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Low cost artificial recreational coastal lagoon: Hydrographic, and design guidelines in development resorts

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Abstract

The objective of the research is to find low cost alternative for conventional recreational lagoons that consume water and energy used for desalination which is the only alternative for water treatment in most touristic villages all over the world. The study uses low cost recreational lagoon with new technology that use brackish water from deep wells and purify this water before entering the lagoon by controlled pulses and energy-efficient ultrasound filtration. This allows to maintain the water within pre-defined parameters, guaranteeing standardized water quality in all lagoons. The research introduces the lagoon new technology and its low cost design including feeding and drainage wells, second, the hydrographic surveying for the coastline in the study area, third water quality modelling for the production and injection wells, fourth, use SOBEK 1-2 Mathematical Model for determine the water depth and perspective water volume for the designed lagoon. The aim of this model: Determine the relation between the water depth and the water volume for the canal and the lakes. Second, calculate the evaporation rate from the surface, Determine the number and capacity of the water wells needed to fill the canal and the lakes, and Find out the relationship between the discharge and the time needed to circulate the water in the canal and the lakes to keep their water quality.

The results of the measurements from the observation well prove that the optimal discharge per each well is 0.022 $m^3 \cdot s^{-1}$. The construction of suggested new green technology lagoon are very low cost, completely environmentally friendly, in addition fulfils the highest standards of environmental safety.

Key words: *artificial recreational coastal lagoon, hydrographic survey, mathematical model, production and injection wells, water quality modelling*

INTRODUCTION

The study area is located in the Sinai desert, 5 km from Sharm El-Sheikh Resort. The tourist complex will contain 30,000 private units, hotels, golf areas, marinas, a historical center, and a strip mall. The huge lake with an area of 12.5 mln m^2 is part of tourism development in Sharm El Sheikh. A total of 12 lakes, which will be part of 1 mln m^2 of recreational water in the middle of the desert, using salt water from salty wells, which have no alternative use at the present time [GEF 2018; KARMANY 2016]. The 7.5 mln m^2 mixed-use community will include 12 crystal lagoons utilizing 1 mln m^3 of salt water sourced from underground deep wells. It will get a salt water supply from wells in the middle of the desert that are useless, allowing a tropical recreational lake in the desert. Also, the salt water used in the recreational lake is characterized by higher levels of purity and will be used for desalination by reverse osmosis, which reduces the costs of desalination [City Stars undated; Crystal Lagoon 2017].

MATERIAL AND METHODS

STUDY AREA HYDROGEOLOGICAL CONDITIONS

Before lagoon construction the hydrogeological conditions of the area under consideration is studied to evaluate the available water supply, and the impact of flash flood on

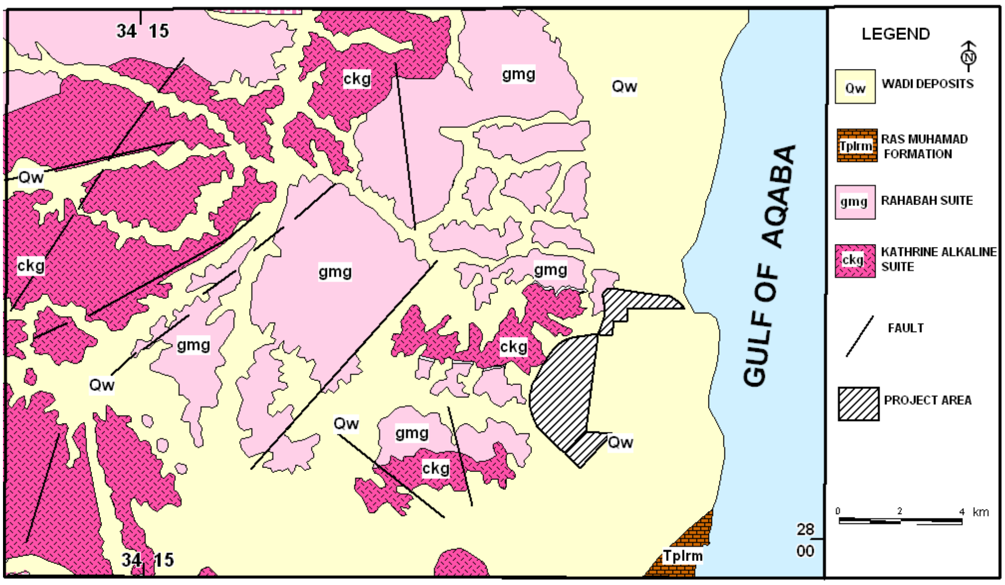

Fig. 1. Location map for the geophysical profiles; source: own elaboration

the proposed infra-structure in the area. To cover the objectives, several studies have been carried out, these studies, can be summarized as follows: field investigations which include, survey, topography and geology, geophysics hydrology, and hydrogeology.

Topography and geology. The topographic features of the area are characterized by the presence of beach plains restricted between the Gulf of Aqaba and the mountainous area in the East, and slopes toward the Gulf, while the geology of the area is characterized by many Gebles of different elevations, these Gebles composed of igneous and metamorphic rocks. The area is subjected to a strong tectonic movement, consequently some geological structures as faults, joints and others are formed, which may affect direct or indirect on groundwater occurrence, movement and direction, in addition to the Quaternary deposits which composed of sand, gravel, rock fragments and limestone as shown in (Fig. 1).

Hydrogeology. This study deals with the groundwater aquifers, were the area of study is suffering from fresh water supply, and the main source of water is saline and very saline water which occur in the sedimentary succession, meanwhile the salinity depends mainly on the hydraulic connection to the Gulf and the pumping rates of the existing wells [RIGW/IWACO 1999]. From the available data collected from the existing wells, it concluded that the thickness of the sedimentary succession varying from 250 to 300 m nearby the coast and decreases gradually towards the mountainous area, the static water level ranges from 30 to 50 m below ground level therefore it seems that the groundwater flow towards the Gulf.

Survey. The necessary survey works have been carried out by using modern surveying tools to allocate the suitable sites for construction the industrial works in the main stream and its tributaries and to follow up the natural passage of flash flood, determination of the coordinates of those passages, conducted a number of cross sections and calibration curve to find out the relationship between the required distance for storage of flash flood and the expected volume of water in addition a contour map for the main stream. The study area is shown in a topographic map (Fig. 2).

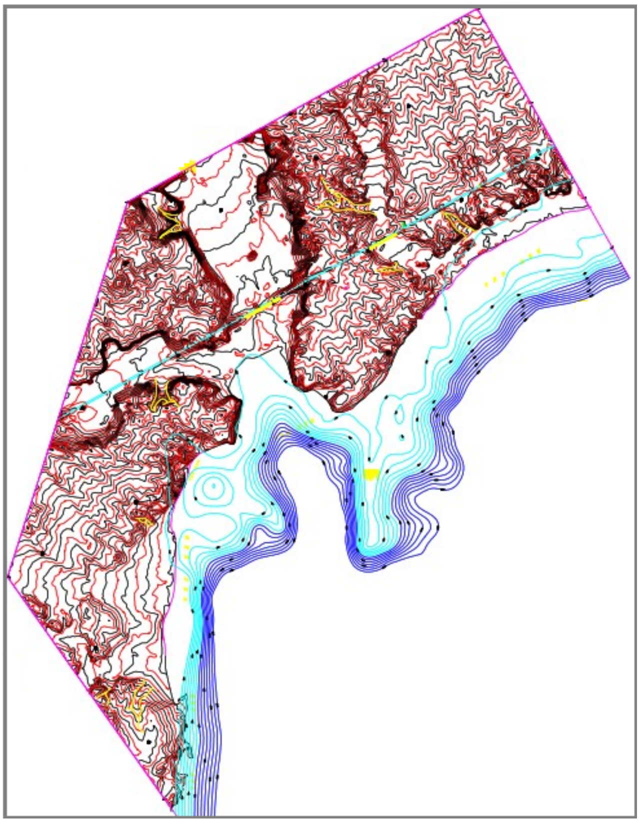

Fig. 2. Topographic map of the study area; source: own elaboration

Hydrology. A hydrological study has been carried out for the study basin. The basin area is about 16 km^2. A topographic map of scale 1:50 000 is used to create the digital elevation model (DEM) for study basin using Geographical Information System (GIS). The DEM and the resulted drainage network of the basin is shown in (Fig. 3).

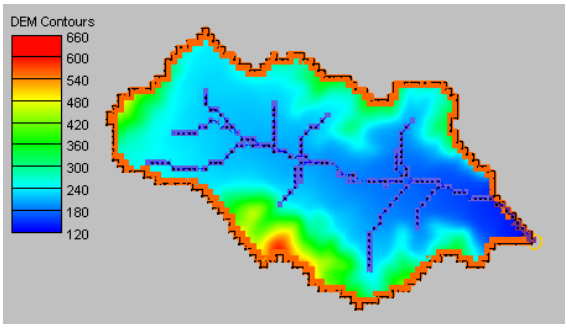

Fig. 3. The digital elevation model (DEM) of the study basin; source: own elaboration

Source of fresh water in the area. Desalination is the only source for fresh water in the study area according to integrated water resources study in the area as the area far from the Nile River [EL GOHARY 2017a, b; GHODEIF 2002].

Alternatives to providing fresh water in the study area:
- providing water by cars;
- connecting to a public network;
- establishing a desalination plant serving the project.

