FINAL REPORT

June 2008 – March 2009

ARCE Groundwater Lowering Response Project, Luxor

"Preservation of the Sacred Lakes – Mut Lake Dewatering"

Magdy Mokhtar

The Egyptian Antiquities Conservation Project (EAC)
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Awarded to

THE AMERICAN RESEARCH CENTER IN EGYPT (ARCE)

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Egyptian Ministry of State for Antiquities

AMERICAN RESEARCH CENTER IN EGYPT

Project Report
2008/2009

Abbreviations

ARCE	- **A**merican **R**esearch **C**enter in **E**gypt
GWLRP	- **G**roundwater **L**owering **R**esponse **P**rogram
JHU	- **J**ohns **H**opkins **U**niversity
SCA	- **S**upreme **C**ouncil of **A**ntiquities
SMT	- The monitoring survey company
USAID	- **U**nited **S**tates **A**gency for **I**nternational **D**evelopment

UNITS AND MEASURES

m	- meter
m.a.s.l.	- meters above sea level
µS/cm	- micro siemens per centimeter (Electrical Conductivity unit)
ppm	- part per million. (concentration unit)
mg/l	- milligram per liter (concentration unit)

This study is prepared by ARCE technical department as a part of the Luxor East Bank Groundwater Lowering Response Project. This is a unique work, as the lake was dewatered and a contour map for the bottom of the lake made for the first time.

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1 Introduction

The Mut Precinct's Isheru lake (Fig.1) is the only sacred lake of its type remaining in Egypt. It is located in the southern section of the Karnak temple precinct. As a result of the recent start-up of the Karnak groundwater lowering system, the lake water level has dropped. Due to the high evaporation rate the water Electric Conductivity (*EC*) increased to 14,500 **µ**S/cm equals to salinity of 8700 ppm and the lake has become susceptible to algae growth, encroachment by vegetation, and to in-filling by wind-borne silt and subsidence of the embankments.

Fig.1 Aerial photo shows the Mut Temple Complex and Mut lake (Isheru)

For most of the twentieth century the Mut Isheru had extremely little vegetation growing above water level. This situation changed very rapidly during the second half of the 1980s and the 1990s. By early 2001 extremely tall (10 - 15 meters) thick and dense reeds began to fill the lake and cover structures at its edges. (Fig. 2.). As a result, the present view of the site has been changed from what was thought to have been its original appearance. The reeds also present at least two threats to some of the site's monuments. One is damage by fires, of which there have been several that have scorched nearby stonework before the local firefighters could arrive to fight the flames. The other is damage to stone and mud brick monuments by the roots of the vegetation.

Fig.2 A photo shows the reeds and dense vegetation around Mut lake

2 Climate Description

Luxor lies in a desert climate with significant temperature differences between day and night, and very little rainfall, with the exception of some major rain storms on the eastern

mountains during the unstable Spring and Autumn seasons (March, April, October and November) which can create severe flooding in wadis. During summer and winter the weather is stable, whereas during Spring and Autumn weather is unstable with sand storms and occasional rainstorms. The annual climatic conditions are summarized in *Appendix A*.

3 Project Overview

The lake conservation project is intended to complete the preliminary step of draining the lake to permit archaeological excavations and removal excessive vegetation from the lake shore.

The previously high water level in the Karnak precinct has been reduced by the recent completion and operation of the USAID funded groundwater lowering drainage system. The groundwater level in the Karnak precinct has now been stabilized. It is anticipated that the lake can be economically maintained in an empty state, with a minimum amount of pumping.

Mut Lake conservation, including completion of archaeological excavations in the lake bed and removal of excessive vegetation, will prepare the Mut sacred lake for general improvement and restoration of the lake to support the establishment of an interpretative environment conducive to tourist education about the historical importance of the Mut Lake and Mut temple location.

Mut Lake Conservation will include the following elements.

a) Preparation, review and implementation of a detailed and comprehensive project plan.
b) Physical surveys and observations of the Mut Lake environment.
c) Sampling and laboratory analysis of water, plants and sediment from Mut Lake.
d) Preparation of an Environmental Impact Assessment.
e) Installation and testing of dewatering equipment.
f) Lowering the lake water level by pumping lake water to a sewer disposal point.
g) Maintenance of a low lake level for a period of several months by continuous or periodic operation of the dewatering pumps.
h) Clearance of lake weeds.
i) