School of Earth Sciences
University of Birmingham

City Water Balance

A new scoping model for Alexandria

Mahmoud Jaweesh
September 2010

Submitted in partial fulfilment of the requirements for an MSc in Hydrogeology

ABSTRACT

Water demand in Alexandria, like all other cities in Egypt, increases with time. However, water resource is subject to decrease due to climate change and the increases in water consumptions on the upstream of Nile River[1]. In order to solve this problem, Integrated Urban Water Management (IUWM) concepts started to be implemented in Alexandria by SWITCH[2]. SWITCH is an EU funded program aims to improve sustainable water management within cites. Urban water modelling is an essential tool for water management. Therefore, SWITCH was interested in developing a model that represents the urban water cycle in Alexandria. The suggested code was City Water Balance (CWB).

Alexandria model was developed to simulate all water components in the city. Then the model was calibrated and validated based on the available data. The calibrated model was used afterwards to simulate several initial scenarios. Detailed visions and scenarios are currently being developed for Alexandria. These scenarios will be modelled to investigate the best water management option and consequently to set Alexandria strategic plan accordingly.

[1] The Nile River is the main source of water for Alexandria

[2] SWITCH stands for Sustainable Urban Water Management Improves Tomorrow's Cities Health

ACKNOWLEDGMENT

It is a pleasure to show my grateful to everybody who made this work possible and I initially praise the Lord for his continuance blessings and support. I also present my gratitude to my great family who stands up for me back home and provides me with the determination and encouragement for every single day during my work.

I owe my deepest thankfulness to my supervisor, Rae Mackay, for his guidance, encouragement and untiring efforts that helped me to complete this project successfully. Moreover, it is an honour for me to address Philip Sharp, the Learning Alliance coordinator in Alexandria, for his following up, advice and continual assistance throughout the project. I would like also to show my gratitude to Learning Alliance members in Egypt, especially Khaled abu-Zeid, Mohamed Elrawady, Noha Donia, Ayman Ramadan, in addition to Dionysis Assimacopoulos and Elina Manoli in Greece, for the time they spent with me and for the data they provided me with, which was essential to carry on with my work.

I would like to send particular thanks to my colleagues in Birmingham, Rebecca Simister, Ewan Last and Ellen Spencer, in addition to all of my colleagues on the M.Sc course, for the special teamwork environment they offered me during the project.

Lastly, I present my regards and blessings to all of my friends and colleagues who keep supporting me in all respects.

Mahmoud Jaweesh

Table of Contents

Table of figures

List of Tables

List of Abbreviations

- AWCO Alexandria Drinking Water Company
- AsDCo Alexandria Drainage Company
- CWB City Water Balance
- IUWM Integrated urban water management
- IWRM Integrated Water Resources Management
- LA Learning Alliance
- m.a.s.l meter above sea mean sea level
- MC Miniclusters
- NRW Non-Revenue Water
- SWITCH Sustainable Urban Water Management Improves Tomorrow's Cities Health
- TDS Total Dissolved Solids
- UB Unitblock
- UFW Unaccounted for Water
- UWOT Urban Water Optioneering Tool
- WWTP Waste Water Treatment Plant
- WTP Drinking Water Treatment Plant

1. INTRODUCTION

Rivers, lakes and springs, used to be the only sources of water for all beings. However, increases in demands and the need for expansion pushed human beings to use other sources like groundwater and precipitation. Currently, water resources are under more pressures due to growth in population, higher standards of living and increases in human activities (Agarwal et al., 2000). This increasing pressure induced researchers to look for new freshwater sources in addition to manage the available sources using better techniques. One of the suggested approaches, which is proposed by the Integrated Urban water management (IUWM), is to utilize the generated water in urban water cycle. Moreover, IUWM suggests several water management options, within the cities, which change every drop of water into a potential source. The proposed IUWM options provide sustainable amount of water and it solves part of the water problems in cities that are facing serious shortages in their traditional water sources.

Alexandria is one of the cities that already has a limited water sources. At the same time, the growth in population is relatively high. Moreover, the demands dramatically increases due to the expansion in the tourist and industrial sectors. These, among several other reasons, suggested Alexandria to be one of demonstration cities as a part of an EU funded research program called 'Sustainable Urban Water Management Improves Tomorrow's Cities Health (SWITCH)'. SWITCH aims to test several options that could develop the integrated urban water management and presents several methods to manage water for 'City of The Future'.

City water Balance (CWB) is a new scoping model, which is being developing as part of SWITCH project, can be used as a projection tool for the future water situation in a city. Furthermore, several water management options for the city can be tested and evaluated to achieve the best scenario for sustainable urban water management. City water balance was developed based on the same concepts of Aquacycle and UVQ and both of them urban water models that were developed the Australian water balance program.

In Alexandria, Donia et al. (2010) already developed an Aquacycle model for the city. However, the next step was to develop a City water Balance model for Alexandria that represents the urban water system including the natural system, which is missing in Aquacycle. The model was developed using (CWB_1-1) based on the data that is collected from different institutions and stakeholders, in addition to the available reports and literatures. The main purpose of the model is to have a better understanding of the urban water system and then use the model to predict the outcomes of

applying different water management options in the city. The results ultimately will highlight the best scenarios for planning Alexandria water policy and make a better use of the water sources in the city.

This report contains an overview for Alexandria, then an introduction for the main concepts of the code (City Water Balance). The modelling processes are discussed afterwards including the conceptual model, the numerical model and the calibration and validation with a detailed discussion for each step. The model finally implements several scenarios to test the future water-situation in Alexandria.

2. OVERVIEW OF ALEXANDRIA

2.1. Introduction

Alexandria is the second largest city in Egypt. It is located on the southeastern cost of the Mediterranean Sea and to the North-west of the Nile Delta (figure 1). The city is surrounded by the Mediterranean Sea from the North, Mariout Lake from the South, Abu Qir Bay from the East and Burg El-Arab city from the West.

Figure 1: Political map of Egypt shows Alexandria location

Alexandria has the largest port in Egypt that receives more that 75% of the overall exports and imports for Egypt. Furthermore, the city holds more than 35 % of Egyptian industry and several main industries in Egypt based in it. Alexandria also one of the best resorts in Egypt, where people spend their holidays to enjoy its beautiful weather during summer period. The number of people who live in Alexandria is slightly more than four million people but this number increases about 30% during summer.

The city extended in the longitudinal direction, to accommodate the growth in population, between the Mediterranean coast and Mariout Lake and that gave the city a semi rectangle shape with more than 30 km length and around 6 km width (figure 2).

Figure 2: Satellite image for Alexandria city

2.2. Climate in Alexandria

Egypt is classified as arid regions in general. However, being located on the Mediterranean Sea, Alexandria has relatively a moderate climate in comparison to other cities in Egypt. The annual average temperature in Alexandria is 20.1 ˚C. The maximum is 26.4˚C in summer and the minimum 13.5 ˚C in winter. The rainfall occurs only during winter which last from November to March while the summer is considered a dry season that lasts from April to October. The average annual rainfall is about 190 mm/year. However, during the last few years the amount of rainfall hardly excesses 130 mm/year. Even the distribution of the rainy days has changed recently where the precipitation occurs less frequently with higher amount of water during a single storm. As regards the evaporation, the average daily value is around 5 mm/day. This value increases during summer to reach more than

10 mm/day and the minimum in winter is about 3.5 mm/day. The evaporation rates increases from north of the city towards the south where the arid zone is dominated (Dawoud et al, 2005), table 1.

Station name	Temperature(˚C)			Relative humidity (Annual average %)	Evaporation (Annual average mm/day)	Rainfall	
	Annual average	Max.	Min.			Annual (mm/yr)	Max (mm/day)
Alexandria	20.1	26.4	13.5	68.7	5.0	190.9	53.5

Table 1: Annual Meteorological data for Alexandria (Dawoud et al, 2005)

2.3. Geomorphology

Alexandria governorate, including Mariout region, is divided into six main geomorphologic units (figure 3). These units from the coast in the north to the south are:

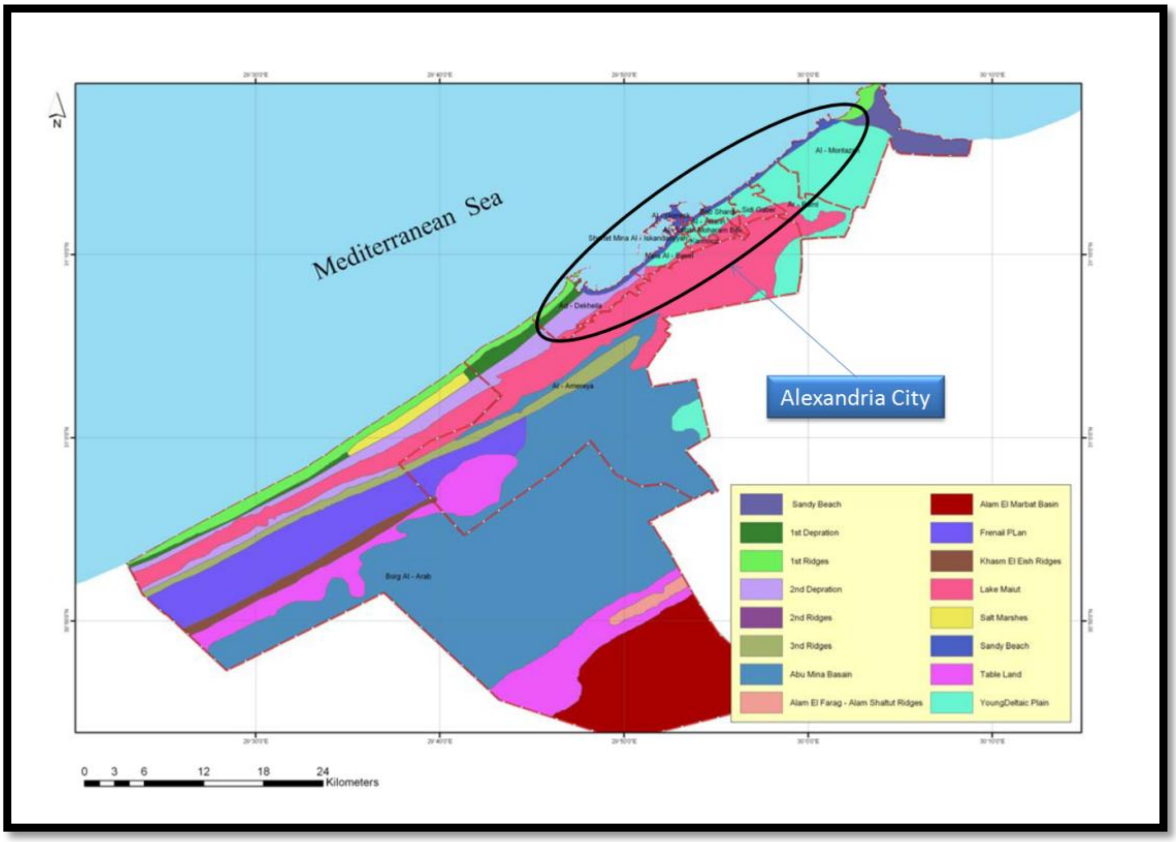

Figure 3: Geomorphologic map for Alexandria governorate (El-Arabi et al, 2009)

2.3.1. The coastal plain

A narrow zone extends along the city parallel to the shore. It has an average width of 5 km starting from the sea. The coastal plain is subdivided into the Recent Coastal Plain, which corresponds to the tidal zone, and the Pleistocene Coastal Plain. The latter is consists of three ridges split into each other by lagoon depressions. The depressions filled with loamy deposits

and have almost the same elevation as the sea level while the elevation of the Recent Coastal Plain varies from Sea level elevation near the coast to around 50 meters in the south. (El-Arabi et al., 2009)

2.3.2. Piedmont Plain

It is located to the south of the third coastal plain ridge. The width varies from of 3 to 6 km with a ground elevation between 10 and 20 meter above sea level. This plain is covered by the washed alluvial from the southern Tableland (El-Arabi et al., 2009).

2.3.3. The Tableland

The Tableland extends to the south of Piedmont Plain with an average width of 4 km and a maximum elevation of 110 m above sea level. It consists of two parallel ridges that are separated by a lagoon depression. The ridges consist essentially from oolitic-hard limestone with well-rounded sand (El-Arabi et al., 2009).

2.3.4. The Depositional Basin

There are two main basins within Alexandria: Abu Mina Basin and Allam El-Marbat Basin. The former one lies to the south of the coastal plain and to the east of the Tableland and it covers an area of 500 km^2, while the latter one lies to the northeast of tableland with an elevation between 10 and 35 meter above mean sea level (El-Arabi et al., 2009).

2.3.5. The Deltaic Plains

The dominated plain in the Nile Delta which is located between the Nile River in the East and Abu Mina basin in the West. It is mainly a cultivated area that has a very smooth slop towards the sea. The ground elevation is around 20 meters in the south to 3 meter in the north (El-Arabi et al., 2009).

2.3.6. Brackish Lagoons

It is represented mainly by Mariout Lake that is located to the south of Alexandria city. The lake covers an area of almost 67 km^2 with an average depth around 1.2 m. The lake is not connected to the sea and the water level is about (-4) m above mean sea level. Several canals and drains discharge into the Mariout Lake and the water is pumped out of it to the sea to avoid water overflow out of the lake.

2.4. Geological sequences

The exposure surface in Alexandria governorate mainly belongs to recent deposits. El-Arabi et al. (2009) classified the geological settings in the area (figure 4) from younger to older as following:

2.4.1. Holocene deposits

It covers the western part of the Alexandria governorate and it is divided into two main deposits:

- Littoral Deposits: it is either a white carbonate sands deposited along the Mediterranean Sea from in marine environment, or an Evaporates, mostly crystalline gypsum that deposited due to the evaporation of water in the depressions, mixed with sand and clay.
- Terrestrial Deposits: this is divided into four main components:
  - Coastal Sand Dunes Deposits: consist of calcareous oolite sand with shell along the Mediterranean coast.
  - Inland Dune Sand Deposits: which is mainly a yellow quartz sand with shell fragments to the south of Alexandria city
  - Alluvial Deposits of Desert Wadeis is loamy deposits extends over a large area to the south of Alexandria city.
  - Recent Deltaic deposits that are formed of silt-clay with fine sand deposited recently in the Nile River basin, the thickness increase towards the East where the Nile River is located.

2.4.2. Pleistocene

- Inland lagoon deposits compose of clay and sand that expose in the depressions between the coastal ridges.
- The Cardium Limestone, which is sandy oolite deposits, interbedded with the lagoon deposits. The thickness is about few centimetres up to 3 meters.
- Oolite limestone ridges that has a wide distribution in the study area, it is covered locally by alluvial loamy deposits.

2.4.3. Pliocene

It is represented by El-Hagif formation that has a thickness of almost 30 meter. The formation consists of calcarenite sandstone covered by chalky limestone that has gypsum and sandstone beds.

2.4.4. Miocene-Pliocene

Conglomerate and conglomeratic sandstone underline El-Hagif formation

2.4.5. Lower Miocene

It is essentially represented by Moghra Formation which is almost 200 meters fine to medium deltaic marine sediments interbedded with carbonate beds. (El-Arabi et al., 2009)

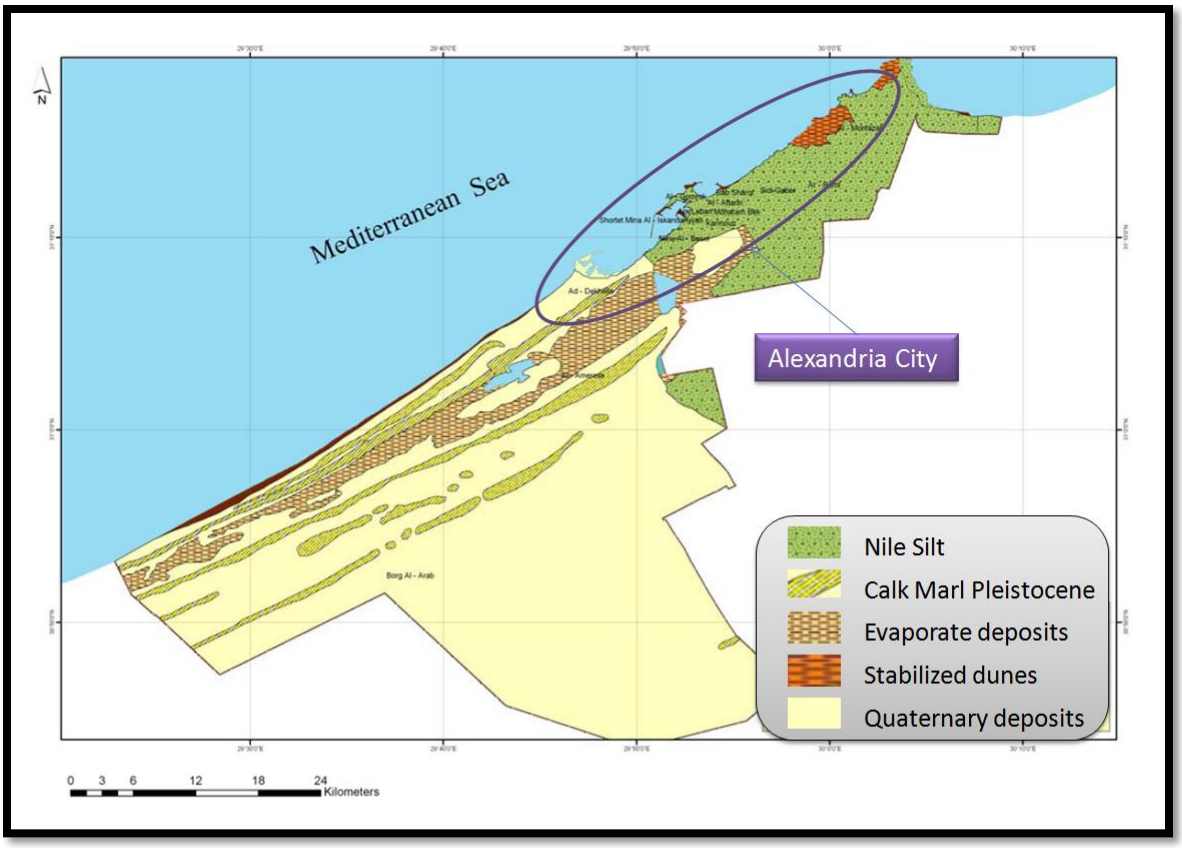

Figure 4: Geological map for Alexandria governorate (El-Arabi et al, 2009)

2.5. Hydrology and surface water

The Nile River is considered the main source of water in Egypt. It provides most Egyptian water-use along its way to the Mediterranean Sea. The Nile River splits into two main branches, The Rosetta and Damietta, just to the north of Cairo. The Nile Delta spreads around these branches to from the main agriculture area in Egypt. There are complicated network of canals that drag water from the Nile branches to cover the whole delta.

Alexandria City is located about 40 km to the west of Rosetta branch. There are two main canals that supply the city with the clean water, Al-Mahmoudia canal and Al-Nubaria canal (Figure 5). These two canals supply the city with the needed water for all demand including residential, industrial, tourist, agriculture and recreational areas. There is another Network of drains collects the wastewater from the wastewater treatment plants to discharge it in Mariout Lake. Most water, which is currently discharged in the lake, is primary treated water.

Figure 5: The main canals and drains in the western Delta
(Source: Ministry Of Water Resources and Irrigation)

Mariout Lake is a shallow lake covers a huge area to the south of Alexandria city. In 1801, Mariout Lake had an area exceeded 700 km^2. However, land reclamation and road construction decreased the area of the lake and it is currently less than 65 km^2 (Shaalan, et al. , 2009). The lake has an average water depth of 1.3 m with the water level around (-4) meter above mean sea level. There are no connection between Mariout Lake and the Mediterranean Sea but the water level is kept below (-3) meter above sea level by pumping the water to the sea from El-Mex pumping station.

The lake receives water form several drains and canals, it also receives most of the drainage effluents from Alexandria city. The majority of these effluents primary-treated wastewater and that causes deterioration in quality of water within the lake. The main drains that discharge in the lake are (figure 6):

- El-Qalaa drain that supplies the Lake with primarily treated wastewater from the wastewater treatment plants within Alexandria city.
- El-Omoum drain which hold a huge amount of wastewater in the Delta
- Al-Nubaria canal supplies the west of Nile Delta by irrigation water (Fishar, 2008)

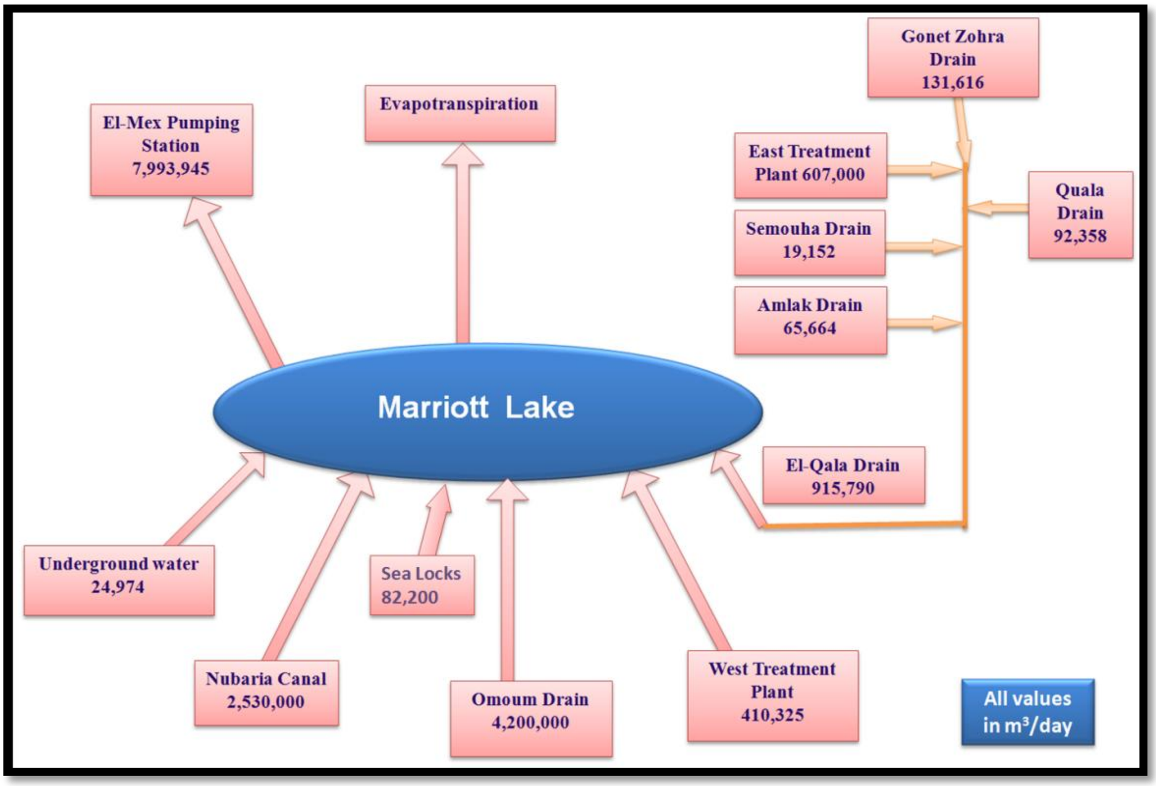

Figure 6: The inputs and output for Mariout Lake
(Source: Dr. Helaly Abdel Hady Helaly from Alexandria Drainage Company)

The lake includes currently five basins (figure 7) according to Shaalan et al. , (2009) as following:

1. The main basin has an area of 21 km^2 with an average depth of 1.2 meters
2. The northwest basin has an area of 10.5 km^2 with an average depth of 1.25 meters
3. The fishery basin has an area of 4.2 km^2 with an average depth of 1.35 meters
4. The southwest basin has an area of 21 km^2 with an average depth of 0.5 meters
5. The west basin has an area of 8.4 km^2 with an average depth of 0.6 meters.

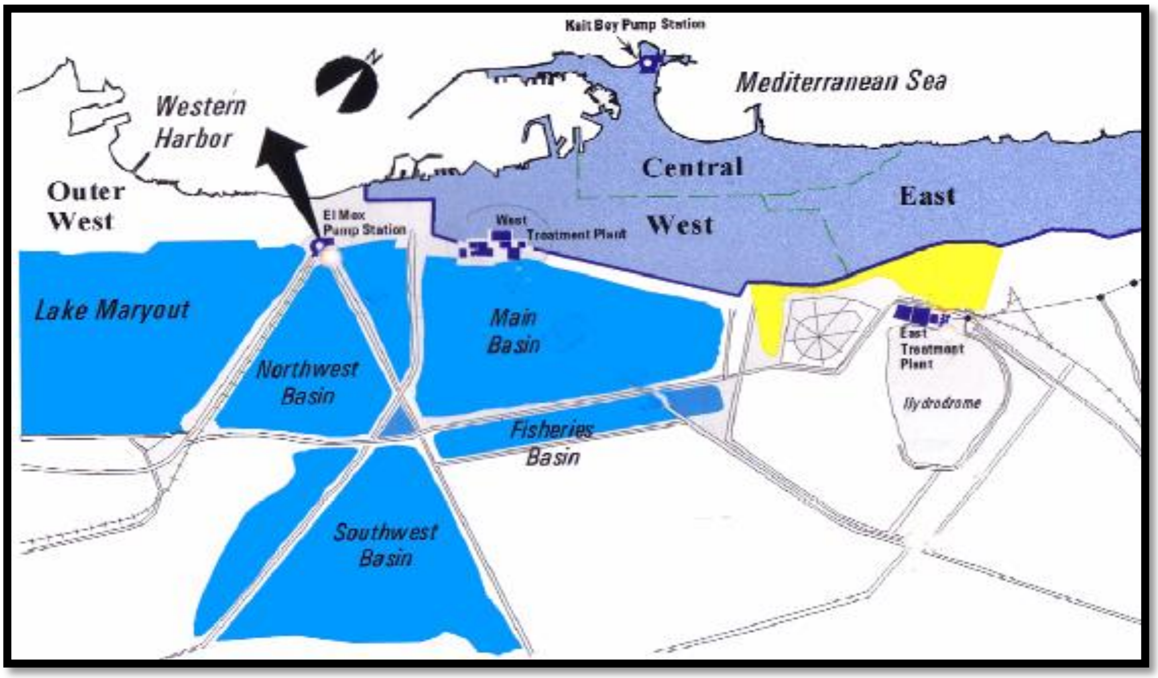

Figure 7: The main basins in Mariout Lake (Shaalan et al, 2009)

2.6. Hydrogeology and groundwater

The hydrogeological characteristics within Alexandria governorate is distinguished according to the main aquifer (figure 8) in the area. El-Arabi et al. (2009) defined four aquifers as following:

2.6.1. Nile Delta Aquifer

A regional semi-confined aquifer covers the whole Nile Delta and it extends in the western part of Alexandria governorate. It consists of sand and gravel in the south that change into fine sand and clay to the north. The depth of the aquifer increases gradually from few meters in the west to reach about 450 meter to the east near the Nile River. Nile Delta Aquifer is recharged mainly from the excess irrigation water. However, it contains brackish water due the inland flow of seawater from the north. The transmissivity range from 500 to 5000 m^2/day. (El-Arabi et al., 2009)

2.6.2. Coastal aquifer

A local unconfined aquifer consists of oolite limestone that extends on the surface along the Mediterranean coast. Precipitation infiltrates directly into the costal aquifer to be the main source of water. The coastal aquifer discharges in Mariout depression in the south and the Sea to the north. A marine carbonate succession fully saturated with seawater underlies the coastal aquifer, while the water in the coastal aquifer is less saline. Depth to ground water is around 5 to 10 meter below ground level (El-Arabi et al., 2009).

2.6.3. El-Ralat Aquifer

It is a local low productive aquifer, which has a transmissivity less than 500 m^2/day, covers the western part of Alexandria governorate. El-Ralat aquifer has a hydraulic interaction with the coastal and the Nile delta aquifer (El-Arabi et al., 2009).

2.6.4. Moghra aquifer

It is a regional confined aquifer underlies the study area beneath the coastal and the Nile Delta aquifer. It consists of sand and gravel that change into clay near the Mediterranean Sea. The aquifer thickness is more than 800 meter with a transmissivity between 500 m^2/day and 5000 m^2/day. The water within this aquifer tends to have high salinity (El-Arabi et al., 2009).

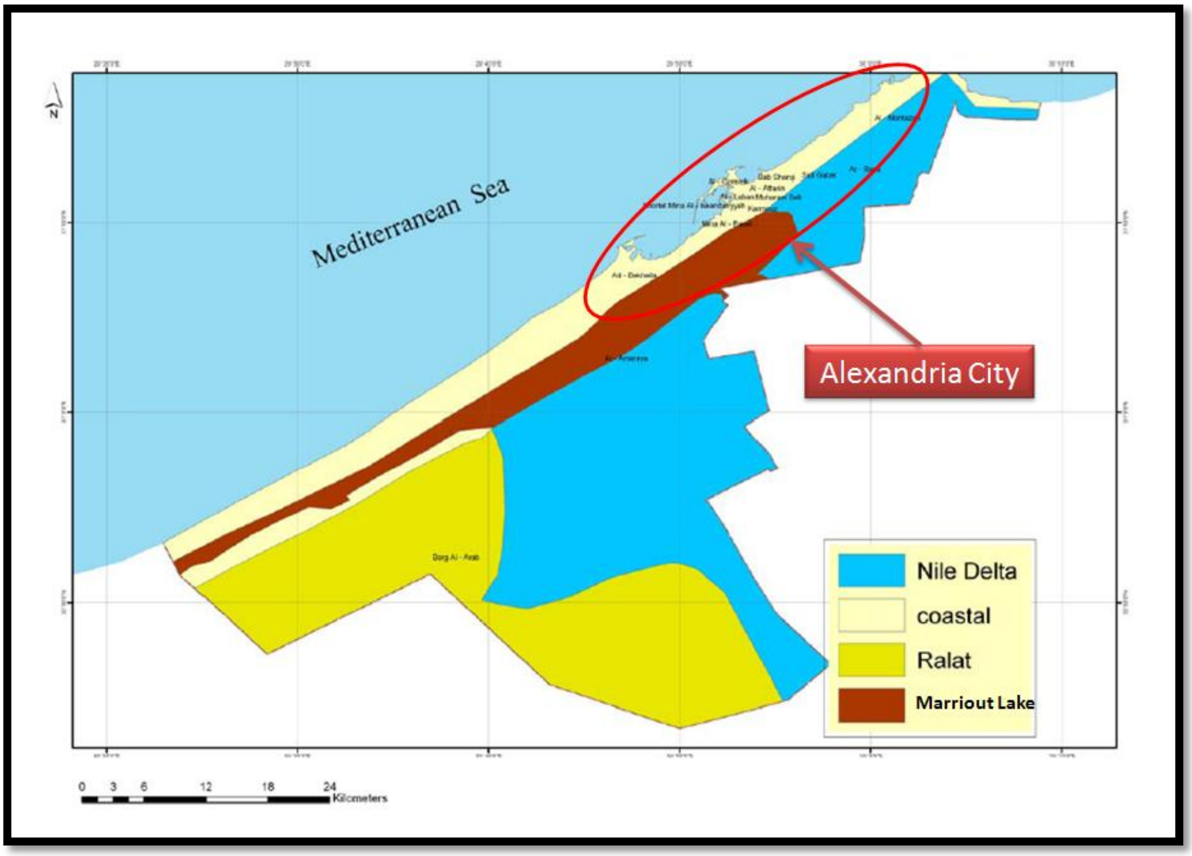

Figure 8: The main aquifers in Alexandria governorate (El-Arabi et al., 2009)

The piezometric contour map (figure 9) shows the water level, within Alexandria governorate, increases gradually from around 1 meter above sea level near to cost to almost 20 meter inland. The maximum values exist where there is an excess irrigation or leakage from the canals (El-Arabi et al., 2009).

The amount of groundwater that is currently abstracted from Alexandria's aquifer is very limited and that is essentially due to:

- Groundwater quality is not suitable for most uses due to high Total Dissolved Solvent (TDS)
- The potential seawater intrusion
- The abstraction cost is relatively higher than the current cost of the available surface water.

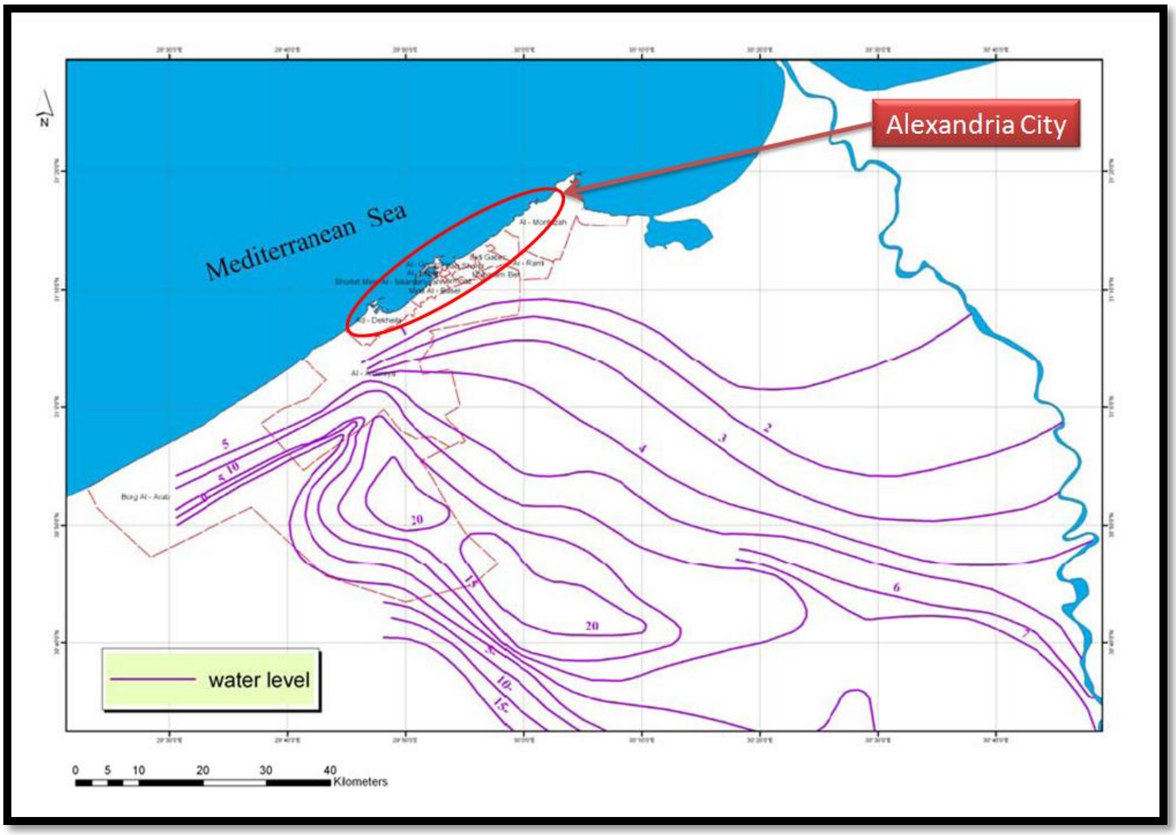

Figure 9: The piezometric map for Alexandria (El-Arabi et al., 2009).

2.7. Urban water System in Alexandria

The Nile River is the source of water for all usage in Alexandria. The water is delivered to the city through several canals. Al-Mahmoudia canal and Al-Nubaria canal drag water from the Nile River (Rosetta branch) to deliver it to eight Water Treatment Plants (WTPs) that are run by Alexandria Drinking Water Company (AWCO). The water treatment plants aim to provide safe, reliable drinking water for all sectors in Alexandria by using the following techniques:

1- Flocculation and Sedimentation: it aims to isolate the suspended particles from the water itself by adding a coagulant to the water then mixing them together. The coagulant makes the particles stick together to form bigger particles. The flux is diverted afterwards to sedimentation tanks in order to allow the suspend particles to precipitate by gravity.
2- Filtration: this is the next step after sedimentation. The water is directed to filter beds that remove the smaller suspended particles. Most treatment plants in Alexandria use sand filters to this process.
3- Chlorination: it is the last step before the water distributed into the city. A sufficient amount of chlorine is added to the water to produce a safe drinking water. The clean water is stored in clean tanks just before the distribution through pipe networks to consumers.

Eight water treatment plants (WTPs) in Alexandria were designed to produce 3.5 million m^3/day (table 2). The WTPs currently produce (2.5 to 3) million m^3/day of clean and safe water according to the Egyptian code.

NO	Water Treatment plants (WTP)	Capacity (m^3/day)
1	El-Maamoura	240,000
2	El-Siouf	940,000
3	El-Nozha	200,000
4	El-Manshia	380,000
5	Rond Point	620,000
6	Forn El-Geraia	50,000
7	El-Noubaria	510,000
8	Borg El-Arab	566,000
	Total capacity	**3,506,000**

Table 2: The water treatment plants in Alexandria with their capacities (Taha et al., 2010)

The water, produced by Alexandria water treatment plants, is the main source of water for all sectors in the city, i.e. residential, commercial, industrial, irrigation and tourism. Alexandria drinking Water Company covers more than 95 % of the whole water demand within the city. Furthermore, Part of the produced water is sent through five-transmission line to Matrouh Governorate and Behera Governorate to supply its water deficit (Taha et al., 2010).

The wastewater, which is generated by all users in the city, is then sent to Wastewater Treatment Plants (WWTPs) though the drainage network. Thirteen WWTPs are currently run by Alexandria Drainage Company which treats about 1.5 million m^3/day (table3). Most plants already have a secondary treatment. However, the main two plants still produce primary treatment and they are currently under the process of changing them into secondary treatment. The treated water, which corresponds to the Egyptian code, is mostly discharged into drains that carry the water to Mariout Lake (Donia, et al., 2010).

No	Wastewater Treatment Plant WWTP	Designed Capacity (m^3/d)	Type of Treatment
1	East treatment plant	607,000	Primary (is being changed into secondary)
2	West Treatment plant	462,000	Primary (is being changed into secondary)
3	Iskan Mubarak	15,000	Secondary
4	El-Hannovile	50,000	Secondary
5	Abis Villages	18,000	Secondary
6	Khorshid	15,000	Secondary
7	El-Seiouf	7,000	Secondary
8	El-Maamora	10,000	Secondary
9	El-Amriya	100,000	Secondary
10	El Agamy	200,000	Secondary
11	Km 26	4,000	Secondary
12	New Borg El Arab	36,000	Secondary
13	El-Nubaria	6,800	Secondary
	Total capacity	**1,530,000**	

Table 3: Wastewater Treatment Plant WWTP with their capacity (Donia et al, 2010)

2.8. Water-related problems

Alexandria Water Company currently supplies more than 95% of the city by potable water (Taha et al., 2010). However, water demands within Alexandria increases dramatically and the sources of water may not be enough to cover all future demands. Furthermore, several problems related to the quality and quantity of water may have great effects on the future availability of water. The main predicted water problems in Alexandria can be summaries as following:

2.8.1. Increase in demand due to growth in population

Alexandria Water Company (AWCO) is responsible to supply the whole population in Alexandria with potable water. However, if the number of inhabitants increased dramatically, AWCO would not be able to cover the whole water demands. According to (Donia et al, 2010) the estimated number of inhabitants in Alexandria by 2037 will increase by a factor of 47 % (Table 4). Therefore, AWCO will defiantly not be able to support all needed demand if the current per capita consumption still the same.

Estimated number of inhabitants in Alexandria						
Year	2012	2017	2022	2027	2032	2037
During winter	4,262,000	4,605,000	4,973,000	5,371,000	5,800,000	6,264,500
During Summer	5,607,920	6,089,200	6,547,900	7,072,720	7,636,970	8,246,230

Table 4: Estimated number of people in Alexandria (Donia et al, 2010)

2.8.2. Climate change

Alexandria is located near the downstream of the Nile River, which supports the city with all water demand. Therefore, Alexandria share of water depends on the upstream water usage and any excess use of water upstream will have an impact on Alexandria share of water. For the mean time, Egypt receives 55 billion m^3/year, according to the water-share agreement between the Nile basin countries. Assuming this amount is fixed, the gradual increase in temperature will definitely increase the losses by evaporation. Furthermore, water demand will be increasing in all upstream cities like Cairo and Tanta and that would reduce the available water for Alexandria.