The first alternative relies on transporting water by a 10-ton transport vehicle, and this water is transported either from a desalination plant or from the city's water, and given that the nearest desalination plant is that located about 30 km North of the project and is a station for one of the resorts and its current capacity is not sufficient to extend the project to be established, this alternative is considered very expensive and very difficult to implement. The second alternative is not possible due to the lack of a public network in the region. The third alternative, despite its high cost, is the most appropriate to ensure the availability of water for the area safely and continuously, knowing that the desalination plant will use reverse osmosis technology, which is the most common technology in such projects, and the brine solution will be disposed of by injection into deep wells of the project land, including it does not affect the soil or the freshwater aquifer.

In this study the purified water from lagoon will discharged to reverse osmosis desalination plant and thus the cost for desalination will be less than if we input the water from production wells directly. Figure 4 shows outline of water supply and sewerage system in Sharm El-Sheikh City.

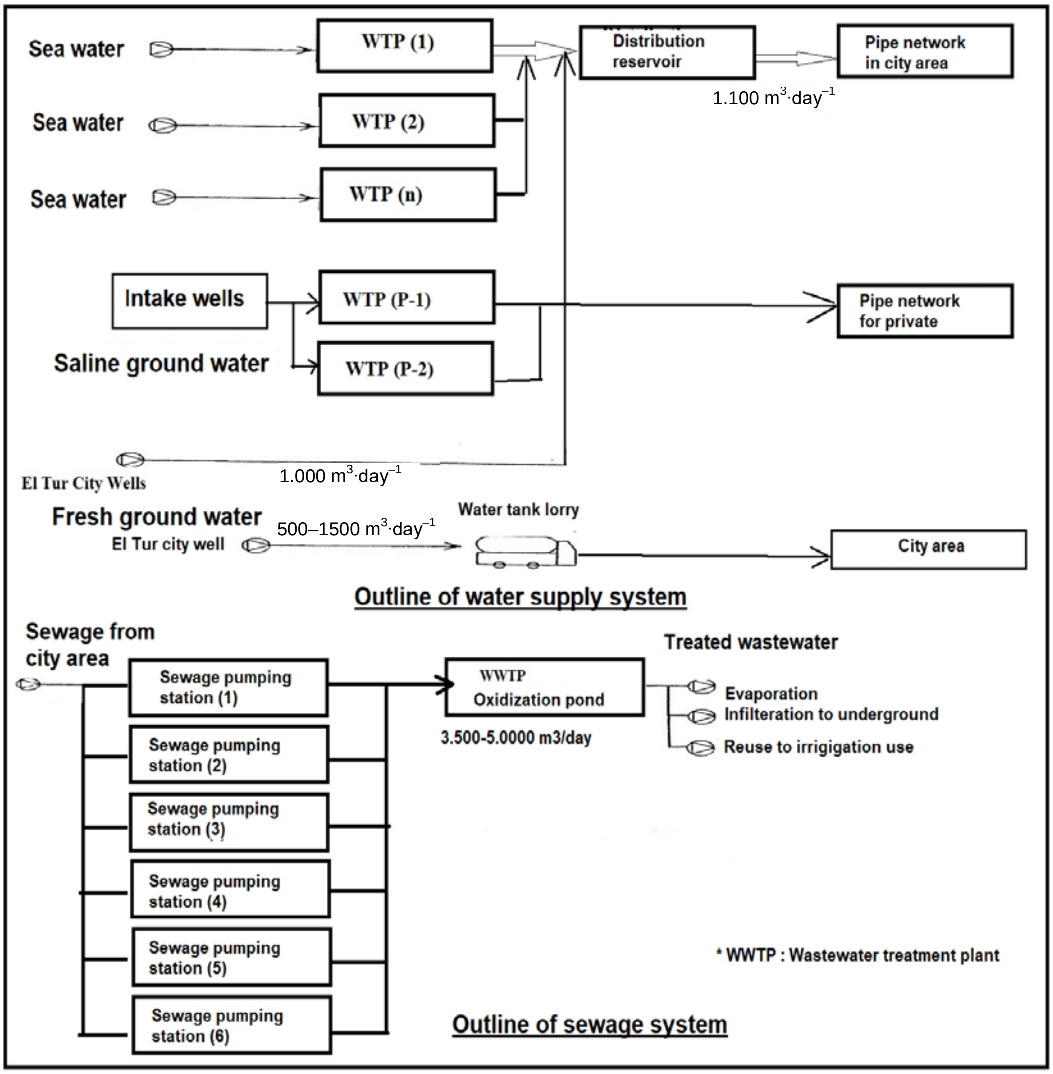

Fig. 4. Outline of the water supply and sewerage system in Sharm El-Sheikh City; source: JICA, WRRI [1999]

Desalination plant 6000 $m^3 \cdot day^{-1}$, deep (bore) well and lagoon disposal saline water feeding system requirements. Average flow requirements around 715 $m^3 \cdot h^{-1}$. These flow requirements shall be provided through both, the lagoon disposal water and deep (bore) wells. According to lagoon discharge 324 $m^3 \cdot h^{-1}$ (90 $dm^3 \cdot s^{-1}$) will be available as the lagoon saline discharge (disposal) water. Accordingly, the rest feeding saline water average flow supplied by deep (bore) wells will be as follows:

715 $m^3 \cdot h^{-1}$ (required) – 324 $m^3 \cdot h^{-1}$ (available by lagoon) = 391 $m^3 \cdot h^{-1}$ (from wells).

OBJECTIVES AND SCOPE OF THE STUDY

There is an urgent need to study the construction of the current recreational lagoon to ensure a source of attraction for the interior coastal lands and the development of tourism activity in Sharm El Sheikh [EMBAB 2004; MOP 2016; SIS 2016]. This green technology has attracted global attention due to its apparent efficiency in the generation and use of clean and less energy. It will use remote controlled system and energy-saving ultrasonic filtration, thus lagoon will use up less chemicals and only 2% of the energy required by conventional pools. All lagoon hydraulic systems, chemicals and mechanical systems are controlled and operated remotely through the internet platform. This permits to keep up the water inside pre-characterized parameters, ensuring institutionalized water quality in all tidal lagoon. The water used in the lakes is of the highest purity, it is suitable even for human utilization, according to the regional regulations. Through sustainable and environmentally friendly methods, this will lead to the creation of large bodies of water for recreational purposes using fresh, marine and brackish water, or the use of water from aquifers in the desert as in this research. Low cost lagoon technology uses only 2% of the energy required by conventional water treatment technologies for traditional swimming pools and drinking water. In the case study, salt water is obtained from unused aquifers in the desert. The salty water used in the lagoon is characterized by higher levels of purity and will be used for desalination by reverse osmosis, which reduces the cost of water treatment. Figure 5 shows the site location showing artificial lagoon layout. The total area will contain 12 lagoons its volume around 1 mln m^3, using 1 mln m^3 of salt water from deep wells in the area, each lagoon has a volume around 111 000 m^3, the mathematical model for three lagoons total volume 450 000 m^3 each lagoon 111 000 m^3. All the other lagoons will be similar to the detailed one in the study.

The objective of the research is to find low cost alternative for conventional swimming pools and recreational lagoons that consume water and energy used for desalination which is the only alternative for water treatment in most touristic villages in Egyptian coast and all over the world. The study uses low cost recreational lagoon with new technology that use brackish water from deep wells and purify this water before entering the lagoon by controlled pulses and energy-efficient ultrasound filtration. This allows to maintain the water within pre-defined parameters, guaranteeing standardized water quality in all lagoons. The salt water used in the lagoon features higher levels of purity and will be used for reverse osmosis desalination processes, lowering the cost of water treatment. The research consists of: first, introduces the lagoon new technology and its low cost design including feeding and drainage wells, second, the hydrographic surveying for the coastline in the study area, third the mathematical model for determine the water depth and perspective water volume for the designed lagoon, finally water quality modelling for the production and injection wells.

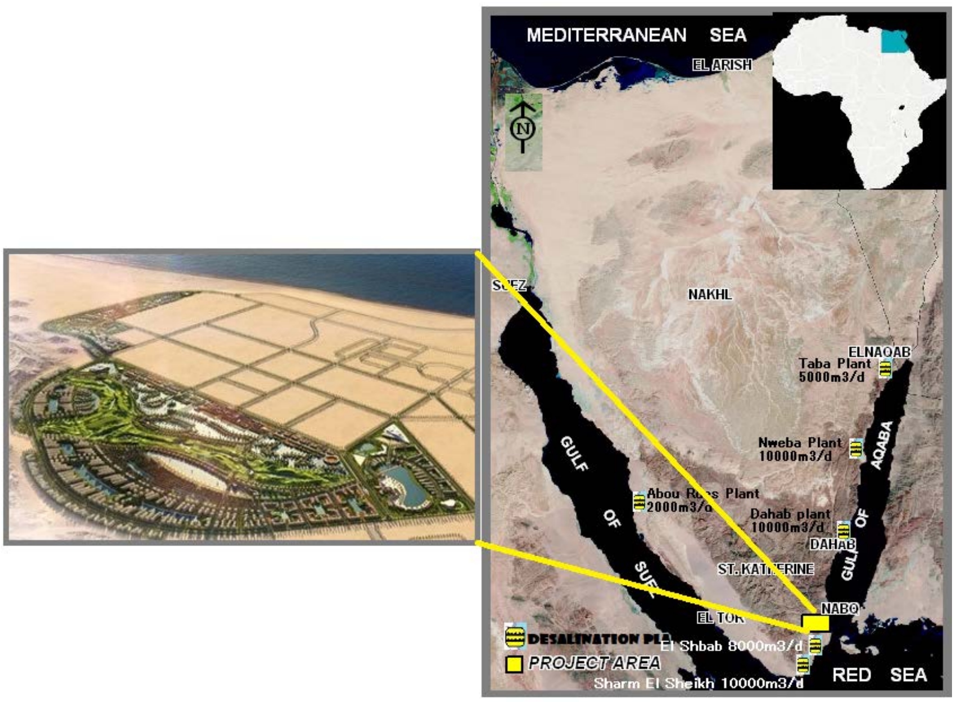

Fig. 5. Site location showing artificial lagoon layout, and desalination plants in South Saini Governorate; source: own elaboration

