INTEGRATED SOLUTION FOR THE WATERLOGGING PROBLEM: A STUDY ON EL- MINYA, EGYPT

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The waterlogging in the low lands is caused by the seepage coming from the cultivation of the neighboring cultivated new high lands. This seepage is due to the unlined surface water canals and the use of flooding irrigation system in both the old and the new cultivated lands. In addition, the existence of clay lenses with shallow depth in the soil zone of the old cultivated lands creates a perched condition leading to a rapid rise in soil water table. The aim of this paper is to embrace an integrated approach to minimize the waterlogging problem in the low lying lands for better crop production.

El-Edwah region in El Minya governorate, is one of the most areas suffering from waterlogging problem. Visual MODFLOW was used to simulate the groundwater system in the Quaternary aquifer trying to mitigate the problem. The model was calibrated for both steady and transient states; three mitigation measures scenarios were applied to solve the waterlogging problem. The three scenarios are; the installation of pumping wells around the waterlogged area, the execution of subsurface drains and the construction of cutoff wall barrier. The results of these scenarios were compared from the groundwater drawdown and the implementation cost point of views. The most efficient scenario was the pumping wells with high drawdown values and low cost, the cut off wall scenario hasn’t any significant observed draw down regardless the cost, and the scenario of subsurface drains has the highest cost. It’s highly recommended to apply the pumping wells as a temporary solution as fast as possible to mitigate waterlogging problem in the suffering areas. For permanent solution for the waterlogging, subsurface drains should be used even though its high cost.
INTRODUCTION

The waterlogging problem has become a severe problem throughout the world. Waterlogging is the condition where the upper boundary of saturated zone i.e. the piezometric surface rises up and reaches into the root zone. The depth of the root zone generally depends on the crop pattern. Usually the depth of the root zone is determined at the level above which 90% of the roots occur. If the piezometric surface exceeds the depth of the root zone, it will influence root development and crop production as it will reduce the aeration zone required for crops growth, Houk et al. 2006.

In Bangladesh, the Teknaf area was subjected to waterlogging due to rain fed flooding. Anisha. N.F et al., 2014 investigated the problem and provided recommendations to minimize its adverse effects. Kaiser M. Fet al., 2013 utilized the waterlogging problem and the management of the drainage deficiency along Wadi EL Tumilate basin in north Eastern Nile Delta of Egypt by integrating GIS and remote sensing data with ground water modelling. Ahmed A. Abd El Monem et al, 2016 use of numerical modeling to predict the impacts of desert development schemes and water resources management schemes on groundwater in west El Minya Governorate. El Bastawesy et al., 2013 recommended that; the geomorphology of closed drainage basins has to be considered when planning for a new cultivation in dry land catchments e.g. the Farafra and Baharia Oases to better control waterlogging hazards. The dry drainage concept can be implemented as the drainage and seepage water can be conveyed through the inactive alluvial channels into certain abandoned playas for evaporation. El Kashouty, 2012 studied the above mentioned problem, where groundwater levels at observation wells were measured to generate groundwater levels profile with respect to ground surface elevation in order to determine groundwater depth below ground surface to determine waterlogged areas. It was concluded that, in the northern part of the study area; from Edwah to Matai village, the groundwater levels are above ground surface elevation which reflects the existence of waterlogging problem.

The previous studies show that there are several reasons for the waterlogging problem such as the drainage deficiency and the soil type that allows the ground water table to rise. In this study the seepage due to the difference in elevations between the cultivated lands is considered.

One of the most benefits from the construction of High Aswan Dam HAD is safeguarding water resources in Egypt for agriculture and other purposes, that encourages the horizontal expansion of the cultivated lands. Before HAD construction, the cultivated area in the Nile valley was about 2 million Feddan, after HAD construction this figure increased by around 750,000 Feddans Attia, 1989. During the last decades more than 1.6 million Feddan of new lands have been reclaimed and cultivated.

Most of the new reclaimed areas are situated in the elevated desert lands, adjacent to the Nile valley. Consequently several parts of old cultivated lands in the Nile valley are subjected to waterlogging problem due to subsurface drainage system in these high elevated lands towards the west and the east. The existence of subsurface faults acting as conduits for water drainage increase groundwater levels in the Quaternary aquifer.

