence of air conditioning systems (A/C)
- Buildings with larger volumes of air to be exchanged in order to make it profitable (e.g. public buildings)
- Collector system
- Retention reservoirs

#### **Examples**

• San Antonio Public Library, Texas (Wilson 2008)

#### Applicability in Al Rehab

Applicable. Restaurants and Cafés at the Food Court, the shopping malls as well as the different department buildings of the management might be suitable as A/C are used intensively. It is easy to introduce were a central A/C system is used. If several small split A/C devices are used, an extra piping system to collect the condensate water from each device is necessary.

#### Measure B

Stormwater harvesting

#### **Preconditions**

- Enough rainfall
- Collector system
- Retention reservoirs

#### **Examples**

- Storage tanks under roundabouts in Doha, Qatar (Interviewee: El-Bahrawy 2013)
- Dry detention ponds in Gelsenkirchen, Germany (Hoyer et al. 2011: 21)

#### Applicability in Al Rehab

Applicable in areas, which are not constructed yet. Due to quite low annual rainfall the potential water harvest is rather low. For this reason, this measure is just profitable if it can be integrated in the landscape design without additional costs.

#### Measure C

Reuse of ablution water from mosques

#### **Preconditions**

- Separate pipe network (for grey and black water)
- Retention reservoirs

**Examples** 

n/a

Applicability in Al Rehab

Applicable.

### Measure D

#### Reuse of drainage water

The reuse of drainage water is common in Egyptian agriculture. Excess water from irrigation infiltrates into drainage canals and is either reused directly for irrigation, blended or alternately used with water of better quality.

#### **Preconditions**

- Development of collector system for the urban context
- Retention reservoirs
- Plant selection which tolerates salinity (accumulation in the soil)

#### **Examples**

• Nile Delta, Egypt (Kielen 2002)

#### Applicability in Al Rehab

Applicable. As described previously a geomembrane has been installed in some meter depth in the courtyards of the apartment building areas. This system leads the water that is not used by the plants, but infiltrates into the ground, to a pipe connected to the sewerage system. This system could easily be adapted for direct reuse of drainage water for irrigation.

#### **Reduce water consumption: Reduce demand**

#### Measure A

Decrease of amount of green open spaces

The easiest option to reduce the water demand is to decrease the amount of green open spaces. Especially nonfunctional green open spaces can be reduced to a minimum and replaced by other urban spaces without greenery, with artificial greenery or, alternatively, they can be used for redensification.

#### **Preconditions**

• Reallocation of existing green open spaces

#### **Examples**

Replacement with artificial greenery:

- Whitehead Institute, Cambridge, MA USA (Martha Schwartz Partners 2013)
- Use of artificial turf in private garden design, Las Vegas (Synthetic Lawns of Las Vegas LLC 2011)

Applicability in Al Rehab

Applicable. However, good reasoning will be necessary to convince the investors to decrease the amount of green open spaces.

#### Measure B

#### Utilization of plants with low water demand

#### **Preconditions**

- Further studies about water demands and usage in urban context of potential plants with ornamental value to increase the diversity of existing plant repertoire with low water demand are required
- Availability of plants/ seeds

#### **Examples**

- Desert garden at the Aswan Campus of South Valley University (Springuel 2006: 40)
- Private desert garden of Dina Aly, Giza (Springuel 2006: 44)
- Tree plantations along the Cairo-Alexandria Desert Highway (Springuel 2006: 36)

Applicability in Al Rehab

Applicable.

#### **Reduce water consumption: Reduce losses**

#### Measure A

Automation of irrigation system

Weather stations can calculate the daily water demand based on temperature, humidity and wind and accordingly, the irrigation process is automatically adapted.

**Preconditions** 

• Professional maintenance and operation

#### **Examples**

• Al Azhar Park, Cairo (Aga Khan Trust for Culture 2005)

Applicability in Al Rehab

Previous considerations determined this system as not applicable for Al Rehab.

#### Measure B

# Decentralized treatment of waste water to decrease losses during transportation and treatment process

Waste water, especially grey water, can be treated on site in small systems on house hold level, or in constructed wetlands, lagoons or treatment reservoirs. These can be integrated into the design of green open spaces, providing infrastructural, climatic as well as recreational benefits at the same time.

#### **Preconditions**

- Availability of space for the decentralized treatment plant
- Separated pipe network for grey and black water, if just grey water is treated on site
- Retention reservoirs
- Awareness of inhabitants to ensure suitability of input water and behavior around the treatment plants
- Professional maintenance and supervision to ensure quality of water

#### **Examples**

Grey water treatment on house hold level:

• Garden Angel System from Perpetual Water (Perpetual Water 2008)

Decentralized treatment of different kinds of waste water and integration of treatment plants into the open space design:

• Waste water treatment park proposal within the Research project "Sustainable Water And Wastewater Management In Urban Growth Centres Coping With Climate Change - Concepts for Metropolitan Lima (Perú)" (Eisenberg et al. 2013: 194 ff)

#### Applicability in Al Rehab

Generally applicable. Green open spaces, which currently serve as landscape scenery can be transformed into treatment parks. However, if separated pipe networks are required, the measure is just applicable in areas which are not constructed yet.

#### Measure C

Direct reuse of grey water for irrigation

#### **Preconditions**

- Separate pipe network for grey and black water
- Retention reservoirs
- Plant selection, which tolerates chemical residues and varying pH levels
- Subsurface irrigation system to avoid direct contact

#### **Examples**

n/a

#### Applicability in Al Rehab

Applicable in areas, which are not constructed yet. However, due to potential health hazards and lack of awareness this measure is not suggested to be implemented on a larger scale. It might be adequate on household level when individuals decide to make use of it.


Fig. 39 Focus areas for the two conceptual design proposals (satellite image: Google Earth 2011)

### **Design implementation**

The feasibility of implementation of measures depends on various factors. One very fundamental one is the current state of the site: is everything already constructed and inhabited or is there still the possibility to make bigger modifications, e.g. in the underground infrastructure? In Al Rehab, both situations exist: the districts 1-5 are readily constructed, whereas districts 6 to 10 are currently under construction or still in the planning stage. This gives the opportunity to develop different conceptual design proposals:

**Conceptual design proposal I** explores, which measures are feasible in a readily constructed and inhabited area. A part of district 2 is chosen as an exemplary area (see Fig. 39).

For the *Conceptual design proposal II* a part of district 8 is chosen. This area gives the opportunity to intervene at planning stage (see Fig. 39).

Selection criteria for the measures are their applicability for the specific case of Al Rehab and their feasibility within the scope of this master thesis. The lack of data for some measures made the evaluation of feasibility of certain measures not possible.

In the following, the two conceptual design proposals are presented. First of all, the selected focus areas are briefly described. Next, measures for the implementation of the strategies and preconditions are suggested and applied for the specific site. To conclude, potential water savings are presented.

#### Conceptual design proposal I: Intervention in built environment

#### Introduction

For this conceptual design proposal the focus area is the upper part of district 2. The area has approximately 385 486 m<sup>2</sup> and comprises a villa area (approx. 82 916 m<sup>2</sup> = 21.5%) and an area with apartment buildings (approx. 191 521 m<sup>2</sup> = 49.7%), the Food Court with various restaurants and cafés (approx. 17 470 m<sup>2</sup> = 4.5%), public areas including a public park (10 068 m<sup>2</sup> = 2.6%) and the streetscape (83 511 m<sup>2</sup> = 21.7%). The existing school has not been taken into consideration, because neither the area nor information about the green open spaces were accessible.

Green open spaces account to 122 671 m<sup>2</sup> (31.8%). Figures 18 – 27 in chapter *Landscape design* give an impression about the appearance. The approximate total water consumption for irrigation for these green open spaces is 1167.83 m<sup>3</sup>/ day (calculated with an average amount of 9.52 l/m<sup>2</sup> · day for irrigation).

The measures "Utilization of plants with low water demands (Reduce demand)" and "Reuse of condensate water from air conditioning systems (Add other water sources)" have been chosen for this conceptual design proposal in order to implement the main strategy and achieve a minimization of the usage of potable water for irrigation. To fulfill Precondition I the measure"TWW polishing on site" is suggested to be applied and integrated into the main strategy. Generally, the measure "Creation of incentives program for the gardeners" is meant to be implemented on the scale of whole Al Rehab. Potential impacts are calculated for the focus area after concluding calculations of the amount of conserved water achieved through the suggested measures.

The measure "Reuse drainage water" is also suggested for implementation in the courtyards of the apartment area. However, it was not possible to calculate potential water gains within this thesis due to lack of data (infiltration rate and exact locations of existing installations to discharge the drainage water).