PROPOSED ARTIFICIAL LAGOON

The general layout of the proposed lagoon study and the distribution of the feeding and drainage wells and the contracted design indicators are shown in (Fig. 6), the basic units of the lagoon are compatible with local legislation and include the following:

- feeding system (9 feeding wells including 7 workers + 2 reserves) as well as a pipeline linking the lake's feeding wells;
- sewage system (9 drainage wells 7 working + 2 reserve + reservoir regulating the work of drainage wells and drainage pipeline);
- treatment and sterilization room (automatic addition of chlorine by dose) and injection of feeding water with sediment and blockages;
- plant slow sand precipitation and filtration;
- bottom cleaning and scraping line, recycling rooms and machinery.

Design of feeding and drainage wells for the proposed lagoon

The amount of groundwater abstracted and the volume of water needed to inject it to the ground depend on lagoon operation, recycling effectiveness, and storage capacity. The proposed lake was designed to accommodate 111,000 m^3 at the start of operation and then continue to supply it with the required water and drainage on an equal footing 6000 m^3 to maintain the water level in the lake. Therefore, the lake needs to recharge the groundwater with about 6000 m^3 per day, then re-spend it in the deep-water aquifer. It is assumed that the feed water is extracted from the nine wells for production from the groundwater reservoir at the same level as the drainage wells (9 wells) in order to work in a closed system where the quantities of water are pumped back into the groundwater layer. It is then re-extracted in a closed cycle that helps to purify natural water that has no effect on the surrounding areas.

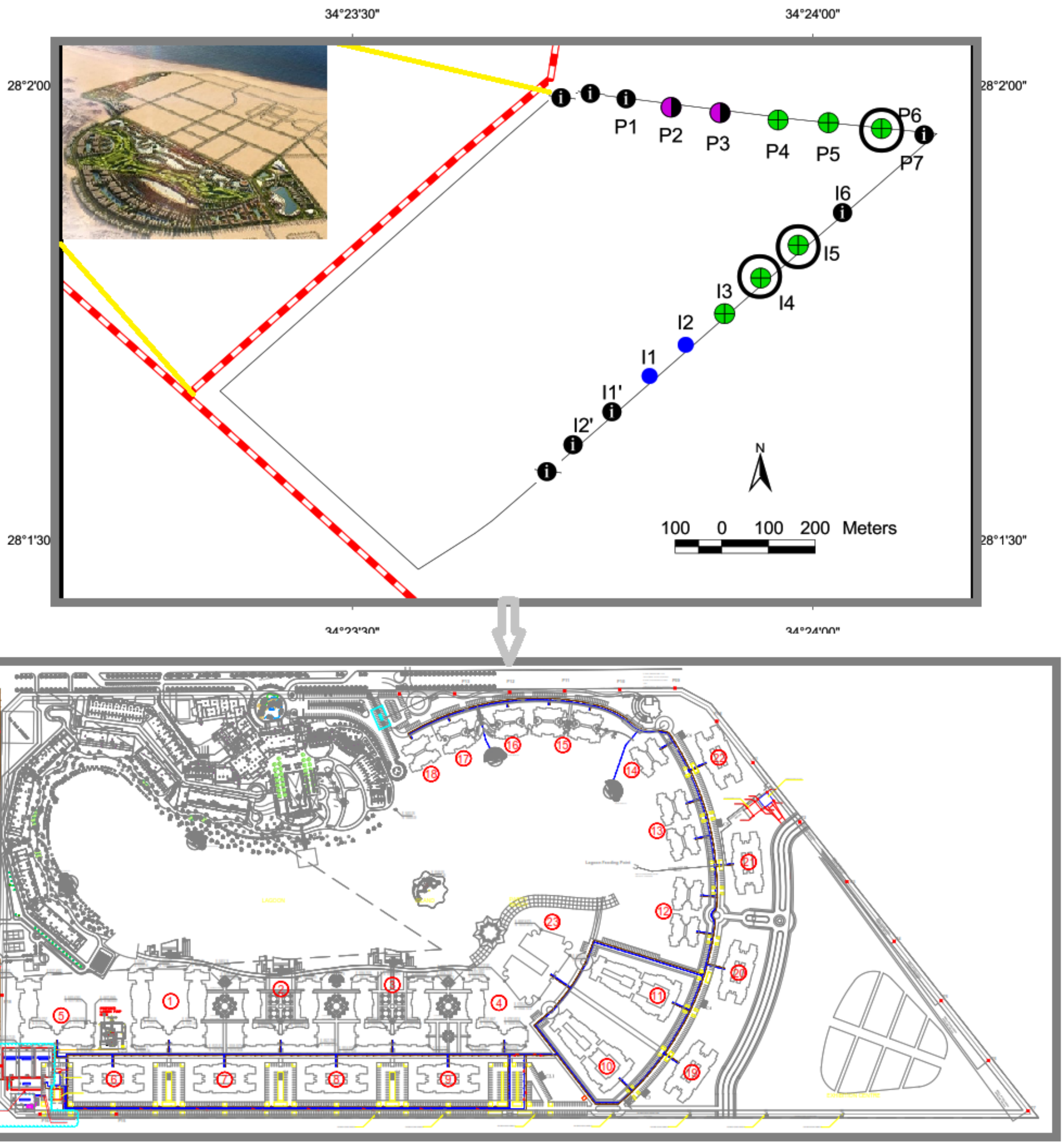

Fig. 6. A layout showing the proposed distribution of production and injection wells; source: own elaboration

The proposed design of the feeding and drainage wells takes into account the surrounding local hydrogeological conditions and practical considerations. Production wells are designed to achieve the highest low throughput productivity and continue producing sand free water. Production and drainage wells are placed at the top of the aquifer to obtain saline groundwater and work in a closed cycle. Lake drainage pumps should be placed away from the accommodations and recreation areas for resort guests and in the back area.

Lagoon borders and waterproofing. The lagoon bottom considers a lining consisting of a white Crystal Lagoons LLDPE geomembrane to waterproof the surface to minimize water losses due to infiltration. The entire perimeter of the lagoon is a beach-type boundary consisting of a sloping bottom of up to 12% that delves into the lagoon. The first 10 m of these sloping boundaries will be constructed using a layer of cement layer 10 cm thick (4 cement sacks per meter), with a 0.5 mm waterproof HDPE geomembrane and a bottom 2 mm geographic Lagoons LLDPE crystal film on top. Sand surface treatment is considered to increase the roughness of this geomembrane.

Level and location of discharge connection point. Connection point for discharge pipe is located at the side of the machine house. Coordinates are: E = 6450.481; N = 15188.171. Pipe elevation is 60 m.

Level and location of inlet water pipe. The coordinates are: E = 6725.14; N = 15813.57. Elevation for the pipe is 64.632 m.

Critical time to react (inlet flow). The critical time to react regarding fresh water inlet flow is 14 days for salinity standards and 4 days for lagoon level.

Machine house energy power consumption. The power consumption of the machine house is distributed as the follows:
- recirculation system: 25 kW,
- skimmer system: 8 kW,
- bottom cleaning system: 25 kW,
- illumination: 3 kW,
- drainage system pump: 2.5 kW,
- additional equipment (Sentinel pumps, etc.): 14 kW,
- total consumption: 77.5 kW.

Earth~~l~~ing system. The earth~~l~~ing system shall be in accordance with the machine house consumption. Additionally, regarding the pipes earthling, all the pipes are connected with steel flange connections in walls.

Machine house power critical time. Power critical time for machine house is 12 h.

Lagoon water quality management system

It will use a pulse disinfection system that proves to be more efficient than any other known system. It depends on a chemical treatment that is propagated at a certain time frequency according to the growth cycle of the specific microorganisms.

The main water quality parameters are constantly monitored by a telemetry system that uses sensors located along the lagoon that accurately indicate when additives must be applied, and in properties and exact quantities, allowing the quantities of additives to be reduced up to 100 times compared by traditional swimming pools. The application of additives is linked by a large number of sensors and injections with a specific location. The whole process is managed remotely by telemetry connected to a control central lab.

Filtration system. Certain additives and a mixture of different ultrasound will be applied to the water in the lagoon, causing the pollutant particles to accumulate into large particles. Large particles settle to the bottom of the lagoon, and are absorbed by a specially designed portable suction device. After that, the water that is sucked in is sent to a small filtration system, and the filtered water is returned to the lake. The effective filtering process and various types of extraction devices are protected. The filter energy consumption is greatly reduced to two effects: the filtered water is greatly reduced which results in a water flow of 300 times less than the flow that was filtered into the traditional pool filter system. Since the particles in the suction water flow are large and small due to the ultrasound system, they are easier to remove from the bottom and thus the filter energy requirements are lower. Therefore, the efficient filtration system consumes up to 2% of the energy used in traditional pond filtration techniques. As the energy consumption of the filtration system is reduced by 98%, significant environmental benefits are generated, which can go from reducing the world's fossil fuel consumption to reducing CO_2 emissions.