The aim of this research is to study groundwater system in El-Edwah region which is located North of El-Minya governorate and suffer from the waterlogging problem due to the seepage caused by the difference in the cultivated land elevations. The MODFLOW model was applied to detect the most waterlogged areas in EL-Edwah region. Also, it was used to simulate the groundwater aquifer to define the most efficient mitigation measures from groundwater drawdown and the implementation cost point of views.
MATERIALS AND METHODS

The DEM-derived hydrological parameters are integrated with the groundwater modelling in order to determine the relation of waterlogging patterns to the drainage networks, geomorphology and soil properties of the catchments. This is to determine the most suitable remedial action, which should be uniquely compatible with the inherited hydrogeological setting and characteristics of each catchment. In the following sections the location, climate, geomorphology, hydrogeology and hydrology of the study area is well explained.

Study Area

El-Edwah region is located in El-Minya governorate, Egypt, between latitudes 28° 35 30' to 28° 46'37"N and longitudes 30° 38' 53" to 30° 57' 4"E . It extends from El-Edwah to Maghagha city and is bounded by the Nile River from the east and western Desert fringes from the east as shown in Figure 1. The climate is arid to semi-arid, hot climate, dry, rainless in summer and mild to rare in winter. The minimum and maximum temperatures vary from 4.6° C in January to 20.5° C in July and from 20.4° C in January to 37.1° C in June, respectively, while the average temperature ranges from 10° C in January to 27°C in June . The cropping pattern for the project area includes different crops like Clover, Grape, Groundnuts, Maize, Potatoes, Sesame, Sorghum, Soybean, Sugar beet, Sugar cane, Vegetables and Wheat, El Deeb et. al, 2015.

![Figure 1. Location of the Study Area](image)

Geomorphology of the study area

The study area located to the west of the Nile River flood plain, it passes through high eastern and western calcareous plateaus with general slope from South to North of 0.1m/Km Korany et al., 2006 . Nile River covers the eastern portion of its valley making the cultivated areas in the west wider than in the east, Shabana, 2010. The Digital Elevation Model DEM file with resolution 90m x 90m was utilized, the ground level in the low lands gradually vary from 20m to 60 m above mean sea level amsl , while the new high reclaimed lands located at the western side vary from 60m to 140m amsl, as shown in Figure 2.
Hydrogeology of the study area

Generally, the surface and subsurface geologic characteristics have vital importance for detecting the hydrogeological configuration in terms of aquifer characteristics, water potentiality and water movement. The geology of the study area shows that the surface and subsurface are occupied with sedimentary rocks belonging to Tertiary - Quaternary deposits. The surface stratigraphic sequence from top to base is built up from Holocene silt and clay forming the cultivated flood plain where the high sand/clay ratio content of the soil cover of these deposits, especially in the southern area decreases the drainage efficiency and consequently causes a waterlogging problem. Pleistocene sands and gravels forming a narrow strip extending between the flood plain and the valley slopes and the Eocene limestone which is encountered in the subsurface, they form the rocky plateau bounding the valley westwards as shown in Figure 3, Said, 1981.

The subsurface Tertiary stratigraphic sequence in the study area was recorded by Tamer et al. 1974. The Eocene deposits 385 m include Middle and Upper Eocene deposits. The Pliocene deposits include Kom El Shelul Formation and undifferentiated clay, sand and conglomerates. The subsurface Quaternary succession reached about 214m, it is subdivided into Plio-Pleistocene of Old Nilotic deposits with total thickness of 150m, Pleistocene of Old lacustrine deposits and Young Nilotic sediments 5m and 44m, respectively and Holocene section with 15m. The Quaternary deposits are underlain by the impermeable Pliocene clays and/or the Eocene carbonate Tamer et al, 1974 as shown in Figure 3 and Figure 4.

