Examensarbete
TVVR 09/5009

A groundwater flow model for water related damages on historic monuments

-Case study West Luxor, Egypt

Edgar Herbas Campos

Division of Water Resources Engineering
Department of Building and Environmental Technology
Lund University

Avdelningen för Teknisk Vattenresurslära
TVVR-09/5009
ISSN-1101-9824

A groundwater flow model for water related damages on historic monuments

Case study West Luxor, Egypt

© Edgar Herbas Campos, 2009

Institutionen för Teknisk Vattenresurslära
Lunds Tekniska Högskola, Lunds Universitet

Department of Water Resources Engineering
Faculty of Engineering, Lund University
Box 118
SE-221 00 Lund
Sweden
http://aqua.tvrl.lth.se

ISSN-1101-9824
TVVR-09/5009

Cover: Observation well at Sacred Lake, temple of Medinet Habu in West Luxor.
All photographs by Edgar Herbas, 2005.

Printed in Sweden

Summary

Title: A groundwater flow model for water related damages on historic monuments – Case study West Luxor, Egypt

Author: Edgar Herbas Campos

Supervisor: Associate Professor Rolf Larsson
Head of Department, Water Resources Engineering, Lund University, Sweden.

In 1979 "The Ancient Thebes and its Necropolis" entered in the World Heritage List in a core zone of 7390 ha. Western Thebes holds the remains of about 36 temples in varying degrees of preservation and dating from archaic times (3100 – 2686 B.C.) to the Greco-Roman Period (332 B.C. – 395 A.D.). The temples of Medinet Habu, Ramesseum and Sethos I, are located in the western side of modern Luxor and are of special interest for this project. The Supreme Council of Antiquities (SCA), which belongs to the Ministry of Culture, has the main responsibility for all historical sites in Egypt. Research cooperation between SCA, the Department of Irrigation and Hydraulics at Ain Shams University in Cairo, and the Department of Water Resources Engineering (TVRL) at Lund University, was established as part of SIDA's Swedish research Link program, for the purposes and realization of this project.

Shallow groundwater is an important factor contributing to the deterioration of the Pharaonic monuments in Egypt. After the construction of the Aswan High Dam in the 1970s, the groundwater levels in many places along the River Nile valley have stabilized close to the ground surface (in Western Luxor between 0.5 and 4 m approximately). While the annual amplitude of the Nile was between 7 and 9 m before the High Dam was constructed, the amplitude today is approximately 3.5 m. The corresponding annual amplitudes for the groundwater level at Karnak Temple are approximately 4.5 and 1 m, respectively. The construction of the High Dam also meant that large quantities of water were used for irrigation of agricultural land. Since ancient times, the Nile has deposited layers of fine-grained alluvial soil several meters thick in the valley. The capillary zone of these soil layers reaches the ground surface, and constant transport of salts and water takes place in an upward direction due to evaporation. The result of this is a concentration of salts in the upper soil layers under and near the surface of the temple walls. The crystallization of these salts causes discolouring, and owed to the expansion during crystallization the building material can be crashed and the surfaces deteriorated. This combination of raised groundwater level, large irrigation schemes, and salinization, constitutes the problems encountered at the historic heritage sites.

The main objectives of this research were to investigate the hydrogeological conditions at the West bank temples in order to identify where detailed field data is necessary for the success of a future groundwater model, and to propose engineering measures to lower the groundwater levels by at least 2.5 m, avoiding in this manner deterioration of the monuments caused by evaporation driven salt transport. The principal objective in the methodology was to use the available data to simulate the groundwater flow system in the specific area, using the computer code Modflow, which is an interface to the program GMS (Groundwater Modeling System), version 6.0.

In order to improve the validity of the model, the access to reliable data related to inflows and outflows from the principal internal canals inside the model area is required. With a second set of field data, model verification could be completed and consequently the level of confidence of the model would increase.

Results show that a reduction of irrigation rates over the model area is not sufficient to lower groundwater levels and it has to be combined with other measures, such as pumping and a better management of the internal canals and drainages flows. The fundamental problem is the raised groundwater table due to increased irrigation and reduced water level variations in the Nile, therefore, the most sustainable solution is to change or improve the irrigation systems in the area. Reducing urban and agricultural development impact is also important, and could be attainable with cooperation between local authorities, agencies and ministries.

Keywords: Groundwater, conceptual model, irrigation, GMS 6.0, World Heritage, Luxor, Egypt.

Acknowledgment

I would like to thank my supervisor Associate Professor Rolf Larsson, Head at the division of Water Resources Engineering, Lund University, for his kind assistance during the study visit in Egypt, and during the thesis work at Lunds University in Sweden.

To Dr. Mohamed Nour El Din, Assistant Professor at the Irrigation and Hydraulics department, Faculty of Engineering, Ain Shams University in Cairo, my appreciation and gratitude for his guidance and support during my visit in Egypt.

Also, I express my gratitude to the Supreme Council of Antiquities in Egypt, in particular thanks to Eng. Hany Ibrahem El Sisi for the good cooperation and hospitality.

Finally I want to thank my family and friends for their unconditional support. I would especially like to thank Matilda Ottelid, Andreja Peternelj, Oskar Ljungqvist, Elise Roudier, Benjamin Destinson and Dahlia Hassan.

Edgar Herbas Campos

Malmö, 2009

Table of contents

List of Tables

List of Figures

1 Introduction

1.1 Background

The “Arab Republic of Egypt” is located in the north part of Africa, covering an area of about 1 001 450 square kilometres. It borders Libya to the west, Sudan to the south, the Gaza strip and Israel to the east. The northern coast borders the Mediterranean Sea and the eastern coast borders the Red Sea.

Groundwater has started to play an important role in Egypt and in other arid countries. Dawoud (1997), suggested that in the coming decades the annual extraction is expected to be increased by about 90%, which approximately will be equivalent to the annual recharge rate, estimated to be 4.9 billion m^3.

Due to the continuous growth of population and the needs for food security, the reclamation of new lands for agriculture has started within the desert fringes of the Nile Valley and Delta. This, combined with excessive irrigation, contributes for extensive areas of traditionally cultivated lands in the Nile Valley to become affected by waterlogging and soil salinity (see, for example, Shamrukh, 2001).

Shallow groundwater is an important factor contributing to the deterioration of the Pharaonic monuments in Egypt. After the construction of the Aswan High Dam in the 1970s, the groundwater levels along the River Nile valley have stabilized near to the ground surface (see figure 2.2). The construction of the High Dam also meant that large quantities of water were used for irrigation of agricultural land.

Since ancient times, the Nile has deposited layers of fine-grained alluvial soil several meters thick in the valley. The capillary zone normally reaches the ground surface and continuous transport of salts takes place in an upward direction when water is available from the saturated zone (Høybe, 2005). These facts combined with the water capillary forces, make that shallow groundwater moves upwards where the driving force is the high rate of evaporation at the ground surface and at the surfaces of the monuments themselves. Salts are dissolved in the water and enriched at surfaces, where they crystallize. This causes discolouring, and owed to the expansion during crystallization, the building material can be crashed and the surfaces deteriorated (see figure 1.1).

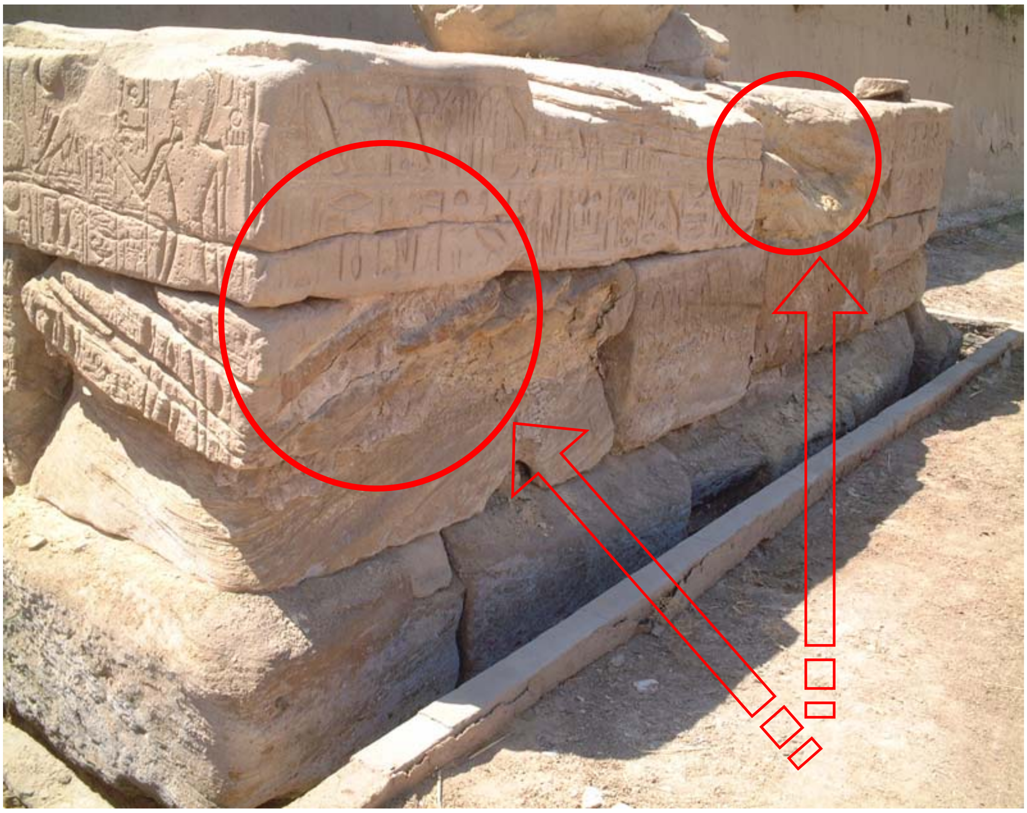


Figure 1.1 *Discolouring and deterioration on the building material of a monument at the first pylon of the Temple of Sethos I (2005).*

The temples of Medinet Habu, Ramesseum and Sethos I (or Sity) are located in the western side of the Nile and the city of Luxor (see Figures 1.2 and 1.3). These three temples are among the Pharaonic monumental sites affected by shallow groundwater levels, and they are of special interest for the present project. According to visual observations during the study visit and personal communication with the Supreme Council of Antiquities representatives in Egypt, sometimes during summer the groundwater level is less than 1 m below the surface in this particular area.

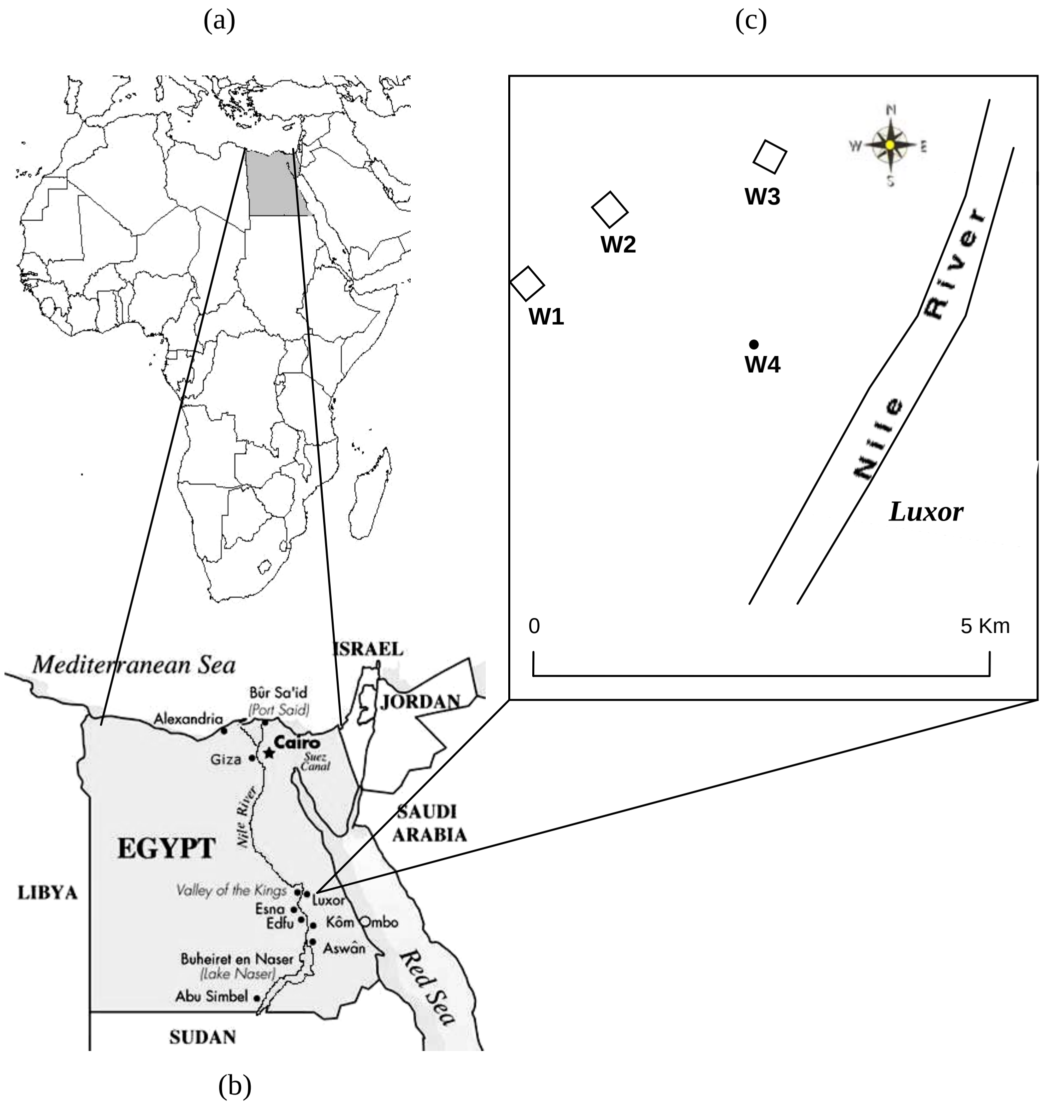


Figure 1.2 *Situation Maps of (a) Africa, (b) Egypt: showing the location of the city of Luxor; and (c) the study area and the observation wells (W) at the three temples, and the fourth one closer to the Nile.*

In 1979, “The Ancient Thebes and its Necropolis” entered in the World Heritage List including the west Luxor temples in a core zone of 7390 Ha (UNESCO, World Heritage, 2008). The Supreme Council of Antiquities (SCA), which belongs to the

Ministry of Culture, has the main responsibility for all historical sites in Egypt. Research cooperation between the Department of Irrigation and Hydraulics (DHI), Ain Shams University in Cairo and the Department of Water Resources Engineering (TVRL) at Lund University, was established as part of SIDA's Swedish research Link program for the purposes and realization of the present project.

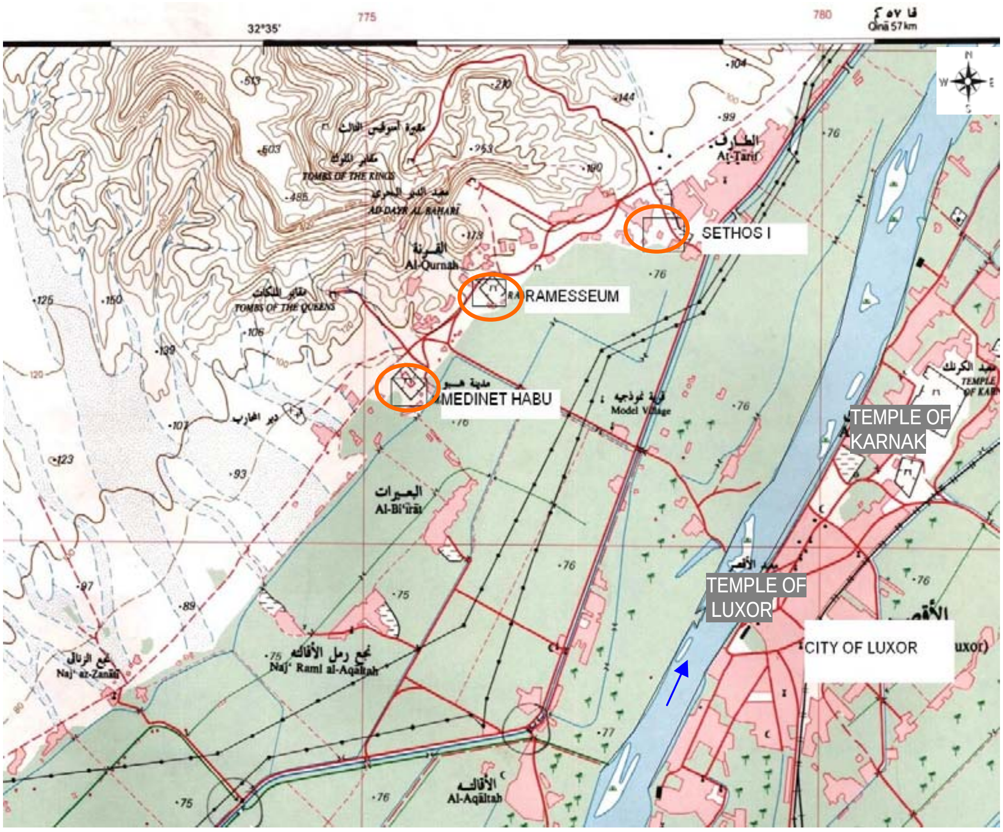


Figure 1.3 *Location of the three Temples of west Luxor: (1) Medinet Habu, (2) Ramesseum and (3) Sethos I, and Temples of Karnak and Luxor at the east side of the Nile (Sheet NG 36 F6a (LUXOR), RIGW, 1997).*

1.2 The temples of Ancient Thebes

The temples of Egypt are without doubt among the most impressive monuments that have survived from the ancient world. Both the east and west banks of the Nile in the area of Luxor represent the site of ancient Thebes. Western Thebes holds the remains of about 36 temples in varying degrees of preservation and dating from archaic times to the Greco-Roman Period. The following are short descriptions presented by Wilkinson (2000) and Siliotti (2002) about the three major temples in the area.

1.2.1 Medinet Habu (Temple 1)

Medinet Habu is a complex of temples in which the most important one is Ramesses III. The main temple itself is considered the best preserved among the mortuary temples of Thebes, containing more than 7,000 m^2 of decorated surfaces across its walls (Siliotti, 2002). The temple is aligned approximately southeast to northwest, but conventionally the southeast side facing the Nile is described as east. Anciently the site was called Djamet by the Egyptians, and according to popular belief its holy ground was the place where the primeval gods where buried. As such, the site was particularly sacred long before the construction of the Ramesses' temples.