Surface cleaning. To remove all floating impurities from the surface of the water, scrapers are located in the direction of the prevailing wind in order to capture floating materials. This automatic system is able to handle external pollutants such as oil spills, protection cream, leaves, etc.

Bottom cleaning. Contaminate sediment and pollutants at the bottom of the lagoon, where it is aspirated by a vacuum device specially designed to clean the lagoon bed. At a rapid speed, the vacuum device is able to handle stable particles and is compatible with the lagoon's water insulation system. Unlike a conventional cleaning device, rough surfaces can be cleaned and kept completely clean to provide attractive water body colouring.

The water flow is sent under the suction by a specially designed vacuuming system in the filtration system, which allows filtering a small portion of the entire water volume, up to 300 times less than the filtered flow in conventional swimming pool purification systems in the same period.

Reverse osmosis cost reduction

In general, desalination processes can be divided into two main types of technology: thermal distillation and membranes. Nowadays, membrane technology has accounted for more than 73% of global desalination installation capacity. Several studies have shown that renewable energy powered reverse osmosis (RO) desalination system is more reliable and sustainable than other energy sources, due to lower operating costs and environmental impacts. Several studies have discussed many factors to consider before choosing renewable energy, such as salinity of product and water feed pressure, plant site, wind speed, solar radiation at site, plant size, and cost of product water.

These factors play an important role in estimating total energy consumption. Since Egypt has about 3,000 km of the Red Sea and Mediterranean coastline, desalination can be used as a sustainable source of water for domestic use in many coastal areas. Currently, the reverse osmosis process is widely used for desalination in Egypt, especially for coastal areas, as these remote areas are far from the national water and electricity networks. While the RO needs a large amount of energy, power is mostly generated using fossil fuels, which affects the environment in this area [AMIN *et al*. 2020; EL KOMY 2019; EMBAB 2004; IRENA 2013; METWALLY, ABDALLA 2006]. Therefore, unconventional RO technology plays a vital role for fresh water resources in coastal areas in Egypt. Therefore, the study uses low cost RO technology that allows pre-treatment of sea water at low cost through a treatment lake, providing high--quality water to fuel the reverse osmosis process. This method greatly reduces investment and operating costs in the treatment phase, leading to the creation of an effective and sustainable alternative to current pre-treatment operations, while creating a high-quality water tank that allows recreational use. Reverse osmosis is a widely used technique that can produce fresh water from salt water (sea water or salt water). This process is driven by a pressure gradient between the saltwater flow and the freshwater flow, separated by a semi-permeable membrane. When the salt water pressure exceeds the system's osmotic pressure, it produces a flow of pure water through the membrane, resulting in fresh water. However, for this process to work properly, high-quality seawater must be used to ensure that the membranes are not clogged and damaged. Therefore, the highest cost of reverse osmosis occurs in the complex and costly pre-treatment of seawater required to obtain high-quality water. By this method it could decrease the desalination cost, also focal fuel used. As the energy consumption of the filtration system is reduced by 98%, significant environmental benefits are generated, which can go from reducing the world's fossil fuel consumption to reducing CO_2 emissions.

HYDROGRAPHIC SURVEYING AT NABQ AREA – SHARM EL SHEIKH-RED SEA – EGYPT

Recording current, temperature, and salinity

The recording current-meters RCM was set up to record a ten-minute vector mean current speed and direction as well as temperature and salinity values. The measurements were performed at station LOC1 at E = 641803.30, N = 3105594.00, it is recorded current speed and direction, salinity, and temperature at the station.

Marine physicochemical environment

Wind direction. The prevailing wind direction is from north to south, throughout the year. In the winter months, however, disturbances to this settled regime do occur.

Currents. The surface current in the Gulf of Aqaba is known to change direction with the tidal changes. Records show that the main surface current pattern is moving from south to north during the high tide and from north to south during low tide.

Seawater temperature. The lowest sea surface temperature occurs in February, with an average reading of 17.5–20.0°C. While the maximum temperature averages a little over 27°C. As the sun moves back northwards in the spring, temperatures increase only slowly during March and April, however, the maximum values are not reached until August with a degree higher than 26°C [ABDELMONGY, EL-MOSELHY 2015].

Water salinity. High evaporation throughout the year results in water salinity increase a little over 40.0–42.5%. There is some evidence that evaporation is higher in the winter half of the year than the summer half (due to higher wind speeds). In the shallow waters along the coasts some increase in salinity is to be expected in parallel with the higher temperature of it [EDWARDS 1987].

Oxygen content. Biologically, the oxygen content of seawater is of great importance. However, the amount of oxygen required to saturate seawater decreases with both increasing temperature and increasing salinity. The concentration from a little under 4.5 cm^3 $O^2 \cdot dm^{-3}$ to a little over 4 cm^3 $O^2 \cdot dm^{-3}$. The concentration at the minimum level is about 1.5 cm^3 $O^2 \cdot dm^{-3}$ to 1.75 cm^3 $O^2 \cdot dm^{-3}$ [EDWARDS, HEAD 1987].

Phosphate and nitrate content. The distribution of inorganic phosphorus and nitrogen in the surface water is relatively low. Maximum values are found at the level of minimum oxygen. The average concentration of phosphate is less than 0.10–0.15 $\mu mol \cdot dm^{-3}$, while the nitrate readings are less than 0.5–1.0 $\mu mol \cdot dm^{-3}$ [EDWARDS 1987].

Hydrographic survey required field data

A detailed hydrographic survey for an area of 7 km, and extend into the sea till a water depth of some 100 m. Simultaneous tidal level and tidal flow measurements at a water depth of 9–10 m for five days.

Bathymetric survey. The bathymetric surveys covered an area of 7.0 km parallel to the shoreline and extend into the sea till a water depth of some 100 m [HRI, MWRI 2007]. The survey was carried out in beach profiles (cross--sections), eight beach profiles were measured with 1000 meters' distance apart as. The bathymetry of each beach profile was carried out Echo sounder (DSF-600 Digital Survey Fathometer) installed in a big boat. Bathymetric maps with the UTM system coordinates were plotted with scale 1:10 000 (Fig. 7).

The cross-sections, which are presented in Figures 8, 9, 10, 11, and for [CS A- CS B- CS C – CS D – CS E – CS F – CS G – CS H] were plotted with horizontal scale of 1:2000 and vertical scale of 1:500.

Tidal levels. The RCM was set up to record a ten-minute time interval, mean current speed and direction as well as temperature and salinity values. These tidal measurements were carried out at one location with E = 641515.6482 and N = 3099594.841. The water depth at this location was 10 m. Figure 12 shows the tidal levels in the study area.