2.8.3. Water leakage

The Unaccounted for Water (UFW) in Alexandria equals 36% of the produced drinking water, which is about 318.4 million m^3/year of treated water (Taha et al., 2010). This is considered a very high percentage in comparison to other countries. According to the European Environment Agency, the UFW is around 19 % in England and Wales and it is less than 10 % in Denmark. The main part of the water losses, in Alexandria, is due to leakage from pipes and old networks. AWCO has recently developed a strategy to reduce the losses to the minimum amounts.

2.8.4. Water consumption per capita

Alexandria Water Company estimated the average water consumption by 230 litters/capita/day and this is considered a high rate in a place facing water shortage like Alexandria. Some other countries like Germany managed to reduce their per capita water use to be 122 litter/capita/day in 2007 according to German Federal Statistical Office (Thomas, 2009).

2.8.5. Sea water intrusion

Alexandria is located on the Mediterranean Sea and, like other cities on the coast, Sea water intrusion is a very serious problem affecting the aquifers. Many studies had been carried out to investigate the fresh-saline interface. Sherif et al. (2002) suggested that the seawater introduced to about 63 km inland in the Nile Delta aquifer. That covers the whole aquifers beneath Alexandria city. Therefore, the government policy for the time being is not to extract any groundwater from Alexandrina in order to hold the saline-fresh interface on its current position.

2.8.6. Groundwater Quality

The TDS value, for most groundwater in Alexandria, is generally higher than 1000 ppm and that makes the water not suitable for domestic uses. Furthermore, Nitrate concentrations in the water samples in Alexandria were higher than the drinking standard values and that is probably due to excess use of fertilizers (El-Arabi et al., 2009).

2.8.7. Beaches and Lake pollution

Prior to 1987, nineteen outfalls were discharging most of Alexandria sewage water into the sea. This sewage, which included industrial, domestic and agriculture wastes, increased the pollution and the heavy metals in the sediments along the beach (Frihy et al., 1996). sewege water currently does not discharge into the sea because all trated wastewater is directed to Mariout Lake. However, there are still around 100,000 m^3/year of untreated water that is diescharged intot Marriout lake, in additon to a huge amout of wastewater that is only primary treated. All of that generates several environmental problem in the area (Hilali et al., 2010).

3. CITY WATER BALANCE: A NEW SCOPING MODEL

3.1. Introduction

The effective disposal of the sewage and wastewater was common approach of Urban Water Management. However, the increasing demand for water with lack of sources converts stormwater and wastewater into potential resources, which may support cities with a sustainable amount of water as an application of Integrated Water Management (Mitchell et al, 2001). The Integrated Urban Water Management (IUWM) aims to consider all parts of urban water cycle as one single system in oder to achevie the best ways of manageing the available water resources (Mitchell, 2006).

Few tools have been developed recently to check the feasability of diferent water managemnet scinaros. One of these tools is Aquacycle that was developed by Grace Mitchell in 2000 in Monash Univeristy. 'Aquacycle is a daily urban water balance model that simulates the total urban water cycle as an integrated whole' (Mitchell, 2005). Mitchell et al. have developed another softwatre called UVQ, which is an enhaced version of Aquacycle, to analyses the contaminats flow in addtion to the water flow through an urban area (Mitchell; Diaper, 2005). Urban Water Optioneering Tool (UWOT) is also another tool based on a water balance model and it investigates the interactions between the urban water cycle componatns (Makropoulos, 2008).

City Water Balance (CWB) is one of the latest codes that simulate urban water system within cities. It is being developed by Ewan Last and Rae Mackay at the University of Birmingham as a part of EU-funded research programme called SWITCH (Sustainable Water Management Improves Tomorrow's Cities' Health) (Last & Mackay, 2007) . CWB concepts are similar to Aquacycle, UVQ and UWOT. However, it combines the water efficiency option and the reuse option of UWOT and Aquacycle respectively. Furthermore, it includes the natural system (rivers, lakes, canals and groundwater) in the simulation, which reflects more realistic results (Last, 2010)

3.2. City Water Balance concepts

CWB aims to represent urban water cycle in one integrated model. This model helps to achieve better understanding for the water system. It also helps to investigate different water management scenarios and options in the city.

City water balance requires dividing the city into three unit types (figure 10) as following:

- Subcatchment: The urban area is divided into number of subcatchments depending on the sewer or drainage networks in the city. Each subcatchment contains one or more miniclusters. 'A subcatchment is defined as an area of cityscape containing a network of foul or combined sewers that drain to a point at its downstream boundary' (Last , 2010). The subcatchments should be in order where each one can receive wastewater from the upstream subcatchments only. Moreover, the flow of wastewater and stormwater has to be from a subcatchment into only one other subcatchment.
- Minicluster (MC): Each MC has one or more unitblocks but all unitblocks should have the same type, i.e. they have the same parameters and properties. The minicluster might also have a public open space (POS) and road area.
- Unitblock (UB): the smallest unit in the urban area. Each UB is defined by set of parameters that specify the water demand, the pervious and impervious spaces. A unitblock can be a house, factory, hospital, hotel or any other type of building (Mitchell; Diaper, 2005).

The modelling process includes dividing the city into the aforementioned three unit types using satellite images and landuse maps. Then a GIS database is build to the city. The database includes vertices of all miniclusters, in addition to the lakes, rivers and canals in the area. The data is then imported to City Water Balance input files. The input files consist of sets of parameters that represent all urban water cycle components, including climate, canals, lakes, soil, groundwater, indoor and outdoor water use and leakage.

Once the input files are ready, the model is run then it is calibrated and validated according to the available data. The calibrated model afterwards can be assigned different water management scenarios to investigate their results.

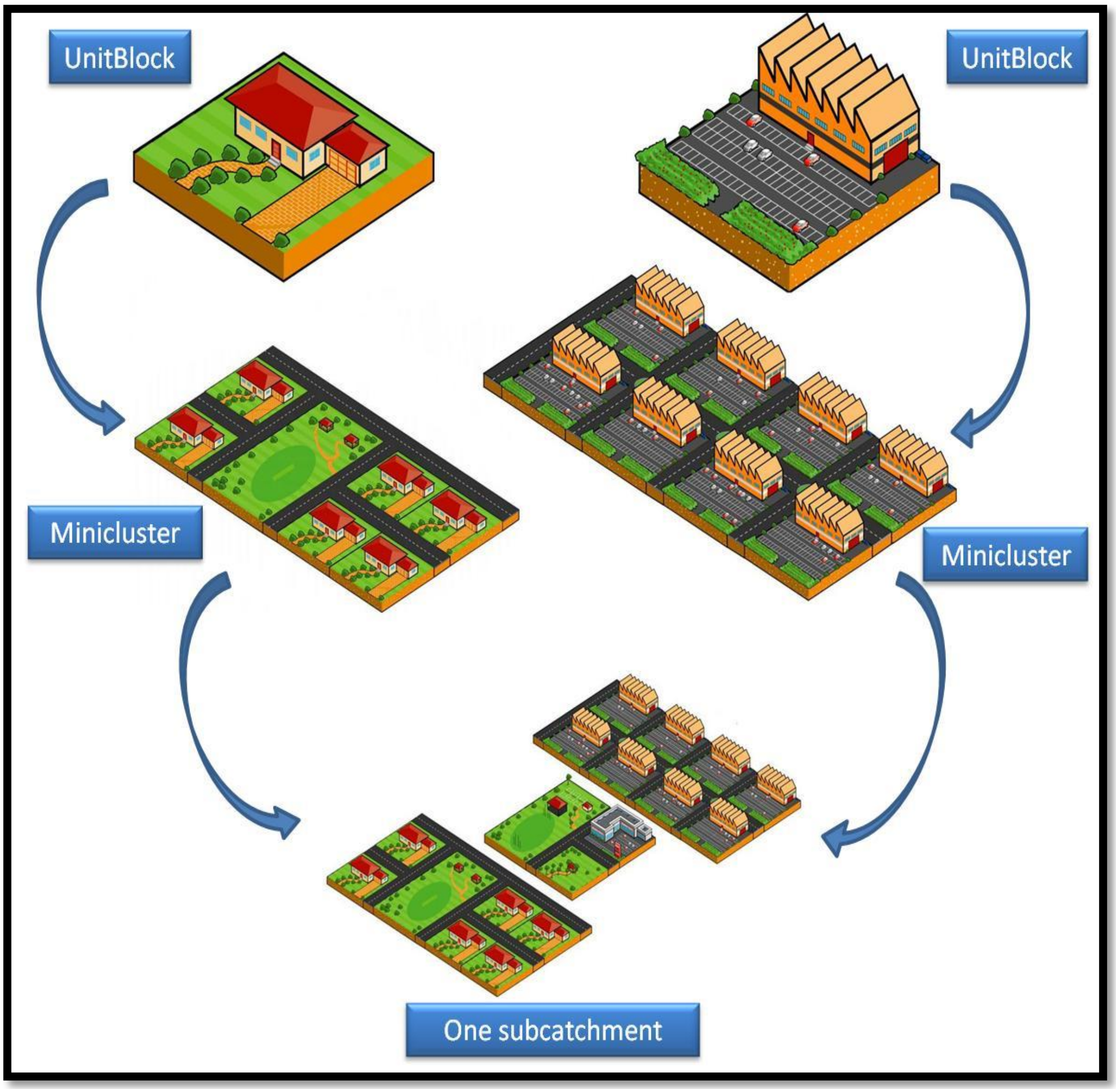

Figure 10: The main unit types in City Water Balance (Mitchel; Diaper, 2005)

4. METHODOLOGY

4.1. Introduction

Alexandria is one out of ten demonstration cities within SWITCH project. SWITCH has several activities to improve the Integrated Urban Water Management (IUWM). A Learning Alliance, which includes members from all water-related sectors in the city, was formed to facilitate SWITCH activities and to produce a strategic plan for sustainable integrated urban water management. The Learning Alliance strategic plan is meant to correspond to Egyptian national plan in the water sector. The national plan has detailed visions for the water resources until 2037. Therefore, the Learning Alliance aims to set an integrated strategic plan for all stockholders until 2037. Several scenarios are being set by the Learning alliance members to predicate the water situation in the future. In order to investigate the suggested scenarios, Donia et al. developed an initial urban water model for Alexandria using Aquacycle. However, an enhanced model that includes the natural system in needed to give a better representation of Alexandria urban cycle. City Water Balance was the suggested model to achieve this purpose and this study will explain elaborately the steps that were followed to develop City Water Balance model for Alexandria.

4.2. Data collection

The data for the model was obtained from four main sources:

4.2.1. Literatures:

Several studies and reports were produced for the area. The main papers were published by:

a. The Learning Alliance subgroups as a part of SWITCH activities
b. Several organisations that had active projects in Alexandria
c. Theses and dissertations from the faculty of science and the faculty of engineering in Alexandria University

4.2.2. Raw data:

The data was collected from different departments in the following institutions:

- Centre for Environment and Development for the Arab Region and Europe (CEDARE) Cairo, Egypt.
- Ministry of Water Resources and Irrigation. Cairo, Egypt.
- Alexandria Water Company (AWCO). Alexandria, Egypt.
- Alexandria Drainage Company. Alexandria, Egypt.
- National Technical University of Athens (NTUA). Athens, Greece.

4.2.3. Calculations:

It includes the spatial information that was extracted from the satellite images and the field trips. In addition to the data that was diverted from the available reports.

4.2.4. Field trips:

Two Field visits were carried out to Alexandria in order to:

d. Understand the urban water system in the city
e. Define the model boundary
f. Investigate the natural water sources (canals, drains and Lakes)
g. Validate the extracted data from the satellite images
h. Check the calculated and assumed satellite images data

4.3. Model development

Modelling development includes several steps that have the following sequence:

- The city was divided into the main unit types (subcatchments, miniclusters and unitblocks) using 'ArcGIS 9.3'
- The GIS data was imported from ArcGIS into CWB using 'ESRI Shape Dump'
- The input files were built for (CWB_1-1) in the required format
- The model was run for the year 2006 which corresponds to the input data
- The model was calibrated and validated based on the data for the same year
- Different scenarios were run in order to assist the Learning Alliance in their object to put an integrated strategic plan for the city.

5. MODELLING

5.1. Conceptual model

Alexandria city extends along the Mediterranean Sea with a length of almost 32 km along the coast and a width of almost 6 km. The modelled area covers the entire urban city, which receives its water supply from Alexandria Water Company (AWCO), in addition to some cultivated area around the city. The border of the model is the Mediterranean Sea from the North, Mariout Lake from the south, Al-Mamoura from the east and Al-Kilo-Twenty-Six village in Al-Ajami from the west, figure 11. Al-Ajami area is actually out of Alexandria City, according to Alexandria administrative divisions, but the residential and industrial areas are continuously connected and there is no clear boundary to separate Alexandria from Al-Ajami. Moreover, the latter receives its water supply from AWCO. Therefore, the model assumes Al-Ajami part of the study area.

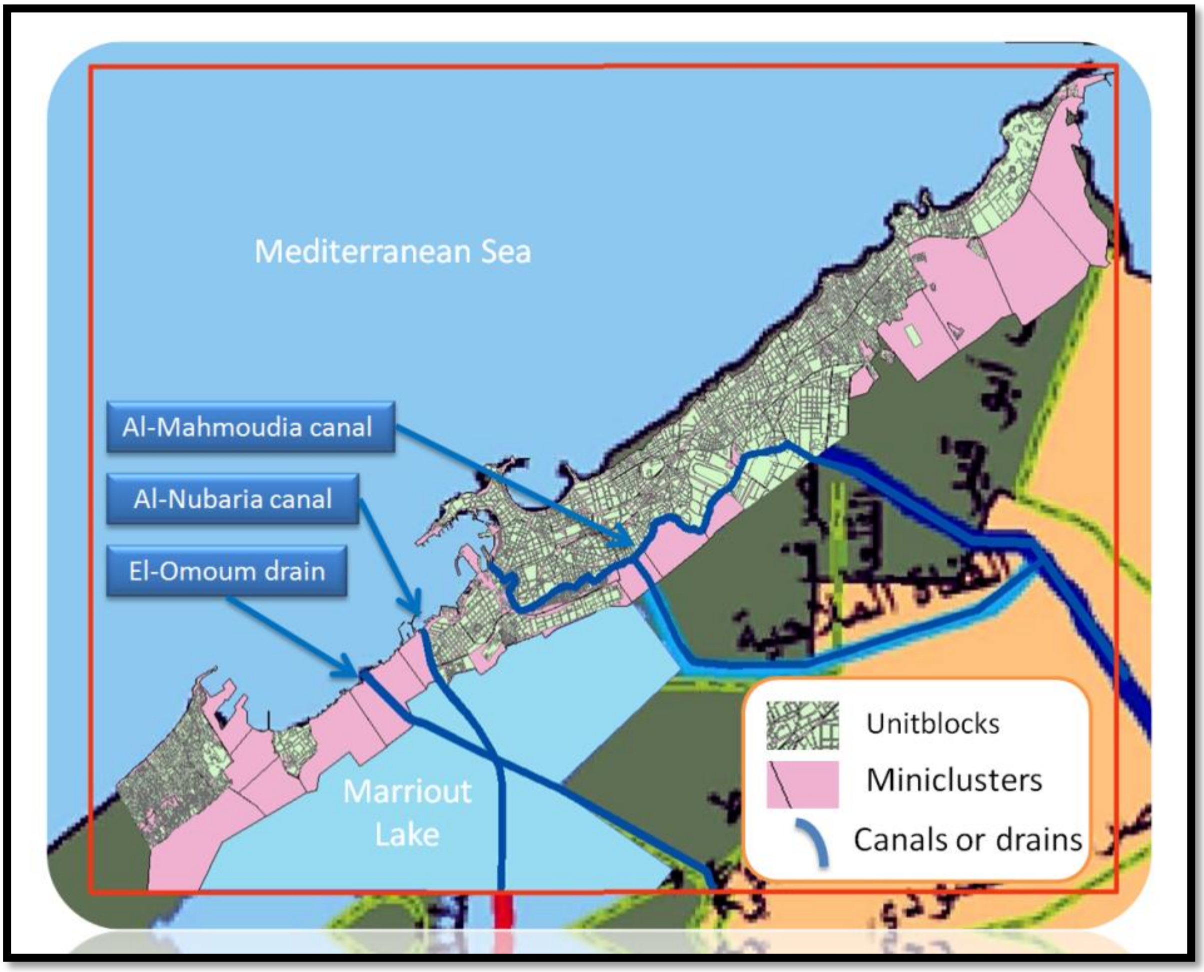

Figure 11: The study area with its main features (canals, lakes, MCs and UBs)

Topographical elevation of the study area ranges between (-8 to 20) meter above mean Sea Level, according to El-Arabi et al. (2009). The available topographical data, figure 12, did not determine the exact elevation of every point in the study area. Therefore, the urban area is considered to have an elevation ranges from (9 to 19) meter above sea level, while Mariout depression, south of the city, generally has minus elevations.

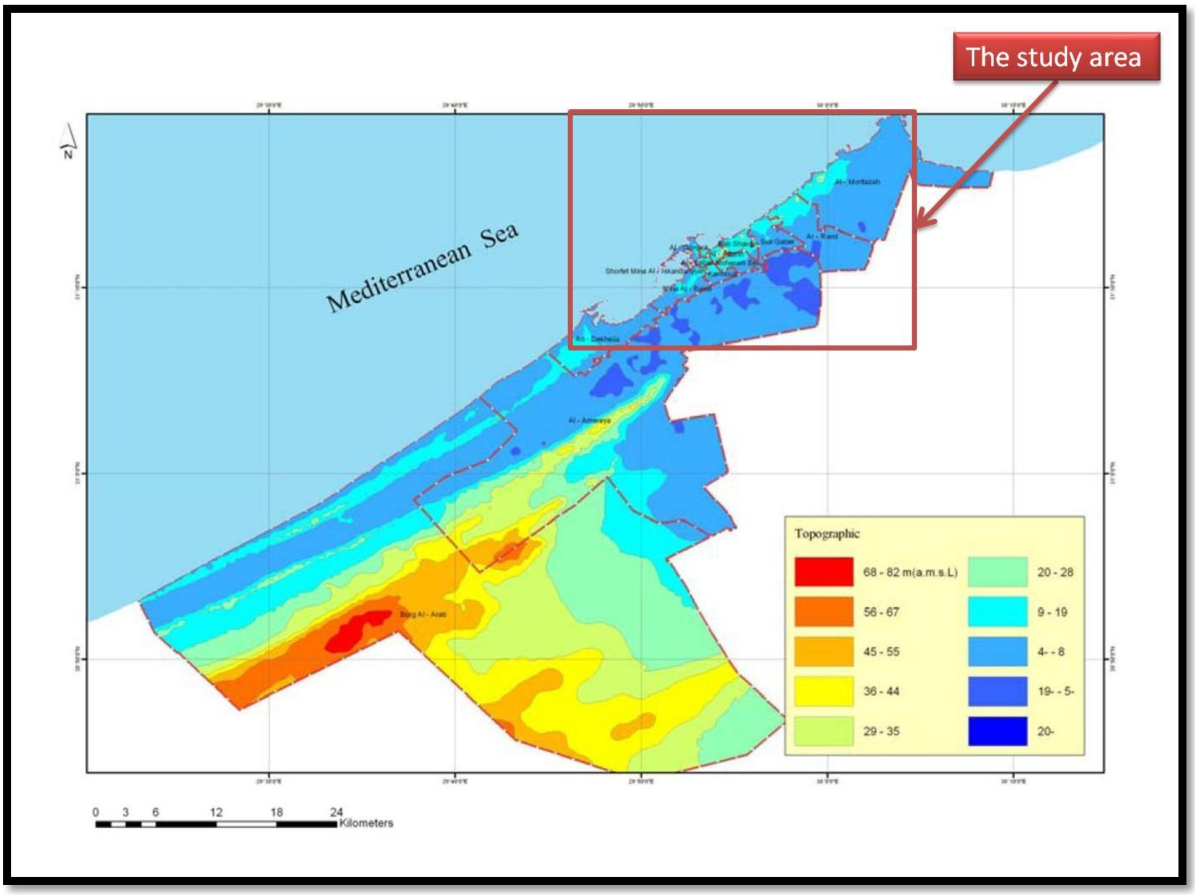

Figure 12: Topographic map of Alexandria governarate (El-Arabi et al., 2009)

5.1.1. Natural system in the study area

- Lakes: Mariout Lake is the main lake that represents a constant head boundary in the study area. It is a shallow, closed lake spread over a large area to the south of the city, figure 11. Several drains and canals discharge into the lake, in addition to the effluents form most Wastewater Treatment Plants (WWTP) in Alexandria. However, the water level for the lake is kept below (-3) meter above sea level by pumping huge amount of water, from El-Mex Pumping station, into the Mediterranean Sea.

  Another lake, called The Water Airport, exists to the east of Mariout Lake and to the south of Alexandria. The lake is used as water airport that is related to El-Nozha airport. The lake has an area of over six km^2. Apparently, some drain discharge into the lake and it must have a

hydraulic interaction with the groundwater system in the area. However, there were no available data about the lake and it is located outside the Alexandria city. Therefore, the lake is assumed not part of the study area.

- Canals: two main canals flow through the city, Al-Mahmoudia canal and Al-Nubaria canal (figure 11). Al-Mahmoudia canal, which is almost 30 meter wide with 3 meter deep, discharges over 8 million m^3/day of drinking water (Farooq et al., 1966). The excess water discharges to the Mediterranean Sea. El-Nubaria canal flows through the western part of the city and discharges around 90,000 m^3/day in the Mediterranean Sea (Samir et al., 2000). There are two other canals are assign to the model. The first is a part of Al-Mahmoudia canal and the other is El-Omoum drain, which discharge into the sea as well figure 13.

Figure 13: El-Omom Drain discharges into the Mediterranean Sea

5.1.2. Groundwater and aquifers

Alexandria area covers four main aquifers according to El-Arabi et al. (2009), figure 8. However, the model essentially deals with only two of them, the Coastal aquifer and the Nile Delta aquifer (figure 14). Moghra aquifer, which is a regional aquifer underlies the study area, has no hydraulic interaction with the Coastal or Nile-Delta aquifers because of an aquiclude overlays Moghra aquifer. Therefore, the model excludes Moghra Aquifer because it is not part of Alexandria urban water cycle.

The available data were inadequate to define groundwater levels and aquifers parameters accurately for modelling purpose. Therefore, estimated values, based on (El-Arabi et al, 2009), were adopted for the first run of the model then the values were calibrated and validated to correspond to the field observations.

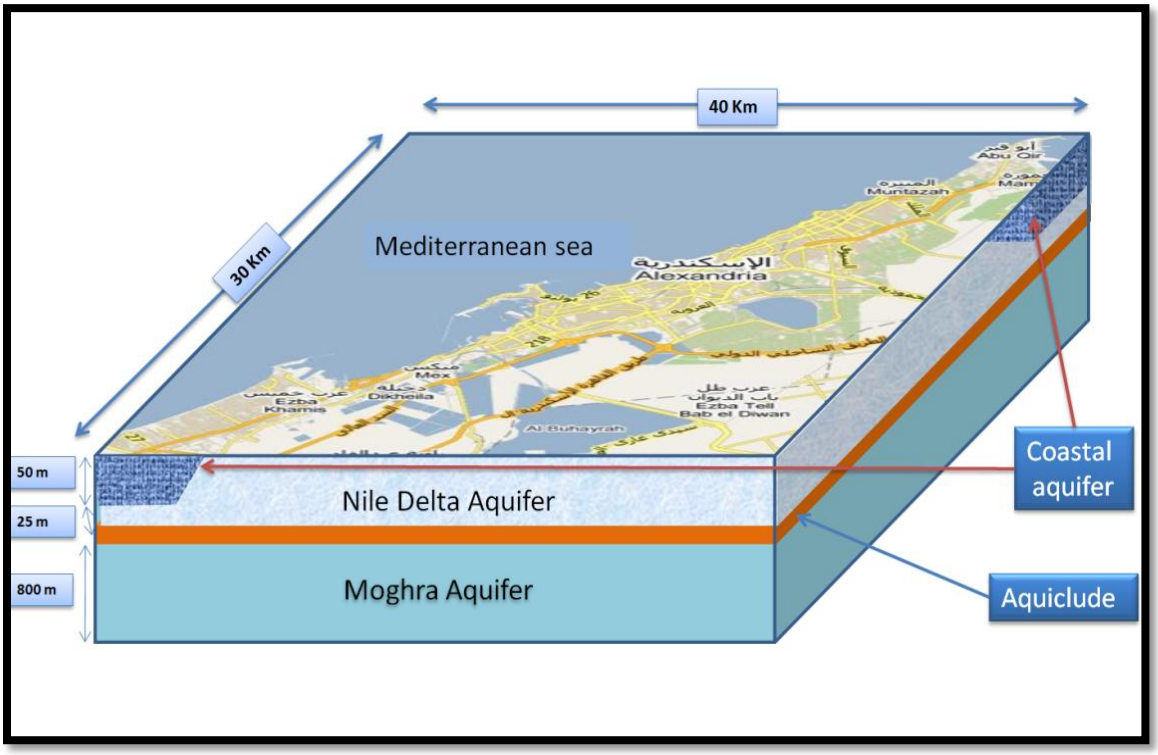

Figure 14: Conceptual model shows the main aquifer in the study area.

5.1.3. Subcatchments, miniclusters and unitblocks:

The model requires dividing the city into subcatchments, miniclusters and unitblocks using the satellite image and the drainage system map. The subcatchments division depends on the storm and drainage networks within the city. For the purpose of this model, the study area is assumed to have one subcatchment only because of the inaccessible maps for the drainage system. Moreover, the water supply pipe network is very complicated and Alexandria has a looped network, where flow direction changes depending on the change in demand. The subcatchments could have been chosen according to the AWCO administrative division but that would not be convenient for the way that the model processes the calculation.

Donia et al (2010) divides Alexandria into seven clusters differ from each other by the land use and their type of building. Similar concepts, generally, were followed in this model for the miniclusters division. However, the number of miniclusters increased and new miniclusters were designed for the

agriculture and industrial areas. As a result, the study area contains 121 miniclusters. Each of them has one type of unitblocks.

As regards the unitblocks, thirty-seven unitblock types were included in the study area, table 2342. Most unitblocks derived from the detailed study of Donia (2010), which was verified by field survey, cross checks and AWCO official data (Donia et al, 2010). Few other Unitblock types were included to fulfil the object of this study and to cover all types of land use in the city. Every single unitblock represent one building in Alexandria. The common style for the building in the city is tower-block buildings that have between 5 to 20 floors and each floor has 2 to 4 flats (figure 15). The tower buildings are distributed in a random way within the study area (figure 16) but general trend can be defined for most areas (figure 17) and that trend is the average that was used to define the unitblocks. The thirty-seven types of unitblocks present the common type of buildings in each minicluster and they are assumed to be the only prevailing types in the city.

Figure 15: The common building styles in Alexandria

Figure 16: The random distribution of unitblocks in Alexandria

Figure 17: similar trend of buildings for each area

5.1.4. The pervious spaces

Most of the urban areas have impervious surfaces that do not allow infiltration to groundwater. The pervious spaces are limited to few gardens, parks and recreational areas that can be seen in figure 18. Therefore, the rainfall does not have a great effect on the groundwater system because the majority of runoff goes to the stormwater system or it evaporates due to the high potential evaporation.

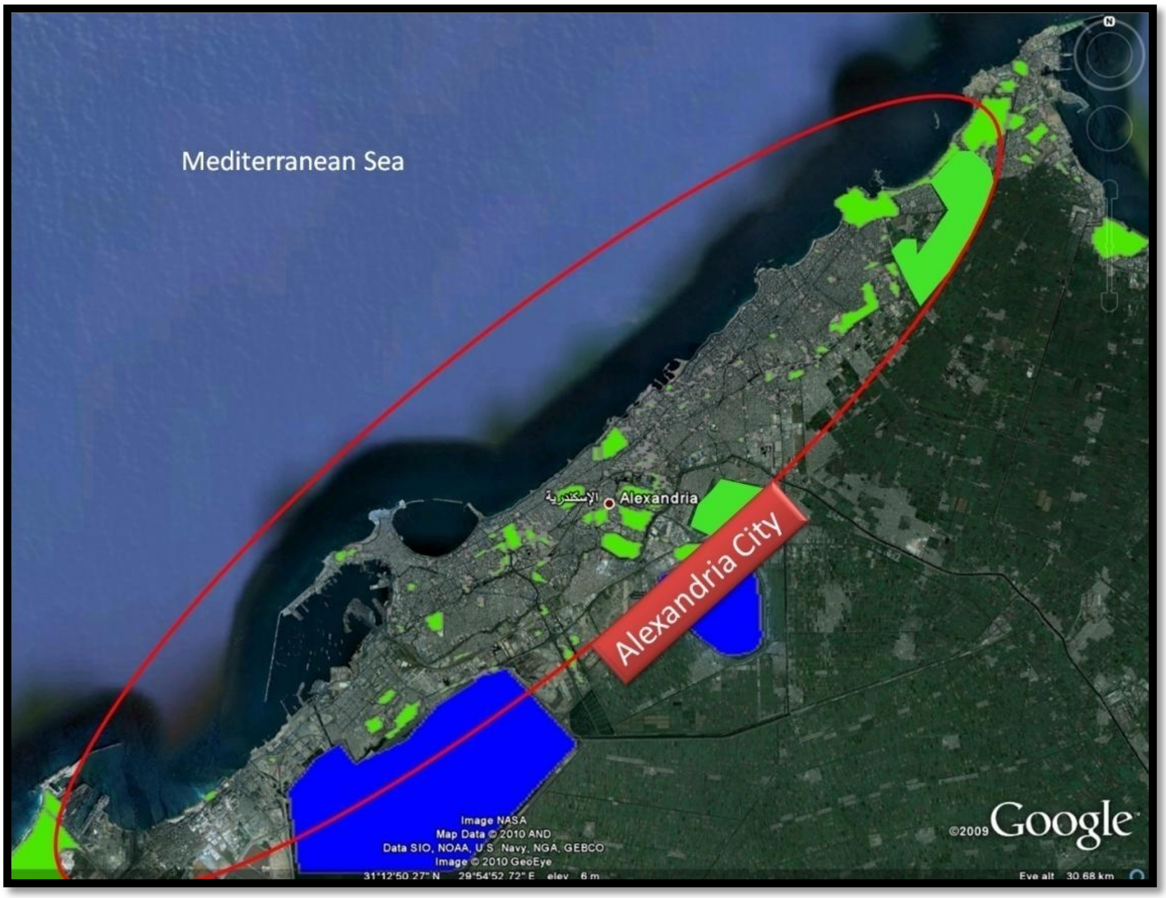

Figure 18: The pervious spaces in the study area

5.2. Numerical model

5.2.1. Sub catchments, Miniclusters and unitblocks:

The first step in building CWB model is to create a GIS database that includes all main features (unitblocks, miniclusters, lakes and canal) in the model area. The satellite images clearly show these features to be digitized for modelling purpose. Google earth and Yahoo maps give high-resolution satellite images for Alexandria. Based on Google earth, the study area was divided into (5196) different Unitblocks, where each unitblock represents one building. The unitblocks that have similar extend and properties form one minicluster. The study area was then divided into 121 miniclusters

to cover the whole study area. The 121 miniclusters were classified into eight main groups (table 8) and each one of these groups includes the miniclusters that have the same parameters. The eight-group divination followed the same concepts in (Donia, 2010). All of the miniclusters reside in the only subcatchment in the model figure 19.

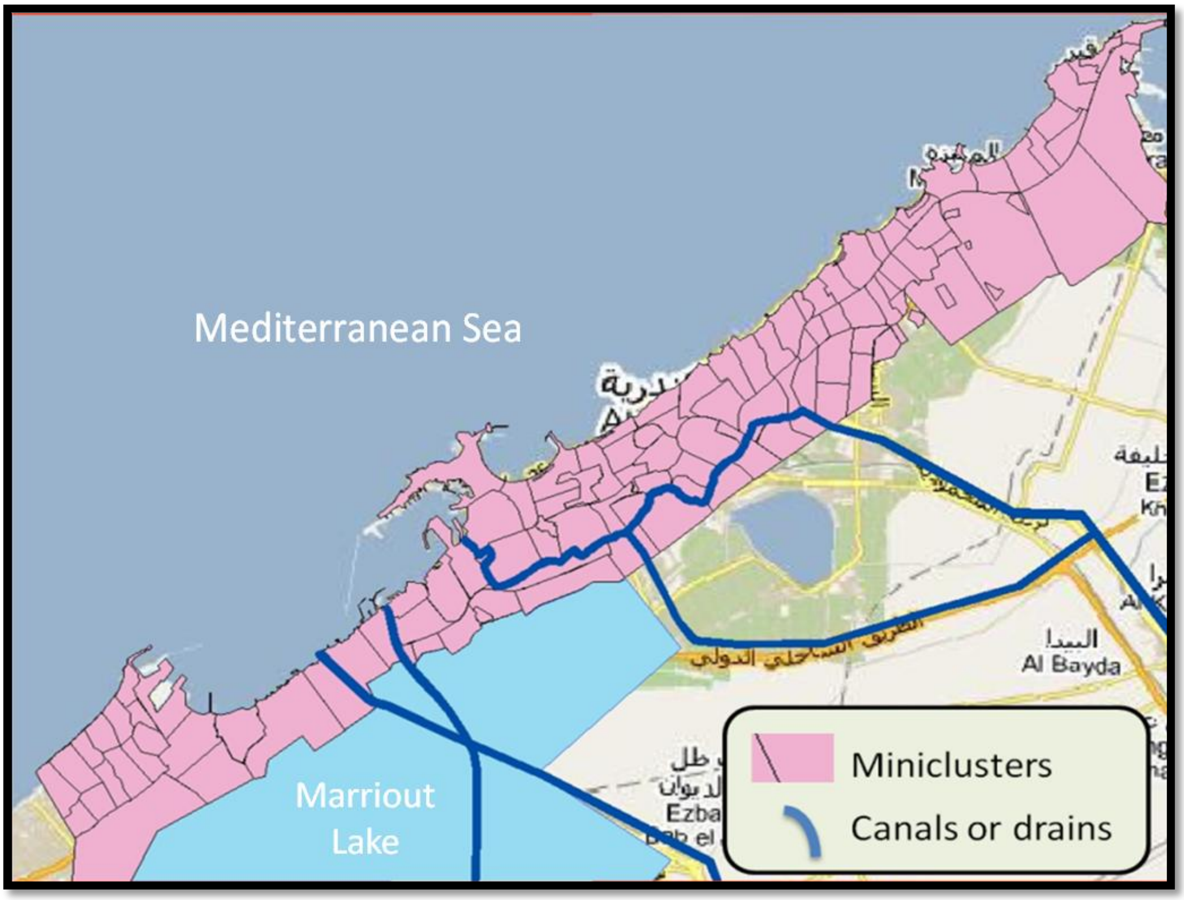

Figure 19: The model area with the 121 miniclusters in the study area

5.2.2. Input data

The data, for City Water Balance (CWB), has to be classified in files that have a specific format (.txt or .csv) and each one of theses files has sets of related parameters. The main input files for the current version of city water balance are:

1. Study area.txt

It has few key parameters for the study area. One of the parameters is the percentage of demand that is supplied by mains water. According to (Taha et al., 2010), Alexandria Water Company (AWCO) supplies more than 95 % of the population in Alexandria. The deficit in water is basicly being taken by an illigal way form the canals or from very few borehols within the city. However, this model assumes that AWCO covers the whole water demined within the city because there were no available data for the deficit supply and it is value is small enough to be negotiable.

2. Subcatchment_flows.txt

It determines the number of subcatchments and the drainage flow system between them. It is assumed that the model has only one subcatchment because Alexandria has a looped complicated stormwater system and there are no available maps to isolate the system into more detailed several subcatchments.

3. Unitblock_defaults.txt

This file contains the main parameters for every Unitblock (UB) type. The study area was divided into 37 Types (table 5) and each of them is assigned the required parameters as following:

- Roof area, paved area and previous area: these areas were mostly derived from (Donia, 1010) or it was calculated from the satellite images.
- The effective areas are the areas that deliver rains to the urban drainage system. Most Unitblocks were assumed to have high values of effective area (around 90 %) except the Informal settlement and the agriculture areas where the percent of rainfall that goes to the drain is relatively low.
- The initial looses represent rainfall that does not flow neither to the drainage system nor to runoff and it mainly evaporates back to the atmosphere. Therefore, the average potential evaporation was used for the initial losses, which is around 6 mm.
- There is also a parameter called Trigger to irrigate that has a value between 0 and 1. It represents the proportion of the moisture content that is maintained within the soil (Mitchell; Diaper, 2005). The initial value that was used for Trigger-To-Irrigate is 0.5 for all unitblocks, the value is changed later in the calibration process.
- The occupancy factor in this model represents the number of people who live in one unitblock. For the residential unitblock, it was calculated according to AWCO findings that assume the average number of inhabitants is five persons in every flat. For the industrial and hotel unitblocks the occupancy factor was calculated from (Donia et al, 2010)
- The water use for each unitblock in City Water balance is calculated form the occupancy factor times the water consumption per capita. The values of per capita water use were assumed to be 230 litter/capita/day (Donia, 2010). AWCO calculated this value according to a detailed study for several places in Alexandria. The study included monitoring the water consumption in isolated zones of well-known resident numbers then the figures were asserted and validated by field scurvies. This value (230 l/c/d) was used for most of unitblocks except the recreational areas where the water consumption was less according to Donia (2009). In addition to that, the industrial water consumption was calculated from the available data in (Donia, 2009)

UB No.	Unitblock type	Roof area (m^2)	Paved Area (m^2)	Pervious area (m^2)	Occupacy factor (capita/UB)	Water consumption (l/c/day)
1	Dense populated area (A)	400	32	57	120	230
2	Suburban Houses (B)	400	65	120	40	230
3	Recreational Area (D1)	800	230	120	40	120
4	Recreational Area (D2)	800	230	120	40	120
5	Recreational Area (D3)	800	230	120	40	120
6	Recreational Area (D4)	800	230	120	40	120
7	Recreational Area (D5)	800	230	120	40	120
8	Recreational Area (D6)	800	230	120	40	120
9	Recreational Area (D7)	800	230	120	40	120
10	Recreational Area (D8)	800	230	120	40	120
11	Informal settlement (E1)	40	20	2	16	230
12	Informal settlement (E2)	40	20	2	16	230
13	Informal settlement (E3)	40	20	2	16	230
14	Informal settlement (E4)	40	20	2	16	230
15	Informal settlement (E5)	40	20	2	16	230
16	Informal settlement (E6)	40	20	2	16	230
17	Informal settlement (E7)	40	20	2	16	230
18	Informal settlement (E8)	40	20	2	16	230
19	Informal settlement (E9)	40	20	2	16	230
20	Informal settlement (E10)	40	20	2	16	230
21	Summer Houses (F1)	400	18	100	120	230
22	Summer Houses (F2)	400	18	100	60	230
23	Summer Houses (F3)	400	18	100	20	230
24	Summer Houses (F4)	400	18	100	50	230
25	Industrial area (G1)	400	8000	100	900	1,244
26	Industrial area (G2)	400	8000	100	270	903
27	Industrial area (G3)	400	8213	100	135	4,518
28	Industrial area (G4)	400	8000	100	630	595
29	Industrial area (G5)	400	5167	100	2250	758
30	Industrial area (G6)	400	8000	100	405	332
31	Industrial area (G7)	400	8708	100	900	1,428
32	Hotels (H1)	800	80	20	255	230
33	Hotels (H2)	800	4112	400	300	230
34	Hotels (H3)	800	180	400	945	230
35	Hotels (H4)	800	3991	400	6528	230
36	Hotels (H5)	800	13164	400	840	230
37	Irrigation area (I)	400	100	100	10	230

Table 5: Unitblock types with their main parameters

The per capita water usage is divided, is CWB, into four main categories: toilets, kitchen, bathroom and laundry. The percent of water consumption for toilets, Laundry and kitchen were calculated according to Mayer et al. (1999), figure 20, while the remain percent, which includes shower, leaks

and other uses, is added to the bathroom water use. The percentage of indoor water use, out of the overall water consumption, in this model is shown in table 6:

Water use type	Toilets %	Kitchen %	Bathroom %	Laundry %
Percent used	26 .7	15.7	35.9	21.7

Table 6: The assumed percentage for the indoor water use

Hotels had a different percentage as most of the water is used in bathrooms and toilets. The industrial unitblocks had also different values due to the additional water usage. The additional industrial consumptions were considered as laundry because the current version of CWB does not include specific consumptions for industrial usage.