Fig. 40 Green open spaces in the focus area (current situation) (own 2013)

#### Implementation

As previously described in chapter *The Strategy for Al Rehab*, the definition of new functions of the different green spaces is the starting point for their restructuring. Depending on the function of the area an appropriate water source can be chosen, and, according to the availability of the chosen of water source, the hydrozone can be defined. An overview of the different categories, which were defined, is given on the following pages. Through an overlay of the three aspects 15 different types of green open spaces are suggested for the focus area. These are presented afterwards.

#### Different green open spaces and their functions

#### TWW polishing plant: Improve the quality of TWW

In constructed wetlands or treatment reservoirs the quality of TWW for irrigation can be improved. These treatment plants comprise vegetation and can be integrated into the landscape design. In combination with other green open spaces they can form so called TWW polishing parks.

#### Green commons: Invite inhabitants

These green open spaces invite inhabitants to use them. They require walkon-able groundcovers, which can stand intensive use. To ensure their pleasant appearance high maintenance is required.

#### Highly ornamental plantations: Attract attention

This highly ornamental green open space attracts the attention of passersby with its impressive plant selection. It highlights the area and requires high maintenance.

#### Pleasant plantations: Create a nice ambience

This green open space comprises an appealing planting with a moderate ornamental value. It is found in areas with larger green open spaces, in which a pleasant ambience is desired. Maintenance requirements are moderate.

#### Concomitant plantations: Provide a decent background

Larger green open spaces with rather concomitant functions comprise a simple and robust planting with low maintenance demands. They provide a decent background to the overall perception of the area and to planting areas with high ornamental value.

#### Tree rows: Provide shade

Tree rows along streets contribute to a comfortable microclimate and require moderate maintenance.

#### Private gardens

Private gardens are designed according to the wishes of the owners.

#### Irrigation water sources and appropriate hydrozones

#### Definition of hydrozones

**Hydrozone H:** plants with *high* water demands (approx.  $5.73 \text{ l/m}^2 \cdot \text{day}$ )

Hydrozone M: plants with *moderate* water demands (approx.  $3.58 \text{ l/m}^2 \cdot \text{day}$ )

**Hydrozone L:** plants with *low* water demands (approx. 1.42  $l/m^2 \cdot day$ )

#### TWW | Hydrozones H, M, L

TWW coming from the WWTP should only be used for irrigation in areas, in which people do not get in contact with the water due to the unreliability of its quality. It can be used in all hydrozones.

#### Polished TWW| Hydrozones M, L

After purification in a TWW polishing plant (constructed wetland or treatment reservoir), the water can also be used in areas where people might get in touch with it. These treatment plants have increasing space demands with increasing water amounts to be purified. For this reason, not all TWW can be polished. Hence, the water requirement of polished treated waste water (PTWW) should be kept low and accordingly, it can be used for hydrozones M and L.

#### Drainage water | Hydrozone undefined

The drainage water from the courtyards in the apartment building areas can be directly led into the irrigation pipe network (instead of leading it into the sewerage), where it is blended with the irrigation water provided to that area. Accordingly, the hydrozone conforms to the water availability of the additional water source.

#### Condensate water | Hydrozone L

The amount of condensate water reclaimed from A/C systems depends on the the amount of exchanged air, its temperature and humidity content, the power of the A/C system and its operating hours. Temperature and humidity vary everyday and, hence, also the amount of produced condensate water, which might not be sufficient to cover all water requirements. For this reason, the green open spaces selected to receive water from this source should be rather small and

belong to hydrozone L to decrease the necessity of additional water sources.

#### Potable water | Hydrozone L

Due to health related concerns to provide villa areas with TWW for irrigation all green open spaces in these areas are currently irrigated with potable water. Options to change this are limited due to lack of awareness of the inhabitants. To decrease the consumption of potable water as much as possible it is suggested that all green open spaces comprise plants with low water demands.

15 different types of green open spaces are proposed for the focus area based on an overlay of suggested functions, water sources and related hydrozones for different parts of the focus area (see Fig. 41). In the following, the different types are described briefly, their location is mapped and plant examples are given.



Fig. 41 Overlay of different functions, appropriate water sources and related hydrozones resulting in 15 different types of green open spaces in the focus area (own 2013)

#### Green open spaces types in the focus area

#### 01 TWW polishing plant | TWW | Hydrozone H





Fig. 43 Canna indica (ILPÖ 2013)



Fig. 44 Cyperus papyrus (ILPO 2013)

Fig. 42 Location of green open space type 01 (own 2013)

The public park located in this part of Al Rehab is suggested to be converted into a TWW polishing park (see Fig. 42). A large part of this park is covered by a constructed wetland, which is fed with TWW. The water is purified and then reaches a quality of Grade A. The PTWW is used in green open spaces, where inhabitants potentially get in touch with the irrigation water such as the Green commons (type 02).

The TWW polishing plant comprises plants, which are suitable for water purification and are of ornamental value such as *Canna indica* and *Cyperus papyrus* (see Fig. 43 and 44). Due to the continuous water provision, the plants are likely to consume a lot of water.

The necessary size of the constructed wetland has been roughly estimated with the help of the "Water demand tool" and the "LEIS Manual", developed within the research project "Sustainable Water And Wastewater Management In Urban Growth Centres Coping With Climate Change - Concepts for Metropolitan Lima (Perú)" (Eisenberg et al. 2013). These calculations just served to evaluate the feasibility of a constructed wetland in this area and further calculations have to be done.

#### 02 Green commons | PTWW | Hydrozone M









ac- Fig. 47 Ficus microcarpa (own 2013)

Fig. 45 Locations of green open space type 02 (own 2013)

Parts of the courtyards in the apartment building areas as well as some part of the area around the pond at the Food Court are intended to be used by the people (see Fig. 45). The irrigation water in these areas has to be of Grade A quality, which is fulfilled after purification in the TWW polishing plant (type 01).

*Cynodon dactylon*, the lawn species used in Al Rehab (see Fig. 46), is a relatively robust walk-on-able groundcover and has a moderate water demand, which determines the hydrozone. *Ficus microcarpa* is one exemplary tree, which can be used in this green open space type (see Fig. 47).

#### 03 Highly ornamental plantations | TWW | Hydrozone H





Fig. 49 Agapanthus Headbourne hybrids (web source)



Fig. 50 Callistemon viminalis (web source)

Fig. 48 Locations of green open space type 03 (own 2013)

This type can be found in roundabouts and is the only green open space belonging to hydrozone H beside the TWW polishing plant (see Fig. 48). They are one of the most representative green spaces in Al Rehab. Due to their relatively small total area and the option to use TWW for irrigation it is accepted that plants with high water demands are selected. This widens the plant repertoire (see for example Fig. 49 and 50). Nevertheless, each roundabout should have a unique design (e.g. through a plant selection with different color highlights for each roundabout) in order to increase their function as landmarks for orientation.

#### Highly ornamental plantations | Condensate water | Hydrozone L 04







Fig. 52 Strelitzia regi-nae (web source) Fig. 53 Senecio ciner-aria (web source)

Fig. 51 Location of green open space type 04 (own 2013)

Especially during hot summer months cafés and restaurants at the Food Court are cooled down with air conditioning systems. It is proposed to use the recovered condensate water for the planting beds in front of the facilities (see Fig. 51). If plants with low water demands are selected, the water requirement of these relatively small areas can be fully covered four months of the year (July -October). During three months (May, June, November) PTWW has to be added (67 % in May, 30 % in June and November). During the other five months of the year condensate water has to be substituted by PTWW. Calculations of the produced water amount and the water requirement are shown in Appendix 04.

As the Food Court is a public area where people go to relax and meet, the plantations adjacent to the terraces should have a high ornamental value to create a special atmosphere. Nonetheless, the plants need to have low water demands to maximize the coverage of irrigation requirements with condensate water. Examples are Strelitzia reginae and Senecio cineraria. As the water is not used directly and has to be stored until irrigation takes places, chlorine should be added to avoid health hazards. Therefore, plants which are not sensitive to chlorine have to be selected. According to Berry, just some species such as avocados, stone fruits, and grapevines are sensitive to chlorine, while plants can generally tolerate it (Berry n.d.). The quality of condensate water is similar to distilled, which makes additional fertilizing necessary.

#### 05 Pleasant plantations | TWW | Hydrozone M





Fig. 55 Pennisetum setaceum (web source)



Fig. 56 Chorisia speciosa (web source)

Fig. 54 Locations of green open space type 05 (own 2013)

A part of the TWW polishing park is designed to be a meeting area (see Fig. 54). The adjacent flower bed creates a pleasant ambience with appealing plants. As the constructed wetland is fed by TWW, the other parts of the park are also irrigated from this water source. The flower bed is small and, therefore, plants can have moderate water demands. Fig. 55 and 56 give two examples.