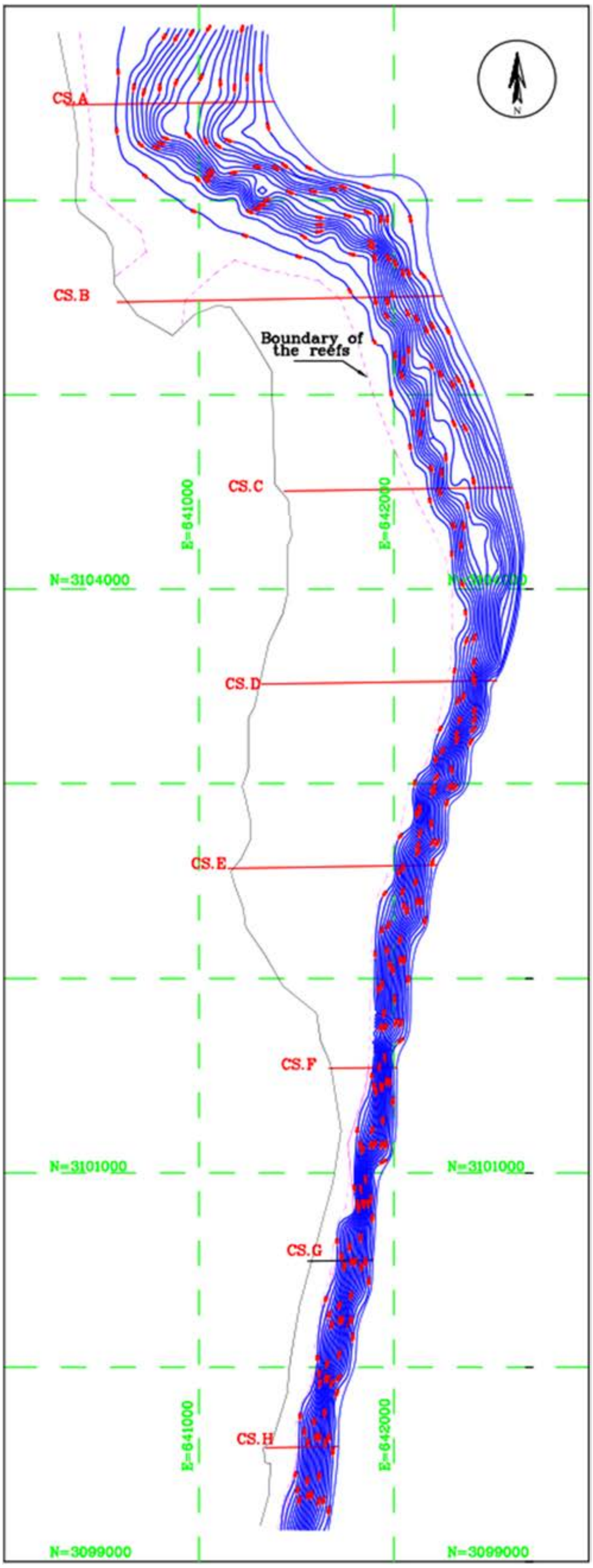

Fig. 7. Bathymetric maps with the UTM system coordinates; source: own study

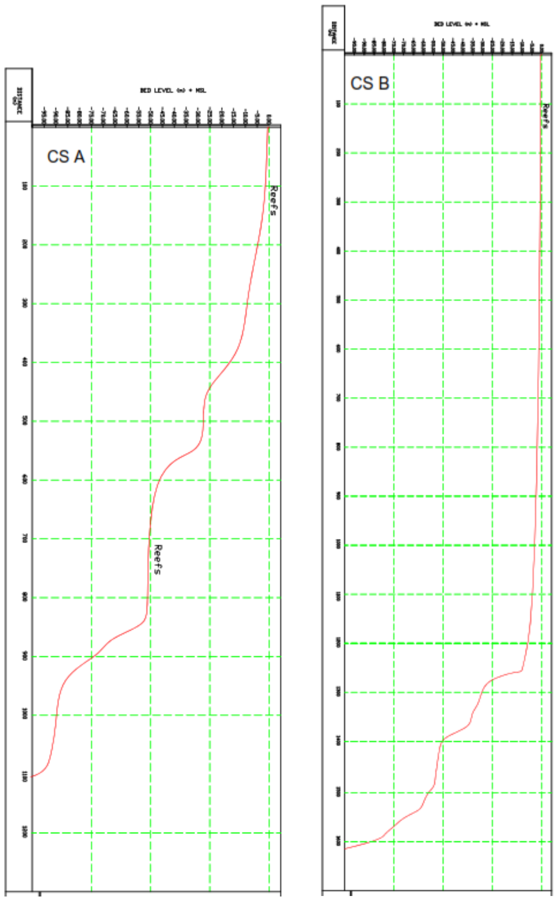

Fig. 8. The cross-sections Cs A and Cs B with horizontal scale of 1:2000 and vertical scale of 1:500; source: own study

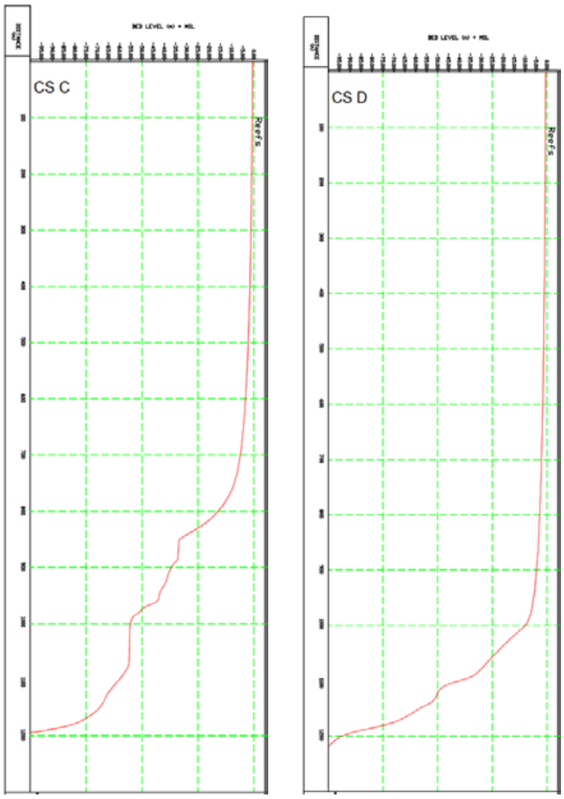

Fig. 9. The cross-sections Cs C and Cs D with horizontal scale of 1:2000 and vertical scale of 1:500; source: own study

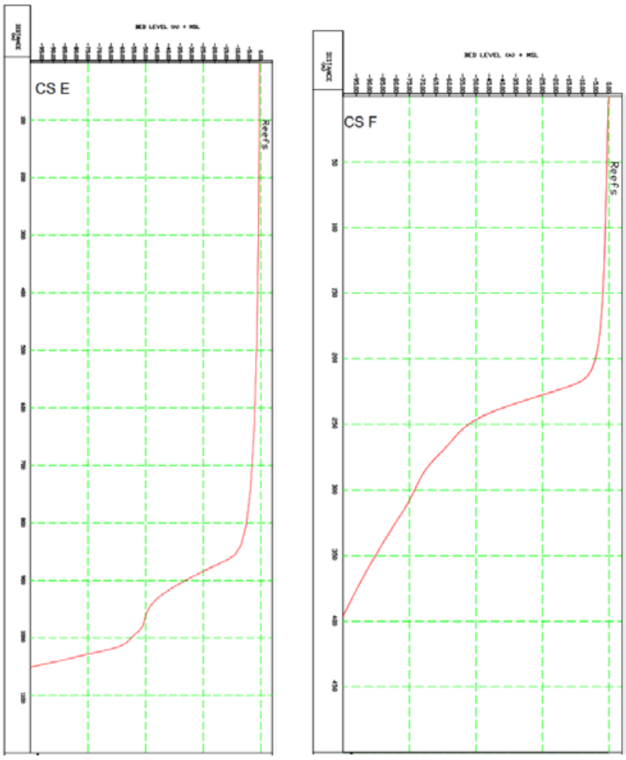

Fig. 10. The cross-sections Cs E and Cs F with horizontal scale of 1:2000 and vertical scale of 1:500; source: own study

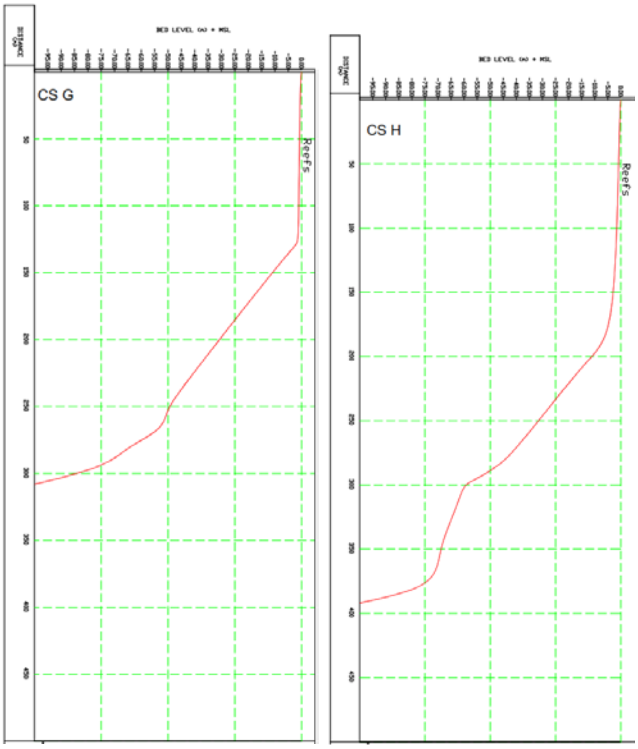

Fig. 11. The cross-sections Cs G and Cs H with horizontal scale of 1:2000 and vertical scale of 1:500; source: own study

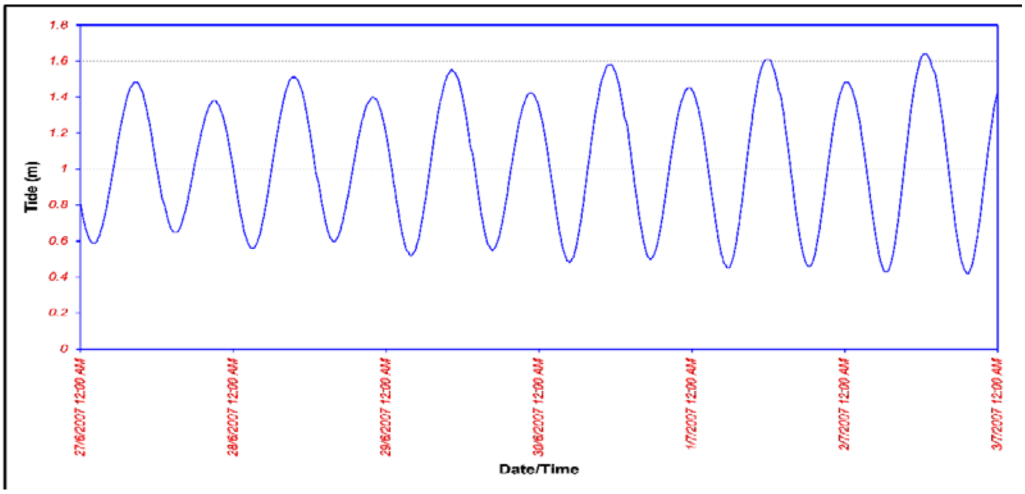

Fig. 12. The tidal levels; source: own study

SOBEK 1-2 MATHEMATICAL MODEL FOR THE MAIN LAKE AND CANALS

The main aims of mathematical model

- First, determine the relation between the water depth and the water volume for the canal and the lakes.
- Second, calculate the evaporation rate from the surface.
- Third, determine the number and capacity of the water wells needed to fill the canal and the lakes.
- Finally, find out the relationship between the discharge and the time needed to circulate the water in the canal and the lakes to keep their water quality.