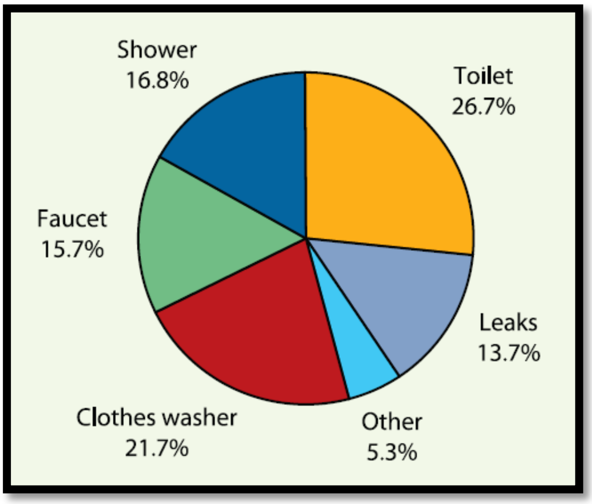

Figure 20: Indoor water consumption according to (Mayer et al., 1999)

4. UB_additional.csv

This file contains few other parameters attached to each type of unitblocks (table 7). The main parameters in this file are the road percent and the public open space (POS) percent. These values represent the total area of roads and POS within one minicluster (figure21) divided into the number of unitblocks in this minicluster, then the result is assigned each unitblock's area. Percent road area and percent POS area were calculated from both the satellite images and the findings of Donia et al. (2010).

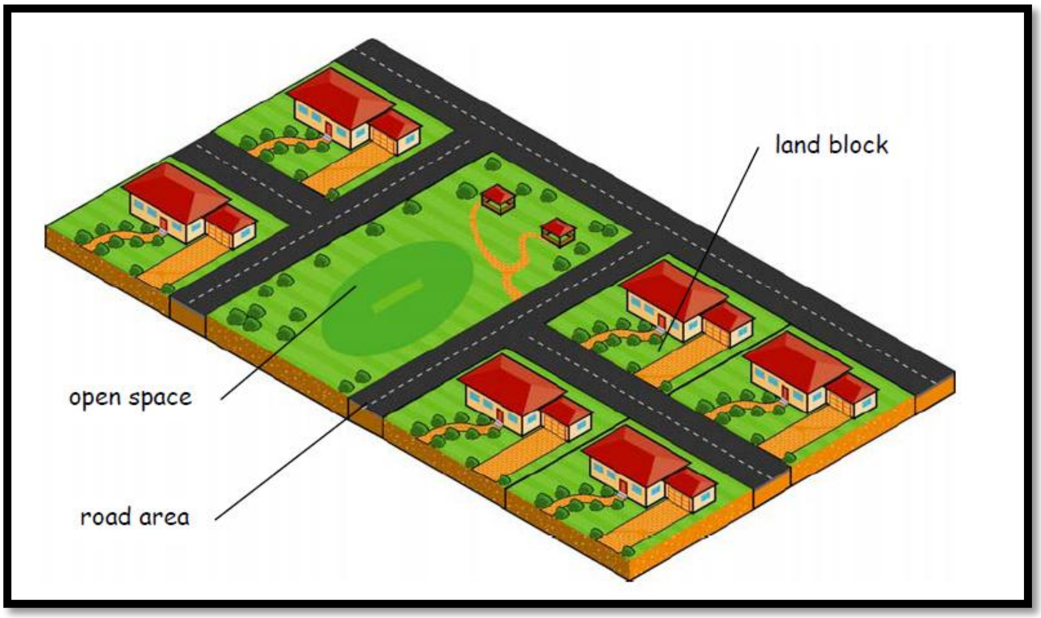

Figure 21: Minicluster with open space area and road areas

This file also has the option to activate supplying the garden and POS by the imported water in order for CWB to consider it when calculation the whole amount of imported water, like the case in Alexandria. Furthermore, trigger to irrigate values were assigned to the POS area as 0.5 for all unitblocks then it is changed in the calibration process.

No	Unitblock type	POS area (%)	Road area (%)	Trigger to irrigate
1	Dense populated area (A)	9	42	0.5
2	Suburban Houses (B)	4	50	0.5
3	Recreational Area (D1)	74	21	0.5
4	Recreational Area (D2)	40	24	0.5
5	Recreational Area (D3)	89.5	10	0.5
6	Recreational Area (D4)	35	20	0.5
7	Recreational Area (D5)	66	22	0.5
8	Recreational Area (D6)	64	29	0.50
9	Recreational Area (D7)	49	32	0.5
10	Recreational Area (D8)	5	32	0.5
11	Informal settlement (E1)	0	40	0.5
12	Informal settlement (E2)	0	63	0.5
13	Informal settlement (E3)	0	54	0.5
14	Informal settlement (E4)	0	63	0.5
15	Informal settlement (E5)	0	16	0.5
16	Informal settlement (E6)	0	82	0.5
17	Informal settlement (E7)	0	67	0.5
18	Informal settlement (E8)	0	11	0.5
19	Informal settlement (E9)	0	47	0.5
20	Informal settlement (E10)	0	35	0.5
21	Summer Houses (F1)	1	52	0.5
22	Summer Houses (F2)	15	48	0.5

23	Summer Houses (F3)	0	63	0.5
24	Summer Houses (F4)	10	39	0.5
25	Industrial area (G1)	21	50	0.5
26	Industrial area (G2)	18	64	0.5
27	Industrial area (G3)	17	53	0.5
28	Industrial area (G4)	25	25	0.5
29	Industrial area (G5)	50	25	0.5
30	Industrial area (G6)	33	33	0.5
31	Industrial area (G7)	0	99	0.5
32	Hotels (H1)	0	15	0.5
33	Hotels (H2)	0	15	0.5
34	Hotels (H3)	0	15	0.5
35	Hotels (H4)	0	33	0.5
36	Hotels (H5)	0	36	0.5
37	Irrigation area (I)	90	5	0.5

Table 7: The main parameters that were assigned to 'UB_additional.csv'

5. Occupancy.csv

This file allows changing the occupancy factor values, which were assigned in 'Unitblock_defaults.txt', on a monthly basis. The population in Alexandria increases by a factor of almost 30% during the summer periods. Therefore, the number of occupants increases to accommodate the population. The model assumed the increasing occurs during June, July and August in few unitblock types which represents the hotels and the summer houses. Donia et al. (2010) stated that the inhabitants' number in these unitblock types double in summer and the same assumption was used for this model.

6. Minicluster_defaults.txt

The study area was divided into 121 miniclusters and those were classified into eight main categories table 8. Every minicluster was assigned to one of the main categories. This classification has the same concepts that were followed to divide the clusters in (Donia et al, 2010). However, the miniclusters areas, in this model, are smaller to fit CWB code and two groups of clusters were added to represent the industrial and the agriculture spaces.

The major parameters in 'Minicluster_defaults.txt' are:

- The proportion of surface runoff that goes to the sewer system: This value is high for most miniclusters (between 80 to 90 %) except for the informal settlement and the irrigation area where the stormwater networks is limited.
- The exfiltration proportion: it specifies the percent of water that is lost from the sewer system to groundwater. This value was assumed very small for most miniclusters.
- The leakage proportion: it defines the volume of water that leaks from the mains pipes to the groundwater system. High Unaccounted for Water (UFW) value was recorded in Alexandria. It

was about 36 % of the overall imported water, (Taha et al., 2010). The UFW is mostly due to the physical leakage form the pipe network, in addition to smaller percentage due to commercial losses.

- The effective road area: it determines the percent of runoff over roads that go to the stormwater system. The proportion of effective roads considered high for most of the Miniclusters except for the informal settlement and the irrigation areas where it is lower.

No.	Minicluster type	Leakage (%)	Sewer exfiltration (%)	Effective road area (%)	No. Of MCs assigned
1	Dense populated area (A)	36	10	90	32
2	Suburban Houses (B)	36	10	90	17
3	Recreational Area (D)	36	8	90	15
4	Informal settlement (E)	36	15	70	11
5	Summer Houses (F)	36	10	90	20
6	Industrial area (G)	36	10	90	17
7	Hotels (H)	36	5	100	5
8	Irrigation area (I)	36	20	70	4

Table 8: Miniclusters categories with their main parameters

7. MC_assigns.csv

The purpose of this file is to assign the dominant unit block type for each of the 121 miniclusters. Consequently, every minicluster in the study area has only one unitblock type.

8. Groups.txt

There are 121 miniclusters in the study are that were divided into eight main groups or categories. In this case, any change in the main minicluster categories will be assigned to all miniclusters under this type.

9. Soil_types.txt

It has several parameters define properties of pervious areas in the city. The pervious spaces have relatively small areas in the city figure18 According to (Reconnaissance Soil Map of Alexandria- El Alamein, 1963), two main soil types exist in Alexandria: coarse sand and loamy sand figure 22. The extension of coarse sand is limited to few meters along the coast. Therefore, it is assumed that the study area is covered only by loamy sand that has the following properties:

Properties	Soil capacity	Field capacity factor	Drain max	Soil depth (m)
Value	0.01	0.13	0.8	0.25

Table 9: The main parameters for the soil in the area

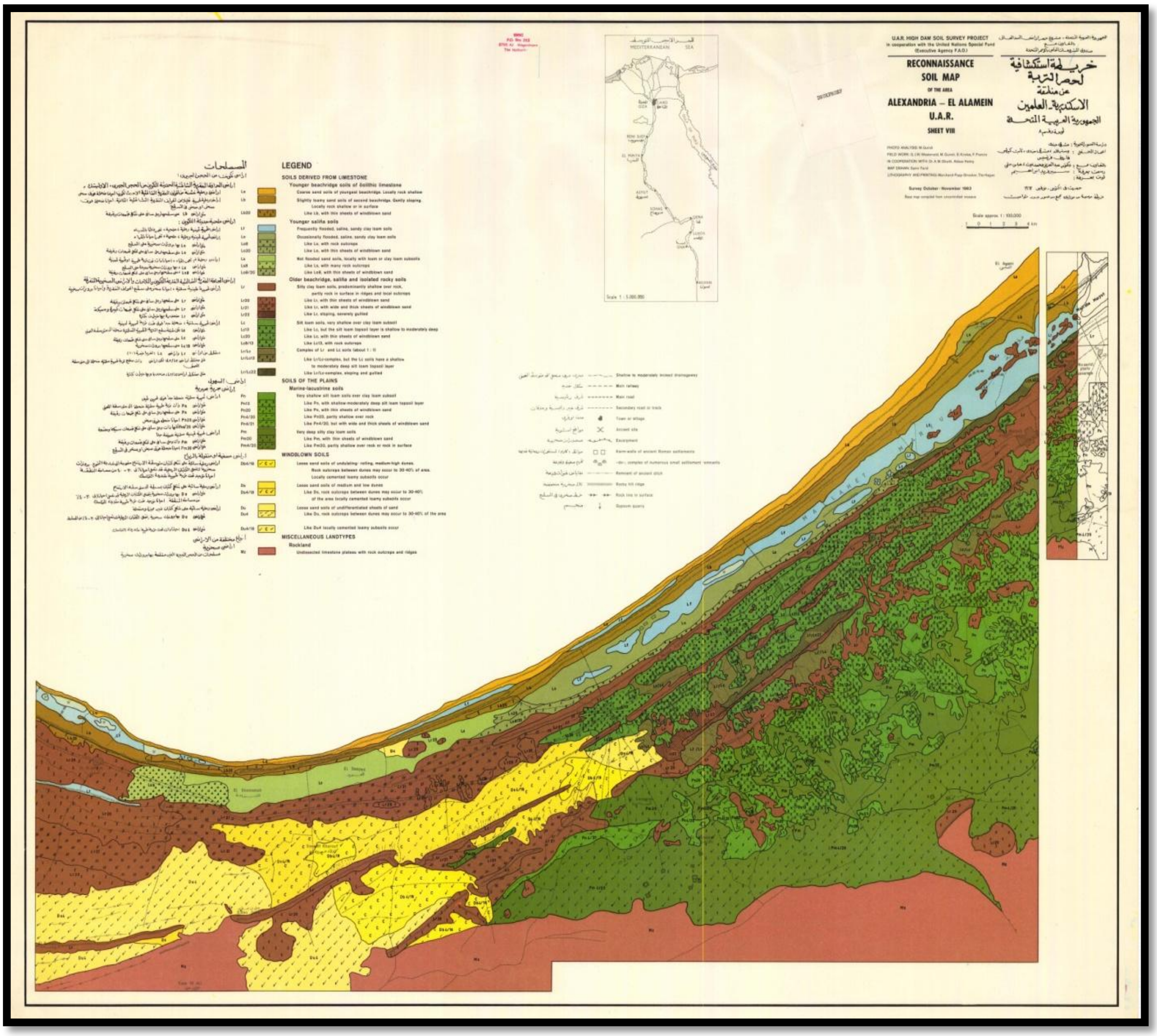

Figure 22: Reconnaissance soil map of Alexandria-El Alamein, 1963

10. Climate_data.csv

The climate has a very important role in the urban water cycle. The main climate parameters are the rainfall and evaporation. The data that was used to calibrate the model was obtained from (Donia et al., 2010) and it represents the value of daily rainfall and the potential evaporation for 2006. The annual rainfall for 2006 was 102 mm/year, while the average potential evaporation was 6.7 mm/day.

11. Lake_input.txt

This file includes the main parameters of the lakes with their water inputs. Mariout Lake is the main lake in Alexandria governorate and it has much bigger extent than the study area. However, the model includes only the part of the lake exists to the south of the city. This part is almost half of the actual lake area. The length of the lake was assigned as 14 km with 2 m as a maximum depth. The average water depth was assumed 1 m (Fishar, 2008). There were no data for the bed conductance

so the average Hydraulic conductivity was assumed 0.05 m/day and the bed thickness 1 meter. These were essential parameters for calibrating groundwater discharge into the lake.

The Wastewater Treatment Plants (WWTPs) currently discharge all their effluents into the lake. Moreover, several canals and drains discharge into the lake. The volume of water, which is discharged into Mariout Lake, is not accurately calculated and it changes along the year. However, it is generally around 8.2 million m^3/day, figure 6. At the same time, El-Mex pumping station pumps a constant value form the lake into the Mediterranean Sea. The pumping rate is around 7.993 million m^3/day. Due to fact that the discharge into the lake occurs at the same time as the discharge out of the lake, it was assumed, in the current model, that a constant flow discharges into the lake, the flow rate equals the different between the input and output, which is around 200,000 m^3/day.

12. Lake_receive.txt

It determines the flow from the miniclusters to the lakes. Basically, all MCs' effluents discharges in Mariout Lake. In order to model that, wastewater form all miniclusters should be diverted to the lake. However, lakes, in the current version of CWB can receive effluents from only 10 miniclusters maximum. Therefore, it was assumed that none of the miniclusters discharges to the lake but the same volume of water flows from an external source to the lake, and this was assigned in 'Lake_input.txt'. This generates an error in mass balance but it keeps the volumes that are received by the lake correct.

13. Canal_info.txt

The four canals in the study area were assumed to have 15 meter width with a leakage rate equals to 0.5 mm/day. The data for the exact flow rate for canals and drains were few. However, the values that were assigned to the canals based mainly on (Farooq et al., 1966) and (Samir et al., 2000). The flow rate for all canals was assumed 15 million m^3/day.

14. Aquifer.csv

This file represents the main groundwater parameters in the area. A groundwater grid was build to the study area. The grid has nine rows and eleven columns and each cell has 3000 m distance. Every cell was assigned the flowing parameters: 1- water level, 2- horizontal transmissivity, 3-specific yield, 4- aquifer thickness and 5- ground level. Mariout Lake, which is the main boundary condition in the study area, has almost a static level which is (-3) meter above sea level (Fishar, 2008). However, the aquifers' parameters for the study area had wide range of values due to the inaccurate data that determine them.

The ground elevation was assumed 14 meter above sea level (m.a.s.l) for the coastal aquifer and (6 m.a.s.l) for the Nile delta aquifer. These represents the median values for ground elevelation, which is extracted from the totopografic map (figure 12) of Alexandira governarate.

The groundwater level was set between (-4.5 m.a.s.l) beneath Mariout Lake in the south and (+1 m.a.s.l) near the coast in the north. No accurate data were available to determine the groundwater level in the study area except one piezometric map for Alexandria governorate figure 23 and that is mainly due to the lack of boreholes, if any, within Alexandria city (El-Arabi et al., 2009).

The thickness of the aquifer was considered 60 m for the coastal aquifer while it ranges from 55 to 100 meter in the Nile Delta Aquifer (El-Arabi et al., 2009).

The transmissivity and specific yield according to (El-Arabi et al., 2009) can be seen in table 10

Aquifer Name	Transmissivity m^2/day	Specific yield	Aquifer thickness (m)
Coastal Aquifer	1000	0.1	60
Nile Delta Aquifer	1500	0.1	75 → 100
Nile Delta Aquifer underneath Mariout Lake	1300	0.1	55 → 70

Table 10: The hydrogeological parameters for the aquifers in the model

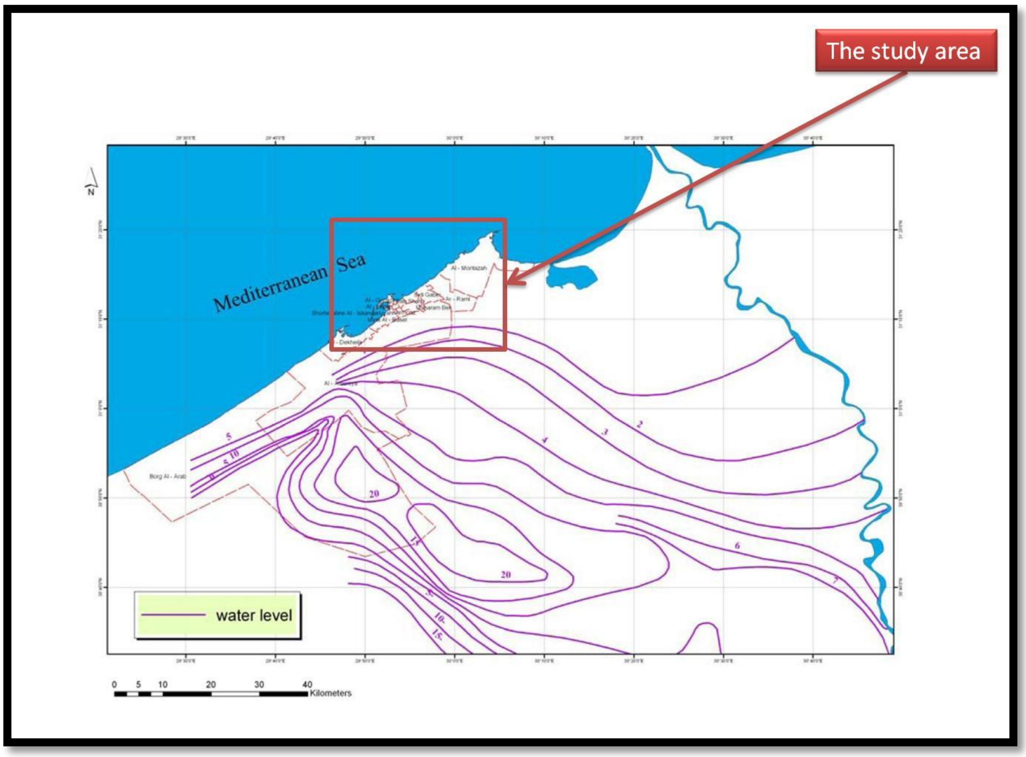

Figure 23: Piezometric map for Alexandria governorate (El-Arabi et al., 2009)

15. vertices.txt

Five text files, which contain vertices data from the GIS database, are required to be set within CWB input files. These files contain vertices for miniclusters, rivers, lakes, canals and ponds. The vertices'

data for all elements were extracted using software called 'ESRI Shape Dump'. Then the files were imported to CWB in the required format.