#### 06 Pleasant plantations | PTWW | Hydrozone L





Fig. 58 Acalypha (web source)



Fig. 59 Parkinsonia aculeate (web source)

Fig. 57 Locations of green open space type 06 (own 2013)

Green open spaces around the Food Court, which do not directly enclose the terraces, are suggested for comprise pleasant vegetation to contribute to an appealing ambience (see Fig. 57-59).

The adjacent Green commons at the Food Court requires PTWW. Thus, also these green open spaces have to be irrigated with this water, because the installation of a second pipe network is not feasible. As PTWW consumption has to be minimized, hydrozone L is required.

#### 07 Pleasant plantations | PTWW + Drainage water | Hydrozone L









Fig. 62 Azadirachta indica (web source)

Fig. 60 Locations of green open space type 07 (own 2013)

Pleasant vegetation is suggested for parts of the courtyards in the apartment building areas (see Fig. 60) in order to create variation in the green open spaces resulting in an appealing ambience. Fig. 61 and 62 show plants to achieve this. The Green commons in this area require PTWW. Thus, also these green open spaces have to be irrigated with this water, since the installation of a second pipe network is not feasible. Hydrozone L is required in order to minimize PTWW consumption.

#### 08 Pleasant plantations | Potable water | Hydrozone L





Fig. 64 Pandanus veitchii (web source)



Fig. 65 Nerium oleander (web source)

Fig. 63 Locations of green open space type 08 (own 2013)

The greenery in the streets of the villa area are converted into areas with pleasant vegetation with low water demands due to their irrigation with potable water (see Fig. 63-65).

#### 09 Concomitant plantations | TWW | Hydrozone L





Fig. 67 Dodonaea viscosa (own 2013)



Fig. 68 Tamarix aphylla (web source)

Fig. 66 Locations of green open space type 09 (own 2013)

The green strips to separate traffic lanes and the green area surrounding the constructed wetland belong to this type of green open space (see Fig. 66).

The green strips currently suffer lack of maintenance. Therefore it is suggested to exchange the vegetation to a type with low maintenance requirements with a decent appearance. Plants with low water demand as shown in Fig. 67 and 68 seem most appropriate in regard to the maintenance level and representativeness. Irrigation can be done with TWW.

The area surrounding the constructed wetland acts as a kind of barrier. Decent groundcovers with heights of 20-40 cm keep people at some distance. As the constructed wetland is fed with TWW also the other parts of the park are irrigated with this water.

#### 10 Concomitant plantations | PTWW + Drainage water | Hydrozone L





Fig. 70 Portulacaria afra (web source)



Fig. 71 Yucca aloifolia (own 2013)

Fig. 69 Locations of green open space type 10 (own 2013)

As the courtyards in the apartment building area comprise large green open spaces it is suggested to decrease the maintenance as much as possible. For this reason, parts of the courtyards belong to this type of green space (see Fig. 69). The Green commons in this area require PTWW. Thus, also these green open spaces have to be irrigated with this water, because the installation of a second pipe network is not feasible. As PTWW consumption is to be minimized, hydrozone L is required. Exemplary plants are shown in Fig. 70 and 71.

#### <u>11 Tree rows | TWW | Hydrozone M</u>





Fig. 73 Delonix regia (web source)



Fig. 74 Peltophorum africanum (web source)

Fig. 72 Locations of green open space type 11 (own 2013)

Trees on traffic lane separating strips without groundcovers (see Fig. 72) are irrigated with TWW and belong to hydrozone M to increase the variety of tree species (for examples see Fig. 73 and 74).

12 Tree rows | TWW | Hydrozone L





#### Fig. 76 Conocarpus erectus (web source)



Fig. 77 Washingtonia robusta (web source)

Fig. 75 Locations of green open space type 12 (own 2013)

Trees on traffic lane separating strips with vegetation shall have low water demands to be able to be combined with the groundcover plantings belonging to the type "Concomitant plantations | TWW | Hydrozone L" (see Fig. 75-77).

#### 13 Tree rows | Potable water | Hydrozone L





Fig. 79 Melia azedarach (web source)



Fig. 80 Psidium guajava (web source)

Fig. 78 Locations of green open space type 13 (own 2013)

Trees in the villa area (see Fig. 78) have to have low water demands due to their irrigation with potable water. Exemplary trees, which can be planted, are *Melia azedarch* and *Psidium guajava* (see Fig. 79 and 80).





Fig. 81 Locations of green open space types 14 (own 2013)

Private gardens in the apartment building areas (see Fig. 81) are provided with PTWW for irrigation. The plant selection is up to the owner and the plantation is most probably not according to hydrozones. A moderate water demand on average is assumed. It is strongly recommended to carry out awareness training to sensitize inhabitants to choose plants with low or moderate water demands in order to conserve water and reduce their water bills.

#### 15 Private Gardens | Potable water | Average water demand M



Fig. 82 Locations of green open space types 15 (own 2013)

Private gardens in the villa areas (see Fig. 82) are provided with potable water for irrigation. The owner selects the plants according to his wishes. Plantation is most probably not done according to hydrozones. On average a moderate water demand is assumed. It is strongly recommended to carry out awareness training to sensitize inhabitants to choose plants with low or moderate water demands in order to conserve water and reduce their water bills.



Fig. 83 Exemplary perspective of courtyard in the apartment building area with three different types of green open spaces: 10 Concomitant plantations | Hydrozone L (left), 07 Pleasant plantations | Hydrozone L (middle) and Green commons | Hydrozone M (right). All zones are irrigated with PTWW. (own 2013)



Fig. 84 Courtyard current situation (own 2013)

With the implementation of these different types of green spaces the amenity value of the green open spaces in the focus area is greatly enhanced. Various appearances create different ambiences, which underline the intended functions. Certain areas create pleasant atmosphere inviting the inhabitants to spend their time there, while other green open spaces subliminally encourage passing by. The lush green appearance remains (see Fig. 83 and 84). Beside the increased amenity value, maintenance and water requirements can be reduced.

The evaluation of the measures in terms of water conservation has to be done from two perspectives:

## I Calculation of the potential decrease of water requirement for irrigation

The water requirement of the proposal is compared to the water requirement of the current situation, which is estimated to be 4.29 l/  $m^2 \cdot day$  on average. This comparison allows the general evaluation of the measures.

#### II Comparison of the water requirement with the actual water consumption

The water requirement of the proposal is being compared to the water consumption of the current situation, which also accounts the losses due to inefficient irrigation behavior and is considered to be 9.52 l/ m<sup>2</sup> · day in average. This comparison shows the drastic extent of potential savings if irrigation behavior efficiency would be increased. This calls for the implementation of measures to achieve Precondition II (Improve irrigation behavior).

The evaluation of the measures from these two perspectives is presented below. Detailed calculations can are shown in Appendix 05.

#### I Calculation of the potential decrease of water requirement for irrigation

The total water requirement of the proposal is 409 209 l/ day. If calculating the water requirement of the current situation with 4.29 l/  $m^2 \cdot day$  (water requirement of plants with upper moderate water demand such as lawn) it adds up to 510 978 l/day. Thus, the implementation of the proposal could theoretically achieve to save 101 769 l/ day (=20%) of water in total, if irrigation were done according to needs. 10 708 l of these account for potable water (= 11%, saved in the green open space types 08 and 13 in the villa area), while 91 961 l of TWW (= 89%) are conserved. The latter could replace 73% of the water requirement in the villa areas. Thus, the use of potable water for irrigation could be decreased to 34 203 l, which equals a total reduction of 78% (current requirement of potable water= 156 568 l/day).

#### II Comparison of the water requirement with the actual water consumption

If calculating the water consumption in the current situation with 9.52 l/ m<sup>2</sup> · day, it adds up to 1 133 918 l/day. The water requirement at present of 510 978 l/ day accounts to 45% of this and it is assumed that 55% of the irrigation water in the focus area is wasted by inefficient irrigation behavior. As previously mentioned, the total water requirement of the proposal is 409 209 l/ day. Thus, the successful implementation of the proposal could theoretically lead to 724 709 l/ day (=64%) water savings in total. This highlights the urgent necessity to improve the irrigation behavior of the gardeners, which has been set as a precondition for the successful implementation of measures.

Within this proposal, the deployment of an incentives program for the gardeners is suggested and its realization is explained in the following.