Methods

The study is executed using a 1–2-dimensional mathematical model. The model was built based on the software SOBEK 1–2 [Deltares 2019]. The model represents the canal and the three lakes.

Design input data

– diameter of the two side lakes: 100 m with vertical walls;
– dimensions of the middle lake is 500 × 500 m, the side slope of this lake is taken 1 *V*: 100 *H* in order to be suitable for swimming activities;

– width of the canal = 25 m;
– length of the canal: almost 3000 m;
– average depth in the canal = 2.5 m.

The layout canal and the lakes are shown in Figure 7.

Design of the numerical model

SOBEK-channel flow is a one-dimensional modeling that can simulates the flow and water quality in river- and estuary systems. It is a tool based on knowledge and experience gained from many rivers and estuaries in the world. The program calculates water depths and velocities in the flood area, which is represented by a two-dimensional grid.

Basic equations used for 1D computation

In the flow module, the flow is described by the full Saint-Venant equations for unsteady open-channel flow, which read for a regular river application.

- Continuity equation (representing the conservation of mass):

$$\frac{\partial A_t}{\partial t} + \frac{\partial Q}{\partial x} = q_{\text{lat}} \tag{1}$$

- Momentum equation (representing the conservation of momentum):

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\alpha_B \frac{Q^2}{A_f}\right) + gA_f \frac{\partial h}{\partial x} + \frac{gQ|Q|}{C^2 R A_f} = 0 \tag{2}$$

Where: A_f = conveying cross-section (m^2), A_t = total cross-sectional area (m^2), C = Chézy coefficient ($m^{1/2} \cdot s^{-1}$), g = gravitation constant ($m \cdot s^{-2}$), h = water level relative to reference level (m), q_{lat} = lateral inflow per unit length ($m^3 \cdot m^{-1} \cdot s^{-1}$), Q = discharge ($m^3 \cdot s^{-1}$), R = hydraulic radius (roughly equal to the water depth) (m), t = time (s), W_f = width of conveying cross-section at water surface (m), x = distance along the channel (m), α_B = Boussinesq coefficient.

The Boussinesq coefficient is a correction factor in the convective acceleration term (in Eq. (2)), to account for non-uniform velocity distribution in the cross-section. It is computed from:

$$\alpha_B = \frac{\sum_{i=1}^{n} C_i^2 R_i A_{fi}}{C^2 R A_f} \quad \text{and} \quad C^2 R = \left(\frac{\sum_{i=1}^{n} C_i A_{fi} \sqrt{R_i}}{A_f}\right)^2 \tag{3}$$

Where: i = index indicating type of sub-section in conveying cross-section ($i \le 3$).

The last expression in Equation (3), computing a representative C^2R, is also used in the bed-friction term in Equation (2). The Chézy coefficient C is in this model computed as a function of Manning's roughness coefficient n_m:

$$C = \frac{R^{1/6}}{n_m} \tag{4}$$

For the Nile River model the Manning type roughness coefficient provides a good representation of hydraulic roughness for a wide range of discharges.

Equation solving method

The equations are solved by a so-called "Delft Scheme". The solution method has been specifically designed to ensure positive solutions, i.e. negative water depths cannot be a result of the computations. Traditional solution methods do not ensure this property and therefore need special control structures to tackle the computation of water levels at shallow levels (the so called "drying and flooding" procedures). The present solution technique is capable to compute bores, hydraulic jumps, supercritical flow and overland flow all in one code. To use this scheme, it is assumed that each grid cell is node, connected to the adjacent cells by four branches (Fig. 13).

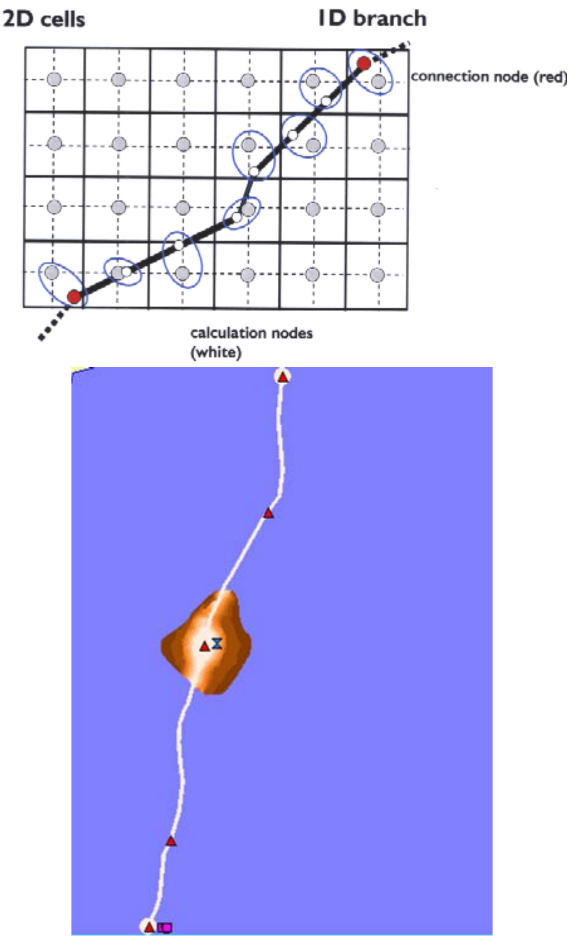

Fig. 13. Connections between 1D and 2D / canal and lakes layout; source: own study

1D-2D connection

The 1D network is linked with the 2D grid in the following ways: the connection between the 1D connection node and 2D grid cell; and the connection between the 1D calculation points and 2D grid cell. The following rules should be kept in mind, only one connection per grid cell is allowed. In other words, you cannot have both a connection node and calculation point in one grid cell, nor more than one connection node or calculation point per grid cell. It is simpler to assume that 1D and 2D network are two independent map layers, with the 2D network map layer overlapping a 1D network. The computational code determines the connection points between 1D and 2D based on the map coordinates for the center of 2D grid cell and the 1D connection node / calculation node. If they fall within certain criteria, then the connection is made between them, else not. The criteria, if expressed in mathematical terms, are as follows:

$$\text{if } (|X1 - X2| \le DX/2) \text{ and } (|Y1 - Y2| \le DY/2)$$

Where: X1 = x map coordinate for 1D point, X2 = x map coordinate for 2D grid cell, Y1 = y map coordinate for 1D point, Y2 = y map coordinate for 2D grid cell, DX = width of grid cell in X direction, DY = width of grid cell in Y direction (DX and DY are equal).

Then the 1D point is assumed to ly completely within the 2D grid cell.

The connection between the 2D cells and the 1D network is done in the following way (see Fig. 13):

– the centre of 1D node is internally moved to match with the centre of 2D grid cell, without changing the length of the connection 1D branches;
– the 2D grid cell is counted as part of 1D node;
– the flow in 1D channel below the 2D grid level is treated as 1D flow, while the flow above the 2D grid level is treated as 2D flow with the area of 2D grid cell.

RESULTS OF THE MATHEMATICAL MODEL

The relation between the water depth and the volume of water for lake 1, 2 and 3 and the relation between the water depth and the volume of the canal and the three lakes are calculated (Figs. 14–16). Because the suggested water depth is 2.5 m, this gives a total water volume of 450 000 m^3.

The evaporation rate from the canal and the three lakes is 0.038 $m^3 \cdot s^{-1}$ in summer, but in winter it decreases to be 0.015 $m^3 \cdot s^{-1}$. Figure 13 shows the relationship between the velocity in the canal and the required discharge, and (Figures 17 and 18) shows the relationship the velocity in the canal and the required time to completely replace the water in the canal and the lakes.

Analysis of the model results

The results of the measurements from the observation well prove that the optimal discharge per each well is 80 $m^3 \cdot h^{-1}$ (0.022 $m^3 \cdot s^{-1}$). This low discharge is needed to keep the salinity and the level of the groundwater, this discharge also allows the operation of the well 24 h daily. The relations ship between the number of the production well and the time required to fill the lakes is shown in Figure 17 and 18.

The number of wells needed to replace the evaporated water is 2.

The number of wells need to circulate the water in the canal and the lakes depends on:

(The total volume of the lakes – The total surface area – The bed and surface slope – The biological analysis for algy types – Ground water quality).