16. Water Management Options

Several water management options are included in City Water Balance. These options are represented in three main scales: Unitblock, Minicluster and Large scale, and each of them has sets of several water management options. For instance: Raintank, septic tank , wastewater recycling, porous paving, swales, green roofs, boreholes, grey irrigation, stormwater harvesting, Soakaway and Filter strips

Most of the aforementioned options in are currently not available in Alexandria except the large-scale wastewater recycling plants where the wastewater is sent from the whole city. The wastewater recycling data was included in 'Large_WW_defaults.csv' where the capacity of the treatment plants table 3 was assigned with the list miniclusters that discharges in each plants. For the first run of the model, the treated waster water was assumed to flow out of the system, due to the fact that all treated water is currently discharged into Mariout Lake. Although, AWCO has several plans to reuse the recycled water for outdoor water use, and this is one of the scenarios that the model will test for the future.

5.3. Running the model

The first run of the model carried out for the data that correspond to 2006. Summery of the modelled urban water cycle, for the study area, can be seen in Figure 24. The arrows determine the direction of flow and the figures represent the volume of water (mm^3) divided by the study are (mm^2).

The Unban water cycle in figure 24 is divided into two main interconnected components:

The first starts with the precipitation that fall over three parts: waterbodies, pervious soil store and unitblocks. The rainfall over unit block goes to roofs, roods and paved areas and the evaporation occurs at same time from the same areas. The rainfall values in 2006 was 102 mm while the evaporation according to the model was 952 mm. the evaporation value is very high comparing to the rainfall because the value correspond to the potential evaporation. The rainfall over unitblocks compensates goes afterwards either to the pervious store or to the surface runoff. Part of the runoff discharges then in the sewer and the remain volume discharges out of the study area.

The other components, in the urban cycle, starts with the imported water that split into indoor-water-use (63%), leakage (36%) and outdoor-water-use (less than 1%). The outdoor-water-use supports the pervious soil store whilst the leakage discharges directly in the groundwater. The

indoor-water-use does not have direct contact with the groundwater as it goes to the sewer system to be discharged out of the system.

The groundwater, the core of the cycle, has a hydraulic interaction with the pervious store and the water bodies and it receives the water from pipe leakage and sewer leakage. The groundwater level changes in daily basis in every cell, in the groundwater grid, as a response to the recharge from and discharge to other components.

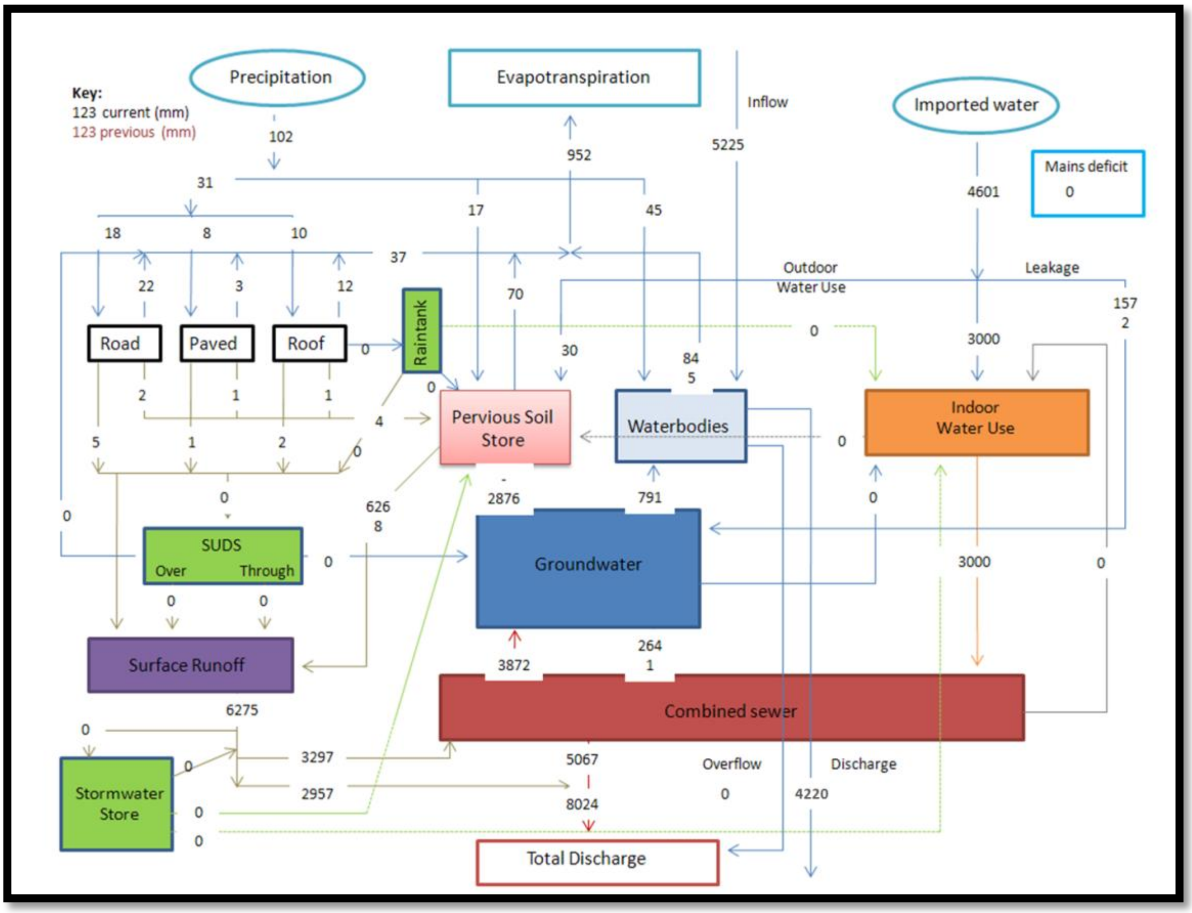

Figure 24: The result for the first run of the model

5.4. Calibration and validation

The objective of calibration is to check how far the model is from the real situation, in order to change the uncertain parameters until the model became better representative to the actual site. The main components that were calibrated according to the available data are the flowing:

5.4.1. The imported water

Figure 24 illustrates that the amount of imported water for the first run of the model was 4601 mm, which equals 957,126,047 m^3/year, while the actual water produced for the study area in 2006 was

around 800.7 million m^3/year, according to Alexandria Water Company. The difference was ascribed to the uncertainty of water-use for some industrial unitblocks due to lack of consumption data for the following miniclusters: (108, 109, 114, 115, 116, 121, 25, 111, 112 and 113). The missing data was the amount of water for the industrial use and the occupancy factors. Hence, the unitblocks in these miniclusters was assumed to have same parameters as the closest industrial miniclusters, which are miniclusters number 106 and 107. Therefore, the water consumption is calibrated for the uncertain miniclusters (table 11) until the modelled results were very close to the real consumption.

Miniclusters Number	Estimated water consumption (litter/day)	Calibrated water consumption (litter/day)
25, 111, 112, 113	1327	805
108, 109, 114, 115, 116, 121, 25	657	251

Table 11: Calibrated water consumption for some industrial miniclusters

5.4.2. Groundwater

The flow direction from the pervious soil store to groundwater equals (-2876 mm). The negative value indicates that groundwater discharges water into the soil. This direction of low generates a very high value of run off (6268 mm). The high level of groundwater also supplies the water bodies and combined sewer by a huge volume of water, which is much higher the real situation. Therefore, one of the main objectives of calibration was to reduce the inputs to groundwater to decrease its level. The main inputs to groundwater are leakage from pipes and sewer leakage.

The leakage from the pipes was initially assumed 36%, which is the Unaccounted for Water (UFW) in Alexandria according to (Taha et al., 2010). However, Taha (2010) referred to substantial percent of commercial losses. For the time being, there is no proper estimation of these commercial losses. Although, Alexandra Water Company (AWCO) has recently started a fundamental project to estimate, control and reduce UFW. Consequently, AWCO will determine exactly the amount of water that leaks to the groundwater system by the end of their project. In this model, the leakage was calibrated to give more reliable recharge to groundwater. The best value for leakage was 24 % of the imported water and that leaves 12 % for the commercial losses.

The sewer leakage also leak to groundwater. There was no clear data to determine the leakage from the drainage system. However, the model was assumed to have relatively low values, of sewer leakage, for all miniclusters except the informal settlements.

In addition to that, several hydrogeological parameters were initially uncertain and they have big range of values due to shortage of data. These parameters have a major role in controlling the

groundwater level. Therefore, the aquifer properties were also calibrated (table 12) to match the real groundwater situation.

Aquifer Name	Groundwater level (m.a.s.l)	Transmissivity (m^3/day)	Specific yield	Ground elevation (m.a.s.l)
Coastal aquifer	0	1000	0.19	14
Nile Delta Aquifer	0	800	0.2	8
Nile Delta Aquifer underneath Mariout Lake	-4.5	500	0.2	-4

Table 12: The calibrated aquifers' parameters

Once the groundwater level decreased, the direction of flow between the pervious store and the groundwater went in the correct direction where the pervious soil store discharges to groundwater. Moreover, runoff reduced to reasonable value.

5.4.3. Recharge to water bodies

The amount of groundwater that discharges into Mariout Lake is around 9,125,000 m^3/year, according to Fisher (2008). The modelled value was much more than that. It was 791 mm, which equals to 163,613,642 m^3/year, and that was mainly due the high heads in the aquifers. However, once the recharge to groundwater had been calibrated, the groundwater discharge into the lake was more realistic. The bed thickness and its hydraulic conductivity were then calibrated until the modelled volume of groundwater, which discharges into the lake, equals to 9,609,477 m^3/year and that is very close to Fisher's estimation (2008).

5.4.4. Waterbodies

The main water body in the study area in Mariout Lake, the lake receives water from inside the study area (WWTPs effluents) and from outside of the study area (canals and detains). In addition to that, specific amount of water discharges out of the lake through El-Mex pumping station. The inflow to the lake is estimated to be 8.2 million m^3/day and the outflow 7.993 million m^3/day, figure 6. The inflow and outflow to the lake in the model were very high due to the huge flow rate. Therefore, the input flow rate was assigned five m^3/sec, which is close to the difference between the input and the output and the output flow rate was assigned zero m^3/sec

6. RESULTS

The model was calibrated and validate for 2006 and summery of the calibrated model can be seen in figure 2. The figures represent the total volume of water that moved between different components divided by the study area, which is the area of MCs, lakes and canals and it equals 234,377,508 m^2. All values are in mm/year. Furthermore, figure 27 illustrate the modelled volume of water for study area.

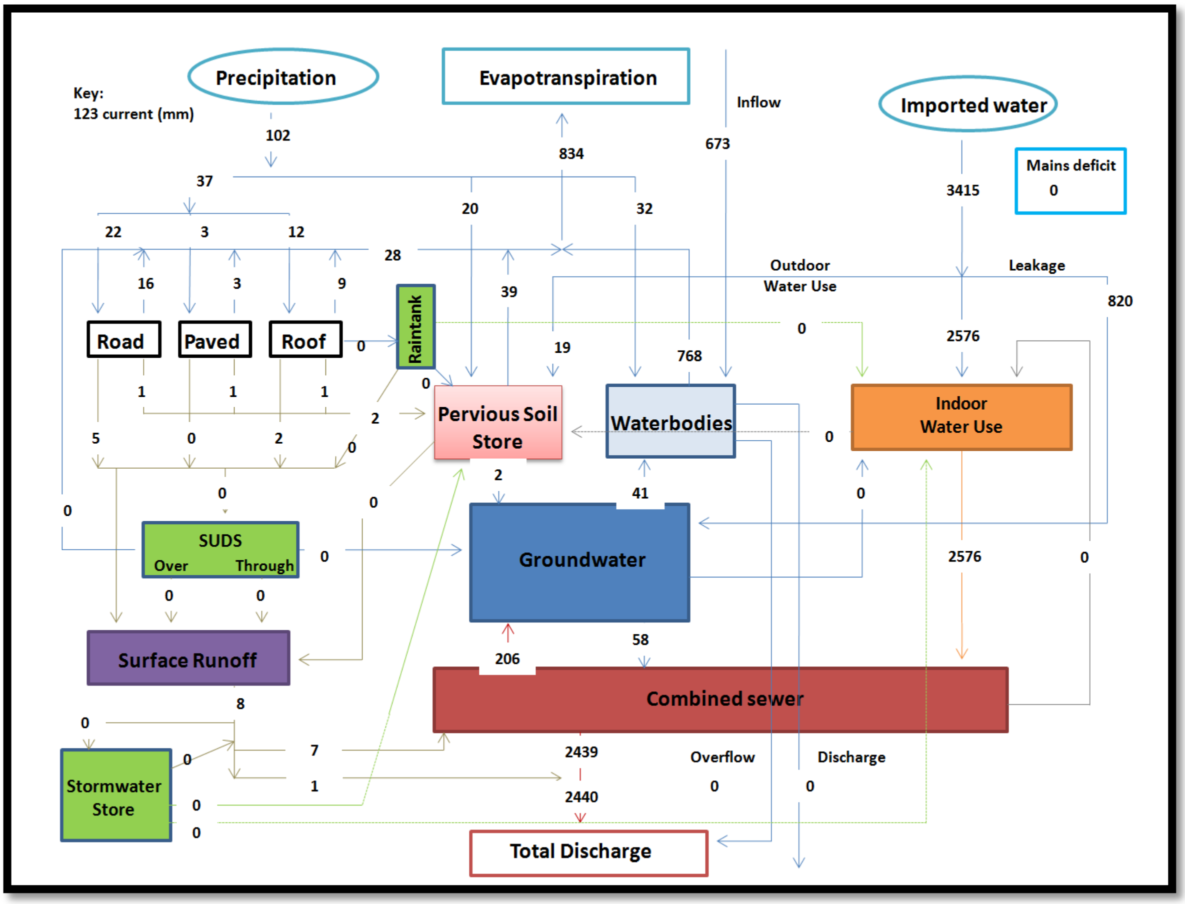

Figure 25: Summery of the result for the calibrated model

6.1. Imported water

It can be noticed that the imported water equals to 3415 mm that represents 800,399,190 m^3.The actual water produced by Alexandria Water Company, for the study area in 2006, equals to 800,367,197 (Taha et al., 2010) and that shows the difference between the modelled and the actual value is less than 0.004 % which is an accepted value. Almost quarter of the imported water leaks to groundwater, the figure shows that the leakage is 820 mm, which equals to 192,189,557 m^3. The

calculated indoor-water-use equals to 2576 mm (603,756,460 m^3). This is almost 76 % of the imported water and the whole amount discharges to the sewer afterwards. The third part of the imported water is the outdoor-water-use, which equals to 19 mm (4,453,172 m^3), and it irrigates the pervious soil store.

6.2. Precipitation and evapotranspiration

The rainfall rate that was recorded in 2006 in Alexandria is about 102 mm. according to the model, almost third of this volume (32 mm) fall over the water bodies (Mariout Lake) and only 20 mm is received by the previous soil while the rest of rainfall, which equals to 37 mm (almost 8,671,967 m3), fall over by the unitblocks. The precipitation over the unit block goes to roofs (9 mm), roads (16 mm) and paved area (3 mm).

The evapotranspiration are relatively high around 834 mm and this value represents the potential evaporation. The main portion comes from the water bodies (768 mm) that spread over a large area.

6.3. Surface runoff

Surface runoff is generated by either runoff of unitblock components or by the excess water form pervious soil. The calibrated model does not have any water overflow from the pervious soil store. The Sustainable Urban Drainage System (SUDS) also does not have any runoff because none of the water management options is activated for the calibrated model. All runoff comes from the unitblock components directly. The amount of surface runoff is about 8 mm, which equals to 1,875,020 m^3/year, and most of it discharges into the combined sewer while only 12% goes directly out of the system. The amount of water that discharges out of the system is mainly in the irrigation and the informal settlements areas where the drainage system does not cover the area probably.

6.4. Pervious soil store

The pervious soil store receives the water from precipitation and outdoor-water-use in addition to proportion of the runoff that does not inflow to the sewer system. The amount of water that recharges through the soil in the calibrated model is about 41 mm/year. However, most of this amount, around 39mm, evaporates back to the atmosphere and only 2 mm infiltrates to groundwater.

6.5. Waterbodies

The waterbodies in the study area is mainly Mariout Lake, the lake receives 41 mm form groundwater and that equals 9,609,477 m^3/year. According to (Fishar, 2008) the lake receives around 9,125,000 m^3/year. The difference between the two figures is assumed to be accepted due to the uncertainty in calculating groundwater inputs to the lake (Fishar, 2008). The lake receives also huge amount of water from several canals and drains and most of this inflow is discharged out of the lake by El-Mex pumping station. However, the model assumes the inflow to the lake is only the difference between the input and the output as they both occur at the same time. Therefore, there was no overflow or discharge out of the lake. The modelled value for the inflow is 751 mm and that equals 157,736,062 m^3/year.

6.6. Groundwater

The groundwater receives huge volume of water from mains leakage and smaller amount from sewer leakage and very little recharge from the soil. However, it discharges in the water bodies and in the aquifer below the Mediterranean Sea, there is also a hydraulic interaction between the coastal and Nile-Delta aquifer. There is no groundwater abstraction from Alexandria so the amount of groundwater that supplies the indoor-water-use equals to zero m^3

The model calculates the daily change in groundwater level for every cell in the grid and the change in groundwater level is presented in the output files in CWB. Figure 26 summaries the modelled value of groundwater depth below ground level that was generated by the model.

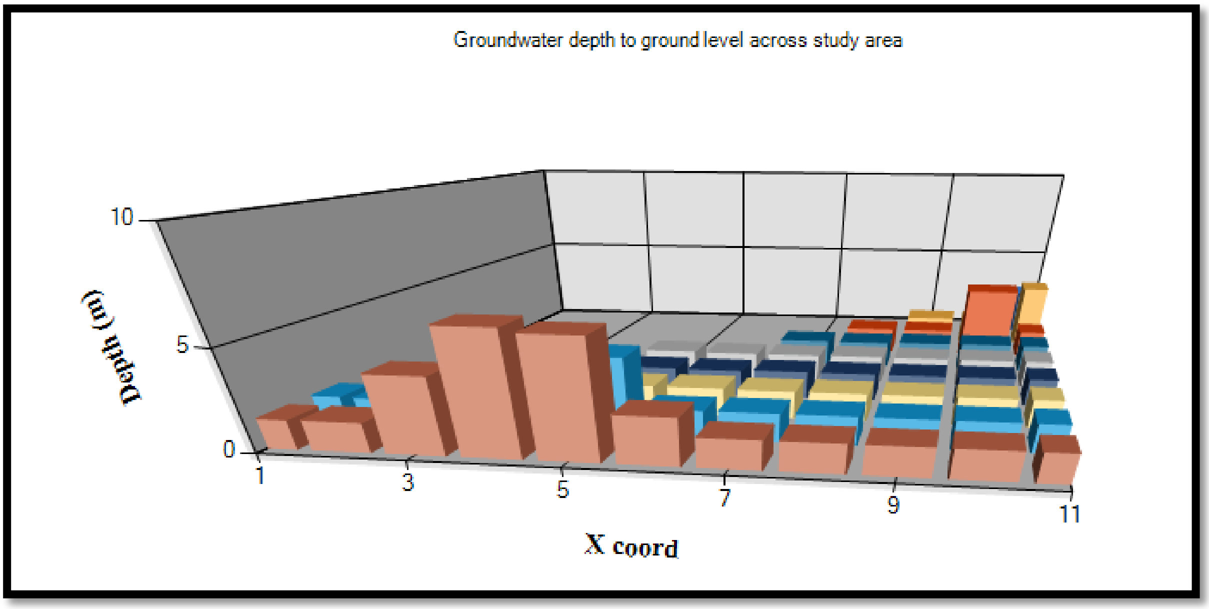

Figure 26: Groundwater depth to ground level across study area

6.7. Total discharge

The amount of water discharges out of the system equals to the sum of the sewer system discharge plus the runoff. This value is 2,440 mm which is 542,041,082 m^3/year and that included only 1 mm run off, while the majority is the discharge out of the combined sewer. The sewer discharge is the water produced by the Waste Water Treatment Plants in addition to the effluent from the informal settlement or factories that discharge directly in the lake.