Precondition II: Increase the efficiency of the irrigation behavior of the gardeners

#### **Incentives program**

Currently, the water consumption for irrigation exceeds the requirement by about 55%. Irrigation often takes place during the day and is also not done according to the plants needs. Engineers know about the needs, but the gardeners usually do not know them and, according to Eng. Hazem, they are also simply not able to fulfill the task properly due to the large area they have to irrigate. About 200 gardeners are in charge of irrigation.

Beside the development of a management plan, the gardeners should be motivated to help to conserve water. This can be fostered with an incentive program: If the gardeners manage to reduce the water consumption, while maintaining the quality of the green open spaces, and accordingly the water costs, they will receive a certain percentage of the money which has been saved as a reward to their effort. An irrigation water meter for whole Al Rehab should be installed, so that the water consumption can be monitored. If just the overall water consumption is counted, this may also lead to a feeling of responsibility towards the other gardeners as their own behavior effects their salary as well. In turn, a kind of social control towards adequate behavior will evolve.

As previously described, the implementation of the proposal could theoretically achieve to save 724 709 l/ day (= 64% of the current consumption). Depending on the amount of water conserved in reality due to change of their irrigation behavior, the gardeners are rewarded some extra salary. They will probable not be able to save the total 724 709 l. For this reason calculations are done for saving 50%, 75% and 100% of the water. It is suggested that the rewards for the gardeners make 20% of the money that was saved. This is distributed equally among the gardeners responsible for the area. In the case of the focus area there are 8 gardeners.

As shown in Table 06 the potential reward per gardener and day range between LE 7.05 and LE 14.11 depending on the water savings. These amounts represent an attractive addition, since the usual income of the gardeners lies between LE 30-50/ day.

In this way, the gardeners will be motivated to pay more attention to the way they are working and large amounts of water can be conserved. The implementation of this measure is fairly simple as it just requires the installation of a water meter. The benefits, however, are multisided: Beside the conservation of water for the sake of the greater public good, the TMG can save up to LE 11 599/ day in irrigation (cost savings in the focus area projected to total area of Al Rehab – 20% rewards for the gardeners), while the gardeners can increase their salary.

As described before, the consumption of potable water for irrigation could be reduced by 80% with the decrease of the water requirement. If also the water losses due to inappropriate irrigation behavior can be minimized, the irrigation requirement can easily be covered with TWW, condensate water and drainage water.

However, the usage of TWW in villa areas is currently considered to be too risky as aforementioned. Villa owners could easily connect the pipes for potable water with the ones for irrigation water to increase the water pressure. If the delivered irrigation water was TWW, this could lead to health hazards. Awareness of the owners has to be raised in order to eliminate this risk. The conceptual design proposal II deals with ways to increase awareness through the implementation of certain measures.

Water consumption for irrigation (current situation)	1133.918 m³/ day
	(Potable water: 347.413 m <sup>3</sup> /day = 31 %, TWW: 786.505 m <sup>3</sup> / day = 69%)
Current costs (potable water = LE 1.4, TWW = LE 0.5)	LE 879.63
	(LE 486.38 for potable water= 55 % + LE 393.25 for TWW = 45%)
100 % water savings due to improved irrigation behavior	724.709 m <sup>3</sup>
Potential costs savings (100% saved)	LE 564.54
	(LE 314.52 for potable water + LE 250.02 for TWW)
Reward/ gardener/ day (100% saved)	LE 14.11
Potential costs savings (75% saved)	LE 423.39
	(LE 235.89 for potable water + LE 187.5 for TWW)
Reward/ gardener/ day (75% saved)	LE 10.58
Potential costs savings (50% saved)	LE 282.27
	(LE 157.26 for potable water + LE 125.01 for TWW)
Reward/ gardener/ day (50% saved)	LE 7.05

Table 06 Calculation of rewards/ gardener/ day in case of 100%, 75% and 50 % water savings



Fig. 85 Modified water cycle for the focus area (Conceptual design proposal I). Modifications are shown in orange. (own 2013)

#### Conceptual design proposal II: Intervention in planning stage

#### Introduction

Similar to the other districts, also the 8th comprises villa areas as well as apartment building areas. While the latter is already being constructed, the villa area is still in the planning stage. According to the master plan a large public park separates the apartment building and villa area spatially.

In the Conceptual design proposal II the main aim is to replace potable water for irrigation with another kind of water. Therefore, the focus area just comprises green open spaces irrigated with potable water, namely the villa area with 65 416 m<sup>2</sup> private gardens, 10 413 m<sup>2</sup> greenery in the villa area and roadside vegetation (one roundabout with 177 m<sup>2</sup> and green strips in the middle of the streets (2 260 m<sup>2</sup>). Moreover, about 687 trees are planted a long the streets in this area. The green open spaces represent 37% (78 953 m<sup>2</sup>) of the total area (215 328 m<sup>2</sup>).

Locally produced grey water is chosen as the water source. This requires the availability of irrigation water with a good and reliable quality and an increased awareness on the side of inhabitants to avoid health hazards. Both can be achieved through waste water treatment on site. Besides, water losses during transportation and treatment process can be reduced (measure "Decentralized treatment of waste water to decrease losses during transportation and treatment process"). To fully cover the irrigation needs, the amount of green spaces has to be reduced (measure "Decrease amount of green open spaces").

#### Implementation

It is suggested that the grey water produced in the villa areas is treated in a socalled waste water treatment park, which is located in the large public park adjacent to the villa area. It comprises a constructed wetland and further green open spaces. The public park has a total size of 30 890 m<sup>2</sup>. To minimize health risks only grey water is treated. Therefore, a separate pipe network is required, which can still be installed since the construction of the villa area did not start yet. The purified water is used for irrigation after the treatment process.

The amount of green open spaces in the villa area as well as the water requirement of private gardens have to be reduced so that the available treated grey water (TGW) can cover the water requirements. About 187 000 l of grey water



Fig. 86 Green open spaces in the focus area (current situation) (own 2013)

are produced daily by about 1712 inhabitants living in 323 housing units in the villa area. With this amount, 131 690 m<sup>2</sup> of green open spaces belonging to hydrozone M can be irrigated. However, according to the current master plan, the villa area comprises 78 953 m<sup>2</sup> green open spaces (see Fig. 86). A reduction by 34 % is necessary to cover the irrigation water requirements with TGW.

Consequently, the following reductions are suggested:

 Currently, the greenery in the streets of the villa areas only serves as landscape scenery. It is not used by the people and, therefore, it is suggested to replace them with additional semi-detached villas. In total, 40 additional units can be constructed, leading to an increase of available grey water. The total amount of produced grey water is 210 150 l/day, which is sufficient to irrigate 58 701 m<sup>2</sup> of green open spaces with low water demand. 10 413 m<sup>2</sup> of greenery in the streets are reduced to 2 904 m<sup>2</sup> private gardens.



Fig. 87 Green open spaces in the focus area (proposal) (own 2013)

2. It is suggested to replace 18% of the current private gardens by garden elements, which do not require irrigation. For example, pergola constructions providing pleasant shade to a seating corner can be added to the garden design. Also artificial lawns can be taken into consideration

This results in a new total amount of green open spaces of 53 641  $m^2$  (see Fig. 87), which can be irrigated with the available TGW. Detailed calculations are shown in Appendix 06.

With the "Water demand tool" and the "LEIS Manual" developed within the research project "Sustainable Water And Wastewater Management In Urban Growth Centres Coping With Climate Change - Concepts for Metropolitan Lima (Perú)" (Eisenberg et al. 2013) a rough estimation of the necessary size of the constructed wetland has been done. The result is that approximately half of the park has to be transformed into a contructed wetland.

An efficient irrigation behavior is necessary in order to substitute the whole water requirement with TGW. If gardeners are in charge of the maintenance of the private garden, this can be achieved through the incentives program. Besides, awareness has to be raised on the inhabitants' side. With the treatment of grey water on site, a closer relation and a better understanding of the treatment process of waste water can be established. Water sensitive behavior can be promoted through additional awareness raising campaigns such as the spreading of information sheets. This also ensures the outreach to all inhabitants. The waste water treatment park can act as an educational facility, for example with boards providing information about the purpose of this area, the treatment process and the reuse of the purified water for irrigation. The park should be well accessible and comprise "Green commons" to invite the inhabitants there.

Another benefit of grey water treatment on site is that the quality of the output water can be controlled more easily leading to reliable irrigation water quality. Moreover, the water does not leave Al Rehab resulting in a relief of the sewerage system. Especially regarding the continuous extension of New Cairo this might be of increasing importance in the future. Energy costs for pumping waste water to the WWTP and advanced treatment will decrease. Furthermore, the amount of available irrigation water augments: currently, Al Rehab just receives 60% of its produced waste water back. If grey water is treated on site, the full amount is available for irrigation after the purification process.