As the lakes are going to be used in swimming activities, a detailed water quality study is needed. This study

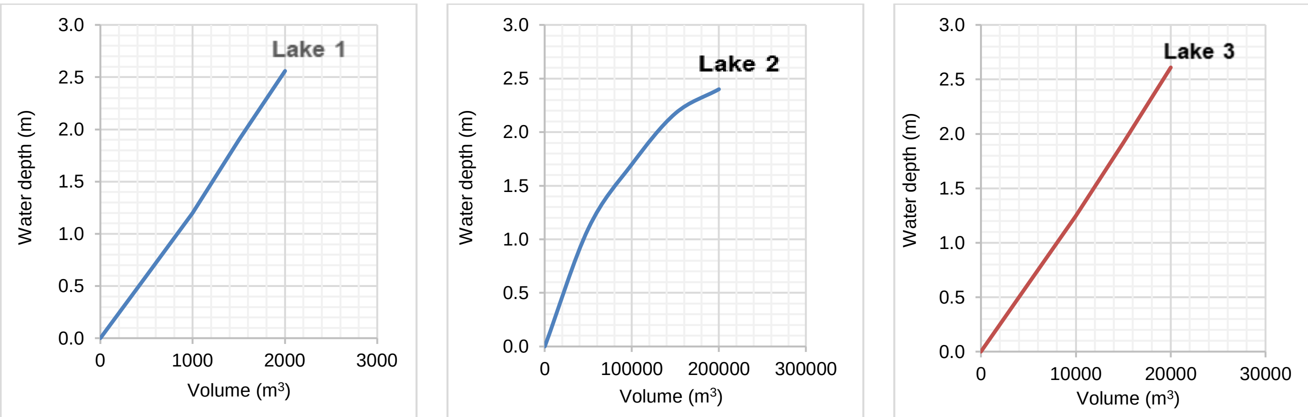

Fig. 14. Relation between water depth and volume of lake No. 1, 2, 3; source: own study

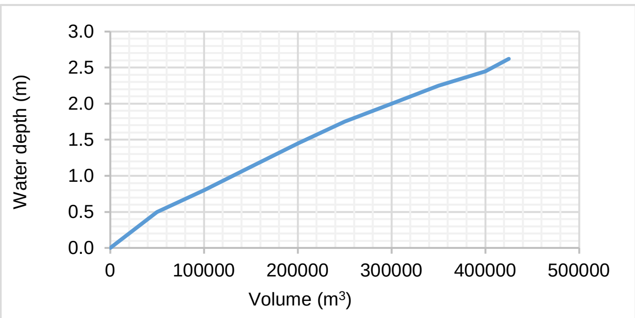

Fig. 15. Relation between water depth and volume of canal and lake; source: own study

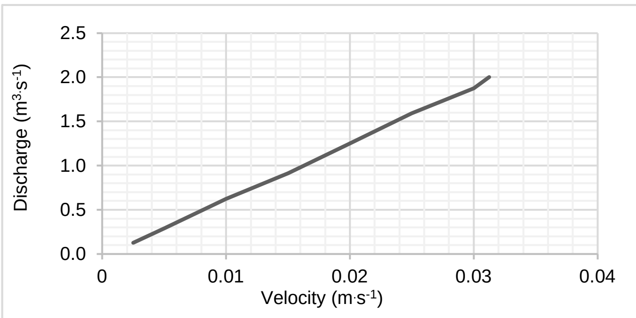

Fig. 16. Relation between velocity and discharge in the canal; source: own study

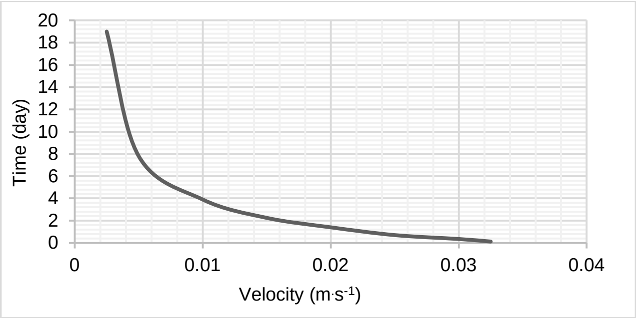

Fig. 17. Relation between velocity in the canal and time needed for water replacement; source: own study

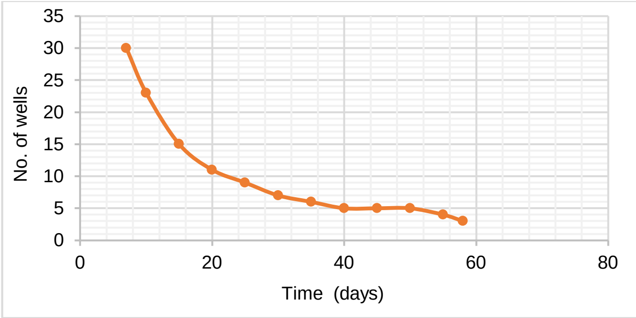

Fig. 18. Relation between the no. of wells and time; source: own study

should using be carried out a water quality mathematical model. The model results will show the dissolving and accumulation of each water quality parameter. Those parameters which may cause any harms for swimmers, will be the main factors when determine the circulation rate.

Water quality modelling for production and injection wells

It is conducting a complete water quality analysis for nine production wells feeding the lagoon and nine injection wells discharging the water from the lagoon in order to perform the treatment inside the lagoon and adjust the percent of chemicals used and infiltration efficiency in the lagoon system. (Fig. 19) represents the water quality analysis for production well No. 5 for pH, HCO_3, total alkalinity, electrical conductivity, total dissolved solids, Ca, and Fe. (Fig. 20) shows analysis of the same parameters for nine injection wells discharging water from the lagoon. The water samples were transported to the laboratory according to international best practices. Laboratory analyses were carried out for nutrients, BOD, TSS, heavy metals, and microbiological parameters according to standard methods [EDWARDS, HEAD 1987; FREEZE, CHERRY 1979; FRIHY *et al.* 2006; HOPNER, LATTEMANN 2002; MORCOS 1970; PANTELL 1993].

Table 1 shows the results of groundwater analyzes at the proposed site, which confirms that groundwater quality is not suitable for drinking or agriculture purposes and the water available in the groundwater reservoir is brackish water (TDS = 38 563 mg·dm^{-3}) This value is well above the Egyptian standards for good water (TDS = 38 563 mg·dm^{-3}) [EWQS 2007].

The groundwater used in the feeding is colorless, odorless, and the average temperature is around 34.5°C and pH 7.3. The salinity concentration is very high in the Red Sea water, reaching about 44 495 mg·dm^{-3} [INFRA – CONSULT 2004; PURNAMA 2003; RAMADAN 2008]. There is no significant difference in salinity between the Red Sea water and groundwater wells at the proposed site to feed

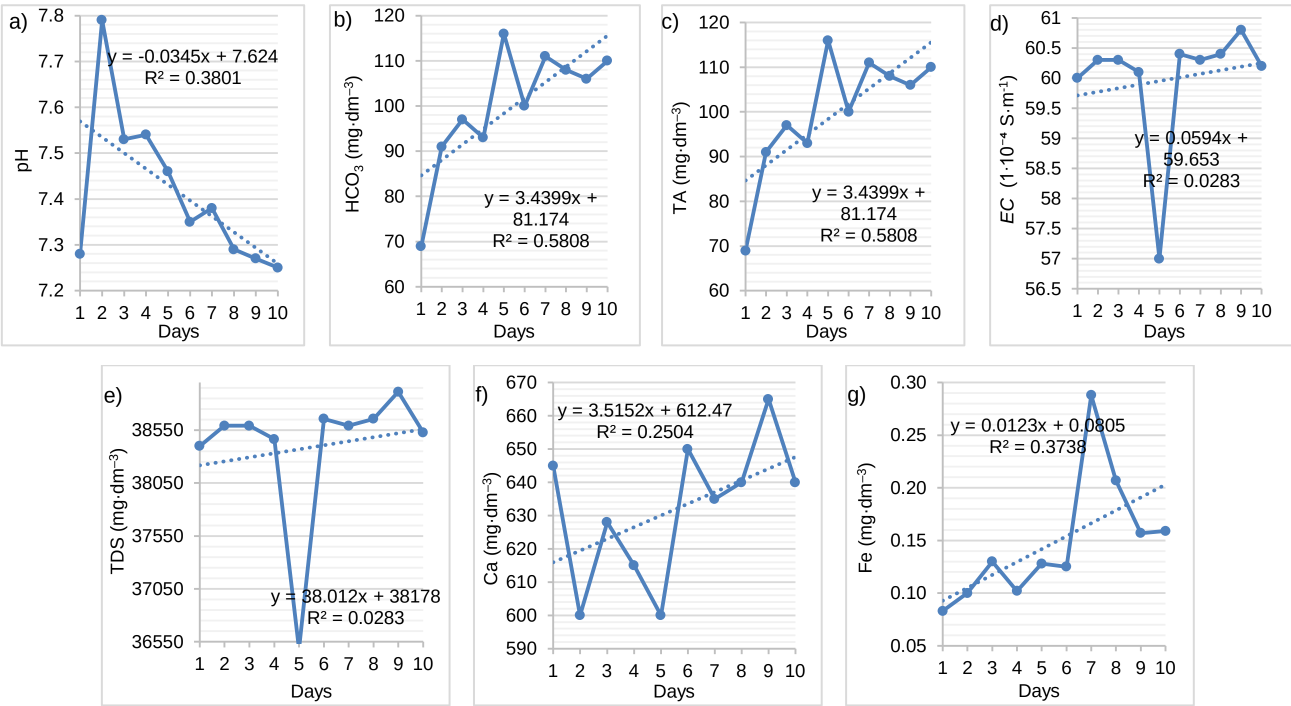

Fig. 19. Water quality analysis for production well No. 5 for chosen physico-chemical parameters: a) pH, b) HCO_3, c) total alkalinity (TA), d) electrical conductivity (*EC*), e) total dissolved solids (TDS), f) Ca, g) Fe; source: own study