The water resources in the study area are represented in the River Nile, Ibrahimia Canal and Bahr Youssef canal as well as El-Moheet Drain forming the surface water systems, while the Groundwater system falls into two broad categories; aquifers having primary porosity including the Quaternary and the Oligocene-Pleistocene aquifers and consolidated fractured aquifer including the Eocene fractured limestone aquifer. Quaternary aquifer is the main aquifer in the study area. It has a wide areal extension especially in the northern side of the study area. The aquifer is formed of relatively thick formation of the Quaternary deposits that range from 100 m to 130 m, RIGW/IWACO, 1989 and is composed of sands, gravels and alluvial sediments of sand and gravel intercalated with clay lenses. The aquifer is...
Figure 3. Geological Map of the Study Area

Figure 4. Hydrogeological cross-section in E-W direction showing the groundwater aquifer
overlaid by a layer of Holocene Nile silt and sandy clays extending into semi-permeable and impermeable layer. This top layer receives excess water after irrigation of new cultivated lands and seepage from wetted perimeter of irrigation canals and conduits. The thickness of the top Holocene silt and sandy clay layer vary between zero at desert fringes to 16 meters near the River Nile with an average depth of 9-10m as shown in Figure 4. There are hydraulic connections between Quaternary aquifer and the underlying aquifer either by upward or downward flows through the open faults and fractures, taking into consideration that the Eocene rocks are fractured Korany, 1984. The aquifer has high potentiality for storing and transmitting groundwater from the recharge areas to nearby areas. It discharges naturally towards River Nile effluent stream condition, drains and adjacent aquifer systems as it can be detected from the groundwater movement in Figure 5, Gad 2004.

![Figure 5. Piezometric surface contour map and groundwater movement at March 2003 (right map, Gad 2004) and 2012 (El Kashouty et al., 2012 left map).](image)

**Water Table Fluctuation Maps - Resultant map**

The resultant water table map was developed from the observed groundwater levels at years 2003 and 2012 Gad, 2004 and El Kashouty et al., 2012, respectively to determine the vulnerability of the aquifer in the study area to the occurrence of waterlogging. From Figure 6, it can be noticed that; the maximum and minimum observed groundwater fluctuations records are +2.0m near Nile River and -7.5m near cultivated boundaries with total groundwater fluctuation of 9.5m. The minor change in groundwater levels is close to Bahr Youssef canal. The area characterized by zero contour line means that there is no change in the groundwater levels, the area characterized by positive contour lines means that there is an increase in the groundwater levels and exceedance of the probability of waterlogging occurrence. On the other side, the area characterized by negative contour lines means that there is a decrease in groundwater levels and there is no threatening from waterlogging occurrence.

The change in water table means the change in the stored volume of groundwater. If the effective porosity of the subsurface soil is known, the change in groundwater storage over a given period can be expressed as:

\[
\Delta S = \mu \Delta h
\]
where, $\Delta S$ is the change in storage of groundwater over a given period and per unit of horizontal surface area $m^3$, $\mu$ is the effective porosity of the soil dimensionless and $\Delta h$ is the change in water table elevation over the given period $m$.

Figure 6. Resultant map showing annual fluctuations of groundwater level 2003-2012

The resultant water table map was developed from the observed groundwater levels at years 2003 and 2012 Gad, 2004 and El Kashouty et al., 2012, respectively to determine the vulnerability of the aquifer in the study area to the occurrence of waterlogging. From Figure 6, it can be noticed that; the maximum and minimum observed groundwater fluctuations records are $+2.0m$ near Nile River and $-7.5m$ near cultivated boundaries with total groundwater fluctuation of $9.5m$. The minor change in groundwater levels is close to Bahr Youssef canal. The area characterized by zero contour line means that there is no change in the groundwater levels, the area characterized by positive contour lines means that there is an increase in the groundwater levels and exceedance of the probability of waterlogging occurrence. On the other side, the area characterized by negative contour lines means that there is a decrease in groundwater levels and there is no threatening from waterlogging occurrence.