Fig. 88 Modified water cycle for the focus area (Conceptual design proposal II). Modifications are shown in orange. (own 2013)

# 04 Conclusion

### **04** Conclusion

The landscape design and water management of Al Rehab suffers some major deficits. Nonfunctional "landscape scenery design" with high maintenance requirements and excessive water consumption are the main challenges to be tackled. Conceptual design proposal I shows how the implementation of different measures can lead to a more attractive and adequate landscape design while large amounts of water can be conserved. Especially the incentives program can have a significant impact on the water consumption. The restructuring of green open spaces according to functions, water sources and hydrozones results in differentiated green open space types, which meet the inhabitants' expectations of a lush green landscape. At the same time, the water requirement for irrigation can be reduced and clearly distinguishable zones facilitate irrigation for the gardeners. Conceptual design proposal II presents how potable water can be eliminated as a water source for irrigation. Key measure is the decentralized treatment of grey water to increase awareness on the inhabitants' side and to ensure a reliable water quality for irrigation. Moreover, the amounts of public and private green open spaces are reduced without significant quality losses regarding the amenity value. In this way, the available treated grey water can cover the irrigation water requirements.

Several measures to conserve water already exist and can be used to direct planning towards a more sustainable development. This thesis shows how they can be applied and integrated into the landscape design of the gated community Al Rehab. A continuous examination of existing and innovative measures to conserve water is necessary to broaden the spectrum of possibilities of water sensitive open space design, especially for the future. However, a continious population growth cannot be accompanied by a continious increase of green open spaces in the case of Egypt. Therefore, at one point of the growth of the **new towns**, the decrease of green open spaces shall gain more importance and acceptance. Awareness of the problem of water scarcity has to be raised and water sensitive behavior has to be promoted. If people, e.g. the gardeners, do not behave in an appropriate way, infrastructure can hardly help. Thus, their **consideration and involvement in the development and implementation of** measures is essential. The use of green open spaces by the people is a major aspect in landscape design. This point should be further studied for the case of Egypt in order to develop more adequate design solutions.

Calculations within this thesis are based on assumptions. Further research needs to be done to reassess these. The suitability of the Landscape Coefficient Method for Egypt has to be evaluated; factor values might have to be adapted. Especially the field of water demand of plant species is an important topic, which requires further intensive studies in order to do more adequate estimations. Moreover, the utilization of native species can open up interesting opportunities regarding reduced water demands as well as ornamental features of the landscape design. Due to lack of information it has not been possible to suggest amendments of the plant repertoire within this thesis. Another aspect, which has not been considered, is the potential vacancy of villas and apartments. Ways to deal with this have to be found.

Generally, the selected strategies and measures can be transferred to other case study areas. However, the existing potentials and challenges have to be identified for each case and context. Landscape architects should use the chance to take a leading role towards a more adequate, sustainable and integrated urban and landscape planning and design in arid countries and present existing as well as innovative strategies and measures to minimize the water consumption for irrigation, develop them further and combine them in new ways. A collaborative approach with other disciplines such as water infrastructure and irrigation engineering is crucial in order to achieve the best possible outcome in terms of landscape design as well as water conservation. Besides, also social studies have to be included to be able to respond to the needs and interests of the people.

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#### Fig. 84 Current situation (own 2013)

Fig. 85 Modified water cycle for the focus area. Modifications are shown in orange. (own 2013)

Fig. 86 Green open spaces in the focus area (current situation) (own 2013)

Fig. 87 Green open spaces in the focus area (proposal) (own 2013)

Fig. 88 Modified water cycle for the focus area. Modifications are shown in orange. (own 2013)

# 06 Appendices

### Water demands of plants frequently used in landscape design in Egypt

### **Key to Symbols**

#### Plant types

- T Trees
- P Palm trees
- S Shrubs
- G Ground cover
- Su Succulents

- Categories of water demands
- H High
- M Moderate
- L Low

Botanical name	Туре	Water demand		
Acacia farnesiana	Т	М		
Acacia saligna	Т	Н		
Acalypha	S	L		
Acasia nilotica	Т	L		
Acer palmatum	S	М		
Achillea millefolium	G	М		
Agapanthus headbourne hybrids	G	Н		
Agave marginata	Su	М		
Ageratum houstonianum	G	М		
Albizzia lebbeck	Т	М		
Aloe vera	Su	М		
Alternathera versicolor	G	М		
Althaea rosea	G	Н		
Antirrhinum majus	G	Н		
Aptenia cordifolia	G/ Su	М		
Araucaria araucana	Т	Н		
Archontophonix	Р	M		
Arctotis breviscapa	G	М		
Arctotis hybrida	G	Μ		

Botanical name	Туре	Water demand
Areca vestiaria	Р	Μ
Asparagus densiflorus	G	Н
Atriplex halimus	S	L
Azadirachta indica	Т	L
Bauhinia purpurea	Т	М
Bauhinia variegata	Т	М
Beaucarnea	Р	М
Begonia semperflorens	G	Н
Bismarkia nobilis	Р	М
Bombax malabaricum	Т	М
Bougainville aspectabillis	S	М
Brachychiton acerifolius	Т	М
Caesalpinia pulcherrima	S	М
Calendula officinalis	G	М
Calendula officinalis geisha girl	G	М
Callistemon viminalis	Т	Н
Canna indica	S	Н
Carica papaya	Р	Н
Carpobrotus edulis	Su	L
Caryota mitis	Р	Н
Cassia alata	S	Н
Cassia fistula	Т	М
Cassia glauca	Т	М
Cassia javanica	Т	Н
Cassia nodosa	Т	М
Cassia senna	S	М
Celosia argentea	G	Н
Ceratonia sisliqua	Т	М
Chamaerops humilis	Р	М
Chlorophytum comosum	G	М
Chorisia speciosa (Ceiba speciosa)	Т	М
Chrysalidocarpus cabadae	Р	М
Chrysalidocarpus lutescens	Р	М
Chrysanthemum morifolium	G	Н
Citrus limon ponderosa	Т	Н

Botanical name	Туре	Water demand			
Citrus reticulata	Т	Н			
Citrus sinensis	Т	Н			
Cocos nucifera	P M				
Coleus	G	Н			
Companula medium caycanthem	G	Н			
Conocarpus erectus	Т	L			
Conocarpus species	Т	Μ			
Cordia myxa	Т	Μ			
Cotula barbata	G	Μ			
Cupressus arizonica	Т	Μ			
Cycas revoluta	Р	Μ			
Delonix regia	Т	Μ			
Dodonaea viscosa	S	L			
Duranta repens	S	Μ			
Echinocactus grusoni	Su	L			
Entrolobium cyclocarpum	Т	Μ			
Erythrina caffra	Т	М			
Euphorbia lactea	Su	L			
Euphorbia milii	Su	L			
Ficus altissima	Т	Μ			
Ficus benghalensi	Т	Μ			
Ficus carica	Т	Μ			
Ficus elastica	Т	Н			
Ficus infectoria	Т	Μ			
Ficus lyrata	Т	Н			
Ficus microcarpa (nitida)	Т	Μ			
Ficus religiosa	Т	Μ			
Ficus retusa	Т	Н			
Ficus salicifolia	Т	Μ			
Ficus virens	Т	Μ			
Gazania uniflora	G	Μ			
Gerbera	G	Н			
Helianthus annuus	G	Μ			
Hibiscus rosa-sinensis	S	Н			
Hibiscus tiliaceus	Т	Μ			

Botanical name	Туре	Water demand
Hymenocallis narcissiflora	G	Н
Hyphaene thebaica	Р	Μ
Iresine	G	М
Jacaranda acutifolia	Т	М
Jacaranda ovalifolia	Т	М
Jatropha integerrima	S	М
Kalanchoe blossfeldinana	Su	L
Koelreuteria paniculata	Т	М
Lagerstroemia indica	Т	М
Lampranthus spectabilis	G	М
Lampranthus roseus	Su	L
Lantana	G	Н
Lantana camara	G	М
Lantana montevidensis	G	Н
Lavandula dentata	G	М
Lawsonia inermis	Т	М
Livistona chilensis	Р	М
Magnolia grandiflora	Т	Н
Mammillaria seitziana	Su	L
Mangifera indica	Т	Н
Melia azedarach	Т	L
Mesembryanthemum crystalinum	Su	L
Morus alba	Т	М
Myoporum parvifolium	G	М
Myrtus communis	S	М
Nerium oleander	S	L
Ocimum basilicum	G	М
Ocimum basilicum	S	Н
Olea europaea	Т	М
Opuntia dillenii	Su	L
Opuntia ficus indica	Su	L
Oreodoxa	Р	М
Pandanus utilis bory	Su	М
Pandanus veitchii	Su	L
Parkinsonia aculeata	Т	L

Botanical name	Туре	Water demand
Pedilanthus tithymaloides	Su	L
Pelargonium peltatum	G	М
Peltophorum africanum	Т	М
Pennisetum setaceum	G	М
Petunia	G	Н
Petunia hybrida	G	Н
Petunia hybrida pink satin	G	Н
Phoenix canariensis	Р	Μ
Phoenix dactylifera	Р	М
Pinus halepensis	Т	Μ
Plumbago capensis	S	Н
Portulaca grandiflora	Su	L
Portulaca oleraceae	Su	L
Portulacaria afra	Su	L
Prosopis juliflora	Т	M
Prunus domestica	Т	М
Prunus persica	Т	M
Psidium guajava	Т	L-M
Pyrus communis	Т	M
Quercus robur	S	М
Ravenala madagascariensis	Р	M
Rhapis excelsa	Р	М
Rhoeo discolor	G	М
Roystonia regia	Р	М
Ruellia tuberosa	G	Н
Russelia juncea	S	Н
Sabal palmetto	Р	М
Salvia	S	М
Sansevieria trifasciata	Su	М
Schinus molle	Т	Н
Schinus terebinthifolius	Т	Н
Selaginella biformis	G	Н
Senecio cineraria	G	L
Setcreasea purpurea	G	М
Spathodia	Т	М

Botanical name	Туре	Water demand
Sterculia diversifolia	Т	Н
Strelitzia reginae	G	L
Suaeda fruticosa	Su	L
Suaeda monoica	Su	L
Syagrus romanzoffiana	Р	М
Tabernaemontana coronaria	S	М
Tamarix aphylla	Т	L
Tecoma capensis	Т	Н
Tecoma stans	T/ S	М
Tecomaria	S	М
Terminalia catappa	Т	М
Thespesia populnea	Т	М
Thevetia nerifolia	Т	М
Verbena	G	М
Verbena hybrida	G	М
Vinca minor	G	М
Vinca rosea	G	Н
Vitex agnus castus	S	М
Washingtonia filifera	Р	М
Washingtonia robusta	Р	L
Wedelia trilobata	G	М
Wodyetia bifurcata	Р	М
Yucca aloifolia	Su	L
Zephyranthes	G	М
Zizyphus spina christi	Т	L
Zygophyllum species	Su	L

Table A Water demands of frequently used plants species. Information taken from data sheets provided by the landscape architecture office "Nature for landscape architecture and planning", Cairo (Dr. Mohamed Refaat, landscape architect)

### The Landscape Coefficient Method

The Landscape Coefficient Method is used to estimate the water demand and water requirement of landscape plantings in this thesis. Within this method, the water demand of the planting comprises the demand of the different species, the density of the planting, the microclimate and the reference evaporation rate of the site. To calculate the water requirements, also irrigation efficiency and **potential soil evaporation losses are taken into account**. These calculations can serve as estimations, but field adjustments as well as upward adjustments due to low water quality, e.g. if reclaimed water is used, might still be necessary. Besides, special planting situations, e.g. newly planted or well established planting or trees in turf, can influence the amount of water required for irrigation.

ET<sub>L</sub> formula to calculate the water demand of a planting

 $ET_{L} = K_{L} * ET_{O}$ 

 $ET_L$  = Landscape evapotranspiration (water demand)  $K_L$  = Plant coefficient  $ET_O$  = Reference evapotranspiration

Calculation of plant coefficient ( $K_L$ )  $K_L = K_s^* K_d^* Km_c$ 

K<sub>s</sub>= Species factor K<sub>d</sub>= Density factor Km<sub>c</sub>= Microclimate factor

(University of California Cooperative Extension and California Department of Water Resources 2000: 9ff)

Factor	High	Medium	Low	Very low
Species factor K <sub>s</sub>	0.7-0.9	0.4-0.6	0.1-0.3	Less than 0.1
Density factor <b>K</b> <sub>d</sub>	1.1 -1.3	1	0.5-0.9	
Microclimate factor K <sub>mc</sub>	1.1 -1.4	1	0.5-0.9	

The values of the different factors depend on the location. A summary of possible values is given in the following table:

Table BSummary of values of factors contributing to the plant coefficient (University of California Cooperative Extension and California Department of Water Resources 2000: 22)

### Factors influencing the water requirement

On one hand, the water required to meet the plant's demand depends on the application efficiency of the irrigation system or application method; on the other hand, potential losses due to soil evaporation, which usually range between 10-20%, influence the water requirement. In the following table, application efficiencies for different systems and methods are shown.

System/method	Application efficiency in %
Earth canal network surface methods	40-50
Lined canal network surface methods	50-60
Pressure piped network surface methods	65-75
Hose irrigation systems	70-80
Low-medium pressure sprinkler systems	75
Microsprinklers, micro-jets, minisprinklers	75-85
Drip irrigation	80-90

 Table C
 Approximate application efficiency of various on-farm irrigation systems and methods (Phocaides 2000:74)

# Apportionment of water consumption for irrigation in Egypt

Water consumption for irrigation of privately owned green open spaces in Egypt Privately owned green open spaces (in contrast to governmentally owned green open spaces) are irrigated with 30-50 m<sup>3</sup>/feddan  $\cdot$  day (= 7.14 – 11.90 l/m<sup>2</sup>  $\cdot$  day). During site visits it was observed that large amounts of irrigation water get lost due to broken systems and wasteful irrigation behavior. It is assumed that the above described water amounts also cover these losses, as they are very high compared to water requirements of plantings in other arid cities. According to Ascencios Templo, in Lima (Peru) the average requirement of lawn, which is considered to belong to the group of plants with moderate to high demands, accounts to 3.40 l/m<sup>2</sup>  $\cdot$  day to give an example (Ascencios Templo 2013:18). For Egypt, the following calculations using the Landscape Coefficient Method (described in Appendix 02) verify the assumption, that high losses are considered in the consumption of 30-50 m<sup>3</sup>/feddan  $\cdot$  day for irrigation.

Species factor	Density factor	Microclimate factor	Plant coefficient (K <sub>L</sub> )
0.5	1	1.2	0.6

Table D Definition of factors and resulting plant coefficient

The calculation of water demand and requirement is done for a plant with moderate water demand, in a medium dense planting and an extreme microclimate due to high solar radiation (resulting in the water demand) (see Table D). The irrigation efficiency is defined as 85% and soil evaporation losses account for 10% (resulting in the water requirement).

Table E shows that the average water requirement per year for this case is  $3.58 \text{ l/m}^2 \cdot \text{day}$ , which is comparable with the above mentioned average water requirement of  $3.40 \text{ l/m}^2 \cdot \text{day}$  for lawn in Lima. With  $9.52 \text{ l/m}^2 \cdot \text{day}$  being the moderate amount for irrigation suggested in Egypt, this would mean that the water consumption exceeds the water requirement by 62%.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ø
ETo	2.21	3.03	4.22	5.58	6.85	7.65	7.01	6.36	5.38	4.24	2.69	2.06	4.77
WD	1.33	1.82	2.53	3.35	4.11	4.59	4.21	3.82	3.23	2.54	1.61	1.24	2.86
WR	1.66	2.28	3.16	4.19	5.14	5.74	5.26	4.78	4.04	3.18	2.01	1.55	3.58

Table E Calculation of water demand and water requirement for irrigation for a planting with plant coefficient = 0.6 and  $\text{ET}_0$  values in mm/l for Giza Governorate (Eid et al.(n.d.)); WD = Water demand (l/m<sup>2</sup> · day), WR= water requirement (l/m<sup>2</sup> · day)

### Calculation of condensate water production and water requirement of planting beds of the Food Court

The water produced by air conditioning systems can be calculated with the help of a condensate calculator provided by the San Antonia Water System (San Antonio Water System 2010).

Calculation of condensate water production throughout the year

Assumptions:

Inside temperature: 20°C Inside humidity: 50% Power of the air conditioning system: approx. 16 kW Air exchange: 20% Average time during which the air conditioning systems are running at the Food Court: 9 am - 12 pm= 15 hours Number of cafés and restaurants: 11

Month	01	02	03	04	05	06	07	08	09	10	11	12	Ø
ذC	13.9	15.6	17.6	21.6	24.8	27.3	28.1	27.9	26.5	23.8	19.3	15.3	21,8
H (%)	59	54	53	47	46	49	58	61	60	60	61	61	56
PrW1	/	/	/	0.1	0.6	1.2	2.0	2.2	1.8	1.1	0.4	/	0.8
PrW2	/	/	/	1.7	8.6	17.6	30.6	32.4	27.3	16.5	6.3	/	12
PrW3	/	/	/	19	94	193	337	356	300	182	69	/	129

Table F Daily condensate water production during the year (Ø °C= Average temperature (Wikipedia 2013); H (%)= Humidity (Wikipedia 2013); PrW1= Produced water (l/h) (Calculator: San Antonia Water System (2010)); PrW2= Produced water during opening times (l/15 h); PrW3= Produced water at the Food Court (l/ 11 Cafés and restaurants)

# Calculation of water requirement of planting beds with plants with low water *demand*

Species factor	Density factor	Microclimate factor	Plant coefficient
0.2	1	1.2	0.24

Table G Calculation of plant coefficient for plants with low water demand

Month	01	02	03	04	05	06	07	08	09	10	11	12	Ø
ETo	2.21	3.03	4.22	5.58	6.85	7.65	7.01	6.36	5.38	4.24	2.69	2.06	4.77
WD	0.5	0.73	1.01	1.34	1.64	1.84	1.68	1.53	1.29	1.02	0.65	0.49	1.14
WR	0.63	0.91	1.26	1.68	2.05	2.3	2.1	1.91	1.61	1.28	0.81	0.61	1.42
WRt	89	128	178	237	289	324	296	269	227	180	114	86	200

Table HCalculation of water demand and water requirement for irrigation of 141 m² planting<br/>with plant coefficient= 0.24 and  $ET_0$  values in mm/l for Giza Governorate (Eid et al.(n.d.)); 85%<br/>irrigation efficiency, 10% evaporation losses; WD= Water demand (l/ m² · day), WR= water requirement (l/ m² · day), WRt= water requirement total (l/ 141 m² · day)

Calculation of potential coverage

Month	01	02	03	04	05	06	07	08	09	10	11	12	Ø
PrW3	/	/	/	19	94	193	337	356	300	182	69	/	129
WRt	89	128	178	237	289	324	296	269	227	180	114	86	200
CIR	0	0	0	8	33	60	114	133	108	101	61	0	65

Table I Calculation of percentage of irrigation requirements which can be covered with condensate water from air conditioning systems for 141 m<sup>2</sup> planting beds at the Food Court; PrW3= Produced water at the Food Court (l/ 11 Cafés and restaurants), WRt= water requirement total (l/ 141 m<sup>2</sup> · day), CIR= Covered irrigation requirements (%)

### **Calculations Conceptual design proposal I**

Calculation of water demands in the different hydrozones

Species factor	Density factor	Microclimate factor	Plant coefficient
0.8	1	1.2	0.96

Table J Calculation of plant coefficient for plants with high water demand (Hydrozone H)

Month	01	02	03	04	05	06	07	08	09	10	11	12	Ø
ETo	2.21	3.03	4.22	5.58	6.85	7.65	7.01	6.36	5.38	4.24	2.69	2.06	4.77
WD	2.12	2.91	4.05	5.36	6.58	7.34	6.73	6.11	5.16	4.07	2.58	1.98	4.58
WR	2.65	3.64	5.06	6.7	8.22	9.18	8.41	7.63	6.46	5.1	3.23	2.47	5.73

Table K Calculation of water demand and water requirement for irrigation of planting with plant coefficient= 0.96 and  $\text{ET}_0$  values in mm/l for Giza Governorate (Eid et al.(n.d.)); 85% irrigation efficiency, 10% evaporation losses; WD= Water demand (l/ m<sup>2</sup> · day), WR= water requirement (l/ m<sup>2</sup> · day)

Species factor	Density factor	Microclimate factor	Plant coefficient
0.6	1	1.2	0.72

Table L Calculation of plant coefficient for plants with upper moderate water demand (Hydrozone M with lawn)  $% \mathcal{M} = \mathcal{M} = \mathcal{M} + \mathcal$ 

Month	01	02	03	04	05	06	07	08	09	10	11	12	Ø
ETo	2.21	3.03	4.22	5.58	6.85	7.65	7.01	6.36	5.38	4.24	2.69	2.06	4.77
WD	1.59	2.18	3.04	4.02	4.93	5.51	5.05	4.58	3.87	3.05	1.94	1.48	3.43
WR	1.99	2.73	3.8	5.03	6.16	6.89	6.31	5.73	4.84	3.81	2.43	1.84	4.29

Table M Calculation of water demand and water requirement for irrigation of planting with plant coefficient= 0.72 and ET<sub>0</sub> values in mm/l for Giza Governorate (Eid et al.(n.d.)); 85% irrigation efficiency, 10% evaporation losses; WD= Water demand (l/ m<sup>2</sup> · day), WR= water requirement (l/ m<sup>2</sup> · day)

Species factor	Density factor	Microclimate factor	Plant coefficient
0.5	1	1.2	0.6

Table N Calculation of plant coefficient for plants with moderate water demand (Hydrozone M)

Month	01	02	03	04	05	06	07	08	09	10	11	12	Ø
ETo	2.21	3.03	4.22	5.58	6.85	7.65	7.01	6.36	5.38	4.24	2.69	2.06	4.77
WD	1.33	1.82	2.53	3.35	4.11	4.59	4.21	3.82	3.23	2.54	1.61	1.24	2.86
WR	1.66	2.28	3.16	4.19	5.14	5.74	5.26	4.78	4.04	3.18	2.01	1.55	3.58

Table O Calculation of water demand and water requirement for irrigation of planting with plant coefficient= 0.6 and ET<sub>0</sub> values in mm/l for Giza Governorate (Eid et al.(n.d.)); 85% irrigation efficiency, 10% evaporation losses; WD= Water demand (l/ m<sup>2</sup> · day), WR= water requirement (l/ m<sup>2</sup> · day)

Species factor	Density factor	Microclimate factor	Plant coefficient
0.2	1	1.2	0.24

Table P Calculation of plant coefficient for plants with low water demand (Hydrozone L)

Month	01	02	03	04	05	06	07	08	09	10	11	12	Ø
ETo	2.21	3.03	4.22	5.58	6.85	7.65	7.01	6.36	5.38	4.24	2.69	2.06	4.77
WD	0.5	0.73	1.01	1.34	1.64	1.84	1.68	1.53	1.29	1.02	0.65	0.49	1.14
WR	0.63	0.91	1.26	1.68	2.05	2.3	2.1	1.91	1.61	1.28	0.81	0.61	1.42

Table Q Calculation of water demand and water requirement for irrigation of planting with plant coefficient= 0.24 and  $\text{ET}_0$  values in mm/l for Giza Governorate (Eid et al.(n.d.)); 85% irrigation efficiency, 10% evaporation losses; WD= Water demand (l/ m<sup>2</sup> · day), WR= water requirement (l/ m<sup>2</sup> · day)

#### Summary of water requirements (annual average)

Hydrozone H: 5.73 l/ m<sup>2</sup>  $\cdot$  day

Hydrozone M (with lawn): 4.29 l/  $m^2 \cdot day$ 

Hydrozone M: 3.58 l/ m<sup>2</sup> · day

Hydrozone L: 1.42 l/ m<sup>2</sup> · day

	Green open space type	m² in focus area	WR (l/ m <sup>2</sup> · day)	WRt (l/ day)
01	TWW polishing plant   TWW   Hydrozone H	2 847	5.73	16 131
02	Green commons   PTWW   Hydrozone M (with lawn)	23 291	4.29	99 918
03	Vegetation highlights   TWW   Hydrozone H	3 423	5.73	19 614
04	Vegetation highlights   Condensate water   Hydrozone L	141	1.42	200
05	Pleasant vegetation   TWW   Hydrozone M	345	3.58	1 235
06	Pleasant vegetation   PTWW   Hydrozone L	2 366	1.42	3 360
07	Pleasant vegetation   PTWW + Drainage water   Hydrozone L	3 425	1.42	4 864
08	Pleasant vegetation   Potable water   Hy- drozone L	2 185	1.42	3 103
09	Concomitant vegeta- tion   TWW   Hydro- zone L	14 061	1.42	19 967
10	Concomitant veg- etation   PTWW + Drainage water   Hydrozone L	15 622	1.42	22 183
11	Tree rows   TWW   Hydrozone M	136	3.58	487
12	Tree rows   TWW   Hydrozone L	312	1.42	442
13	Tree rows   Potable water   Hydrozone L	311	1.42	442
14	Private Gardens   PTWW   Hydrozone M (with lawn)	16 644	4.29	71 403
15	Private Gardens   Po- table water   Hydro- zone M (with lawn)	34 000	4.29	145 860
Tota	al	$\Sigma$ 119 109 m <sup>2</sup>		∑ 409 209 l/day