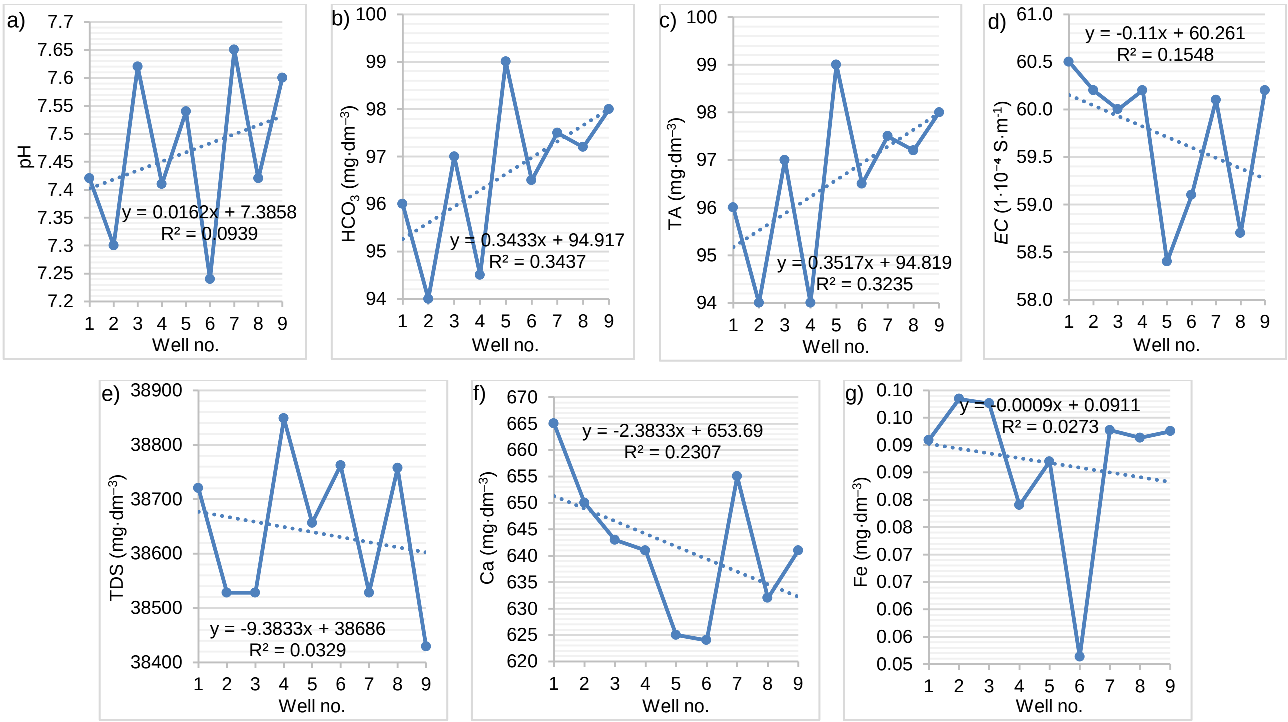

Fig. 20. Analysis of chosen physico-chemical parameters for nine injection wells for the lagoon area: a) pH, b) HCO_3, c) total alkalinity (TA), d) electrical conductivity (*EC*), e) total dissolved solids (TDS), f) Ca, g) Fe; source: own study

Table 1. Reference groundwater quality for the Red Sea waters and Egyptian standards for potable water

Parameter	Measurement unit	Limit value according to EWQS [2007]	Red Sea sample	Average groundwater sample
Ammonia (NH_3)	mg·dm^{-3}	0.5	–	–
Nitrite (NO_2)	mg·dm^{-3}	0.2	–	<0.2
Nitrate (NO_3)	mg·dm^{-3}	45	–	5.53
Turbidity	NTU	1	–	clear
Temperature	°C	33	–	34.5
Total dissolved solids (TDS)	mg·dm^{-3}	1000	44 495	38 563
pH		6.5–8.5	–	7.3
Total hardness ($CaCO_3$)	mg·dm^{-3}	500	131	94
Calcium (Ca)	mg·dm^{-3}	350	512	639
Magnesium (Mg)	mg·dm^{-3}	150	1 535	818
Sodium (Na)	mg·dm^{-3}	200	13 850	11 575
Potassium (K)	mg·dm^{-3}	85	420	296
Chlorides (Cl)	mg·dm^{-3}	250	24 663	19 544
Sulphates (SO_4)	mg·dm^{-3}	250	3 384	2 484
Iron (Fe)	mg·dm^{-3}	0.3	1.3	0.18
Manganese (Mn)	mg·dm^{-3}	0.4	–	0.018
Faecal coliform	unit·(100 cm^3)$^{-1}$	2	–	0

Source: own study.

the lake. The content of manganese and iron is much lower than the standards for safe drinking water and the safe operation of the proposed lake. According to groundwater quality, the only possible use of groundwater on site is to feed the lake rather than direct discharge from the sea that damage the marine ecosystem [UNEP 2001; WHO 2007].

It will conduct a monitoring system to control a huge artificial lagoon with excellent water quality and very low costs. It will cover all aspects of lagoon maintenance needs, including water quality management, bed cleaning, filtration system, and surface cleaning. To achieve good water quality for large artificial water bodies, clarity and transparency, and microbiological and physical chemical properties at a low cost and in an environmentally friendly manner. The obtained water quality easily meets the bacteriological requirements of the (U.S. Environmental Protection Agency, standards for recreational bathing for the entire body). According to the U.S. EPA [1986], in coastal waters, marine waters are exposed to multiple types of uses. Accordingly, basic water quality standards have been defined to follow the top five uses: 1) salt pans, shell fishing, mari culture and ecologically sensitive zone, 2) bathing, contact water sports and commercial fishing, 3) industrial cooling, recreation (non-contact) and aesthetics, 4) harbour, 5) navigation and controlled waste disposal. Lagoon water quality will meet standards for bathing and contact water sports and commercial fishing guideline (Tab. 2).

Table 2. Primary water quality criteria for class SW-II Waters (for bathing, contact water sports and commercial fishing)

Parameter	Standards
pH range	6.5–8.5
Dissolved oxygen	4.0 mg·dm^{-3} or 50 percent saturation value, whichever is higher
Colour and odour	no noticeable colour or offensive odour
Floating matters	nothing obnoxious or detrimental for use purpose
Turbidity	30 NTU (nephelometric turbidity unit)
Faecal coliform	100·(100 cm^3)$^{-1}$ (MPN)
Biochemical oxygen demand (*BOD*) (3 days at 27°C)	3 mg·dm^{-3}

Source: U.S. EPA [1986].

CONCLUSIONS

The construction of a lagoons with this technology are very low cost, a 10,000 m^2 lagoon consumes only 50% of the water needed to maintain a garden of the same size, and a medium sized lagoon consumes about 30 times less than a golf course. In addition, operating costs are very low, due to the efficient use of chemicals and energy. This technology also stands out in its low water consumption, working in a closed circuit, and only needs to replace water lost due to evaporation. As an added advantage, lagoon can capture direct rainwater, which reduces the amount of water needed to compensate for the loss by evaporation, and in some heavy rain sites it is estimated that lagoon can only be refilled with rainwater, without the need for additional waters.

The experiments conducted on the cloud wells confirmed that the safe behavior of these wells ranged from 80–90 $m^3 \cdot s^{-1}$ and that the dynamic decline of the wells ranges between 1–4 m and that the inter-wells between about 100 m and there is no effect on any well the other at the moment.

Experiments conducted on the drainage wells also confirmed that the injection rates for these wells ranged from 25–65 $m^3 \cdot s^{-1}$ and that the amount of rise (recoil) in the depth of water ranges between 7–33 m and that the distances between the wells about 100 m and there is no effect on any other well at this time.

The results of the measurements from the observation well prove that the optimal discharge per each well is 80 $m^3 \cdot h^{-1}$ (0.022 $m^3 \cdot s^{-1}$). This low discharge is needed to keep the salinity and the level of the groundwater, this discharge also allows the operation of the well 24 h daily. The number of wells needed to replace the evaporated water is two wells. The number of wells need to circulate the water in the canal and the lakes depends on:
- the total volume of the lakes,
- the total surface area,
- the bed and surface slope,
- the biological analysis for algy types,
- ground water quality.

Low cost lagoon technology could be an efficient solution with respect to cost and environment especially in coastal areas where water accessibility is rare and reversed osmosis desalination is the only source of fresh water.

Field visits and investigations indicated that the region is completely lacking fresh groundwater and that its presence is limited to salt and brackish water, which is the main source of water for the Gulf waters. Therefore, the entire region relies on desalination of Gulf water or water transported from the Sinai bottom plain.

Hydrography in the area confirms the presence of saline and brackish groundwater in limestone fissures that have direct or indirect contact with the Gulf waters.

Periodical maintenance of the drainage and drainage wells at close intervals in order to maintain the safety of these wells and ensure their long-term safety.

A mathematical model must use to represent the hydrographic conditions of the well and drainage wells to study the hydraulic behavior of the tank under the influence of continuous operation in the long term.

As the lagoon are going to be used in swimming activities, a detailed water quality study is needed. The model results will show the dissolving and accumulation of each water quality parameter.

Although developers often view artificial lagoon as an attractive natural feature economically, they may actually interfere with environmental cycles in the region. The presence of a huge artificial lagoon may affect migratory birds passing through the Sinai this should take into account.

Due to the highly increase in population and insufficient water management, Egypt faces water scarcity, it should develop programs for water desalination to overcome the lack of fresh water with a low cost plus environmental benefits, especially in coastal areas. Renewable desalination systems, and seawater desalination powered by marine renewable energy could be a sustainable alternative solution, especially for coastal cities which are located far from the national water service.

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