Visual MODFLOW Model Set Up

MODFLOW was applied to calibrate the physical parameters to define the flow mechanism, and the initial conditions for flow were evaluated accordingly. The model describes the groundwater flow of constant density under non-equilibrium conditions in a heterogeneous and anisotropic medium according to the following equation Bear, 1979 and Bear & Verruijt 1987:

$$
\frac{\partial}{\partial x} \left( K_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left( K_{yy} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left( K_{zz} \frac{\partial h}{\partial z} \right) - W = S_s \frac{\partial h}{\partial t}
$$

(2)
where $K_{xx}, K_{yy}, K_{zz}$ are values of hydraulic conductivity along the x, y and z coordinate axes $LT^{-1}$; $h$ is the piezometric head $L$; $W$ is a volumetric flux per unit volume and represents sources and/or sinks of water $T^{-1}$; $S_s$ is the specific storage of the porous material $L^{-1}$ and $t$ is time $T$.

The Quaternary aquifer hydraulic parameters such as hydraulic conductivity, specific yield, specific storage, transmissivity and storativity which were taken from previous studies Korany, et al. 2006, Gad, 2007, Ibrahim, 2007, El Kashouty, et al. 2012, and Dawoud, et al. 2013 are presented in Table 1.

Table 1. Aquifer characteristics after different authors

<table>
<thead>
<tr>
<th>Hydraulic parameter</th>
<th>upper Holocene deposits</th>
<th>Quaternary aquifer</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_{xx}, K_{yy}$</td>
<td>0.07 - 0.2 m/day</td>
<td>100 - 200 m/day</td>
</tr>
<tr>
<td>$K_z$</td>
<td>0.007 - 0.02 m/day</td>
<td>10 - 20 m/day</td>
</tr>
<tr>
<td>Specific yield $S_y$</td>
<td>0.04</td>
<td>0.15</td>
</tr>
<tr>
<td>Specific storage $S_s$</td>
<td>0.00011 1/m</td>
<td>0.001 1/m</td>
</tr>
<tr>
<td>Porosity</td>
<td>0.3</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Conceptual model of the studied aquifer

Generally, success of a numerical model depends upon the approximation of the conceptual model to the reality. Conceptual model must include all the sources and sinks, different hydrogeological units with their areal extent and thickness and the boundaries of the problem domain. The model is composed of two layers; Quaternary aquifer layer with 75m thickness overlaid by the Holocene layer with 17m thickness Tamer et al., 1974. The two layers are hydraulically connected and vertically homogeneous so it is considered as a single layer.

The sources of water to the conceptual model are the infiltration from rainfall with an estimated value of 23.5 mm/year, Ismail et al, 2015 and the seepage from the irrigation process and it is taken into consideration through western boundary condition. The sinks are the evapotranspiration which estimated to be 1077.12 mm/year, Ahmed, 2009; and the discharge from pumping wells located in the study area for irrigation purpose with an average extraction rate of 600 m$^3$/day Gad 2004 as shown in Figure 7.

Based on the resultant map shown in Figure 6, the model domain of the water logged area reaches about 5240 Feddans in El-Edwah region. It is divided into 100 columns and 100 rows with cell area of 40*50 m$^2$ as shown in Figure 7.

The hydraulic boundaries specified in the modeled area are; Nile River in the eastern side as a constant head boundary and the zero contour line extracted from the resultant map in the western side as a general head boundary Figure 7.

Model Calibration

Due to the limited availability of groundwater level measurements, the steady state calibration was run based on the observed groundwater levels at year 2003 Figure 5 and the data of seven observation wells distributed in the model domain Gad, 2004.
Figure 7. Model domain and boundary conditions of the study area

In steady state calibration, the dominant factor is the hydraulic conductivity, where the adjustment of its value was done until the calculated heads from the model match the measured head values as represented in Table 2.

In transient calibration, the model allows to run in the period from year 2003 to year 2012. Storage coefficient was the dominant factor in the calibration process. Its values were adjusted by trial and error till reaching a good agreement between observed and calculated groundwater level, as presented in Table 3.