Figure 1.4 *Temple (1) Ramesses III at Medinet Habu (2005).*

1.2.2 Ramesseum (Temple 2)

Ramesses the Great (II) began this mortuary temple in the second year of his reign, and completed it 20 years later during the 19th dynasty. A number of original features

Figure 1.5 *Temple (2) Ramesseum (2005).*

were built at this temple, for example the temples pylons were built of stone when up to this time were usually constructed of mud-brick; also, its colossus "*Ozymandias*" was the largest free-standing statue ever made in Egypt. By the 22nd dynasty the complex was already in use as a necropolis for members of the Theban clergy and several princesses were buried there. From the 29th dynasty onwards the Ramesseum was subject to much destruction through the dismantling of its walls, pillars and other features, with many blocks used in the late additions to Medinet Habu.

1.2.3 Sethos I (Temple 3)

It is located south of the hill of Dra Abu el-Naga at the northern end of the line of the temples constructed during the New Kingdom, on the western side of the ancient village of Qurna, being known in this way as the "Qurna temple". The sand-stone temple was built first by Sethos and completed by his son Ramesseum II. Today the pylons and courts of this temple are largely destroyed, making it seem much less insignificant then it once was.

Figure 1.6 *Temple (3) Sethos I (2005).*

Figure 1.7 *Temple (3) Sethos I. Execution of the first borehole using rotary boring equipment inside the area of the temple, (2005).*

1.3 Research objectives

The main objectives of this research can be summarized as follows:

- To investigate the hydrogeological conditions at the West bank temples in order to identify where detailed field data is necessary for the success of a future groundwater model.
- To propose measures to lower the groundwater levels by 2.5 m and in this way avoid deterioration of the monuments caused by salt transportation through evaporation.

1.4 Research activities

In order to fulfil the mentioned objectives of the study, the following activities were carried out:

1. A study visit to Cairo and Luxor during the summer of 2005, with the support of the Swedish International Development Cooperation Agency (SIDA), The Division of Water Resources Engineering at Lund University in Sweden, The Ain Shams University in Cairo, and the Supreme Council of Antiquities of The Ministry of Culture in Egypt.
2. Collection of grey literature on site; including maps in Arabic and German, photographs, archeological investigations reports and information through personal communication.
3. Review of the available literature relevant for the subject, including previous studies at Karnak and Luxor Temples (See Figure 1.3 for location), executed by the Swedish company SWECO International, (2002).
4. A preliminary site investigation for the west bank of the Nile River in Luxor, carried out by the Egyptian consulting company Amin Loutfi and Associates (A&A), including laboratory activities, execution of borings for observation wells, water elevation readings for four piezometers, a collection of soil samples for testing and a survey work for the area of study.

5. A groundwater monitoring from September 2005 to May 2006, executed by the Egyptian consulting company A&A.
6. A groundwater model setup, using the computer program Groundwater Modeling System (GMS), version 6.0, which includes a graphical interface to the code MODFLOW 2000.

2. General considerations

2.1 Introduction

Modern civilization in Egypt is founded in a rapid agricultural, social and industrial development, and generally, the most dangerous factors affecting the Pharaonic monuments are agriculture, urbanization and tourism (Høybe, 2005).

Groundwater modelling is an important tool that facilitates the comprehension of the hydrogeology of a region. A model is a representation of reality and if properly constructed, can be a valuable predictive tool for management of groundwater resources. The validity of the predictions will depend on how well the model approximates field conditions. Good field data are essential when using a model for predictive purposes, however, an attempt to model a system with inadequate field data can also be instructive as it may serve to identify that area where detailed field data are criteria to the success of the model (Herbert, 1982). In this manner, a model can guide data collection activities.

This chapter gives a short description of some of the available literature related to this project, and some of the physical processes and environmental conditions related to the causes of the groundwater problem.

2.2 Previous studies in the area

According to the general information available, the hydrological regime in the Nile valley was changed considerably after the construction of the High Aswan Dam (HAD) in 1970 (Abu-Zeid, 1997). The construction of the dam made it possible to control the water levels of the river and the canals, and in this way achieve the most favourable conditions for irrigation. Høybe (2002) presents in the figure 2.1 how the groundwater regime in the area has changed during time.

The difference between the groundwater level before and after the intensive regulation and irrigation is indicated in figure 2.1, meaning that the water level was increased considerably (2-3 m) in the period March to September, providing a surplus of water which in turn is evaporated during warm seasons.

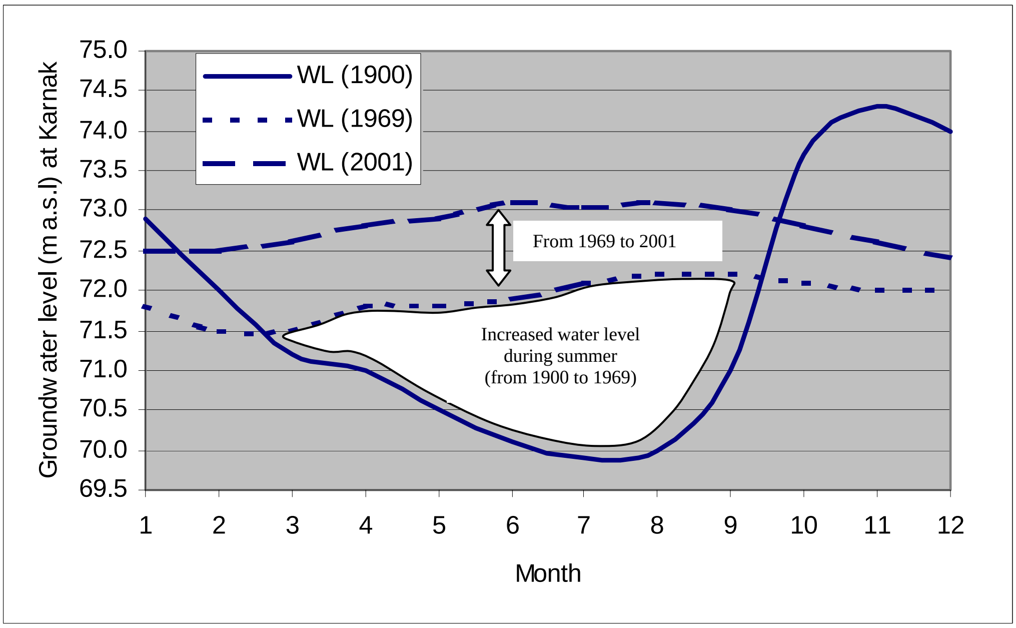


Figure 2.1 *Change in groundwater regime (well 31 at Karnak).*

Traunecker (1970, 1971 and 1975) installed approximately 20 groundwater observation wells at Karnak and measured groundwater levels in these and some old wells for a total time of more than 2 years. This information was utilized in the project for the Salvation of Karnak and Luxor Temples executed by SWECO INTERNATIONAL (2002). The Salvation project included several field investigations similar to water level observations, pumping tests, water quality analysis, settlement observations, surveying and mapping, groundwater modelling including calibration and validation processes.

In 1997 the Egyptian Research Institute for Ground Water (RIGW, 1997) performed a study of the problem with shallow groundwater at Karnak. This study included field investigations (surveying, drilling of groundwater observation wells, geoelectrical investigations and water samples). The RIGW produced Topographical and Hydrogeological Maps for Luxor.

In 2001 Shamrukh and others, presented a study with some of the hydrogeological conditions in Tahta, a region situated about 200 km north from Luxor. These conditions were basically based on the studies executed by the RIGW.

2.3 Deterioration of the monuments caused by shallow groundwater

The description below is mainly based on reports by SWECO INTERNATIONAL (2002), Rolf Larsson's Travel Report, (2005) and personal communication with local representatives during the study visit.

2.3.1 Capillary rise and transport of water-soluble salts

Capillary transport of salts and salts crystallization are considered the main cause of material degradation of the monuments. The capillary zone in the Nile valley normally reaches the ground surface. The temporally fluctuations of the ground water table were much higher before the construction of the High Dam than what they are today, but the upward capillary transport from the groundwater table to the monuments took place only during certain periods of the year at most locations. Today, the average water levels in the Nile are more or less continuous, and so is the capillary transport.

However, the conditions vary due to local heterogeneities. Usually the upper soil layer consists of silt and clay where the capillary rise is several meters high.

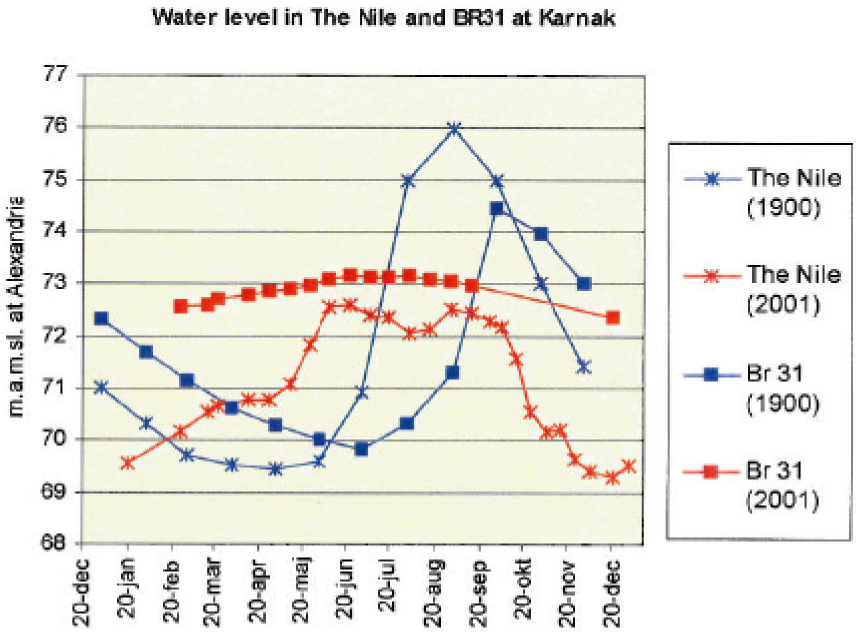


Figure 2.2 *Water Levels in the Nile and borehole 31 at Karnak temple from years 1900 and 2001. The ground surface at borehole 31 has an elevation of 74.6 m.a.s.l. at Alexandria (SWECO Report, Appendix 6.1, 2002).*

2.3.2 Salt Weathering

The groundwater in the area contains very hygroscopic water-soluble salts. During the crystallization of the salts, which are dissolved in the evaporating water, the volume increases comparing to the fluid phase. The grade of weathering varies depending on the type of salts and their water-absorbing properties, meaning that some salts may cause more pronounced weathering than others.

3 Methodology

The principal objective in the methodology is to use the available and useful data to simulate the groundwater flow system in the specific area, with the aid of the computer program GMS (Groundwater Modelling System), version 6.0.

3.1 Groundwater Flow Models

In studying a ground water flow system, we develop a conceptual model which is static. It describes the present condition of a system. To make predictions of future behaviour, it is necessary to have some kind of dynamic model. There are many types of dynamic models of ground water flow; they include physical scale models, analogue models, and mathematical models (see, for example, Fetter 2001).

A mathematical model is based on the equations of groundwater flow, heat flow and mass transport. The simplest mathematical model of groundwater flow is Darcy's law, which is an example of an analytical model. To solve an analytical model we need to know the initial and boundary conditions of the flow problem. These are described in more detail in the next section 4.

3.1.1 Ground-Water Flow Equation

The partial-differential equation of ground-water flow used in MODFLOW is

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_s\frac{\partial h}{\partial t} \qquad (3.1)$$

where Kxx, Kyy, and Kzz are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity (L/T);

h is the potentiometric head (L);

W is a volumetric flux per unit volume representing sources and/or sinks of water, with $W<0.0$ for flow out of the ground-water system, and $W>0.0$ for flow in (1/T);

Ss is the specific storage of the porous material (1/L); and

t is time (T).

Equation (3.1), when combined with boundary and initial conditions, describes transient three-dimensional ground-water flow in a heterogeneous and anisotropic medium, provided that the principal axes of hydraulic conductivity are aligned with the coordinate directions.

The equation (3.1) is solved using the finite-difference method in which the groundwater flow system is divided into a grid of cells (fig. 3.1). For each cell, there is a single point, at which head is calculated.

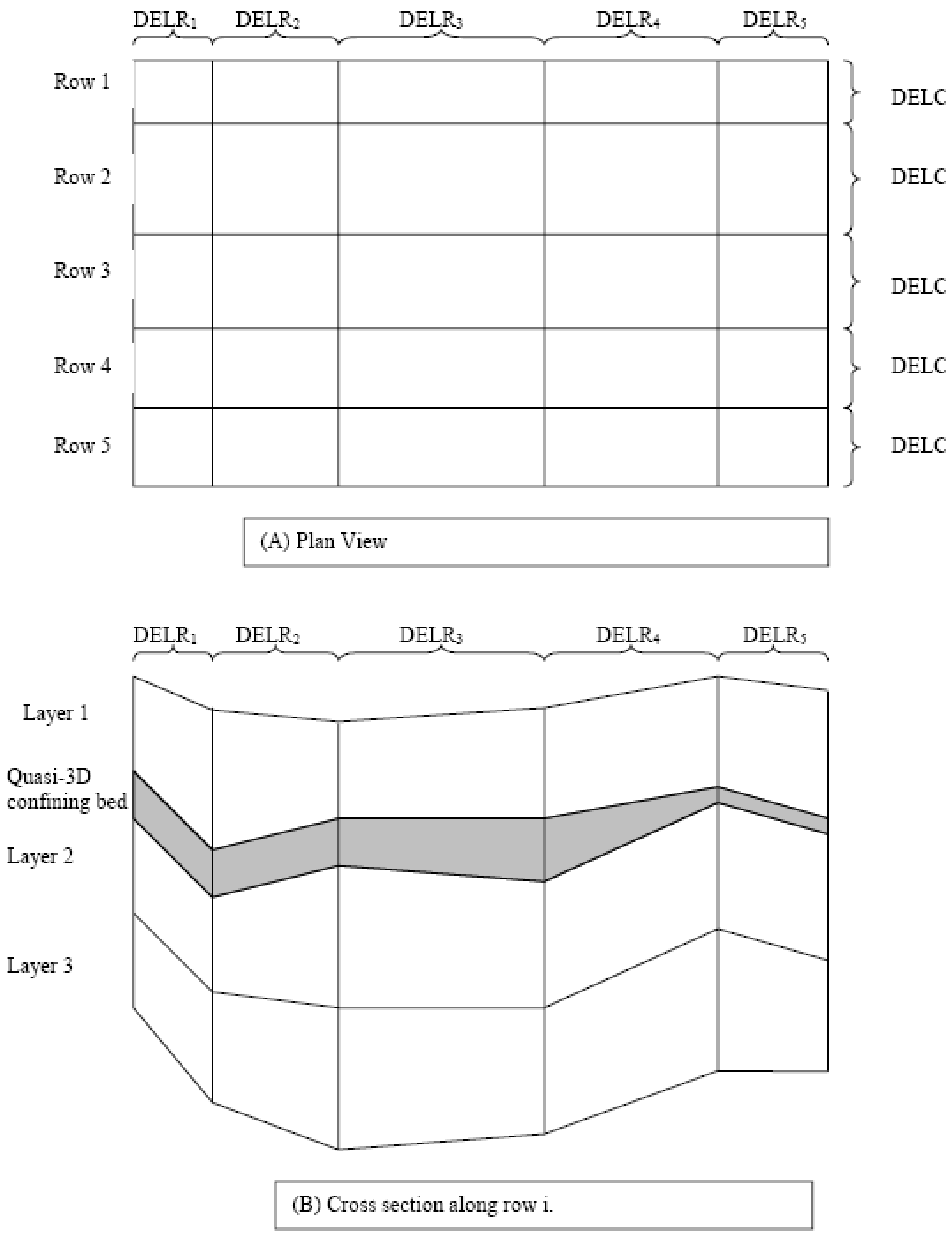


Figure 3.1 *Finite-difference grid with (A) plan view and (B) cross-section view, for a general example (MODFLOW Manual, 2002).*

3.2 Field investigation

3.2.1 Introduction

Many studies have been performed at the Luxor region (see section 2.2 for details), principally for the east side of the Nile River. In 1997, the Research Institute of Groundwater performed a study of the problem with shallow groundwater at Karnak. This study included field investigations as surveying, drilling of groundwater observation wells, water sampling and geoelectrical investigations which in turn led to the production of hydrogeological maps that provided important hydrogeological information for the present work. However, supplementary field investigations were necessary and the following is a summary of the preliminary site investigation factual report: “Salvation of Ramisium, Habu and Sity [Sethos I] temples, Luxor city – West bank”, dated on October/2005 and executed by the Egyptian company A&A Engineers and Consultants. The entire report is presented in the appendix section.

3.2.2 Objectives

The objectives of the supplementary field investigations were to:

- collect more information about the stratigraphy of the area
- get a better understanding of the groundwater flow and groundwater levels
- analyze the groundwater quality and relate it to possible recharge sources and salt concentrations
- localize groundwater observation point wells
- monitor groundwater level fluctuations for the analysis and presentation of the results.

3.2.3 Scope of the works

The activities performed included laboratory work, execution of borings, collection of water elevation readings for all piezometers, collection of soil samples for testing, and it is presented in the factual report (Appendix 3).

Drilling and soil sampling

1. Drilling of 4 groundwater observation wells; three of them in the interior of each temple area, and a forth one close to the centre of the model area and to the Nile River.

2. Soil sampling, both disturbed and undisturbed

Laboratory soil testing for:

- Denomination
- Water content
- Grain size distribution
- Atterberg limits
- Shrinkage limits

The descriptions of these parameters are explained in more detail in the factual report, (Appendix 3).

3.2.4 Water sampling and analysis

The chemical analysis of groundwater gave the results showed in Table 3.1. The results of the chemical analysis show the difference between the salinity values for boreholes 3 and 4 (close to the Nile River) and for those located more to the west side (far from the Nile River), properly boreholes 1 and 2, with higher values.

3.2.5 Mapping and survey

A topographic study for the model area was carried out by the Egyptian company A&A and presented in a digital CAD format in March 2006. Ground elevation measurements were taken every 20 to 25 meters along some of the principal avenues and streets inside the modelling area. However, in order to facilitate the triangulation for the ground elevations when using the GMS program, so called “scatter points” were marked outside the principal avenues, inside the irrigated land areas and even outside of the modelling area. This feature was completed using information from the topographical maps of Luxor region (both in digital and paper formats) and also using the computer program Google Earth (see figure 3.2 and 3.3).