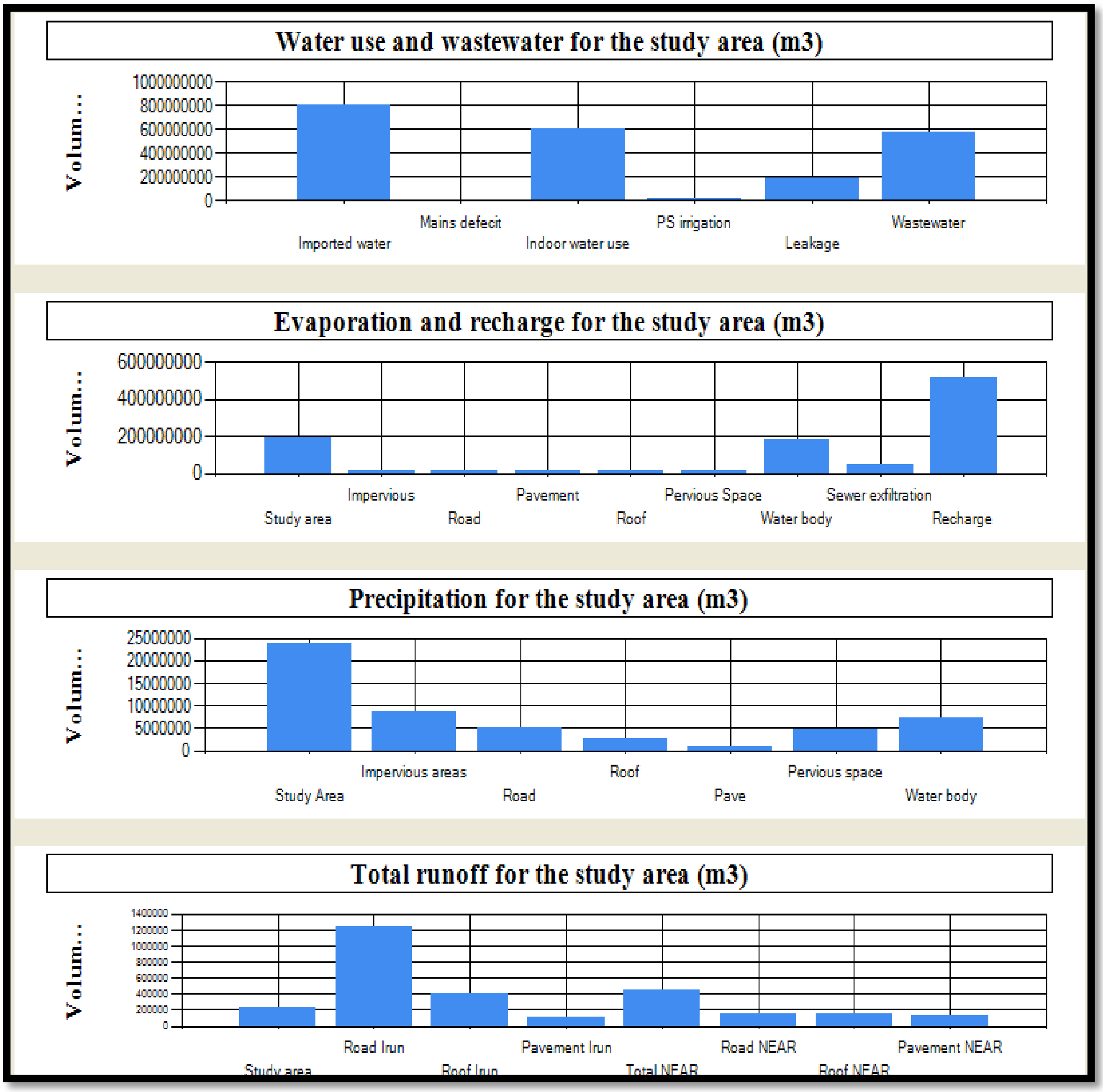

Figure 27: The modelled volume of water for the calibrated model

7. DISCUSSION

Most results in the validated model correspond with the real situation in Alexandria. However, few assumptions in the current model and some general points have to be highlighted for a better understanding of the model and therefore a better implementation of its results.

7.1. Imported water

Alexandria Water Company (AWCO) produced in 2006 sum of 887.45 million m^3. However, part of this volume was sent to Matrouh government and Beheira government through five transmission pipelines (Taha et al, 2010). This volume of water, which supplies other governments, is excluded from the model because it is not part of the city water cycle, table 13.

Area supplied	Volume of water (m^3/year)
Total Water produced by AWCO	887,450,000
Water demand in Alexandria (without leakage)	608,279,070
Water consumed in Alexandria (with leakage)	**800,367,197**
Water demand in Marsa Matrouh (with leakage)	77,577,328
Water demand in Beheira Gov. (with leakage)	11,261,960

Table 13: Total water produced by AWCO with the water demand in the study area

The percent of the Non-Revenue Water (NRW) is 36 % according to AWCO. When leakage to groundwater was assumed 36 % of the imported water, the groundwater level increased to cover the pervious store and therefore, the exceeded water turned into huge volume of runoff. In order to reduce groundwater level, the leakage value was reduced, because part of the NRW includes a commercial loss that does not leak to the groundwater. However, there was no real estimation for physical pipe leakage. The calibration process yield a value of 24 % out of the total import water recharges to groundwater. This seems to be a reasonable value due the old pipe network within the city. However, this value will be verified by the project that has been recently started by AWCO to reduce the NRW.

The model assumes that no water looses occur indoors and all the indoor-water-use goes to the sewer. However, there is small amount of water that is lost during daily activities, especially in a cities like Alexandria where the evaporation values is relatively high and people’s behaviour towards water includes using hoses for cleaning.

7.2. Precipitation and evapotranspiration

The rainfall rate in Alexandria is generally low and evaporation values are high, which makes the amount of effective rainfall that increases the soil moisture content very low. That affects the volume of water recharges to the groundwater. However, the precipitation system in Alexandria, for the last few years, included lower number of rainy days with higher rainfall rate. Such a system might increase the volume of water that recharges into the soil but it does not have huge impact due to fewer number of rainy day.

The evaporation seems to have values higher that the expected, especially form the waterbodies. However, this value corresponds to the available potential evaporation data based on (Donia et al., 2010) that presents the average daily evaporation rate for 2006 was 6.7 mm/day.

7.3. Surface runoff

The total runoff in the validated model equals to 8 mm/year for the whole study area. This value is mainly generated by unitblocks and there is no runoff from the exceeded water in pervious store. However, when the groundwater level is high, the value of runoff increases significantly, because of the groundwater that floods over the surface. Therefore, the groundwater level and the depth to water have to be defined accurately beneath the study area in order to have results that are more sensible.

7.4. Pervious soil store

The pervious spaces within the study area are very limited, as appears in figure 18, which decreases the amount of recharge to groundwater. In addition to that, most water that is received by the soil evaporates back to the atmosphere. As results, very little volume of water supplies groundwater. The soil parameters also have a major role to determine the recharge to groundwater. The soil data that is used in this model was general estimation form the literature and it would be more accurate to have a real data that represents the actual soil in the city

7.5. Waterbodies

Mariout Lake receives its water from several drains and canals and the water is discharged into the Sea through El-Mex pumping station. The Wastewater Treatment Plants, which collect all the indoor water use, discharge their effluents into the lake through drains. Therefore, the model would be

more realistic if the miniclusters effluents were diverted directly to the lake. However, the current version of CWB allows only to 10 miniclusters to discharging into the lake although this model has 121 miniclusters and all of them should discharge in the lake. One of the approaches to solve this issue was to divide Mariout Lake into 13 lakes. Each lake received water from 10 miniclusters then discharged the water into the adjacent lake, which also received water from other 10 miniclusters and then the accumulate water was discharged into third lake and so on. The final lake afterwards received the accumulated effluents from all lakes and it discharges into the Mediterranean Sea. This method created more water than the real values and the flow rates from different lakes seemed to be accumulated, which generate a very huge balance error in mass balance.

The solution that was assumed to overcome this issue was to consider the miniclusters' effluent as a discharge out of the study area and the same amount of indoor water use was added to the lake from an external source. Of course, this amount of water form miniclusters was accompanied with the drains and canals that discharge into the lake. This also caused a mass balance problem but the simulation were more realistic.

The Mediterranean Sea, to the north of the study area, was initially assumed as a huge lake that received water from the Mariout Lake. Therefore, the sea formed a constant head boundary to control the groundwater in the city. However, very high evaporation volumes were generated due to the huge surface from the sea and, apparently, this water is not part of the urban water cycle. Furthermore, this lake, which represents the Mediterranean Sea, did not have any effect on the groundwater level. Therefore, the best solution to restrict the evaporation from the water cycle components only was to disregard the lake that represents the sea.

The water that discharges into the lake was assumed the difference between the inputs to the lake (from all drains and canals) minus the output of the lake (from El-Mex pumping station). This assumption is based on the fact that the input and output occur at the same time. Therefore, the discharge out of the lake was equals to zero. However, the input to the lake changes from season to season and this value is not accurately calculated. Therefore, better estimation might be needed to have a better representation for the natural system in the lake.

Finally, the overflow out of the water bodies is equal to zero because the main purpose of El-Mex Pumping station is to keep the water in the lake at a particular level which is around (-3)meter above sea level (Fishar, 2008), so the lake does not overflow.

7.6. Groundwater

A grid represents the aquifers in CWB where every cell includes the related aquifers' parameters. The code calculates groundwater level in each cell and then the values is assigned to the centroids of relevant minicluster. Therefore, the distance of the cells defines the resolution of head calculation for every minicluster. However, due to lack of aquifer data the distance of the cells was assumed 3000 meter.

According to the model, the majority of recharge in the coastal aquifer beneath Alexandria is from the pipe leakage, while the rainfall has a very limited effect on the groundwater system. The water that recharges into the coastal aquifer, in the current model, discharges to an aquifer below the Mediterranean Sea and part of it to the Nile-Delta aquifer. However, the coastal aquifer has a hydraulic interaction with the Nile Delta aquifer and El-Ralat aquifer and this relation has to be defined for better understanding of the discharge system for the coastal aquifer.

The volume of water from groundwater to water bodies was calibrated to be equal to 25,000 m^3/day. However, Fishar suggested a more accurate calculation for this figure should be carried out (Fishar, 2008). Furthermore, this figure estimates the discharge from groundwater into the whole lake, while the current model covers only half of the lake. Also there were no accurate data for the bed conductance, which determines the flow from groundwater to the lake.

7.7. Total discharge

The total discharge represents mainly the water flows out of the combined sewer, which is basically the water produced by Wastewater Treatment Plants (WWTPs). According to Alexandria Drainage Company, WWTPs produces around 547,500,000 m^3/year. The modelled value for the total discharge in 2006 is 542,041,082 m^3/year. The two values are very close which give more certainty to the model. However, the difference in values might be due to the waste effluents form few informal settlements that discharge directly into Mariout Lake.

8. FUTURE SCENARIOS

One of the main objectives of City Water Balance for Alexandria is to model the possible scenarios for the future then to investigate the best option that approach the integrated management of water reassures. The strategic plan afterwards will depend on the model's results. Alexandria Learning Alliance, which is followed up be SWITCH, has already set several scenarios that corresponds to the national plan until 2037. The suggested scenarios focus on the following points:

8.1. Population growth

There were 3,885,500 people lived in Alexandria during winter 2006. The number increased to 5,109,700 people in summer (Donia, N., et al., 2010). The water resources were enough supply the whole demand according to current situation. However, if the number of inhabitants increased dramatically, AWCO would not be able to cover the water demand by the available sources. Therefore, one of the scenarios is to investigate the expected water demand in Alexandria by 2037 considering the population increases.

According to UNICEF statistics, the Annual Growth Rate[3] in Egypt, between 1990 and 2008, was 1.9 % (UNICEF, 2010). If the same rate occurs in Alexandria, the expected population will be as following:

Date	2006 (Winter)	2006 (Summer)	2037 (Winter)	2037 (Summer)
Number of people	3,885,500	5,109,700	6,174,060	8,119,313

Table 14: The expected population where the annual growth rate equals 1.9 %

The aforementioned assumption presents that the number of people in Alexandria might be more than 8 million during the summer of 2037. Therefore, the city will expand to be able to accommodate the increases in population. The expansion will be essentially to the west of the city because of tow reasons: 1) not enough space within Alexandria governorate is left to the east, 2) the huge area of empty spaces to the west of Cairo-Alexandria-Desert-road. Few projects have already started to establish residential areas to the west of Alexandria city, for instance Eiz-Alarab city, The New Omaria city, the New Nubaria city and Mubarak city (figure 28).

[3] $Annual\ growth\ rate = \frac{Population\ \ at\ end\ of\ the\ year - Population\ \ at\ the\ begining\ \ of\ the\ year}{Population\ \ at\ the\ begining\ \ of\ the\ year}\ x\ 100$

Figure 28: Mubarak City, one of the new residential projects west of Alexandria

In order to simulate this scenario, new minicluster was added to the model to accommodate the increased population, which is around 3 million capita, by 2037. The unitblocks was designed to be generally similar to buildings in Mubarak City (figure 29). The assumed unitblock parameters are as following:

Building type	Number of floors	No. of flats per floor	No. of inhabitants per flat
Tower building	6	4	5

Table 15: Unitbolck parameters for the additional miniclusters for 1st scenario

Figure 29: Buildings style in Mubarak City

In order to simulate the expected water demand in 2037, assuming all parameters are the same as the calibrated model except for the number of inhabitants, two options were taken into account:

8.1.1. The Per capita water use is the same as the current value

The current water consumption is 230 litter/capita/day according Alexandra water company. This value assumed to be the same for the new residential areas in 2037. The results of both the calibrated model in 2006 and the suggested scenario in 2037 can be seen in figure 30.

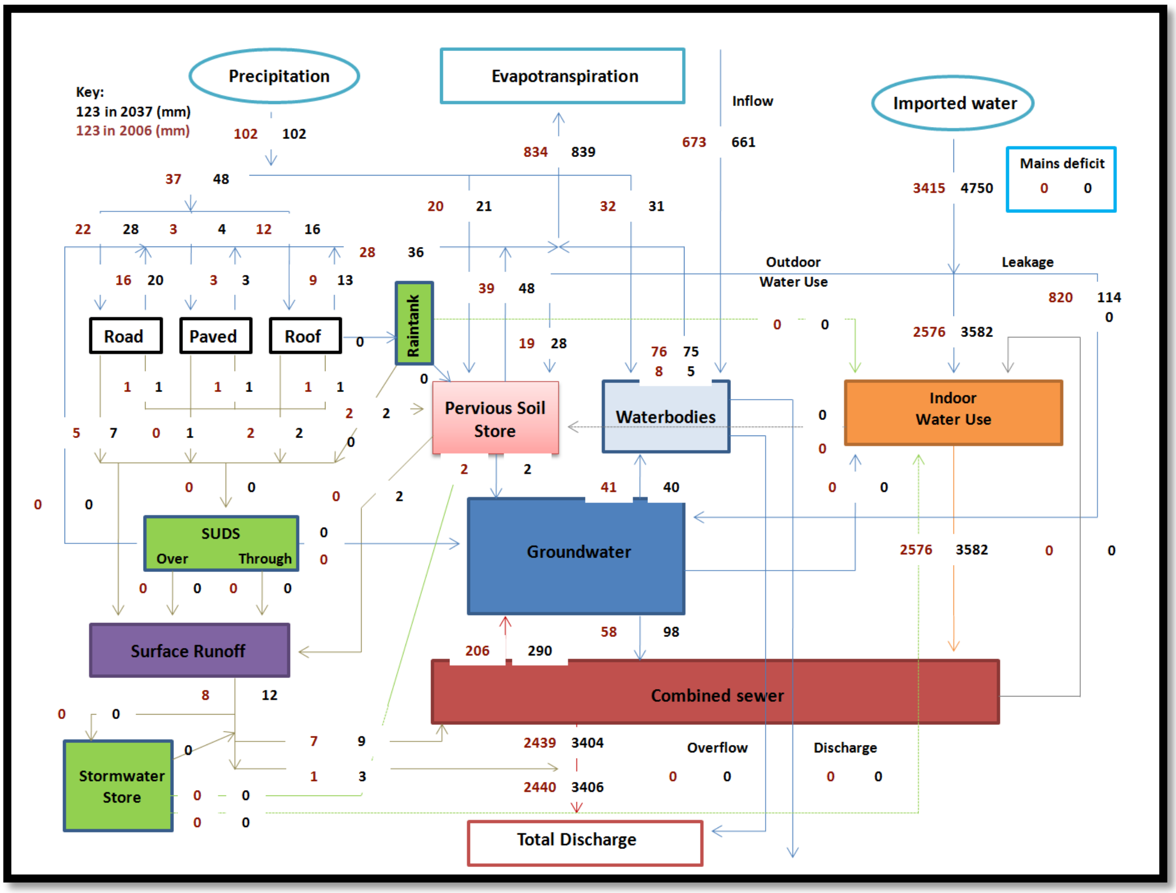

Figure 30: Result of 1st scenario: Population growth & same water-use

It can be noticed that rainfall over unitblocks increased, although it is still not huge volume of water. However, the imported water has increased significantly due to the increase in demand. According to the model, the imported water in Alexandra city by 2037 has to be 1,132,571,886 m^3/year to cover the whole demand, figure 31. This value is the demand for the study area only, without considering the exported water to other governorate. Therefore, the increase in demand will be about 350 million m^3/year, which excesses what AWCO can supple by the current resources.

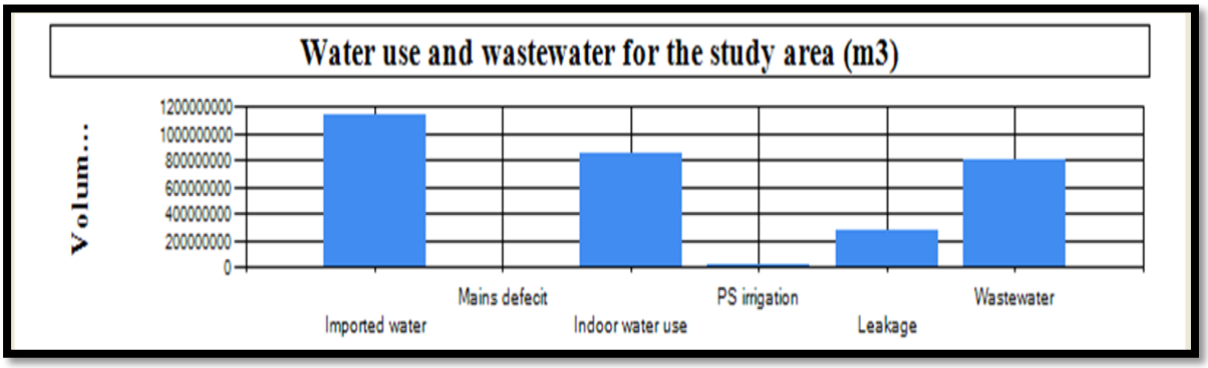

Figure 31: Water volumes for 1st scenario: Population growth &same water-use

8.1.2. The Per capita water use is less than the current value

Due to the expected shortage in water, Alexandria Water Company (AWCO) aims to decrease the per-capita water consumption in the city through several activities like awareness campaigns and increases of water tariff. The target of AWCO is to decrease the water consumption by 50 % and reach 125 litter/capita/day for the domestic use. This is considered a very optimistic value but AWCO will plan to achieve this target and the results will be accepted as long as it approaches the target.

The model was run to test this scenario where all the parameters kept the same as the calibrated model except the number of inhabitants and water-use. The water-use is assumed to be 120 l/c/d for all miniclusters except the industrial miniclusters, recreational areas and hotels. The results are presented in figure 32.

It can be see from the figure that, water demand for Alexandria might decrease to around 700 million m^3/year if the water-use per capita decreased by 50%. This means the AWCO will be able to supply the water demand with the current available resources. However, it is important to indicate that there are many other factors affect this scenario like the industry water consumptions, the ability of AWCO to decrease the individual water consumption by 50 %, the current amount of water might not be available in 2037, in addition to several other factors.

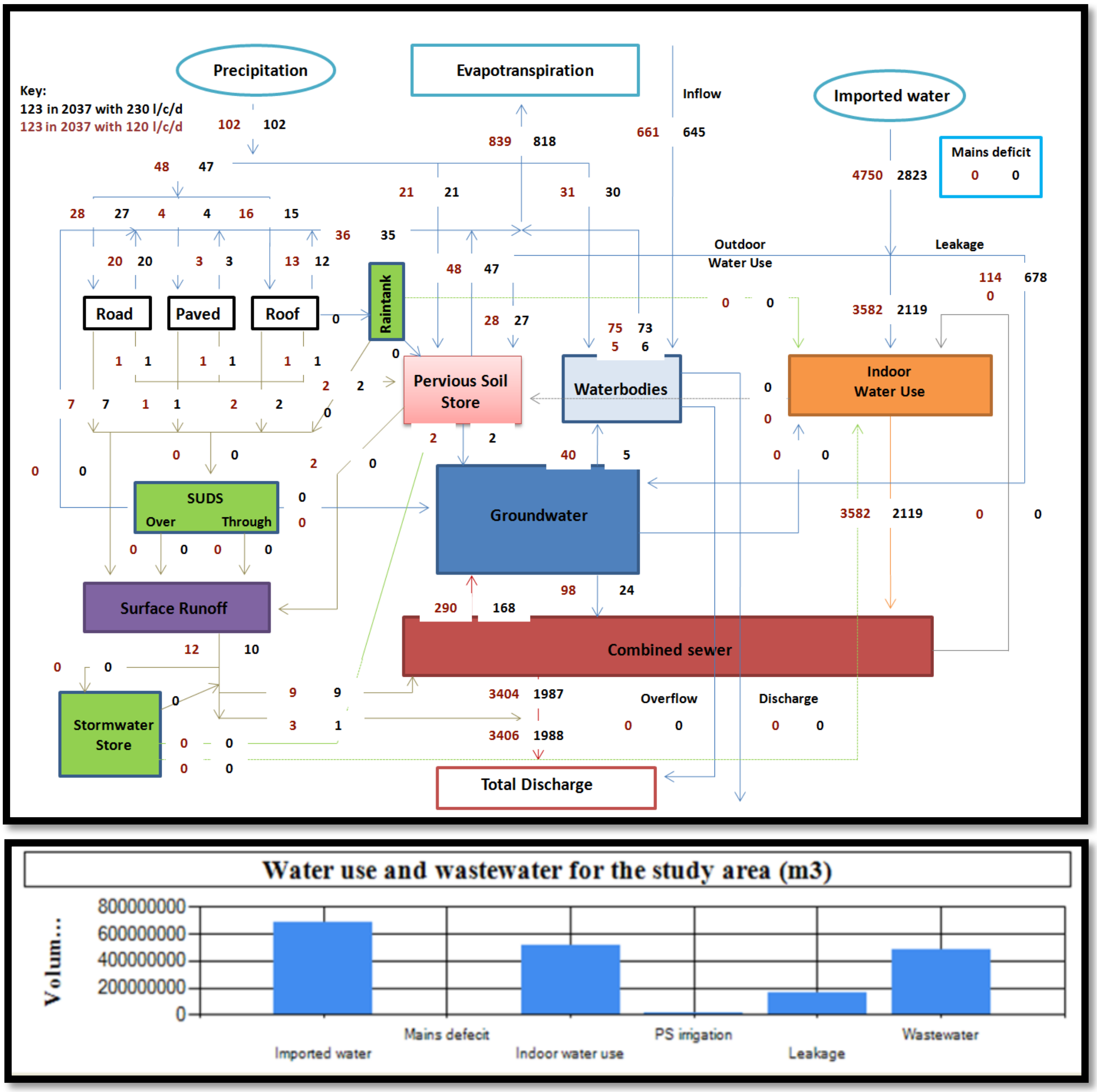

Figure 32: Results for 1st scenario: Population growth & reduction in water use

8.2. Reducing Leakage

The Unaccounted for water according to Alexandria water company (AWCO) is 36 %. The calibrated model assumes most of this amount, more that 65%, leaks to groundwater due to the old pipe networks. AWCO has recently started a new project to decrees the amount of water losses to a reasonable value. In order to check this scenario, the model was run assuming the leakage is decrease by 50 % to be 12 % of the imported water instead of 24 %. The result is shown in figure 33.

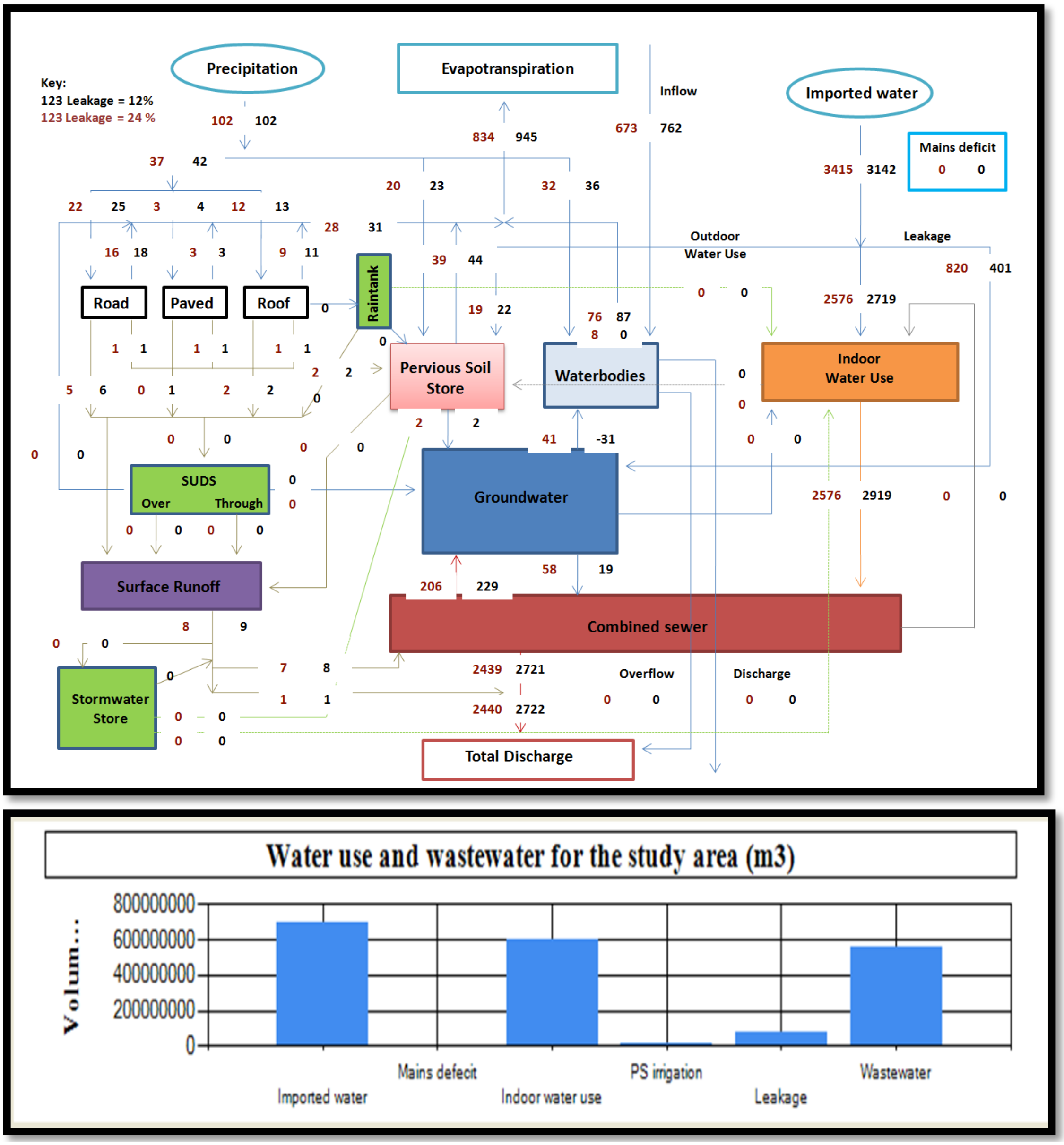

Figure 33: result of 2nd scenario: reduce leakage by 50%

The water demand in the city decreased from around 800 million m^3/year to 690 million m^3/year which represents a very huge amount of water that could be saved by AWCO instead of being leaked to groundwater.

The water that leaks from pipes has a very important role to supply the groundwater system, in general. However, in Alexandria case there is no usage of groundwater due to its quality so it is actually considered avoidable losses.

8.3. Reuse of Wastewater

The Wastewater Treatment Plants (WWTPs) in Alexandria currently produce around 1.4 million m^3/day of treated wastewater. This number might increase to about 2.4 million m^3/day in 2017, according to Alexandria Drainage Company. All WWTPs' effluents currently diverted into drains that discharge into Mariout Lake, except Al-Kilo 26 Treatment Plant that sends its effluents to be used for irrigation west of Alexandria. The amount of wastewater that is currently sent to the lake is too huge and this volume could be a sustainable source of water if it is treated and used probably. Alexandria Drainage Company already has a plane to convert all the (WWTPs) into secondary treatment plants. The next step would be to study the option of supplying Al-Hamam area, and maybe other cities to the west of Alexandria like Marsa Matrouh, by the treated water for their outdoor-water-uses as agree with the Egyptian code.

According to the calibrated model (figure 27), around 70% of the imported water is discharge out of the city to Mariout Lake and this amount should be used properly because it will solve several problems to Alexandria itself and to the adjacent areas, which faces lack in water sources to the west of Alexandria. In order to model the reuse recycled water two options were considered:

8.3.1. The recycled water irrigates gardens and POS within the city only:

For the time being, Gardens and public open spaces (POS) is being irrigated by drinking water that is imported form the Nile River. Gardens and POS have limited areas within the city but AWCO could save their water usage for drinking purpose, although it is not a huge amount of water in comparison to other water usage within the city. Once the recycled water diverted for irrigation in the city, the amount of imported water reduced from 800,399,190 m^3/year to 794,450,954 m^3/year and still there is 571,384,188 m^3/year of treated water that is lost to the lake, figure 34.

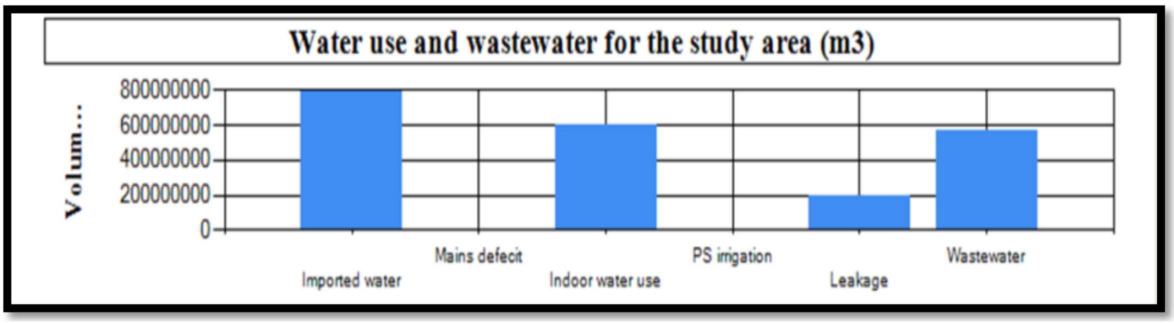

Figure 34: Results for the third scenario: Use recycled water within the city

Consequently, the use of recycled water in the study area for only will only save small amount of water and a very huge amount will keep lost in Mariout Lake. Therefore, Alexandria Drainage

Company should conceder using the water outside the city. Or maybe, if the Egyptian code allows, to use the recycled water for indoor water uses.

8.3.2. The recycled water is used outside the study area

The huge effluents that are lost in Mariout Lake could be used to irrigate the western part of Alexandria. Alexandria Drainage Company is now investigating the possibilities to irrigate El-Hamam area (100 km west of Alexandria) with the treated water. In order to model this option, Part of El-Hamam area is represented by minicluster that extends over 66.7 km^2. This minicluster is included in the study area and all treated wastewater diverted to it. The model shows that the amount of imported water remained almost the same because all miniclusters within the city still depend on the imported water. However, the water consumption for the additional minicluster, that represent huge area in El-Hamam, is totally covered by the recycled water and the total amount that can be recycled and reused is about 500 million m^3/year.

The irrigation consumption depend on the type of crops and the season of irrigation and all of that option should be discussed in order to model and determine the area that the recycled water can irrigate.

8.4. The expansion in tourist and industrial consumption

Alexandria city is an industrial city and it is one of the most popular resorts in Egypt and the increases in industrial and tourist's demand will accompanied with the reduction in agriculture areas. The initial plan was to keep a green belt around Alexandria but this belt is being converting into factories and resorts. The water demand for such activities has to be determined to decide if AWCO will be able to meet the future demand and to check its effects on the total water consumption in the city.

One scenario was developed to check the effects on water consumption if the industrial activities expanded, where all other assumption was kept the same as the calibrated model. The model shows that if the industrial consumption increased by 20 %, the imported water will have to be around 830 million m^3/year instead of the current value which is around 800 million m^3/year, that means an increasing rate in the water demand by almost 4 %. This value seems to be accepted and AWCO can cover it. However, several other factors have to be considered in the strategy plan along this option because it is unlikely for the industry to increase by 20 % while other water demand is kept the same.

9. CONCLUSION

Alexandria, like most cities in Egypt, is subject to shortage in water supply if the current water policy is kept followed. However, Alexandria Water Company, Alexandria Drainage company with support form SWITCH are trying to investigate the best methods to achieve the integrated water management that could help the city to ensure the best usage for the available water. Urban water models are an important tool to check the suggested scenarios. Donia et al has already built an Aquacycle model for Alexandria as intermediate step prior to developing a City Water Balance model.

Alexandria City Water Balance aims to represents the urban water system in the city in order to check different scenarios in terms of visibility, priority and overall outputs. Then the best option can be included in the strategic plan that allows stakeholders in Alexandria to achieve an integrated management for their resources.

Alexandria CWB model was developed, calibrated and validated according to the available data. Huge sets of accurate data gave the model more certainty. Furthermore, several assumptions have been adapted to estimate the uncertain parameters. The lack of accurate data for some parameters was overcome by keeping all parameters within the range of values that was mentioned in the literatures. The results of the calibrated model show the agreement with the real value, which gives more certainty to use this model for future planning.

The current model can be enhanced by reducing the uncertain parameters. For instance, the aquifers' parameters and soil's parameters that have been obtained from the combination between the literatures and the calibration process. Furthermore, data from few boreholes in the study area would dramatically increase the accuracy of the model.

This calibrated model is now ready and it represents the urban water system in Alexandria city. Several scenarios were initially run for the purpose of this study. However, the Learning alliance is currently preparing detailed scenarios for Alexandria. Once their scenarios are ready, they will be able to implement this model to choose the best option for city. Consequently, this model will be a viable management tool and hopefully it will support decision makers with all they need to set an integrated strategy plans for Alexandria.

10. BIBLIOGRAPHY

Agarwal A., et al. (2000). *Integrated Water Resources Management.* Stockholm, Sweden: Global Water Partnership, Technical Advisory Committee (TAC).

AsDCo. Retrieved 2010, from Alexandria Drainage Company: http://www.asdco.com.eg/

AWCO. Retrieved 2010, from Alexandria Drinking Water Company: http://www.alexwater.com/wtp_ar.html

Dawoud, M. A.; Darwish, M. M.; El-Kady, M. M. (2005). *GIS-Based Groundwater Management Model for Western Nile Delta.*

Donia, Noha; Sabry, Noha; Ramadan, Ayman;. (2010). *Whole of system modeling and decision support.* Alexandria: CEDARE.

El-Arabi, N.; Fekry, A.; Meneum M.; Taha K., EL-Karamany S. (2009). *Assessment of Groundwater Potential in Alexandria Governorate.* Cairo: CEDARE.

EU. *SWITCH*. Retrieved 2010, from Managing water for the city of the future: http://www.switchurbanwater.eu/index.php

Farooq M., Mallah M. (1966). The Behavioural Pattern of Social and Religious Water-contact Activities in the Egypt.

Fishar, M. R. (2008). *Current status of Lake Maryut zone.* Alexandria.

Frihy, O. E., Dewidar, K. M., & El-Raey, M. M. (1996). Evaluation of coastal problems at Alexandria, Egypt. *Ocean and Coastal Management* , 281 - 295.

Hilali, H. et al. (2010). *New Strategies for Wastewater Management and Reuse in Alexandria in 2037.* CEDARE.

Kashef, A.-A. I. (1983). Salt water intrusion in the Nile Delta. *Ground Water* , 160-167.

Last, E. (2010). *Model Concepts.* Birmingham: The University of Birmingham.

Last, E., & Mackay, R. (2007). *Developing a new scoping model for urban water sustainability.* SWITCH.

Makropoulos, C. K., Natsis, K., Liu, S., Mittas, K., & Butler, D. (2008). Decision support for sustainable option selection in integrated urban water management. *Environmental Modelling & Software , 23* (12), 1448-1460.

Mayer P., DeOreo W., Opitz E., Kiefer J., Davis W., Dziegielewski B., Nelson J.;. (1999). *Residential End Uses of Water.* Water Research Foundation .

Mitchell, G. (2005). *Aquacycle: a daily urban water balance model.* Monash University.

Mitchell, G.; Diaper, C. (2005). *UVQ User Manual.*

Mitchell, V. G. (2006). Applying integrated urban water management concepts: A review of Australian experience. *Environmental Management*.

Mitchell, V. G.; Mein, R. G.; McMahon, T. A. (2001). Modelling the urban water cycle. *Environmental Modelling & Software* , 615-629 .

Nessim, Ramzy B; Bassiouny, Ahmed; Zaki, Hermine; Moawas, Madelyn; Kandeel, Kamat;. (2010). Environmental studies at El-Mex region (ALexandria-Egypt)During 2007-2008. *World Applied Sciences* , 779-787.

Samir A.M., El-Din A. B. (2000). Benthic foraminiferal assemblages and morphological abnormalities as pollution proxies in two Egyptian bays. *Marine Micropaleontology* , 193±227.

Shaalan, I. M.; Fakhry, A. K.; Khalifa, A.; El-Akrat, M.; Aboul-Magd, A. (2009). *Alexandria Integrated Coastal Zone Management, Environmental and Social Impact Assessment.* Ministry of State for Environmental Affairs.

Sherif, M.; Mohamed, A.; Bobba, A. G.; Singh, V. P. (2002). Seawater intrusion in the Nile Delta aquifer under different pumping scenarios. In *Environmental and groundwater pollution.* A.A.Balkema.

Taha, Hanan; El-Din A. H.; El-Megeed A.; Riad N. (2010). *Water Demand Management.* Alexandria: CEDARE.

Thomas, G. (2009, Oct 02). *Per-capita consumption of water fell to 122 litres a day in 2007*. Retrieved 2010, from German Federal Statistical Office: http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/EN/press/pr/2009/10/PE09__377__322,templateId=renderPrint.psml

Unaccounted for water in EECCA countries . (2007 , Jun 14). Retrieved 2010, from The European Environment Agency : http://www.eea.europa.eu/data-and-maps/figures/unaccounted-for-water-in-eecca-countries-left-water-lost-from-public-water-supply-systems-in-croatia-denmark-and-england-and-wales-1990-2004-of-delivery-right

UNICEF. (2010, March 2). *Egypt Statistics*. Retrieved 2010, from UNICEF: http://www.unicef.org/infobycountry/egypt_statistics.html