Table 2. The final difference between measured and calculated heads at steady state calibration

<table>
<thead>
<tr>
<th>Observation well no.</th>
<th>Coordinates</th>
<th>Heads</th>
<th>Difference m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>Y</td>
<td>Measured</td>
</tr>
<tr>
<td>Ob1</td>
<td>3173366</td>
<td>285071.2</td>
<td>29.00</td>
</tr>
<tr>
<td>Ob2</td>
<td>3174150</td>
<td>280628.9</td>
<td>30.00</td>
</tr>
<tr>
<td>Ob3</td>
<td>3180863</td>
<td>289042.9</td>
<td>29.00</td>
</tr>
<tr>
<td>Ob4</td>
<td>3178860</td>
<td>273463.8</td>
<td>36.00</td>
</tr>
<tr>
<td>Ob5</td>
<td>3174920</td>
<td>272295.2</td>
<td>34.00</td>
</tr>
<tr>
<td>Ob6</td>
<td>3169054</td>
<td>284662.6</td>
<td>29.00</td>
</tr>
<tr>
<td>Ob7</td>
<td>3169388</td>
<td>280236.2</td>
<td>30.00</td>
</tr>
</tbody>
</table>

Table 3. The final difference between measured and calculated heads at transient calibration

<table>
<thead>
<tr>
<th>Observation well no.</th>
<th>Heads</th>
<th>Difference m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured</td>
<td>Calculated</td>
</tr>
<tr>
<td>Ob1</td>
<td>30</td>
<td>30.09</td>
</tr>
<tr>
<td>Ob2</td>
<td>31.00</td>
<td>30.88</td>
</tr>
<tr>
<td>Ob3</td>
<td>31.50</td>
<td>31.46</td>
</tr>
<tr>
<td>Ob4</td>
<td>32.00</td>
<td>32.04</td>
</tr>
<tr>
<td>Ob5</td>
<td>32.00</td>
<td>32.13</td>
</tr>
</tbody>
</table>
The water depth contour map was extracted from mathematical model to determine the regions suffering from waterlogging as shown in Figure 8.

![Figure 8. Depth to Water contour map extracted from the model in m](image)

Mitigation Measures Scenarios

Mitigation measures scenarios of waterlogging problem used in previous works relating to the study area are based on surface/subsurface drainage, pumping wells and biological farms. They assume the homogeneity of the Quaternary aquifer. In this research, heterogeneity of Quaternary aquifer is considered.

The suggested mitigation measures scenarios invoked by the model are; the installation of pumping wells around the waterlogged area, the execution of subsurface drains, and the construction of cutoff wall barrier. The efficiency of each scenario in decreasing groundwater levels was tested through four proposed observation wells as shown in Figure 9.

The first scenario distributes nineteen pumping wells around the waterlogged area in order to lower groundwater levels below ground surface. It is assumed that the discharge rate from each well is 150 m³/hr, 24-working hours per day and The pumping wells are penetrating the Holocene layer to the Quaternary aquifer and the pumped water will be drained into nearest water body in the area, as shown in Figure 10.

The second scenario consists of two subsurface drains perpendicular to groundwater flow in order to lower groundwater levels in the modeled area. The location of these drains were chosen in the unurbanized area. After many trials for adjusting drain levels, the selected drains were 9-10 m below ground surface in the Holocene aquifer with assumed conductance of 90000m²/day, as shown in Figure 11.
To determine the amount of water discharged into the subsurface drain, zone budget analysis has been run. This zone budget analysis shows that the amount of water discharged into the subsurface drains after 300 day is equal to $56431\text{ m}^3/\text{day}$ it is recommended to drain towards the nearest surface water body.

The diameter of the drainage pipe was taken 0.60 m and is determined using Manning Equation as follow

$$Q = \frac{1}{n} * S^{0.5} * R^{2/3} * A \quad (3)$$

Where, $Q$ is the discharge passing through the pipe, $n$ is Manning’s coefficient, $S$ is the longitudinal slope, $A$ is the cross section area of the drainage pipe and $R$ is the hydraulic radius = Area of pipe/Perimeter of pipe.

The third scenario consists of a cutoff wall barrier perpendicular to groundwater flow direction in order to change the direction of groundwater flow. The suggested cutoff wall, assumed to have a thickness of 0.3m until it reaches the end of the Holocene aquifer layer with average depth 20m, as shown in Figure 12.
RESULTS AND DISCUSSION

The results of the three scenarios after a period of 300 days are shown in Figure 13, where in the first scenario, the decline of the groundwater levels in the modeled area is varying between 1.22m and 1.80m at Ob4 and Ob2, respectively. The drawdown values seem to be acceptable taking into consideration the safe aeration root zone for cultivated lands. While for the second scenario the drawdown values reach a least value of 0.78 m at Ob2 and a highest value of 1.37m at Ob3. The drawdown results also satisfy the safe aeration root zone. From Figure 14, it can be seen that the drawdown values resulting from the first scenario are relatively higher than the resulting drawdown of the second scenario. This may be attributed to the relatively high hydraulic conductivity in the Quaternary aquifer which consists mainly of sand and gravel in this area. On the other hand, the proposed subsurface drains are embedded in the Holocene layer which consists of silt and clay with low hydraulic conductivity that affects the groundwater flow towards the drains.

Running the third mitigation scenario on the water logged area achieved minor drawdown values when compared to the previous scenarios. The results of the last scenario proved that the waterlogging phenomena in the study is not only from the horizontal movement of shallow groundwater drained from the new reclaimed lands, but also from the vertical infiltration of irrigation water of these new reclaimed lands deeply to the Quaternary aquifer and then, the rise to the ground surface of the old cultivated lands Brikowski and Faid 2006. The cutoff wall which is the concept of this scenario penetrated only the Holocene layer. The drawdown was achieved only at Ob1 with value of 0.25m, while in the three observation points; the water levels are still above the ground surface. This may be referred to the fact that, the embedded cut wall depth which is not enough to affect groundwater direction. The rising of groundwater level in this scenario is due to existence of the barrier with very low hydraulic conductivity which acts as an obstacle in the way of the subsurface water. From the above explanation there is no effect of this scenario on decreasing groundwater levels.

Figure 13. Groundwater levels for water logged area after 300 days for different scenarios.

Cost Estimation of the Proposed Scenarios

The estimated cost for the different measures of each scenario is calculated, as follow:

In the 1st scenario, the cost per pumping well is 153990 L.E, and as the pumping system consists of 19 wells, then the total estimated cost is 2.92x10^6 L.E. as presented in Tables 4 and 5. Cost of the
Figure 14. Drawdown in observation wells for each scenario.

Pumping well has been increased by 3 times due to dollar price rising against the Egyptian pound. [http://omrasad.blogspot.com.eg/2015/06/blog-post_27.html](http://omrasad.blogspot.com.eg/2015/06/blog-post_27.html).

In the 2\textsuperscript{nd} scenario, the cost for sub-surface drains execution is about 5.3 \times 10^6 L.E. as presented in Table 6. [https://www.facebook.com/permalink.php?id=283005178506164&story_fbid=323204214486260](https://www.facebook.com/permalink.php?id=283005178506164&story_fbid=323204214486260).

In the 3\textsuperscript{rd} scenario the construction cost of the cutoff wall barrier concrete pile wall is about 2.88 \times 10^6 L.E. As presented in Table 7. [http://engmuslim1.blogspot.com.eg/2014/12/2015.html](http://engmuslim1.blogspot.com.eg/2014/12/2015.html).

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit Price L.E</th>
<th>Unit</th>
<th>Total Price L.E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of excavation/m</td>
<td>130</td>
<td>30 m</td>
<td>3900</td>
</tr>
<tr>
<td>Cost of steel pipes of execution</td>
<td>140</td>
<td>30 m</td>
<td>4200</td>
</tr>
<tr>
<td>Well face</td>
<td>1000</td>
<td>--</td>
<td>1000</td>
</tr>
<tr>
<td>Delivery pipes</td>
<td>150</td>
<td>28 m</td>
<td>4200</td>
</tr>
<tr>
<td>Electric cable</td>
<td>95</td>
<td>29 m</td>
<td>4180</td>
</tr>
<tr>
<td>Submersible pump</td>
<td>26000</td>
<td>1</td>
<td>26000</td>
</tr>
<tr>
<td>Fees for one well</td>
<td>2500</td>
<td>1</td>
<td>2500</td>
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Table 4. Cost of items related to each well

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit Price L.E</th>
<th>Unit</th>
<th>Total Price L.E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric generator</td>
<td>95000</td>
<td>1</td>
<td>95000</td>
</tr>
<tr>
<td>Electric unit</td>
<td>5000</td>
<td>1</td>
<td>5000</td>
</tr>
<tr>
<td>Water for ease of execution</td>
<td>500</td>
<td>1</td>
<td>500</td>
</tr>
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</table>

Table 5. Cost of items related to all wells
Table 6. Cost of items related to subsurface drains execution

<table>
<thead>
<tr>
<th>Items</th>
<th>Unit Price L.E</th>
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</thead>
<tbody>
<tr>
<td>Total length of drains m</td>
<td>8800</td>
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<tr>
<td>Cross section area of drain m²</td>
<td>97.2</td>
</tr>
<tr>
<td>Volume of excavation m³</td>
<td>855360</td>
</tr>
<tr>
<td>Cost of 1m of excavation L.E/m³</td>
<td>6</td>
</tr>
<tr>
<td>Total cost of Excavation</td>
<td>5132160</td>
</tr>
<tr>
<td>Cost of pipe L.E/m according to price of EGIC company</td>
<td>20</td>
</tr>
<tr>
<td>Total cost of pipe</td>
<td>176000</td>
</tr>
<tr>
<td>Total cost of drains</td>
<td>5308160</td>
</tr>
</tbody>
</table>

Table 7. Cost of items related to cutoff wall execution

<table>
<thead>
<tr>
<th>Items</th>
<th>Unit Price L.E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of 1m long of the cutoff wall L.E /1m long</td>
<td>385.5</td>
</tr>
<tr>
<td>Length of the proposed cutoff wall m</td>
<td>7480</td>
</tr>
<tr>
<td>Total cost of cutoff wall execution L.E</td>
<td>2883540</td>
</tr>
</tbody>
</table>

Comparisons between the cost of each proposed scenario and the cost of one meter drawdown for each proposed scenario are shown in Figures 15 and 16.

![Figure 15. Comparison between the cost of each proposed scenario](image_url)
From the results of the model and the estimated cost of each scenario, it can be concluded that: -

The first scenario, Pumping wells, is the most effective and economical solution for waterlogging problem in the study area.

• It is worth to mention that the cost of the pipes network required to drain the pumped water to the nearest surface water body in the first scenario is not calculated as well as the maintenance cost of subsurface drains in the second scenario assuming that it is almost the same. The reason for groundwater table rise in the old cultivated lands is not only the lateral seepage from the new cultivated lands but also upward flux from Quaternary aquifer to the top surface layer as a result of infiltration of new cultivated lands irrigation water.

• Even though the pumping well scenario is preferred, using subsurface drainage pipelines is a common practice in Egypt. Based on this fact, the suggested solution to the waterlogging problem in El-Edawah region can be two fold. A temporary solution by using the pumping well system as a temporary and fast solution for the drawdown process to get rid of the excess water and a permanent solution could be to install subsurface pipelines to collect any excess water and eliminate the waterlogging problem.

• This integrated solution for the waterlogging problem by combining the pumping wells and the subsurface drainage pipelines can be generalized considering the suitable design for the pumping wells and the subsurface pipelines for each area suffering from the waterlogging problem.

• Cut-off walls are inefficient in dealing with the waterlogging problem as the flow flux is in both the horizontal and vertical directions at the same time.
• To protect the old cultivated lands located in the Nile Valley from deterioration as a result of groundwater table rise, it is recommended to:

• Transform the irrigation by flooding at any cultivated lands to drip or sprinkle irrigation.

• The installation of surface or sub surface drains around the new cultivated land to collect the excess water before it reaches to the old cultivated lands.

• Applying the pumping wells solution as fast as possible to mitigate waterlogging problem in the study area is a must.

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