Table 3.1 *Results of the chemical analysis performed on soil samples during November, 2005.*

Chemical Compounds (% in weight)	*Temple of Medinet Habu*	*Temple of Ramesseum*	*Temple of Sethos I*	*Close to Nile River*	
	Borehole 1	Borehole 2	Borehole 3	Borehole 4	*Average*
Total mineral soluble salts	0,6	0,64	0,47	0,5	*0,55*
Salinity as NaCl	0,35	0,33	0,25	0,29	*0,31*
Sulphate as SO_3	0,18	0,19	0,13	0,14	*0,16*
pH value	*7,2*	*7,15*	*7,15*	*7,1*	*7,15*
Depth of sample/surface	3 m	2 m	2 m	3 m	

Figure 3.2 (a) *Topographical elevation points in the modelling area: A 3-dimensional view of the Luxor region, the Temple of Luxor at the east side of the Nile River and the three temples at the west side, close to the mountainous area (from Google Earth, 2006).*

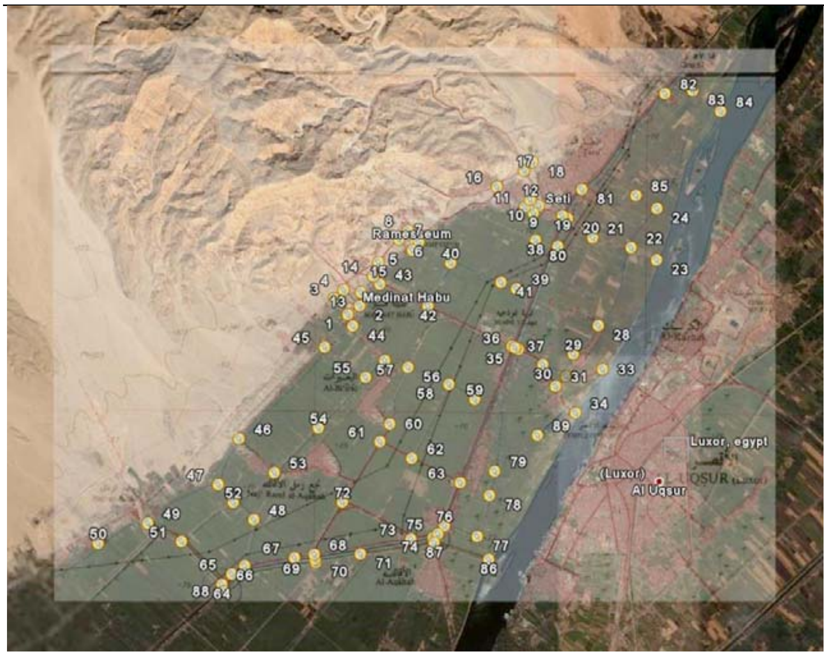


Figure 3.2 (b) *Topographical map of Luxor superimposed over the aerial zone of Luxor region (from Google Earth, 2006).*

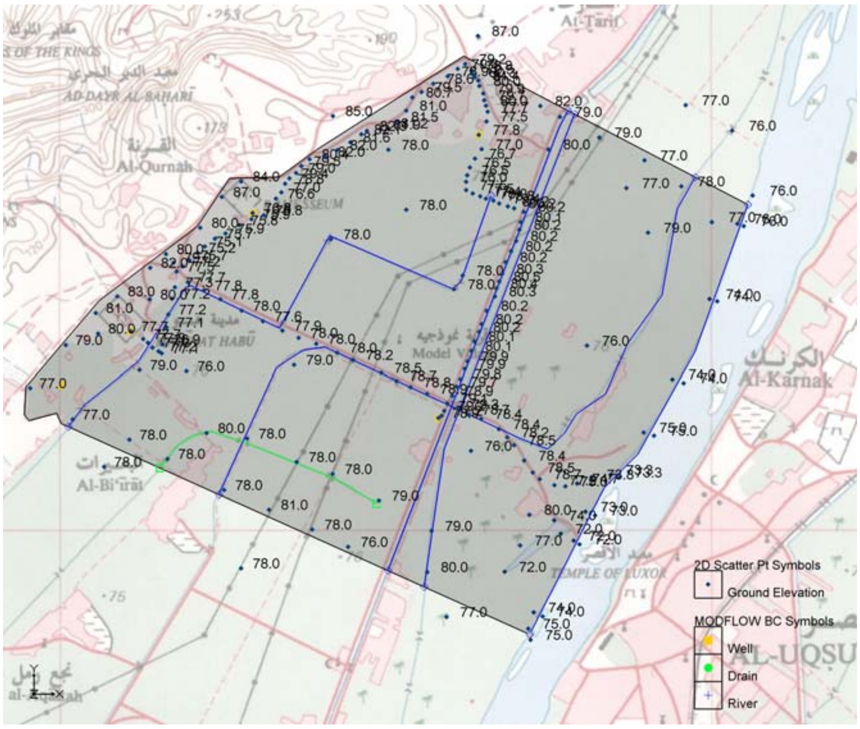


Figure 3.3 *Topographical ground elevation points in the modelling area, from the GMS program.*

The topographical study was performed principally to have the possibility to refer groundwater depth measurements to the mean sea level.

3.2.6 Groundwater monitoring and general Results

The groundwater monitoring works started on the 25th of September 2005 and the readings were taken every 10 to 15 days, for a period of approximately 6 months.

For an average terrain elevation of 78 m for the piezometers, the depth of the groundwater fluctuated between 4 m for well number 4 (near Nile River) and 0.80 m for well number 2 (Ramesseum Temple), respectively. Piezometer readings were left out at Ramesseum Temple from December 2005 until the end of the monitoring, due to unknown reasons (see figure 3.4).

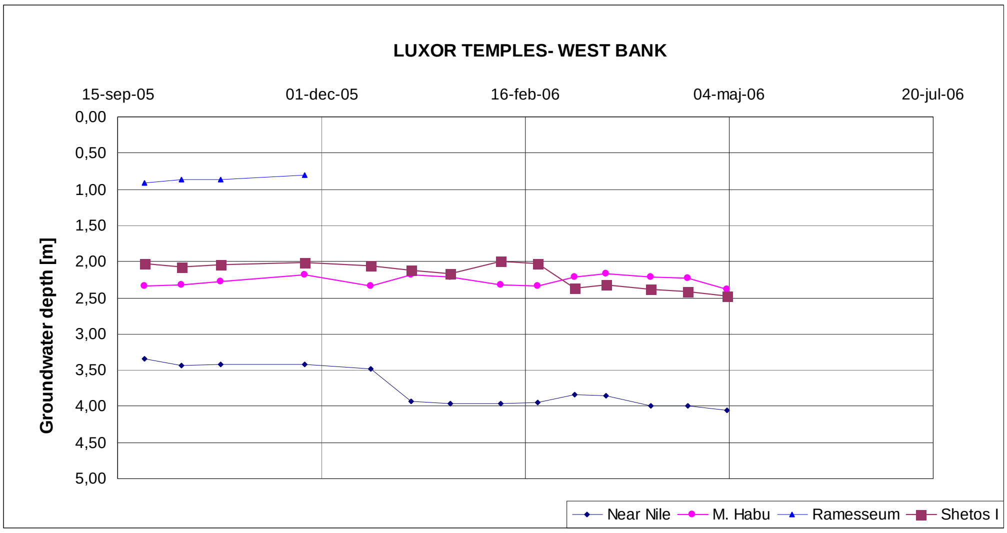


Figure 3.4 *Water Levels for piezometers from September 2005 to May 2006 (A&A Report, March, 2006).*

3.3 Hydrogeological Setting of the Study Area

The geological and hydrogeological conditions prevailing in the West Luxor region are presented in this section. The information is based on earlier studies and on the field investigation presented in section 3.2 and appendix 3.

3.3.1. Location and Topography

The area is located in west Luxor, between latitude 25.44’ and longitude 32.37’, approximately 4 Km North West from Karnak Temple (RIGW, sheet NG 36F6a, Al-Uqsur, Luxor).

The cultivated area extends from the Nile River to the temples of Medinet Habu and Ramesseum, where the area is divided principally by the Asfün Canal (see Figure 1.3).

3.3.2 Geology and Hydrogeology of the Study Area

The general geology of the study area is shown in Figure 3.5.

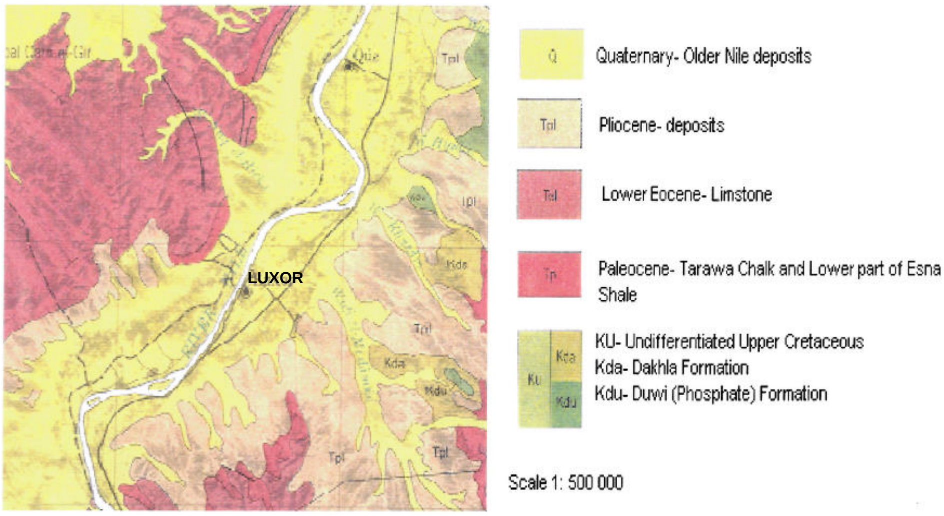


Figure 3.5 *Geological Map of the Luxor Area (Egyptian Geological Survey and Mining Authority, 1978).*

The stratigraphy in the Nile valley begins at the bottom with the Nubian Sandstone; secondly the Lower Eocene limestone that forms the hills at the sides of the valley, underlying the Pliocene Clay that extends to the slope of the limestone. Next we find the sand and gravel deposits of the Late Pleistocene, with a thickness of approximately 40 m in the study area (RIGW, 1997). At the bottom there are the Holocene deposits consisting of silt and clay with inter-bedded layers of sand and gravel. The thickness of these deposits varies between 0 (they disappear at the outer fringes of the valley) and 20 m.

The hydrogeological map of the Luxor area is shown in figure 3.6. According to this map, the aquifers are classified as highly productive, highly to moderated, low and non -productive aquifers. The main aquifer is formed by the Late Pleistocene (Q1) sand and gravel (see cross section A-A’ in Figure 3.7, and Figure 3.8).

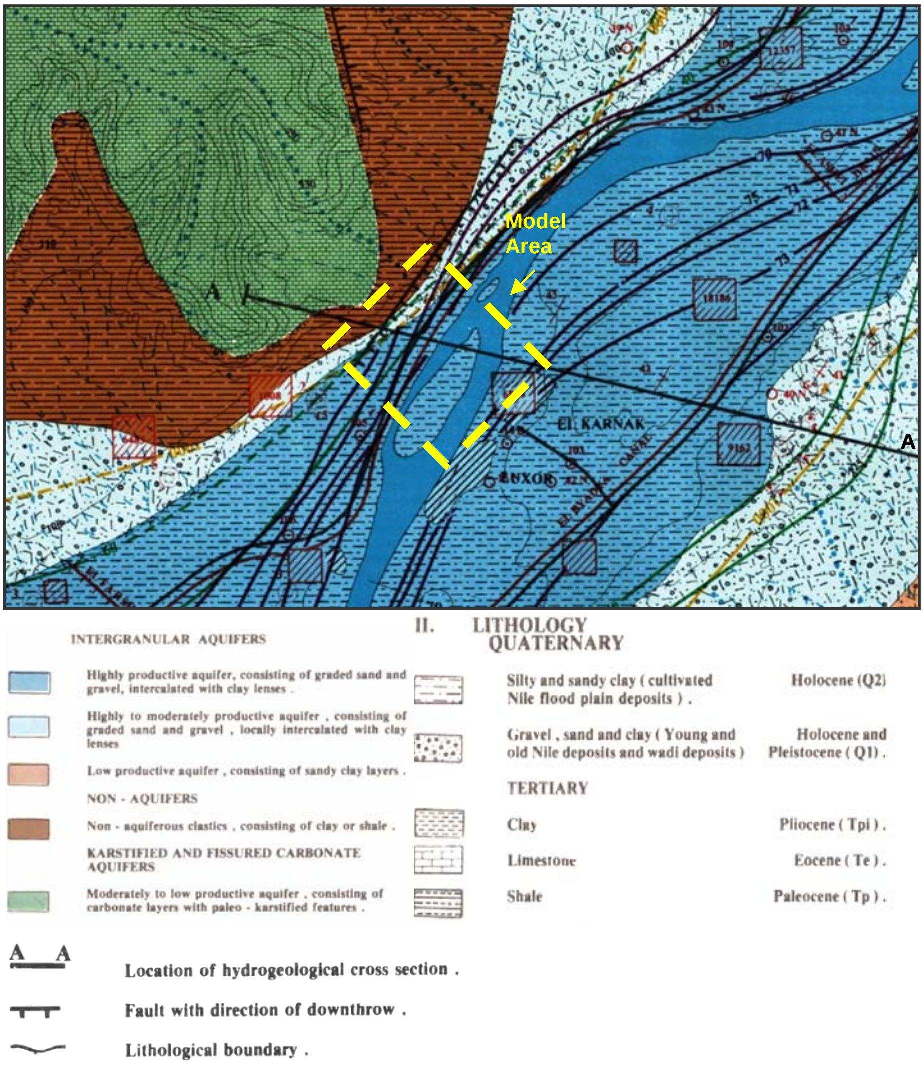


Figure 3.6 *Hydrogeological map of the Luxor area (RIGW, 1997).*

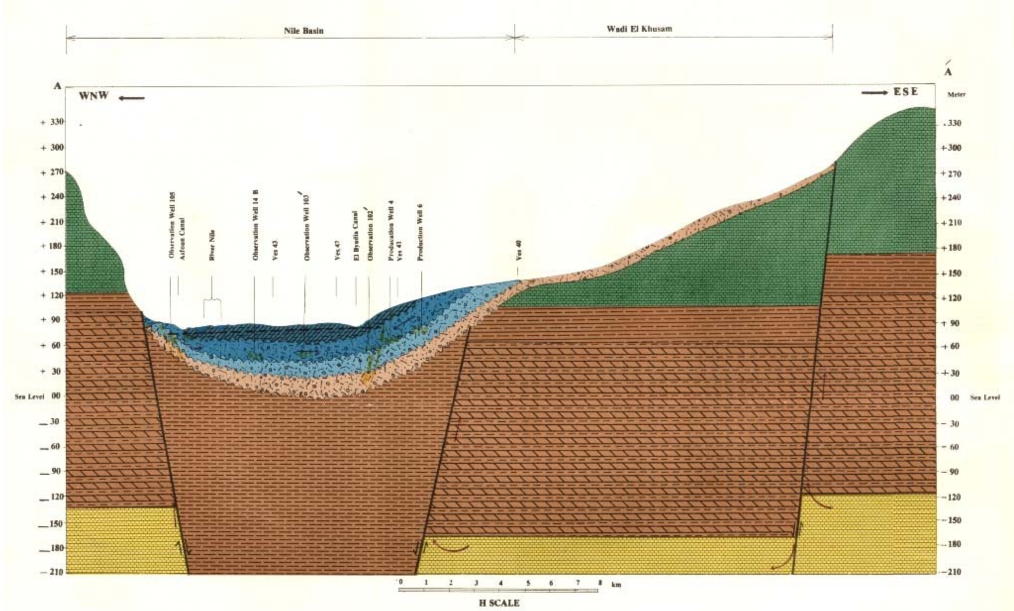


Figure 3.7 *Hydrogeological map of the Luxor area, section A-A' (RIGW, 1997).*

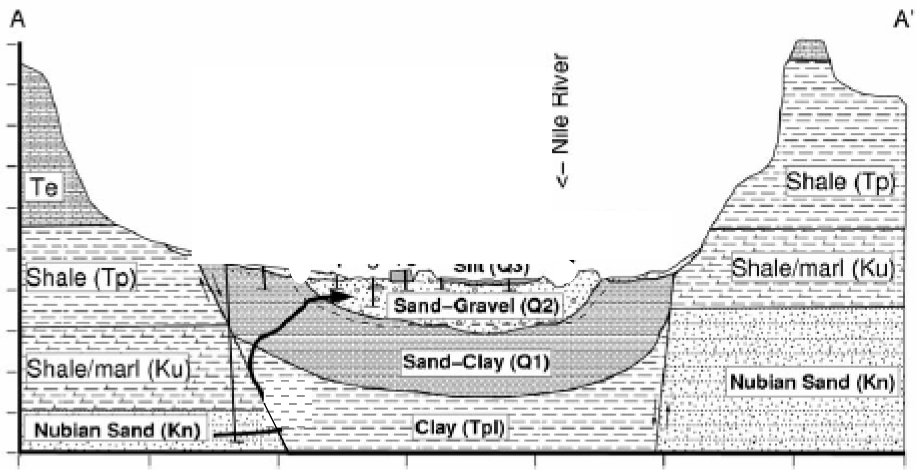


Figure 3.8 *Hydrogeological cross-section from Esna region illustrating the positions for layers: Tpl, Q1, Q2 and Q3 also present in Luxor region, (Graphic from Brikowski, 2005).*

The over-laying Holocene (Q2) silt and clay deposits have a variable permeability and acts at many locations as a semi-confining layer (SWECO Report, 2002). On the outside fringes, where the silty and clayey deposits disappear, the main aquifer becomes unconfined.

The Pliocene Clay (Tpl), below the Late Pleistocene (Q1) sand and gravel deposits, is considered an aquiclude. For the present study, the Pliocene Clay (Tpl) is considered to form a tight impermeable bottom layer, limiting the groundwater system to the Holocene and Late Pleistocene (Q2 and Q1) deposits.

4. Groundwater model set up

4.1 Objective

The main objectives of the groundwater modelling were to identify the area where detailed field data are criteria to the success of the model, and to analyze the effect of groundwater levels for different measures similar to drainage, local pumping, and restriction of some irrigation areas. With the groundwater model it was possible to:

- Analyze the effect of pumping from wells located in the temples areas
- Analyze the effect of limiting the irrigation recharge rate over the modelling area during specific stress periods, in order to reduce the groundwater flow.

4.1.1 Ramesseum Temple.

In view of the fact that:

- the groundwater depth readings for the piezometer at the Ramesseum temple are closer to the ground surface comparing to the other piezometers (see figure 3.4),
- the visual observations on site during study visits in February (Travel Report, Larsson R., 2005) and September of 2005 (see figure 4.1),
- and also because this temple is situated in a representative place between the other 2 temples, close to a principal irrigation canal and agricultural fields,

alternative engineering measures were simulated with focus on the area around this particular temple.

Figure 4.1 *Ramesseum Temple, showing how the water level in some areas is above the surface level. (August 2005).*

4.2 Conceptual Model

4.2.1 Geological framework

The geological framework is characterized by two alluvial unconsolidated layers composed by clays, silts, sands and gravels. The uppermost alluvial layer varies in thickness and is in the model approximated 7 to 20 meters. The greater layer thickness is found closer to the Nile, mainly consisting of silt and clay (see figure 4.2).