### I Calculation of potential decrease of water requirement for irrigation

Table R Calculation of total water requirement of the focus area (proposal); WR= water requirement (l/  $m^2 \cdot day$ ), WRt= water requirement total (l/  $m^2 \cdot day$ )

#### Water requirement total (current situation):

119 109 m<sup>2\*</sup> 4.29 l/m<sup>2</sup> · day = 510 978 l/day

#### Water savings:

510 978 l/day - 409 209 l/ day= 101 769 l/ day (= 20%)

#### Potable water savings:

10 708 l/day (in the green open space types 08 and 13)

TWW savings:

910 61 l/ day

Potential substitution of potable water with TWW

#### <u>Area irrigated with potable water (current situation):</u>

 $36\;496\;m^2$  (Green open space types 08, 13 and 15)

<u>Required potable water for irrigation (current situation):</u>

36 496 m²\*4.29 l/m²  $\cdot$  day = 156 568 l/ day

### <u>Required potable water for irrigation (proposal):</u>

Green open space types 08 and 13: 2 496 m<sup>2\*1.42</sup> l/ m<sup>2</sup> · day= 3 544 l/ day Green open space type 15 (with lawn): 34 000 m<sup>2\*3.58</sup> l/ m<sup>2</sup> · day= 121 720 l/ day Total: 125 264 l/day

91 061 l/ day (TWW savings) / 125 264 l/ day \* 100= 73% 125 264 l/ day - 91 061 l/ day= 34 203 l/ day 34 203 l/ day / 156 568 l/ day (required PW) \* 100= 22%

Accordingly, TWW savings could cover 73% of the potable water requirement. The usage of potable water for irrigation can be decreased to 34 203 l, which equals a total reduction of 78%. II Comparison of water requirement with actual water consumption

### <u>Water consumption total (current situation):</u>

119 109 m<sup>2\*</sup> 9.52 l/ m<sup>2</sup> · day = 1 133 918 l/day

Water requirement total (proposal)

409 209 l/ day

Water savings:

 $(1\,133\,918\,l/\,day$  - 409 209 l/ day) / 1 133 918 l/ day \* 100= 64%

### **Calculations Conceptual design proposal II**

Calculation of grey water production in the focus area Water share per capita and day:  $0.275 \text{ m}^3$ Water consumption per capita and day: 0.182 m<sup>3</sup> (Cabinet Information and Decision Support Center, cited in Abdel-Gawad 2008) Grey water production per capita and day (60% of water consumption (The Greywater Guide n.d.)): 0.1092 m<sup>3</sup> Total number of units in Al Rehab: 37 573 (TMG Technical department n.d.) Estimated persons per unit in Al Rehab: 37 573: 200 000 inhabitants= 5.3 persons/ unit Number of units in focus area and approx. number if inhabitants: 323 units \* 5.3 persons/ unit= 1711.9 inhabitants Grey water production in focus area:  $1711.9^* 0.1092 \text{ m}^3 = 187 \text{ m}^3 = 187 000 \text{ l/ day}$ Potential area, which could be irrigated with this amount:

187 000 l: 3.58 l/ m<sup>2</sup> · day= 52 235 m<sup>2</sup> assumed that the water requirement of green open spaces equals a requirement of green open spaces of hydrozone M (3.58 l/ m<sup>2</sup> · day)

Private gardens	Greenery in villa area	Trees in villa area	Trees along the access road	Green strips along the access road	Rounda- bout	Total green open spaces
65 416 m <sup>2</sup>	10 413 m <sup>2</sup>	632	55	2 260 m <sup>2</sup>	177 m <sup>2</sup>	<b>78 95</b> 3 m <sup>2</sup>

Table S Total amount of green open spaces (current situation)

Percentage of current green open spaces, which could be irrigated with TGW:

52 235 m<sup>2</sup> = 66% of the total green open spaces

Thus, a reduction of green open spaces by 34% is necessary to cover the water requirements.

#### Measures Conceptual design proposal II

<u>Replacement of green open spaces in the streets by 40 housing units leading to</u> <u>an increased amount of produced grey water:</u>

40 units \* 5.3 persons/ unit= 212 inhabitants 212\*0.1092 m<sup>3</sup>/ day= 23.1504 m<sup>3</sup>/ day= 23 150.4 l/ day 23 150.4 l/ day + 187 000 l/ day = 210 150.4 l/day

Potential area, which could be irrigated with this amount:

210 150.4 l/day / 3.58 l/ m<sup>2</sup>  $\cdot$  day= 58 701 m<sup>2</sup>

assumed that the water requirement of green open spaces equals a requirement of green open spaces of hydrozone M

Reduction of planted area in private gardens by 18%:

65 416 m<sup>2</sup> \* 0.82= 53 641 m<sup>2</sup>

Private gardens	Trees in the villa area	Trees along the access road	Green strips along the access road	Round- about	Total green open spaces
53 641 m <sup>2</sup>	632	55	2 260 m <sup>2</sup>	$177 { m m}^2$	56 765 m²

Table T Total amount of green open spaces (proposal)

نظرا لوقوعها في اقليم شبه صحراوي تواجه مصر ازمة ندرة المياه. و أحد السبل التعامل مع مثل هذه القضية هو ترشيد استهلاك المياه خاصةً عندما لا تكون هناك حاجة ملحة إلى استهلاك المياه كما هو الحال في ري المسطحات الخضراء. هذه الرسالة تناقش وتوضح فرص تصميم المناطق المفتوحة المراعية للمياه كمدخل تصميمي يعتمد على التقليل من استهلاك المياه عند ري المسطحات الخضراء المفتوحة وفي نفس الوقت يحافظ عليها خصبة وحسنة المظهر.

نىذة

الرحاب هو مجتمع سكني مغلق بالقاهرة الجديدة يقع على مشارف صحراء القاهرة الكبرى و من ثم تم اختياره كحالة للدراسة. تم تطوير مقترحين للتصميم المبدئي حيث تتيح هذه المقترحات التدخل في المناطق القائمة حاليا أو في مرحلة التخطيط للمواقع المقترحة على السواء فالمقترح الاول يوضح انه يمكن ان تصبح المواقع أكثر جاذبية عند تطبيق معايير وقياسات مختلفة في تنسيق وتصميم المواقع مع الحفاظ على كميات كبيرة من المياه أما المقترح الثاني فهو يقدم عدة أفكار حول كيفية اسياه الصالحة للشرب بدلا من استخدامها كمصدر لمياه الري.

الرسالة تظهر بوضوح ان هناك عدة ستر اتيجيات ومعايير متواجدة بالفعل يمكن استخدامها وتطويعها لمر اعاة المياه وتقليل استخدامها في تصميم المواقع المفتوحة, فهي تشكل نقطة انطلاق للبحث العلمي في هذا المجال في المستقبل.

كلمات البحث : تصميم المواقع المفتوحة المراعية للمياه , ازمة ندرة المياه , ترشيد استهلاك مياه الري , , مجتمعات سكنية مغلقة , مصر

إقرار

هذه الرسالة مقدمة في جامعة عين شمس وجامعة شوتجارت للحصول على درجة العمر ان المتكامل والتصميم المستدام. إن العمل الذي تحويه هذه الرسالة قد تم إنجازه بمعرفة الباحث سنة ...

هذا ويقر الباحث أن العمل المقدم هو خلاصة بحثه الشخصي وأنه قد اتبع الإسلوب العلمي السليم في الإشارة إلى المواد المؤخوذه من المراجع العلمية كلَّ في مكانه في مختلف أجزاء الرسالة.

وهذا إقرار مني بذلك،،،

التوقيع:

الباحث: ليزا ديستر

التاريخ:
## تصميم و تنسيق المواقع كبنية تحتية تصميم المناطق المفتوحة المراعية للمياه في القاهرة

مقدمة للحصول على درجة الماجستير في العمر إن المتكامل والتصميم المستدام

أعداد: ليزا ديستر

لجنة أشراف

أ.د.م. محمد عبد الكريم صالحين

أستاذ مساعد التخطيط العمر إنى

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التوقيع

أستاذ التنسيق الحضرى والبيئي جامعة شتوتجارت

أ أنتيا شتوكمان

لجنة الحكم أ.د. ......الممتحن الخارجي أستاذ..... جامعة ......

ا د استاذ جامعة

ا د استاذ جامعة

تاريخ المناقشة:

الدر اسات العلبا

\_\_\_\_/\_\_/\_\_\_

ختم الإجازة موافقة مجلس الكلية .../.../...

أجيزت الرسالة بتاريخ:.... موافقة مجلس الجامعة .../.../...

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رسالة مقدمة للحصول على درجة الماجستير في العمران المتكامل والتصميم المستدام

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