The second layer is also alluvial and has a thickness of approximately 30 m. This layer consists mainly of sand and is more permeable than the first layer.
There is a third layer composed of clay that acts as a low-permeable bottom layer in the model.

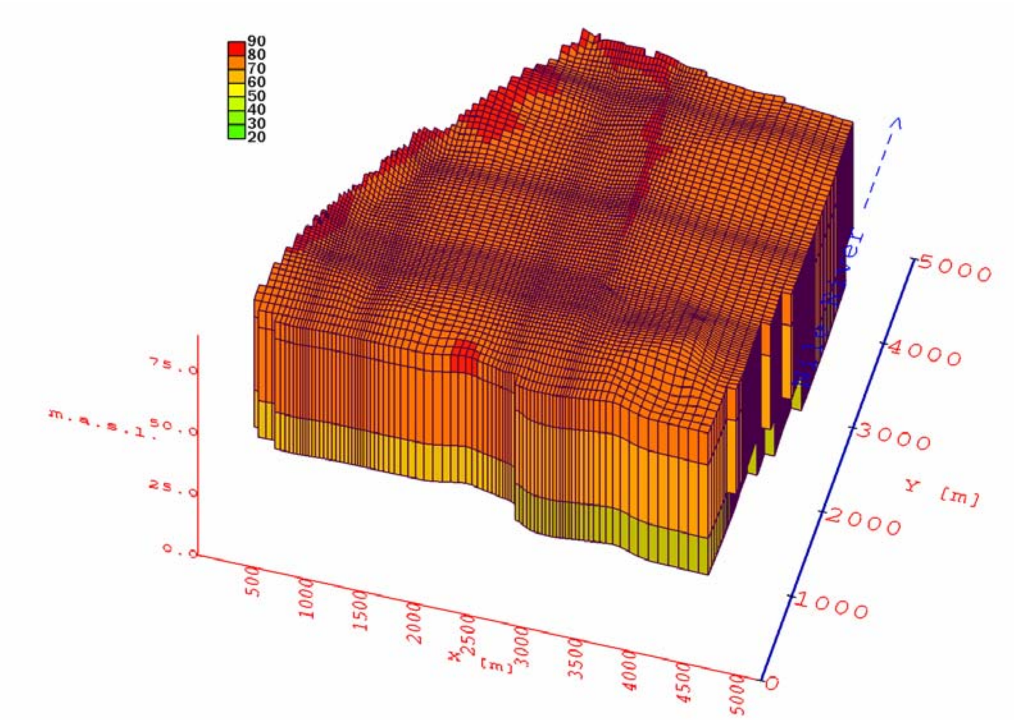


Figure 4.2 *Graphical representation of the model area showing the three principal layers and the top elevation (from GMS 6.0).*

4.2.2 Hydrological framework

Precipitation is insignificant. Instead, the levels in the Nile and crop irrigation recharge govern the overall hydrology of the study area. From upstream intakes, water from the Nile is led into irrigation canals and distributed to the fields.

According to the local authorities, water is led into the fields in a regulated pattern governed by the crop rotation and seasonal changes. Under the prevailing climatic conditions much of the irrigated water is lost through evaporation.

Surplus irrigation water percolates and flows either to the drainage system or forms groundwater. The quantitative relation between these two flow paths in the study area is not known. However, the groundwater model is used to illustrate and analyze possible scenarios presented in section 5.

The Nile water level shows a seasonal pattern where the amplitude is approximately 3.5 m. The Nile level variations affect groundwater levels on a considerable distance from the Nile, but it does not have much influence in the area where the temples are situated. However, the aquifer seems to correspond more or less well with the Nile River in different parts of the study area.

4.2.3 Hydraulic Properties

No pumping tests were conducted to quantify Transmissivity values T (m/d) for the model area. However, the values used in the groundwater model for the salvation project at Luxor and Karnak temples, executed by the Swedish company SWECO International (2002), were selected for the model calibration. For more details see table 4.3.

4.2.4 Data deficiencies and potential sources of error

One of the most difficult parameters to estimate in groundwater study is the groundwater recharge, especially in this case where temporal and spatial irrigation schemes are not known in detail. Furthermore, there is no evapotranspiration loses, leakage, percolation and discharges data measurements available. These uncertainties have to be studied with sensitivity analyzes, and the hydraulic parameters (mostly based on previous studies in the area) were adopted by conservative approaches.

4.2.5 Introduction to the computer code GMS 6.0

For the numerical modelling, the software Groundwater Modeling System, GMS version 6.0 was selected. The entire GMS consists of a graphical user interface (the GMS program) and a number of analysis codes (MODFLOW, MT3DMS, RT3D, SEAM3D, MODPATH, MODAEM, SEEP2D, FEMWATER, WASH123D, UTCHEM). The GMS interface was developed by the Environmental Modelling Research Laboratory of Brigham Young University in partnership with the U.S. Army Engineer Waterways Experiment Station. GMS includes a graphical interface to the “MODFLOW 2000”, well established groundwater model software in hydrological studies.

MODFLOW is a computer program that numerically solves the three-dimensional ground-water flow equation for a porous medium by using a finite-difference method (Modflow-2000 User guide, US Geological Survey). Groundwater flow within the aquifer is simulated using block-centered finite-difference approach. External flows such as irrigation recharge, flow to drains, riverbeds and flow from wells can also be simulated.

4.3 Groundwater model construction

4.3.1 Discretisation in space and time

The orientation of the model was shifted so that its internal coordinate system was parallel to the Nile, with the *Y* axis parallel to the river, as shown in figure 4.3. The simulated area is about 12.3 km^2 and it extends from the Nile to the temples, where there is almost no agricultural land and the terrain begins to be mountainous.

The initial cell-dimension of 40 m was set up for the entire model area, but over the temple areas the grid was refined by a factor of 2, resulting in a grid with the cell-dimension of 20*20 m over the areas of major interest (Wells 1 to 4 in Figure 4.3).

During the transit modelling in section 4.5, the stress periods were entered for every hydraulic boundary (i.e. river stages) and subdivided in times applied into the model, as days elapsed from September 26th of 2005. When all boundary conditions were applied to the model, the total number of stress periods was 31.

4.3.2 Dimensionality in space and time

With the GMS software it was possible to construct a MODFLOW simulation using a conceptual model approach. This involved the use of geographical tools of the software, to develop a conceptual model of the site being modelled. The locations of sources and sinks (internal canals, drainage, wells and the Nile River), layer parameters (such as hydraulic conductivity, vertical anisotropy and specific yield), model boundaries, and other data necessary for the simulation, were defined at the conceptual model level. Once this was complete, a grid was generated and the three computational layers were created, representing:

- The uppermost layer of fine-grained alluvial sediments with an approximate thickness of 7 - 20 meters.

- The second layer of coarser alluvial sediments with an approximate thickness of 30 meters.

- The less permeable third layer of clay.

The terrain model was produced importing the elevation values from the topographical maps described in section 3.2 (Mapping and survey), to the GMS program.

The boundary surface between the first and the second layer was generated using drilling information from the boreholes (A&A report, 2006) and the hydrological maps of the region.

Suitably, the cross section A-A' of the Hydrogeological map of Luxor passes through the modelling area, almost perpendicular to the Nile River and between the Temples of Ramesseum and Sethos I (see figure 4.3). According to this, elevation values between 1 and 24 m were subtracted from the ground surface in a structural way (point by point), in order to create an upper surface for the second layer, using the GMS program tools (GMS Tutorials - Volume I, 2001).

For the generation of the surface between the second and the third layer, a value of 30 meters was subtracted from the upper surface of the second layer (which is also the bottom surface of the first layer). The bottom of the third layer was generated in a similar manner, with a final average value of 25 m above the mean sea level.

With the GMS program it was possible to correct some of the values falling outside the model area, with a set of tools for fixing layer array problems (GMS Tutorial-Volume II, 2001, page 20, chapter 4).

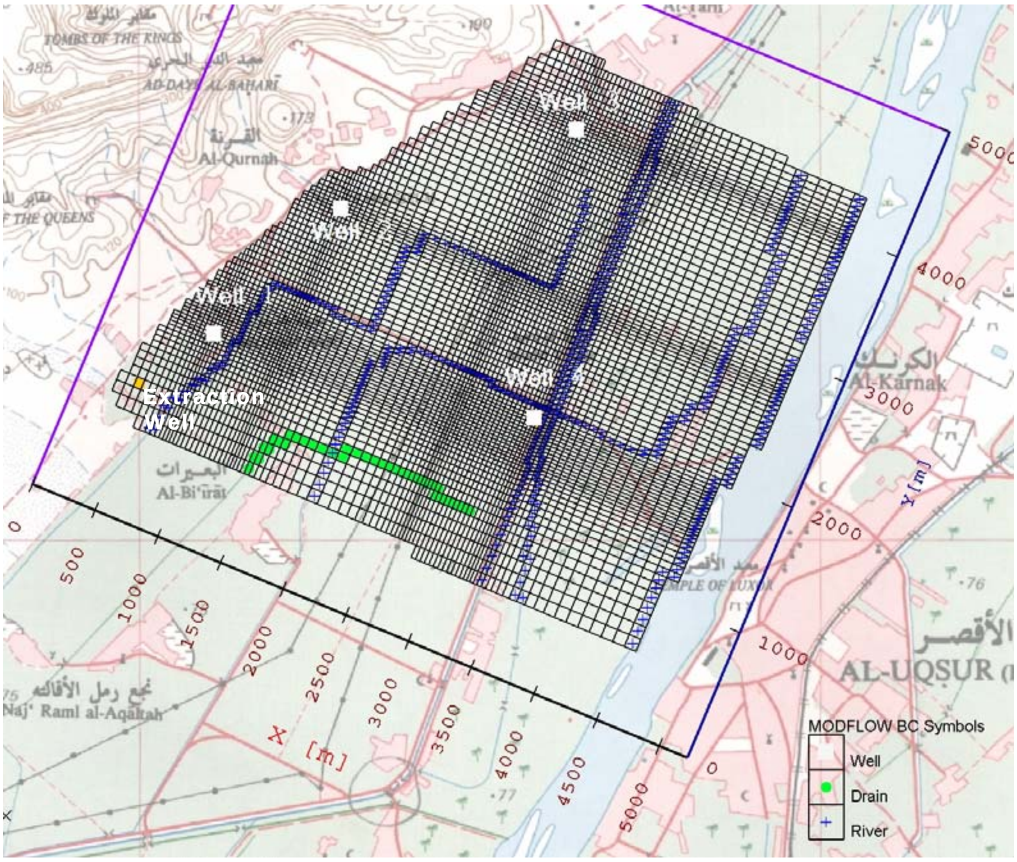
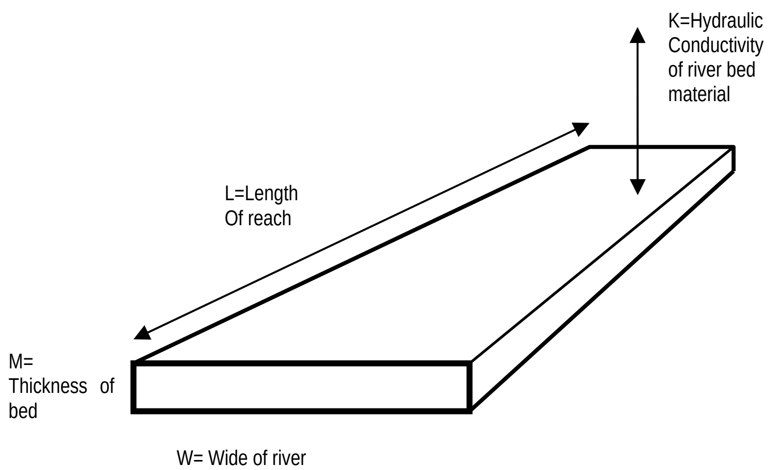


Figure 4.3 *Modelling area with grid showing the location of Wells 1 to 4 in west Luxor; the internal canals are in blue color and the drainage (parallel to the X axis in the low part of the area) is represented in green color. A fifth well is present at the west corner representing localized groundwater extraction in this part of the area (Graphic aid, GMS 6.0 program).*

4.3.3 Boundary conditions

The most complex and dominating boundary is the Nile River, situated at the eastern side of the model area. This boundary was entered with falling river stages along the cells representing it, for the river gradient falling from the south to the north. The river stages were entered as time series, meaning that the model can be run transient with respect to the varying river stages. The length of the Nile River in the model is about 3,6 km and the perimeter of the entire model area is 14,6 km.

As it is internally described in GMS, a river boundary can both receive outflowing groundwater or contribute with induced recharge, depending on the relative level of the river and the groundwater table. A parameter known as Conductance in m^2/day, specifies the internal flow resistance through the river bottom sediments of that respective cell, (see section 3.1).



$$C_{cell} = \frac{KA}{M} = \frac{KLM}{M} \qquad\qquad C_{river} = \frac{KW}{M}$$

Figure 4.4 *Representation of a river cell where "C" is the Conductance in m^2/day.*

The conductance along the Nile is difficult to calculate and is one of the principal unknown parameters for the present study.

The northern, southern and western sides of the model area were considered as no-flow boundaries. Since the rainfall is negligible, there is no groundwater recharge outside the irrigated land that can generate a groundwater flow across this boundary.

The hydraulic heads inside the model area are supposed to be affected to a great degree by internal hydraulic boundaries; irrigation, canals and drains, and groundwater extraction from local wells.

The irrigation canals are specified in the model as internal river boundaries in a similar way as the cells representing the Nile with falling river stages corresponding to the gradient of the canal. The difference comparing to the Nile, is that the values for the water level of the irrigation canals are unknown and have been specified as constant over time, with an average value of 76 m (see section 4.3.4).

According to the hydrogeological map of the region, an average extraction of about 1000 m^3/day is present close to the west corner of the model area, represented as one constant extraction well during all the groundwater model runs. The location of this extraction well can be seen in figure 4.3.

As it is shown in figure 4.3, there is only one drain in the model area. Drains are described in MODFLOW as cells that can receive groundwater only when the hydraulic head of the surrounding cells are not below the stage of the drain. They can never contribute with induced recharge, the flow rate is proportional to the head difference and the constant of proportionality is the Conductance.

Another internal boundary is the groundwater recharge. According to the report by SWECO International of 2002, an effective value of 500 mm/year can be assumed for that entire area (east Luxor). This value was adopted for the model area in the present study, and it is assumed as constant over time. Under the constructed areas the value of 20 mm/year was selected assuming some leakage from water supply, sewerage pipes and cesspits.

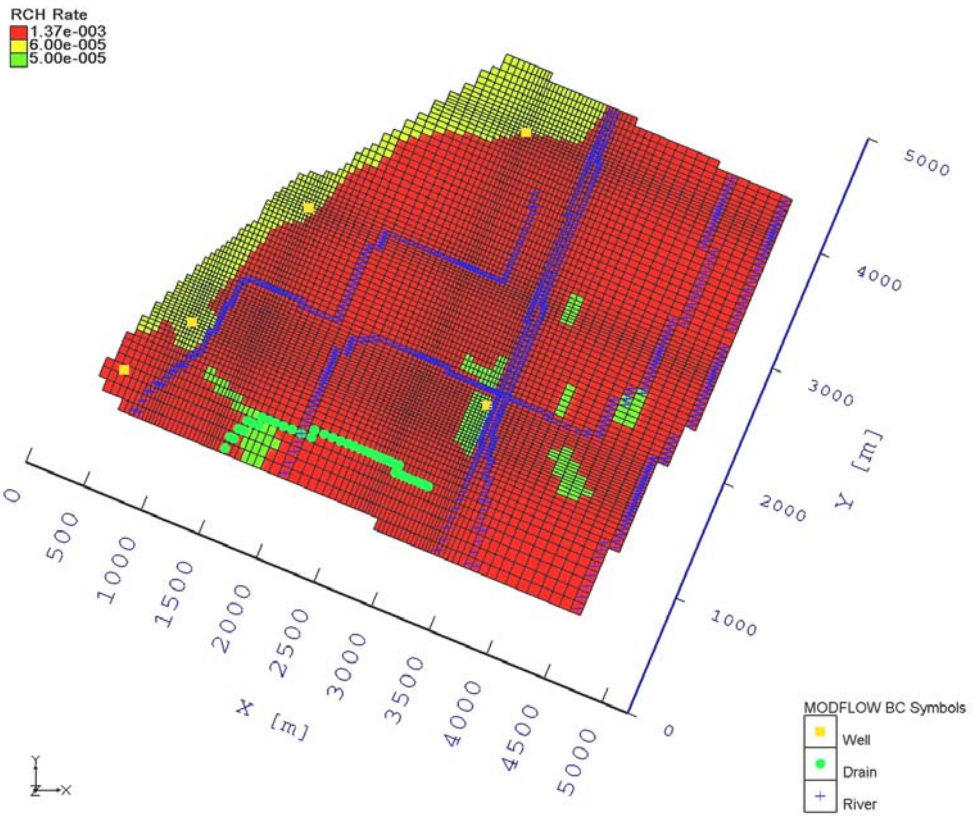


Figure 4.5 *Modelling area with grid showing recharge (RCH) values for irrigated areas (in red color), and under building areas assuming leakage from water supplies (in green), (Graphic aid, from GMS 6.0).*

4.3.4 Initial conditions

Initial conditions when running a model are often specified as the resulting heads of a previously run model, or as ground surface elevation level values (GMS Tutorials-Volume II, Modflow, 2001). During the steady-state runs, the initial heads were setup as ground surface elevations. For the transient runs, the initial conditions were those heads calculated in the previous steady-state calibrated run.

River stages for the Nile were not available for the period of the modelling (September 2005 to May 2006). However, in order to achieve the principal objectives described for the groundwater model, data levels of the River Nile for the year 2001 were available and used for the modelling (A&A report, 2006). The variations of the

Nile River levels are more or less similar for every year (see Hydrographs of River Nile in the appendix 2), but it is worth to mention that there is a major difference between the values of the Nile water levels obtained from the Egyptian Company A&A, and the ones used by the Swedish Company SWECO, for the year 2001. However, all the groundwater model runs were performed with the Nile elevations presented by A&A, (2006).

Bottom elevation values for the Nile River, internal canals and drainage in the model area were adopted considering the general ground surface elevation and information through personal communication with the local authorities on site.

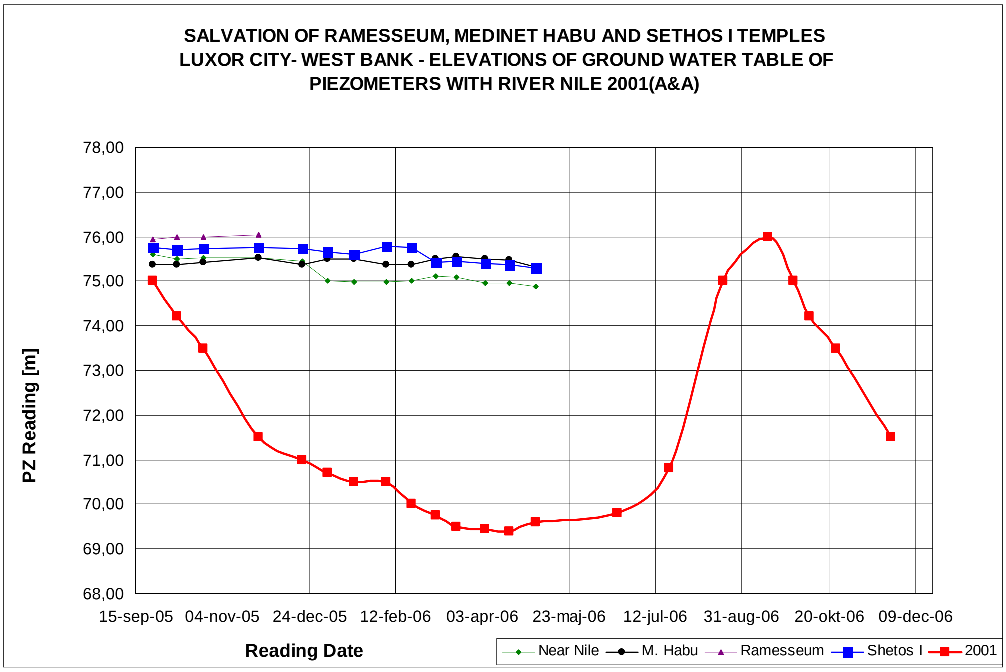


Figure 4.6 *Observation well readings from September 2005 to May 2006 and the Nile elevation stages of 2001 (from A&A report, 2006).*

4.3.5 Hydraulic properties

Values for hydraulic conductivities (K) and Specific yield (S_y) were selected from previous pumping test conducted at Karnak and Luxor by the Swedish company SWECO International, 2002. In table 4.1 it is shown a comparison of hydraulic conductivities and irrigation (recharge) values in the region used by different authors, and the hydraulic properties selected for the groundwater model are presented in table 4.3.

Table 4.1 *Comparison table for hydraulic conductivities and net recharge values used by different authors, in (m/day) and m respectively.*

Layer Aquifer	*Brikowski &Faid(2005)* K_h	K_v	*Recharge*	*Shamrukh (2001)* K_h	K_v	*recharge*	*SWECO (2002)* K_h	K_v	*recharge*
1 (Q3) Semiconfined silty clay (Holocene)	1	0,02	0,001	0,2	0,04	0,0011	1,56	1,56E-01	0,00137
2 (Q2) Graded sand and gravel with clay lenses (Pleistocene)	40	0,8		70 - 120	7-120		23-43	2,38	
3&4 (Q1) Sand and clay with gravel (Pilo-pleistocene)	1	0,02		8-10	0,8		1,56E-04	1,56E-05	
5(Tpl) Clay (Pliocene)	1E-03	1E-05		_	_				

4.4 Calibration

Most of the calibration was done for a steady-state case, with the Nile flow at a low level and with the average value for the four piezometers, during the period of March to May of 2001.

An adequate calibration can be reached when there is access to consistent data of at least two or more hydraulic parameters during relatively long periods (for example the internal flows and river stages data of a few years). In that way, unknown parameters such as conductance, irrigation recharge and hydraulic conductivity can be changed in a trial-and-error manner until acceptable groundwater levels are calculated. However, the calibration of the model was prepared with an average of 69.5 m for the Nile level with bottom elevations of 50 m at both extremes north and south, and an average value of 75.7 m for each of the piezometers (see drawings of Appendix 1).

The water balance was important to analyze during the calibration of the model. Nevertheless, because of the lack of data for the internal canals and the drainage flows, the values presented in table 4.2 are considered as highly sensitive.

Table 4.2 *Water balance for a steady-state case with the Nile River at a low level (level from March 19th in figure 4.6). These net values were automatically calculated by MODFLOW.*

	IN from irrigation recharge	IN from irrigation canals	OUT through drains	OUT through the Nile
m^3/day	14884	83758	55813	42829
mm/year	441	2486	1656	1271

The table indicates both daily flow rates for respective hydraulic boundary and the annual recharge in mm, calculated dividing by the total model area of 12.3 Km^2.

The groundwater flow occurs mainly in the second layer. Tests were performed by multiplying and dividing the K-values of layer 1 both horizontal and vertical, by a factor of 5. The modeling results were not sensitive to these changes. The final results of the calibration are presented in table 4.3, (values selected from SWECO report, 2002).

Table 4.3 *Hydraulic properties applied to the model. Values for horizontal hydraulic conductivity, vertical anisotropy and specific yield.*

Layer Number	***Horizontal K (m/d)***	***Vertical anisotropy.***	***Specific. Yield***
Layer 1 A	1.55	10.0	0.05
B	**35.0**	**10.0**	**0.15**
C	1.55	10.0	0.05
Layer 2	**35.0**	**10.0**	**0.15**
Layer 3	0.00016	10.0	0.05

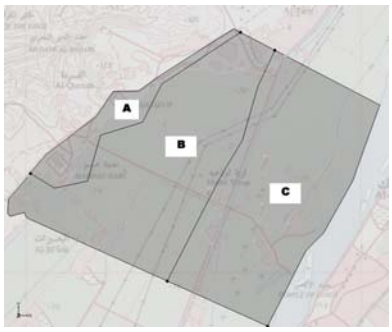


Figure 4.7 *Division of the uppermost Layer 1: Areas A and C mostly consist of silty clay with a low K-value of 1.55 m/day. Area B contains sands and gravels, with a K-value of 35 m/day.*

As it is shown in figure 4.7, the K-values for layer 1B and layer 2 are equal because according to the hydrogeological maps and the lithography of the area, the soil material here is mostly formed by alluvial sands and gravels.

4.5 Transient modelling

The values from table 4.3 with the Nile at a low level were used for further steady-state runs for high stages of the Nile. The residuals (the difference between calculated and observed values) of these runs were greater at well number 4 (the one closer to the Nile), comparing to the other wells located at the temples fairly distant from the Nile river.

A transient model was applied using the Nile river stages of 2001 to analyze the groundwater level changes at the temples of Ramesseum and Sethos I. The river stage of the Nile was allowed to vary over the entire period, according to the recordings obtained from the Egyptian Company A&A.

A first transient model was set up with the same hydraulic parameters and boundary conditions that were used in the steady-state modelling. It showed a good correlation between observed and calculated heads and the response to the change of the river stages in the Nile was satisfactory with respect to the amplitude. In the following runs, the K-value of the second layer was changed from 35 to 43 m/day, given that this last value was finally selected during the simulations for the Salvation project at Luxor and Karnak temples, and they were based on pumping tests (SWECO report, 2002). The response of the calculated hydraulic heads to variations of river stages and stresses applied under the transient simulations for the temples of Ramesseum and Sethos was satisfactorily increased, (see figures 4.8 and 4.9). The difference between the observed and calculated head values at the Ramesseum temple is about 35 cm, and at Sethos (I) varies between 0 and 25 cm.

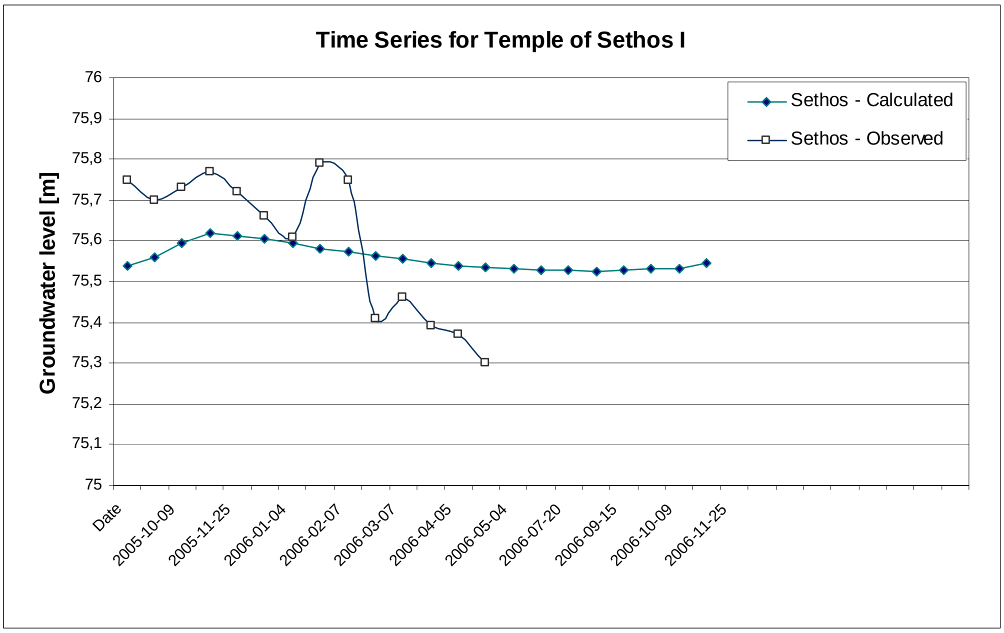


***Figure 4.8** Transient runs at Sethos I. Observed and calculated heads with K-value of 43 m/day for the second layer.*

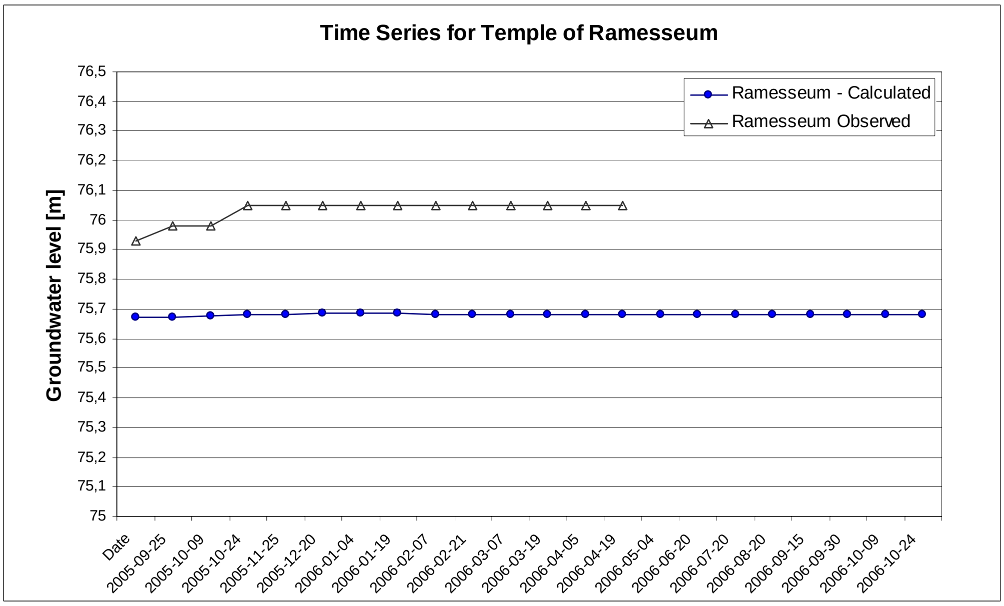


***Figure 4.9** Transient runs at Ramesseum. Observed and calculated heads with K-value of 43 m/day for the second layer.*

5. Development and testing of scenarios

The simulations of alternatives for lowering the groundwater levels were based on a combination of drains, centrally located pumping wells, and reduction of recharge rates of irrigation.

5.1 Scenario 1

The first scenario includes reducing the irrigation recharge rate to 50% over the total area with a continuous withdrawal of 25 l/s during the entire simulation period at both temples of Ramesseum and Sethos I. The run shows groundwater levels lowered by approximately 90 cm at both temples.

Another simulation was performed maintaining 500 mm/year for irrigation net recharge and continuous withdrawal of 25 l/s at both temples. The results showed the groundwater levels lowered by 80 cm, almost the same values as when reducing by 50% the irrigation rate.

5.2 Scenario 2

These simulations take into account the possible variations of the constant head adopted for the internal irrigation canals inside the model area.

One of the assumptions regarding the boundary conditions for running the model was the constant heads for the internal canals for irrigation. The canal which is closer to the temples area seems to play an important role during the transient runs. This was clear when the selected water level of 75.5 m was changed to 74 m, and simulations were performed with the same conditions as in the first scenario. The figures 5.1 and 5.2 show the results of both temples for observed and calculated groundwater levels.

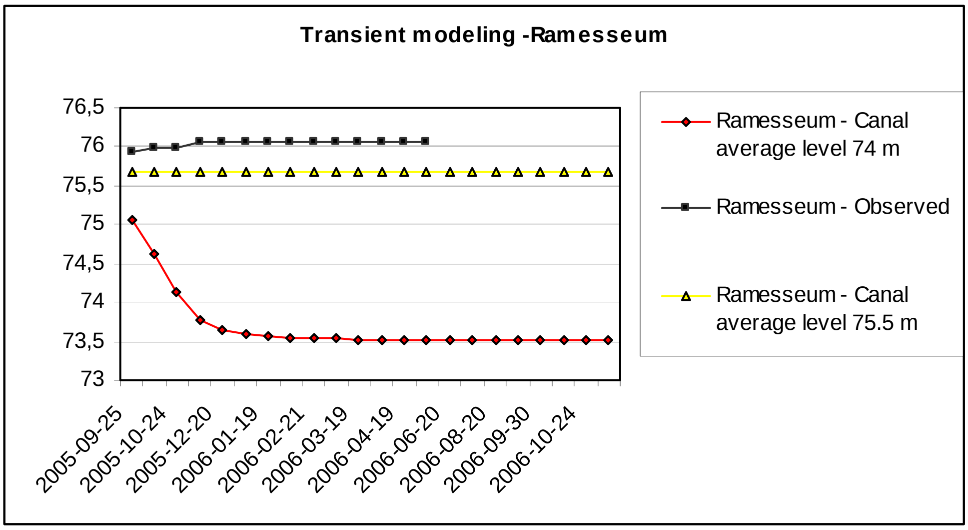


Figure 5.1 *Transient runs at Ramesseum. Observed and calculated heads after reducing the selected water level of the canal closer to the temples, by 1.5 meters (from 75.5 to 74 m).*

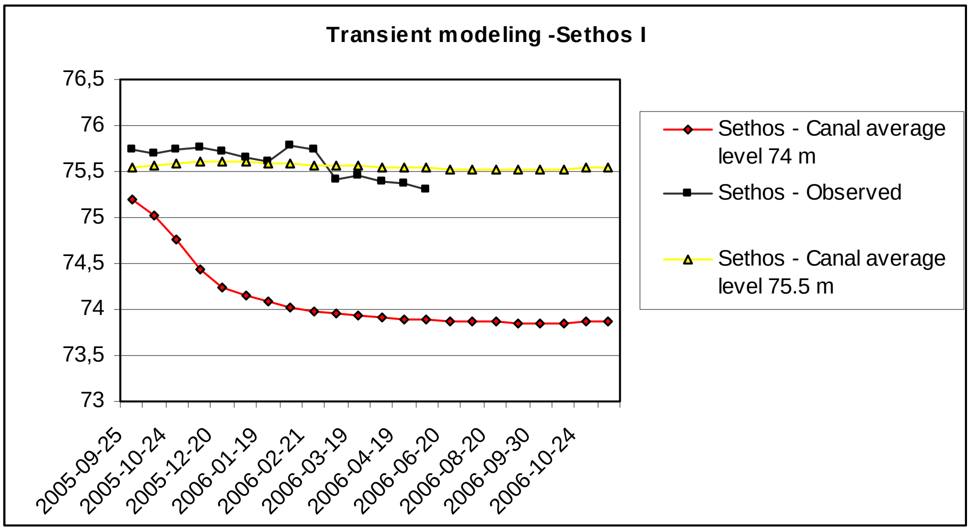


Figure 5.2 *Transient runs at Sethos I. Observed and calculated heads after reducing the selected water level of the canal closer to the temples, by 1.5 meters (from 75.5 to 74 m).*

6. Conclusion

With reference to the objectives of the groundwater model presented in section 4.1 and both scenarios presented in section 5, to improve the calibration and validation estimates of the model, the access to reliable data related to inflows and outflows for some of the principal internal canals, is required. This would give us the possibility to simulate drainage and pumping flow solutions at the temple areas. If there is a second set of field data, for example head changes during a pumping test in one of the temples, a second stage of calibration (verification) will increase the level of confidence in the model (Anderson and Woessner, 1992).

The reduction of irrigation rates is not sufficient to diminish groundwater levels and it has to be combined with other measures. According to some representatives in Luxor, some of the canals work as drainages during certain periods of the year, making the overall hydrology of the area more complex to analyze.

The GMS is a powerful hydrological tool that uses the MODFLOW approach. According to Rushton (2006), MODFLOW was devised for mainly vertical flows from losing rivers, whereas the river conductance depends primarily on the horizontal hydraulic conductivity of the aquifer system, rather than the vertical hydraulic conductivity of the riverbed deposits.

However, the option to construct a greater “regional model”, including the Luxor and Karnak temples with the observation wells and hydraulic parameters used in the Salvation project executed by SWECO, together with the data obtained from A&A for the present project, should be implemented. Subsequently, with the use of the GMS tools, a conversion to a “local model” could be approached, and in this way it would be possible to analyze in more detail the hydrogeological conditions and other measures inside the areas of the temples.

As can be seen in figure 4.10, the Nile River water level reaches its highest elevation point (76 m) during September, and probably the groundwater levels at the temples have more or less the same value. Even so, during the rest of the year, the Nile acts as a gaining river, due to the excessive irrigation and the topography of the area. However, the highest elevation point value of the Nile level for the year 2001 differs by more than 3 m between the data from A&A and the SWECO project.

Høybe (2002) insinuates that using simplified hydraulic properties in a model reduces the validity of the simulation results. The calculated groundwater levels could be improved if coordination between different agencies and authorities also improved. This means that the success of engineering methods will rely on basic and key design data which is not available, generally because of political concerns.

The fundamental problem is the raised groundwater table due to increased irrigation and reduced water level variations in the Nile. This can be solved in various ways, but probably the most sustainable solution is to change or improve the irrigation management in the area; restricting crop types, water uses, etc. To reduce the urban and agricultural development impact is also important, and could be attainable with cooperation between local authorities, agencies, ministries, etc.

A first reconnaissance study was conducted in 1982, showing that already at that time, water related problems as salt actions, settling and increased groundwater level were present at many heritage sites (SWECO, 1982). It is interesting to see the rate of urban and agricultural development; and the limited protection and management of cultural heritage, after more than 20 years of knowledge.

7. References

Anderson, M. P., & W.W. Woessner, 1992. Applied groundwater modeling – Simulation of flow and advective transport. San Diego: Academic Press, Inc.

Brikowski, Tom H., Abdallah Faid, 2005. Pathline-calibrated groundwater flow models of Nile Valley aquifers, Esna, upper Egypt.

Dawoud, M. A., 1997. The numerical simulation for groundwater condition in West Tahta region. M. Sc. Thesis, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

Fetter, C. W. University of Wisconsin - Oshkosh, 2001. “Applied Hydrogeology”, Fourth Edition, Pearson Education.

GMS 6.0, Tutorials Volume I and II, 2001.

Herbert F., Wang and Mary P. Anderson., 1982. Introduction to groundwater modeling - Finite difference and finite element methods - W.H. Freeman and Company, Ltd., Oxford.

Høybe Jan, 2002. Assessment of water related damages and adverse effects on historic monuments. Mission to the World Heritage Sites at Ancient Thebes and Abu Mena, Egypt

Larsson Rolf, 2005. Travel Report - Egypt January 2005.

MODFLOW-2000, THE U.S. GEOLOGICAL SURVEY MODULAR
GROUND-WATER MODEL—USER GUIDE TO MODULARIZATION
CONCEPTS AND THE GROUND-WATER FLOW PROCESS
By Arlen W. Harbaugh1, Edward R. Banta2, Mary C. Hill3, *and*
Michael G. McDonald4
U.S. GEOLOGICAL SURVEY
Open-File Report 00-92

RIGW, 1997 Hydrogeological and Topographical Maps of Luxor. The Egyptian Research Institute for Ground Water

Rushton Ken, 2006. Representation in regional models of saturated river – aquifer interaction for gaining/losing rivers. J. Hydrol 334, 262-281.

Siliotti Alberto, 2002. “Luxor, Karnak and the Theban temples”. The American University in Cairo Press, 2002.

SWECO 1982, Effects of ground water on Pharaonic monuments. Reconnaissance study report. Egyptian Antiquities Organisation.

SWECO 2002, Salvation of Karnak and Luxor Temples, Draft Report – Phase 1. Supreme Council of Antiquities.

Wilkinson Richard H., 2000. “The Complete Temples of Ancient Egypt” Thames and Hudson, 2000.

Zeid-Abu, M. A. & F. Z. El Shibini, 1997. Egypt’s High Aswan Dam. Water Resources Development, Vol 13. No 2, pp 209-217

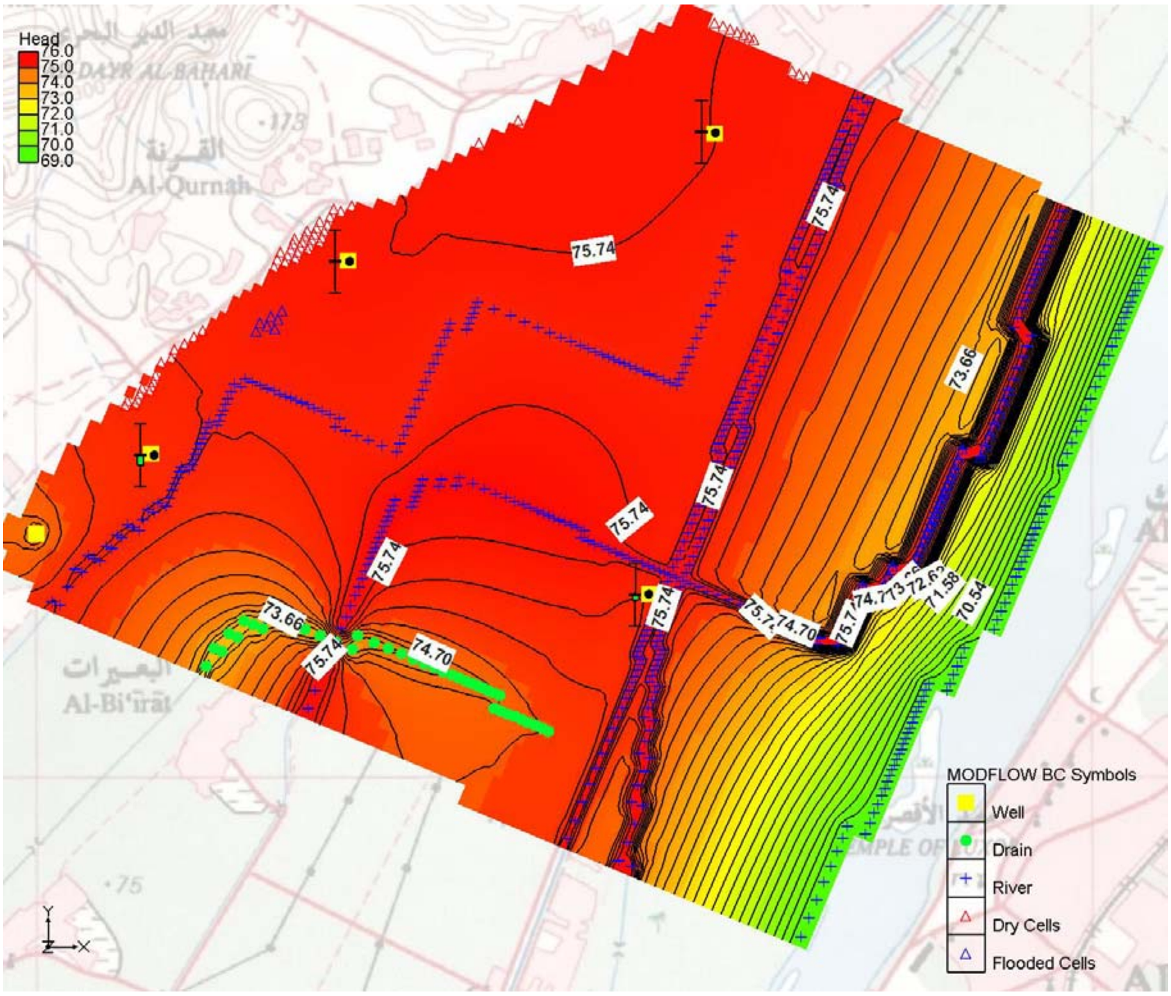
Shamrukh M., M. Yavuz Corapcioglu, and Fayek A. A. Hassona, (2001). Modelling the Effect of Chemical Fertilizers on Ground Water Quality in the Nile Valley Aquifer, Egypt. GROUND WATER – January-February 2001, Vol 39. No 1 (pp 59-67)

Traunecker, C., 1987. Observations faites au IXe pylone: Dégradations internes et humidité, Cahiers de Karnak VIII 1982-1985, pp 355-367, Éditions Recherche sus les civilisations, Paris.

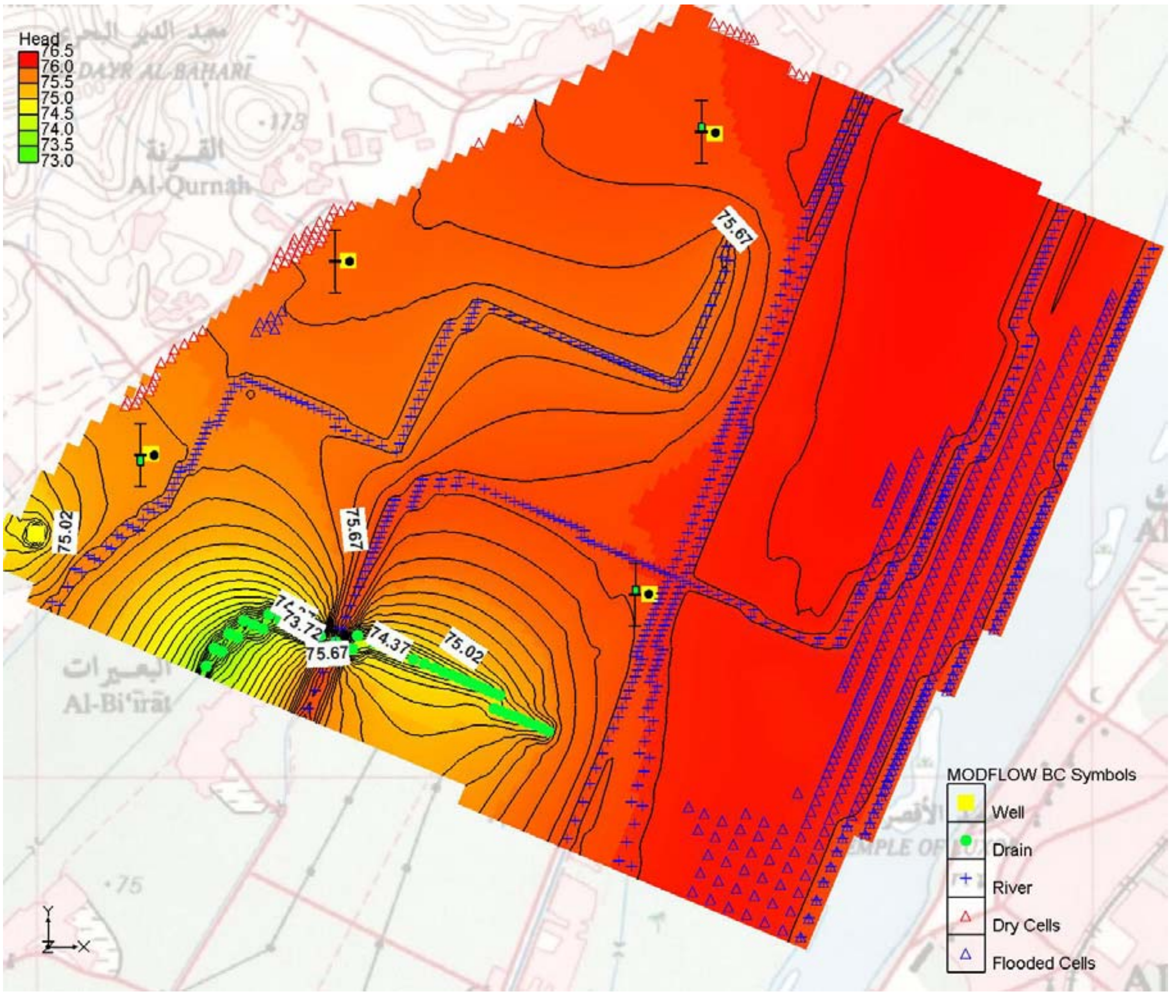
Internet
UNESCO:
http://whc.unesco.org/en/list/87/multiple=1&unique_number=93
(visited October 2008)

8. Appendices

8.1 Appendix 1

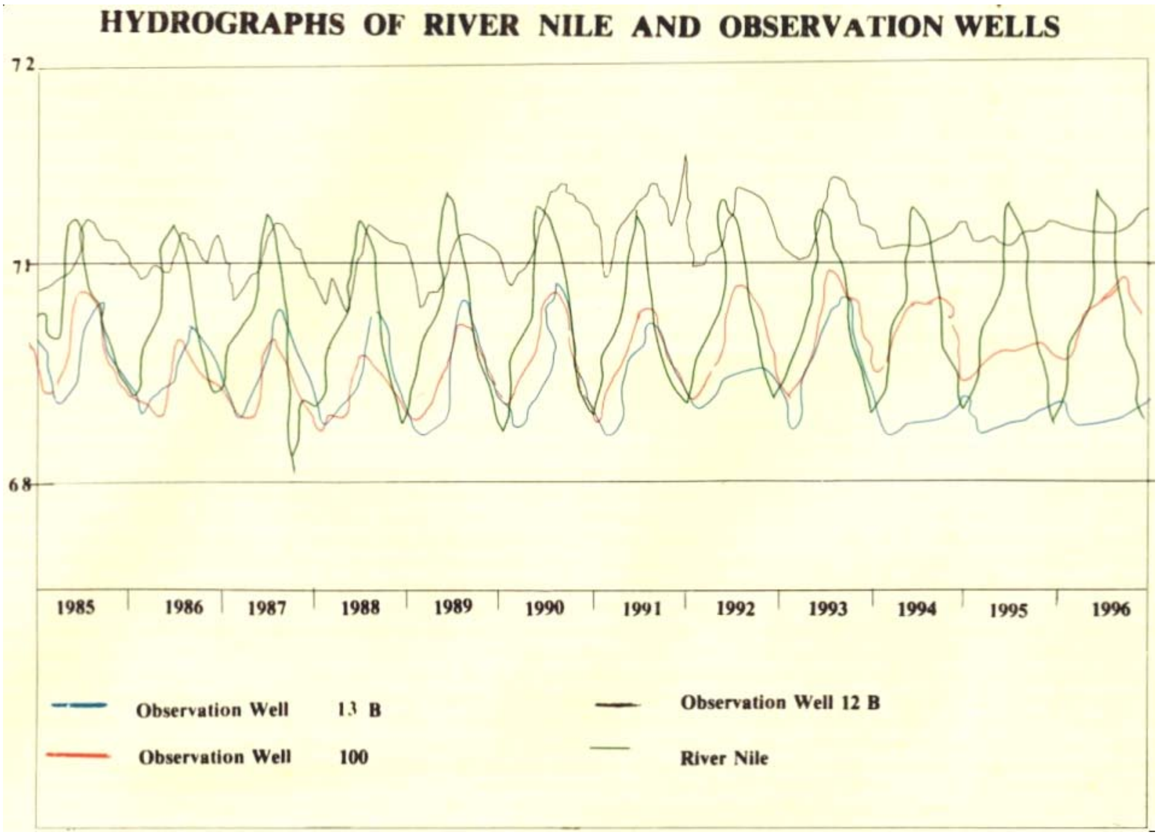


__Drawing 1.1__ Groundwater Heads with the water level of the Nile at 69.5 m.



Drawing 1.2 *Groundwater Heads with the Nile at 76 m.*

8.2 Appendix 2



Drawing 2.1 *Hydrographs of River Nile and observation wells situated close to the modeling area from years 1985 to 1996 (Hydrogeological map for Luxor)*

8.3 Appendix 3

Factual Report A&A.

ARAB REPUBLIC OF EGYPT
MINISTRY OF CULTURE
SUPREME COUNCIL OF ANTIQUITIES

SALVATION OF RAMISIUM, HABU AND SITY TEMPLES
LUXOR CITY- WEST BANK

PRELIMINARY SITE INVESTIGATION FACTUAL REPORT

CONSULTANT

LUND UNIVERSITY

DEPARTMENT OF WATER RESOURCES ENGINEERING

LUND INSTITUTE OF TECHNOLOGY

SWEDEN

GEOTECHNICAL ENGINEER

A&A ENGINEERS AND CONSULTANTS

EGYPT

Rev.	Comments	Prepared By	Checked By	Approved By	Ref.	Date
0	Issued for Approval	A&A Engineers and Consultants	M.H	A.L	40/256	10/2005

TABLE OF CONTENT

1. INTRODUCTION:

This report has been prepared upon the request of **LUND University, Department of Water Resources Engineering (Teknisk Vattenresurslara) SWEDEN,** to carry out the engineering services of the site investigation for **RAMISIUM, HABU AND SITY TEMPLES** located at LUXOR city - west bank. This study is conducted under the care of the **SUPREME COUNCIL OF ANTIQUITIES**.

The site investigation program, as planned by LUND university, includes 4 boreholes, as well as field and laboratory testing.

The site investigation program was conducted by A&A during September 2005 using in house capabilities as well as other specialized soil investigation contractors.

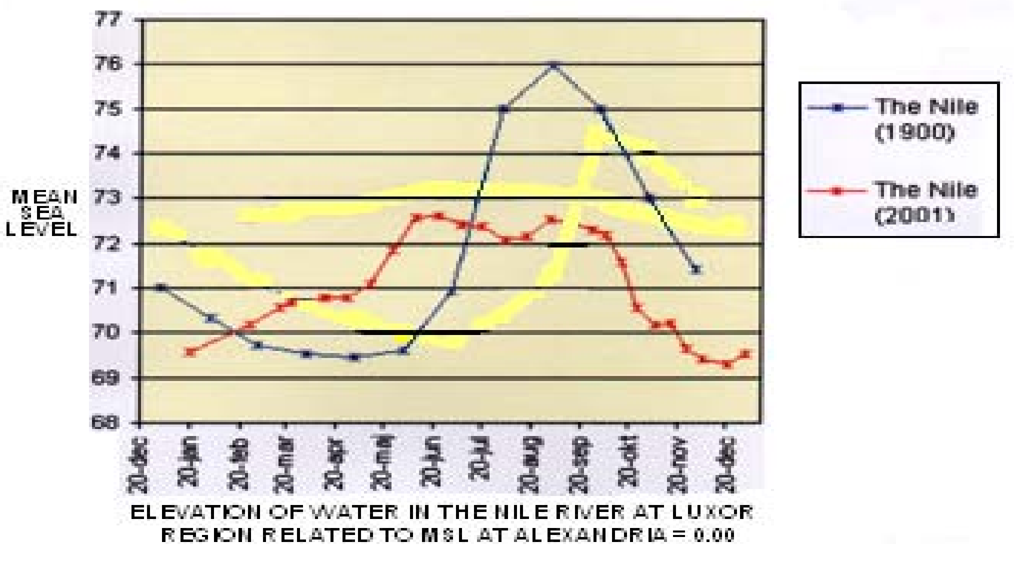
This report is prepared in order to document the activities and to present the results of the site work and to summarize the findings and the geotechnical parameters.

2. BACKGROUND

The **Ramisium, Habu and Sity temples** located at the west bank of the river Nile at Luxor city south of Egypt show severe sign of deterioration by salt enrichment in the temple material due to the presence of permanent shallow groundwater table enabling ground water to move by capillary forces in the temple material (mainly sandstone) and in the adjacent soil. The surrounding areas of the temples are agriculture land irrigated frequently. The main objective of the project is to understand the problem, define the parameters affecting the water flow.

The temples are located at the edge of the agricultural area and the non-agricultural area. The project area includes **Ramisium** temple, situated to the south, **Habu** temple or city situated almost to the center and **Sity** temple situated to the north of the study area as shown on figure No. 1. The general topography of the area is divided in almost two categories:

a. The valley area where the soil is generally cultivated and is bounded from the east by the river Nile and has a general elevation of about 76.00MSL. The arid land and the mountainous area bound this area from west. This area is used for cultivation and is divided with multiple open channels and drains conveying irrigation water to the land. The ground water in this area is connected to the water body flowing in the Nile River and hence it is affected by its elevation. The elevation of the water in the river is fluctuating over the year. The flood season starts on month August – September of every year, the directory of the Naser lake, which is the main storage natural reservoir for surface water in Egypt, starts by month of June - July to decrease the level of the lake to the usual level accepting new flood by discharging water to the river. The water level in the river is the highest during July – September of every year for this reason and to provide the peak water demand of irrigation at this season, which is the season of rice cultivation. The average water elevation in the river Nile in this season is about 73.0 - 76.0MSL in the vicinity of Luxor city. The discharging of water from the Naser Lake is decreased during October – February as the lowest demand of irrigation water is in the winter. The average water elevation in the river Nile in this season is about 70.0MSL in the vicinity of Luxor city. This fluctuation could reach a figure of 3.0 to 6.00M. The following chart is showing the fluctuation of water level in the river Nile.



b. The west area is a mountainous area with higher elevation starting from 77.0 to reaching 450.0MSL. The three temples are located almost at the edge of the two categories. **Ramisium** temple is probably at a lower level than the other two temples and consequently may be affected more by the ground water table.

The specific objectives of the field investigations are to:

- Gather preliminary information on the lithology of the area
- Increase the knowledge about groundwater levels
- Identifying the subsurface conditions in each temple
- Measure the groundwater condition in the recent time

At 9/2005 LUND University issued a work order to A&A Engineers and Consultants to carry out the preliminary works of the field investigations according to a set program sent by A&A.

3. SCOPE OF GEOTECHNICAL WORK

The activities performed by A & A for the subject site included:

1- Managing field and laboratory activities
2- Execution of borings and performing required field tests
3- Collect water elevation readings for all constructed piezometer
4- Collection of soil samples for testing
5- Carrying out laboratory tests on the collected samples
6- Preparing this site investigation factual report presenting the site findings and the field as well as laboratory testing results.

4. SITE INVESTIGATION ACTIVITIES:

4.1 General:

A site investigation program has been carried out in order to provide adequate information on the subsurface conditions at the buildings location. The site investigations were conducted by a specialized soil investigation firm (Misr Lab) under the supervision of A&A Geotechnical Engineer during September 2005. LUND University representative had visited the site during the starting of the drilling work.

The site investigation program comprises boreholes sampling, field tests and laboratory tests. Figure no. (1) presents the general layout of the temples area as well as the approximate locations of borehole conducted on the site for the temples.

Appendix No.1 includes the relevant information related to this program, borehole logs results as well as the results of the field and laboratory tests.

4.2 Boreholes

Four (4) boreholes had been carried out to a depth of 20 m below natural ground level. The drilled boreholes were four inches in diameter. The borings elevations and coordinates were not provided at this stage, the available information can be summarized in the following table:

Table 4.1 Boreholes conducted in the temple area

Borehole No.	Location	Depth (m)
BH1	Ramisium Temple	20
BH2	Near River Nile	20
BH3	Sity Temple	20
BH4	Habu Temple	20

Appendix No.1 provides the borehole logs drawn to suitable scale. On each borehole log the following data are given:

- Borehole number.
- Total depth of the borehole.
- Date of execution.
- Type of borehole.
- Depths and description (classification) of the layers.
- Types of sampling (core, standard spilt spoon, wash).
- Some results of laboratory tests.
- Some results of field tests.

The boring No BH1, BH3 and BH4 were conducted in the vicinity of the temples while boring BH2 was conducted close to the river Nile and converted to open tube piezometer to monitor the ground water table. All samples collected from boreholes were examined, described and classified by **A&A** geotechnical engineer and taken to the laboratory for testing. The ground water table is monitored in the open tube piezometer for a period of about 6 months. **A&A** shall issue a supplementary report at the end of this monitoring phase with all interim readings. Unfortunately, no topographic survey was conducted at this stage; consequently the borings and the open tube piezometer location were not surveyed for coordinates and elevations.

4.3 Piezometers

After finishing sampling every borehole was converted to observation well (piezometers) composed of 2-inch steel pipes fitted with 1.0 m of cupper screen with gravel pack filter.

4.4 Field Tests

4.4.1 Standard Penetration Tests:

During the boring operations, standard penetration tests had been preformed for non-cohesive and cohesive soil at selected depths. The tests were carried out according to ASTM D1586.

The Split-Barrel Sampler shall be of the standard dimension as stated in ASTM D1586. The driving shoe shall be of hardened steel and shall be replaced when it becomes dented or distorted. Flush-joint steel drill rods shall be used to connect the split-barrel sampler to the drive-weight assembly. After boring has been advanced and cleaned to the required testing elevation the test shall be performed. Split barrel sampler shall be attached to the sampling rods and lowered into the borehole. The hammer shall be positioned above the anvil and attached to top of the rods. Own weight of the sampler, rods, anvil and drive weight shall be rest on bottom of the boring and applying a seating blow. If excessive cuttings are encountered (more than 10 cm) at bottom of the boring, bottom of hole shall be cleaned again.

The rods will be marked in three successive 15cm increments so that the advance of the sampler under impact of the hammer can be easily observed for each increment. Sampler shall be driven with blows of hammer dropped from 0.75m height and number of blows applied in each 0.15m increment shall be counted. The test shall be stopped when a total number of 50 blows shall be counted during any of the three 0.15 m increments or when a total of 50 blows shall be counted for 0.30 m. In this case the observed penetration shall be recorded. The first 0.15m of penetration shall be considered to be a seating drive. The sum of number of blows required for the second and third 0.15m of penetration will be the standard penetration resistance or "N_{SPT} value". Once performing the test, the split-barrel sampler shall be recovered and sample shall be stored in the core sample boxes with indication of the number of the test and relative depth. For each performed test, test depth, number of blows per each 15 cm of penetration and weight of the drilling rods per linear meter shall be reported. The test results are given on the boring logs in Appendix 1.

4.4.2 Pocket Penetrometer Tests:

Field pocket penetrometer tests were carried out on the cohesive undisturbed samples in order to obtain the unconfined compressive strength of the samples. The test results are given on the boring logs in Appendix 1.

4.4.3 Core Recovery and Rock Quality Designation

For rock sample both Core Recovery (R) and Rock Quality Designation (RQD) values were determined. The values of R and RQD help in determining the mechanical properties of the rocks. The core recovery is defined as the length of the collected sample divided by the total sampler length while the RQD is defined as the length of the pieces of the sample longer than 10 cm divided by the length of the sample.

R = Length of the sample / Length of the sampler

RQD = Length of the samples > 10 cm / Length of the sampler

4.5 Laboratory Tests

4.5.1 General:

In order to determine the physical, mechanical and chemical properties of the ground materials, laboratory tests were performed on selected samples from boreholes. The following are the relevant tests conducted on the samples:

4.5.2 Physical Properties Tests

Physical properties of soil formation help to verify the visual classification and may be used as a guide to predict the geotechnical and mechanical behavior of the soil. The following tests were carried out in cohesive and non-cohesive soils:

a) Atterberg Limits

Atterberg limits include the liquid, plastic and shrinkage limits. These limits indicate the soil water content at different states of consistency ranging from the very soft condition at the liquid limit, to the very stiff condition at the plastic limit and the hard condition at the shrinkage limit. Atterberg limits were performed where useful in classifying plastic soils and in qualitative evaluation of engineering parameters such as shear strength and compressibility. Test was carried out in accordance with ASTM D 4318-84 “Test for Liquid Limit, Plastic Limit and Plasticity Index of Cohesive Soils”.

b) Natural Water Content

The natural water content was determined for undisturbed cohesive soil samples. The value of the natural water content helps in the soil classification. Test was carried out in accordance with ASTM D 2216-90 “Test for Water Content of Soil”.

c) Dry Unit Weight (Density)

The unit weight of a granular soil is difficult to determine where the soil collected from the site by a sampler is disturbed which gives approximate indication of its original unit weight. The unit weight can be determined only for undisturbed cohesive samples collected from the thin-wall tube sampler. Test was carried out in accordance with ASTM D 4254-91 “Minimum Density of Soils and Relative Density”.

d) Soil Gradation

For classification purpose, grain size distribution test was conducted using ASTM testing method D 422-63 (1990) "Particle Size of Soils". Sieve analysis tests were carried out to determine the grain size distribution of soils. The percentage of fines (silt and clay) was determined by washing the sample on sieve number 200 (0.074 mm). The distribution of clay was determined using hydrometer tests.

4.5.3 Mechanical properties Testing, Consolidation Test

Consolidation (oedometer) tests were conducted on undisturbed cohesive samples extracted from boreholes at different depths to study its behavior when subjected to wetting and to obtain the consolidation settlement parameters. Tested samples were loaded in sequence of 50, 100, 200, 400, 800 and 1200 kPa followed by unloading in reverse sequence. Relation between applied stress and void ratio at the end of each load increment and load decrement during the loading and unloading phases is presented in Appendix (1): The Factual Report. These figures include the initial physical properties of tested samples such as water content, bulk density, void ratio, degree of saturation and specific gravity. In addition, these figures include test results such as compression Index C_c and recompression Index C_s as well as the coefficient of consolidation C_v.

5. GENERAL SUBSURFACE CONDITION

Based on the results of the soil investigation program, the soil subsurface condition at the site was divided for the purpose of this report as follows:

5.1 Location of BH1 (Ramisium Temple):

5.1.1 LAYER 1: Silty CLAY to Clayey SILT, Some sand and gravel, Crushed stone.

This layer appears in borehole from the ground surface and extends down to depth 2.5m below the ground surface with a thickness of 2.5m.

5.1.2 LAYER 2: Silty CLAY, Stiff to Very stiff.

This layer can be visually inspected as silty clay with some pockets of silty sand, and has a color of brown. This layer appears in borehole below layer 1 and extends down to depth 8.2m below the ground surface with a thickness of 5.7m.

5.1.3 LAYER 3: SAND & GRAVEL.

This layer can be visually inspected as graded sand and graded gravel with some silt, and has a color of gray to yellow. This layer appears in borehole below layer 2 and extends down to depth 9.0m below the ground surface with a thickness of 0.8m.

5.1.4 LAYER 4: Silty CLAY, Hard.

This layer can be visually inspected as silty clay with some pockets of sand and traces of iron oxides, and it has a color of light grey to light brown. This layer appears in borehole below layer 3 and extends down to end of borehole.

5.2 Location of BH2 (Near River Nile):

5.2.1 LAYER 1: Fill (Sand, Gravel, Crushed stone).

This layer appears in borehole from the ground surface and extends down to depth 0.8m below the ground surface with a thickness of 0.8m.

5.2.2 LAYER 2: Silty CLAY, Stiff to Very stiff.

This layer can be visually inspected as silty clay with traces of sand and calcareous pebbles, and it has a color of brown. This layer appears in borehole below layer 1 and extends down to depth 12.2m below the ground surface with a thickness of 11.4m.

5.2.3 LAYER 3: SAND.

This layer can be visually inspected as medium sand with some silt, and has a color of brown to gray. This layer appears in borehole below layer 2 and extends down to end of borehole.

5.3 Location of BH3 (Sity Temple):

5.3.1 LAYER 1: Fill (Sand, Gravel, Crushed stone).

This layer appears in borehole from the ground surface and extends down to depth 1.0m below the ground surface with a thickness of 1.0m.

5.3.2 LAYER 2: Crushed LIMESTONE.

This layer can be visually inspected as crushed limestone with a color of light yellow to white. This layer appears in borehole below layer 1 and extends down to depth 3.0m below the ground surface with a thickness of 2.0m.

5.3.3 LAYER 3: GRAVEL & SAND.

This layer can be visually inspected as graded gravel and graded sand with some silt and crushed limestone, and has a color of grey to white. This layer appears in borehole below layer 2 and extends down to depth 11.2m below the ground surface with a thickness of 8.2m.

5.3.4 LAYER 4: Silty CLAY, Hard.

This layer can be visually inspected as silty clay with a color of light grey to light brown. This layer appears in borehole below layer 3 and extends down to end of borehole.

5.4 Location of BH4 (Habu Temple):

5.4.1 LAYER 1: Fill (Sand, Gravel, Crushed stone).

This layer appears in borehole from the ground surface and extends down to depth 3.2m below the ground surface with a thickness of 3.2m.

5.4.2 LAYER 2: LIMESTONE.

This layer can be visually inspected as limestone with a color of light gray to yellow. This layer appears in borehole below layer 1 and extends down to depth 4.1m below the ground surface with a thickness of 0.9m.

5.4.3 LAYER 3: Silty CLAY, Very stiff.

This layer can be visually inspected as silty clay with some pockets of sand, and has a color of brown. This layer appears in borehole below layer 2 and extends down to depth 8.2m below the ground surface with a thickness of 4.1m.

5.4.4 LAYER 4: GRAVEL, Crushed LIMESTONE.

This layer can be visually inspected as graded gravel and crushed limestone with some silt, and has a color of grey to yellow. This layer appears in borehole below layer 3 and extends down to depth 11.2m below the ground surface with a thickness of 3.0m. This layer appears again in borehole below layer 5 and extends down to depth 18.0m with a thickness of 4.5m.

5.4.5 LAYER 5: Crushed LIMESTONE.

This layer can be visually inspected as crushed limestone with successive interlayers of silty clay, and has a color of grey to brown. This layer appears in borehole below layer 4 and extends down to depth 13.5m below the ground surface with a thickness of 2.3m.

5.4.6 LAYER 6: LIMESTONE.

This layer can be visually inspected as limestone with a color of white. This layer appears in borehole below layer 4 at depth of 18.0m and extends down to end of borehole.

6. GROUND WATER TABLE

The readings in boreholes at date of 25 September 2005 were as shown in the following table:

Borehole no.	Location	Water depth below piezometer top	Height of piezometer tube above ground surface (m)	Ground water depth below ground surface(m)
BH1	Ramisium temple	1.84	0.92	0.92
BH2	Near River Nile	3.88	0.54	3.34
BH3	Sity temple	2.51	0.48	2.03
BH4	Habu temple	2.90	0.57	2.33

7. RELATIONS BETWEEN GEOTECHNICAL PROPERTIES AND FIELD AS WELL AS LABORATORY TEST RESULTS

These relations shall be discussed in this section in brief as most of them are given in textbooks and international codes, as well as in the EGYPTIAN CODE OF DESIGN AND CONSTRUCTION FOR FOUNDATION, (EC) part 3. These relations shall be used for estimating the soil parameters needed in the design and geotechnical analysis.

7.1. Correction of measured values of SPT test for non-cohesive soils

7.1.1 Correction due to submergence

For silty sand with high percentage of fines, the measured values of SPT must be corrected due the effect of submergence and the build up of pore water pressure during the test. This correction is given in the EC – PART 1 as follows:

$$N_m = (N-15)*0.5 +15$$

Where N_m = Modified number of blows

N = measured value of SPT > 15 blows

7.1.2 Correction due to overburden pressure

The number of blows as measured in SPT must be corrected due to the effect of the overburden pressure above the test level. According Bazzara method, which is recommended to be adopted by the EC, the corrected $N_{correct}$ value is given by:

$$N_{correct} = \frac{4N_{field}}{(3.25 + \sigma)} \quad ....\sigma > 0.75 \ kg/cm^2$$

7.2 Relation between N values and Relative Density D_r for non-cohesive Soil

The relation between the number of blows in SPT test and the relative density according to the Egyptian code EC Part 3, is given in Table 7.1:

Table 7.1 Relation between N_b values and Dr according to EC

No. Of blows/30 cm	Description	Relative Density
0 – 4	Very loose	0 - 0.15
4 – 10	Loose	0.15 - 0.35
10 – 30	Medium Dense	0.35 - 0.65
30 – 50	Dense	0.65 - 0.85
> 50	Very Dense	0.85 - 1.0

7.3 Relation between Relative Density D_r and the angle of internal angle of friction ϕ for non-cohesive Soil

According to the EC, Part 3, page 23, the relation between the relative density and the angle of internal friction ϕ is given as in Table (8.2):

Table 7.2: Relation between relative density R_D and Angle of internal friction ϕ according to EC

Relative Density R_D%	Angle of internal friction ϕ
0 – 15%	27 – 30
15% - 35%	30 – 32
35% - 65%	32 – 36
65% - 85%	36 – 40
> 85%	> 40

7.4 Relation between Deformation modulus and N_b for Non-cohesive Soils

Many empirical correlations between the standard penetration test results and the deformation modules have been established. Correlation proposed by the following authors are utilized:

1- Denver (1982) gave the following parabolic correlation between N and the drained young's modules E.

$$E = B\,N^{0.5}$$

Where B = 7 MPA.

2- Webb (1970) showed that the relationship between N values and the values of the drained young's modules could be calculated approximated by the formula:

$$E = a\,N + b$$

Where a, b = 478, 7170 KPA

3- Bowles (1982) proposed the following correlation between N values and the drained young's modules:

$$E = 50\,(N + 15)\ t/m^2$$

4- Schmertman (1980) proposed the following correlation:

$$E = 10\,N\ kg/cm^2$$

7.5 Relation between bulk unit weight γ and N_b for non-cohesive soils

According to Bowles design handbook, the relation between the unit weight and the N values is given in table (7.3):

Table (7.3) - Relation between N_b and bulk unit weight γ t/m^3

N_b values	Bulk unit weight γ t/m^3
0 – 4	1.1 to 1.4
4 -10	1.4 to 1.6
10 - 30	1.6 to 1.9
30 - 50	> 1.9

7.6 Relation between shear strength parameters, N_b and Consistency Index Values for cohesive Soils

According to the EC, Part 3, the unconfined compressive strength is related to the N_b values as well as the consistency index as given in table 7.4:

Table 7.4 - Relation between N_b and unconfined compressive strength

N_b Value	Soil Description	Consistency index	Unconfined compressive strength q_u kg/cm^2
0 – 2	Very soft	0.000 to 0.500	0.00 -0.25
2 – 4	Soft	0.500 to 0.625	0.25 -0.50
4 –8	Medium stiff	0.625 to 0.750	0.50 - 1.00
8 –15	Stiff	0.750 to 1.000	1.00 - 2.00
15 –30	Very stiff	1.000 to ($w_{sh} = w$)	2.00 -4.00
> 30	Hard	$w_{sh} > w$	2.00 -4.00

7.7 Relation between undrained modulus and undrained cohesion for cohesive soil

The relation between the undrained modulus of deformation *(E_u)* and the undrained cohesion has been given by DUNCAN (1976) as a function of the over-consolidation ratio and the plasticity index as given in figure (2). In addition for cohesive soil, the E_u is related to Cu conservatively, as given in the EC, Part 4, as E_u is equal to (50 to150) times c_u.

7.8 Relation between plasticity index and drained angle of shearing resistance for cohesive soil.

For normally consolidated clay, the relation between the drained angle of shearing resistance ϕ_d and the plasticity index is given by EPRI 1990 as shown in figure (3).

7.9 Relation between the soil permeability and the particle sizes

Soil permeability is a complex parameter affecting by many factors such as soil type, void ratio, soil structure, direction of flow, soil homogeneity and others. The determination of the soil permeability for non cohesive can be carried out accurately using in-situ pumping tests. However, many empirical correlations can be used for rough estimation of the soil permeability based on sieve analysis results, estimated in-situ porosity and other simple parameters. The following is the selected most known correlations:

7.9.1. HAZEN had indicated that the main factor governing the permeability is the presence of fine size particle and hence he correlate the permeability to the factor of D_{10} in the gradation curve by the formula $K = C (D_{10})^2$ where C is a factor about 90 to 120 usually taken as 100 and D_{10} is the particle size of the soil passing 10% of the sample.

7.9.2 SLICHTER used the same correlation with a second set of constant and used the following formula $K = (C_1/C_2)\ (D_{10})^2$ where: C_1 and C_2 are factors.

7.9.3 TERZAGHI admitted the importance of the size D_{10} but introduced the porosity as a second factor affecting the permeability and gave the following formula: $K = C\ [(n - 0.13) / (1 – n)^{0.33}]^2\ (D_{10})^2$, where n is the sample porosity.

7.9.4 KOZNEY depicted only the use of the porosity as in the following formula: $K = C\ (1/Cs^2)\ [n^3\ (1-n)]$, where C and Cs are factors,

7.9.5 CREAGER based his formula on the use of a second size of particle which is the D20 as follows: $K= C\ (D_{20})^{2.37}$, Where D_{20} is the particle size of the soil passing 20% of the sample.

7.10 Rocks classification according to unconfined compressive strength

The rocks can be classified according to the unconfined compressive strength according to the Egyptian code as follows:

Table 7.5 – Rock Classification According to Unconfined Strength

Unconfined Strength		ROCK TYPE
MN / m^2	**Kg / cm^2**	
> 200	> 2000	Extremely Hard
100 - 200	1000 - 2000	Very Hard
50 - 100	500 - 1000	Hard
12.5 - 50	125 - 500	Moderate Hard
5 - 12.5	50 - 125	Moderate Weak
1.25 - 5	12.5 - 50	Weak
< 1.25	< 12.5	Very Weak

7.11 Rocks classification according to RQD

The rocks can be classified according to the unconfined compressive strength according to the Egyptian code as follows

Table 7.6 – Rock Classification According To Rock Quality Designation (RQD)

Rock Quality	(RQD) %
Very Weak	Less Than 25
Weak	25 - 50
Medium	50 - 75
Good	75 - 90
Excellent	90 - 100

8. GEOTECHNICAL PROPERTIES OF THE SUBSOIL

Based on the available data regarding the soil stratigraphy and the results of field tests as well as laboratory tests, the geotechnical behavior of the layers encountered in the project site shall be as follows:

8.1 FILL Layer:

This layer is heterogeneous fill layer. This layer contains sand, gravel and crushed stone. In general, this material have different shear strength and this causes large non-homogenous settlement especially when subjected to wetting. For the purpose of geotechnical analysis, this layer shall be considered as loose sand has an angle of internal friction of 26 degree and unit weight of 1.6 t/m^3 and hence the geotechnical parameters for this layer can be summarized as follows:

C =0.0

Φ = 26 degree

E_{dry} = 50 kg/cm^2

E_{wet} =20 kg/cm^2.

8.2 Silty CLAY Layer:

8.2.1 General Characteristics

This layer is silty clay with some pockets of sand and traces of calcareous pebbles, and has a brown to grey color. Table 8.1 summaries the laboratory and field testes performed at different depths of this layer:

Table 8.1 – Summary of laboratory and field tests results for the Silty CLAY layer

Borehole no.	Location	Depth (m)	q pocket Kg/cm^2	q pocket Average	Atterberg Limits L.L. (%)	Atterberg Limits P.L. (%)	Wc (%)	Ic	γ_{dry} (gm/cm^3)
BH1	Ramisium Temple	4	1.6	1.7	-	-	-	-	1.41
		5	1.4		-	-	-	-	-
		6	2.0		80	29	32.2	0.94	-
		7	1.8		-	-	-	-	1.37
		8	1.7		-	-	-	-	-
		10	> 4	> 4	-	-	-	-	-
		11	> 4		-	-	-	-	1.58
		12	> 4		-	-	-	-	-
		13	> 4		91	34	16.8	1.30	1.53
		14	> 4		-	-	-	-	-
		15	> 4		-	-	-	-	-
		16	> 4		-	-	-	-	1.53
		17	> 4		-	-	-	-	-
		18	> 4		-	-	-	-	-
		19	> 4		-	-	-	-	-
BH2	Near Nile	2	1.7	1.7	-	-	-	-	-
		3	1.9		-	-	-	-	1.39
		4	2.4		79	29	36.9	0.84	-
		5	2.3		-	-	-	-	-
		6	2.0		-	-	-	-	-
		7	1.5		-	-	-	-	-
		8	1.4		75	30	37.0	0.84	-
		9	1.4		-	-	-	-	-
		10	1.3		-	-	-	-	-
		11	1.5		-	-	-	-	1.34
BH3	Sity Temple	12	> 4	> 4	93	34	24.1	1.17	-
		14	> 4		-	-	-	-	-
		15	> 4		-	-	-	-	-
		16	> 4		-	-	17.0	-	1.58
		17	> 4		-	-	-	-	-
		18	> 4		96	33	17.2	1.25	-
		19	> 4		-	-	-	-	-
BH4	Habu Temple	5	2.0	2.6	74	28	29.9	0.96	-
		6	2.7		-	-	-	-	-
		7	3.0		-	-	-	-	-
		8	2.8		-	-	-	-	-

8.2.2 Physical properties

The laboratory tests showed that the dry unit weight for this clay layer is ranging from 1.34 to 1.58 t/m^3 with an average value of 1.50 t/m^3.

8.2.3 Atterberg Limits

The liquid limit is ranging between 74% and 96% while the plastic limit is ranging between 28% and 34%. The corresponding value of the plasticity index is ranging between 45% and 63%. According to the Unified Soil Classification System (USCS), the clay classification is mainly **CH** (clay with high plasticity). The measured natural water content is ranging between 16.8% and 37% and the corresponding consistency index I_c is ranging between 0.84 and 1.30.

8.2.4 Undrained Shear Strength Parameters

The results of pocket penetrometer tests are shown in table 9.1. The average value for the unconfined strength for all tests is ranging between 1.7 to more than 4 kg/cm^2, while the concluded values from the consistency index (**I_c**) values according table 7.4 are ranging between 1.5 kg/cm^2 and 4.0 kg/cm^2. Consequently, the average value of the undrained cohesion can be considered as it ranges between 0.8 to 2 kg/cm^2.

8.2.5 Deformation Modulus E

According to item 7.7, the undrained deformation modulus can be considered as it ranges between 120 kg/cm^2 to 350 kg/cm^2.

8.2.6 Settlement Characteristics

Table 8.2 summaries the results of consolidation testes performed at different depths of this layer:

Table 8.2 – Summary of consolidation test results for Silty CLAY layer

Borehole no.	Location	Depth (m)	Void ratio (e)	C_C	P_C (kg/cm^2)
BH1	Ramisium Temple	6.0	0.94	0.2	3.90
BH2	Near Nile	8.0	1.01	0.26	3.65

8.3 GRAVEL & SAND Layer:

8.3.1 General Characteristics

This layer is a mixture of graded gravel and graded sand with some silt and crushed limestone, and it has a color of grey to white. Table 8.3 summaries the laboratory and field testes performed of this layer:

Table 8.3 Summary of laboratory and field tests results for GRAVEL and SAND layer

Borehole No.	Location	Depth (m)	N_{SPT} Counted	N_{SPT} Ave.	grain size analysis			USCS
					%gravel	%sand	%fines	
BH1	Ramisium Temple	9.0	-	-	44	48	8	SP-SM
BH3	Sity Temple	5.0	> 50	> 50	-	-	-	-
		6.0	-		75	22	3	SP
		7.0	> 50		-	-	-	-
		10.0	-		55	39	6	SP-SM
BH4	Habo Temple	15.0	-	-	82	17	1	GW

The results of the gradation test are also giving the limits of particle size as shown in the table 8.4.

Table 8.4 Summary of the gradation test results for GRAVEL and SAND layer

Borehole No	Location	Depth (m)	D_{10} (mm)	D_{20} (mm)
BH1	Ramisium Temple	9.0	0.28	0.55
BH3	Sity Temple	6.0	0.90	1.50
		10.0	0.35	0.60
BH4	Habu Temple	15.0	1.10	2.10

8.3.2 Sieve analysis results

The sieve analysis results indicate that the percentage of fines (passing sieve 200, size less than 0.074mm) is ranging between 1% and 8% while the percentage of gravel is ranging between 44% and 82%. According to the Unified Soil Classification System (USCS), the layer can be classified in most cases as **SP-SM** (poorly graded silty sand) .

8.3.3 Standard penetration tests

Standard penetration tests indicate that the number of blows is over than 50 blows. For safety the average number of blows shall be considered as 50 blows.

8.3.4 Relative density

The corrected number of blows in standard penetration tests indicates that this layer in most cases is **very dense.**

8.3.5 Shear strength parameters

The number of blows in SPT test for this layer is over than 50 blows. The corresponding angle of internal friction is 40 degree.

8.3.6 The deformation modulus (E)

The value of the deformation modulus E has been estimated using the set of equations given in item 7.4 and considering the measured number of blows. The above yields that the deformation modulus for this layer can be taken as 400 kg/cm^2.

8.3.7 The soil permeability

According to item 7.9 and to the table in item 8.3.1 the following table is the result of the calculation of coefficient of permeability (***k***) conducted in the calculation sheets enclosed in appendix No2.

Borehole No	Location	Depth (m)	K average (m/sec)
BH1	RAMISIUM	9.0	2.747E-03
BH3	Sity Temple	6.0	5.631E-02
		10.0	3.91E-03
BH4	Habo Temple	15.0	7.433E-02

8.4 SAND Layer:

8.4.1 General Characteristics

This layer is medium sand with some silt, and has a color of brown to gray. Table 8.5 summaries the laboratory and field testes performed of this layer:

Table 8.5 Summary of laboratory and field-tests results for SAND layer

Borehole No.	Location	Depth (m)	N_{SPT} Counted	N_{SPT} Ave.	Grain size analysis			USCS
					%Gravel	%Sand	%Fines	
BH2	Near Nile	13.0	-	65	3	94	3	SP
		14.0	65		-	-	-	-
		16.0	-		2	95	3	SP

The results of the gradation test are also giving the limits of particle size as shown in the table 8.6.

TABLE 8.6 SUMMARY OF THE GRADATION TEST RESULTS

Borehole No	Location	Depth (m)	D_{10} (mm)	D_{20} (mm)
BH2	Near Nile	13.0	0.20	0.38
		16.0	0.20	0.28

8.4.2 Sieve analysis results

The sieve analysis results indicate that the percent of fines percentage of fines (passing sieve 200, size less than 0.074mm) is 3% while the percentage of gravel is ranging between 2% and 3%. According to the Unified

Soil Classification System (USCS), the layer can be classified in most cases as **SP** (poorly graded sand) .

8.4.3 Standard penetration tests

Standard penetration tests indicate that the number of blows is 65 blows. The corrected number of blows can be considered as 50 blows.

8.4.4 Relative density

The corrected number of blows in standard penetration tests indicates that this layer in most cases is **very dense.**

8.4.5 Shear strength parameters

The corrected number of blows in SPT test for this layer is 50 blows. The corresponding angle of internal friction is 40 degree.

8.4.6 The deformation modulus (E)

The value of the deformation modulus E has been estimated using the set of equations given in item 7.4 and considering the measured number of blows. The above yields that the deformation modulus for this layer can be taken as 400 kg/cm^2.

8.4.7 The soil permeability

According to item 7.9 and to the table in item 8.4.1 the following table is the result of the calculation of coefficient of permeability (***k***) conducted in the calculation sheets enclosed in appendix No2.

Borehole No	**Location**	**Depth (m)**	***K* average (m/sec)**
BH2	Near Nile	13.0	2.371E-03
		16.0	2.200E-03

8.5 LIMESTONE Layer:

8.5.1 General Characteristics

The field and laboratory test results carried out on this layer denote that this layer is a limestone. This layer in most cases is found in the form of weathered limestone with some gravel.

8.5.2 Physical properties

The laboratory tests showed that the dry unit weight for this layer is ranging from 2.25 to 2.27 t/m^3 with an average value of 2.26 t/m^3.

8.5.3 Rock classification according to the RQD value:

The RQD value for the Rock is ranging between 20% and 60%. According to relations given in item 7, the rock can be classified according to RQD value as weak to medium.

8.5.4 The unconfined compressive strength

According to relations given in item 7, the unconfined compressive strength of this rock is ranging between 12 to 50 kg/cm^2.

A&A – Engineers and Consultants

Dr. Mohamed Abdel Hamid — Amin Loutfi

Consultant Engineer — **Lecture of Soil Mechanics - Helwan University**

ARAB REPUBLIC OF EGYPT
MINISTRY OF CULTURE
SUPREME COUNCIL OF ANTIQUITIES

SALVATION OF RAMISIUM, HABU AND SITY TEMPLES
LUXOR CITY- WEST BANK

GROUND WATER MONITORING

CONSULTANT

LUND UNIVERSITY

DEPARTMENT OF WATER RESOURCES ENGINEERING

LUND INSTITUTE OF TECHNOLOGY

SWEDEN

GEOTECHNICAL ENGINEER

A&A ENGINEERS AND CONSULTANTS

EGYPT

Rev.	Comments	Prepared By	Checked By	Approved By	Ref.	Date
0	Issued for Approval	A&A Engineers and Consultants	H.M	A.L	40/256	11/2005

TABLE OF CONTENT

APPENDICES

1. INTRODUCTION:

This report has been prepared upon the request of **LUND University, Department of Water Resources Engineering (Teknisk Vattenresurslara) SWEDEN,** to carry out the engineering services of the site investigation for **RAMISIUM, HABU AND SITY TEMPLES** located at LUXOR city - west bank. This study is conducted under the care of the **SUPREME COUNCIL OF ANTIQUITIES**.

The site investigation program, as planned by LUND university, includes 4 boreholes, as well as field and laboratory testing.

The site investigation program was conducted by A&A during September 2005 using in house capabilities as well as other specialized soil investigation contractors.

This supplementary interim report is prepared in order to present the results of piezometers readings in order to obtain the depth of ground water. Furthermore, the monitoring process and readings will be continued until April 2005 and then a second supplementary report will be prepared when finishing all readings.

2. GENERAL SUBSURFACE CONDITION

Based on the results of the soil investigation program, the soil subsurface condition at the site can be summarized as follows:

2.1 Location of PZ 1 (Near River Nile):

2.1.1 LAYER 1: Fill

This layer appears from the ground surface and extends down to depth 0.8m below the ground surface.

2.1.2 LAYER 2: Silty CLAY

This layer appears follows 1 and extends down to depth 12.2m below the ground surface.

2.1.3 LAYER 3: SAND.

This layer appears in borehole below layer 2 and extends down to end of borehole.

2.2 Location of PZ 2 (Habu Temple)

2.2.1 LAYER 1: Fill

This layer appears from the ground surface and extends down to depth 3.2m below the ground surface.

2.2.2 LAYER 2: LIMESTONE

This layer follows layer 1 and extends down to depth 4.1m.

2.2.3 LAYER 3: Silty CLAY, Very stiff.

This layer appears below layer 2 and extends down to depth 8.2m.

2.2.4 LAYER 4: GRAVEL, Crushed LIMESTONE

This layer follows layer 3 and extends down to depth 11.2m below the ground surface. It appears again below layer 5 and extends down to depth 18.0m.

2.2.5 LAYER 5: Crushed LIMESTONE.

This layer follows layer 4 and extends down to depth 13.5m.

2.2.6 LAYER 6: LIMESTONE.

This layer follows layer 5 at depth of 18.0m and extends down to end of borehole.

2.3 Location of PZ 3 (Ramisium Temple):

2.3.1 LAYER 1: Silty CLAY

This layer appears from the ground surface and extends down to depth 2.5m below the ground surface.

2.3.2 LAYER 2: Silty CLAY, Stiff to Very stiff.

This layer follows layer 1 and extends down to depth 8.2m.

2.3.3 LAYER 3: SAND & GRAVEL.

This layer follows layer 2 and extends down to depth 9.0m.

2.3.4 LAYER 4: Silty CLAY, Hard.

This layer follows layer 3 and extends down to end of borehole.

2.4 Location of PZ 4 (Sity Temple):

2.4.1 LAYER 1: Fill

This layer appears from the ground surface and extends down to depth 1.0m below the ground surface.

2.4.2 LAYER 2: Crushed LIMESTONE.

This layer follows layer 1 and extends down to depth 3.0m.

2.4.3 LAYER 3: GRAVEL & SAND.

This layer follows layer 2 and extends down to depth 11.2m.

2.4.4 LAYER 4: Silty CLAY, Hard.

This layer follows layer 3 and extends down to end of borehole.

3. PIEZOMETERS

Four (4) boreholes were carried out. After finishing boring every borehole was cleaned and converted to observation well (piezometers) composed of 2-inch steel pipes fitted with 1.0 m of cupper screen with gravel pack filter.

The readings of the piezometers are enclosed in Appendix 1

4. GROUND WATER TABLE

The readings of the piezometers taken up to 25 November 2005 shows that the depth of ground water can be summarized as follows:

Piezometer no.	Location	Ground water depth below ground surface (m)			
		Date: 25.09.2005	Date: 09.10.2005	Date: 24.10.2005	Date: 25.11.2005
1	Near NILE	3.34	3.44	3.42	3.42
2	HABU	2.33	2.32	2.28	2.18
3	RAMISIUM	0.92	0.87	0.87	0.80
4	SITY	2.03	2.08	2.05	2.01

5. COMMENTS

1. The piezometer readings show water depth. To use these readings efficiently the elevations of the piezometers and the elevation of water in the Nile river should be surveyed as well as distances. The topographic survey work to correlate the project shall be required to start the next phase of the site investigation.
2. During the reading of piezometer “Near Nile” A&A engineer discovered that it was opened and partially buried with sand. Site crew cleaned piezometer and closed it again. We asked SCA personnel to guard this remote piezometer but they say that they have no jurisdiction out of Temple area. We hope we shall not meet any problem in the future.

APPENDICES

Appendix No. (1)

READINGS OF PIEZOMETERS

Date: 25.09.2005

Piezometer No.	Piezometer Location	Piezometer Readings	Height of Piezometer from ground surface (m)	Water depth (m)
1	Near NILE	3.88	0.54	3.34
2	HABU	2.9	0.57	2.33
3	RAMISIUM	1.84	0.92	0.92
4	SITY	2.51	0.48	2.03

Date: 09.10.2005

Piezometer No.	Piezometer Location	Piezometer Readings	Height of Piezometer from ground surface (m)	Water depth (m)
1	Near NILE	3.98	0.54	3.44
2	HABU	2.89	0.57	2.32
3	RAMISIUM	1.79	0.92	0.87
4	SITY	2.56	0.48	2.08

Date: 24.10.2005

Piezometer No.	Piezometer Location	Piezometer Readings	Height of Piezometer from ground surface (m)	Water depth (m)
1	Near NILE	3.96	0.54	3.42
2	HABU	2.85	0.57	2.28
3	RAMISIUM	1.79	0.92	0.87
4	SITY	2.53	0.48	2.05

Date: 25.11.2005

Piezometer No.	Piezometer Location	Piezometer Readings	Height of Piezometer from ground surface (m)	Water depth (m)
1	Near NILE	3.96	0.54	3.42
2	HABU	2.75	0.57	2.18
3	RAMISIUM	1.72	0.92	0.8
4	SITY	2.49	0.48	2.01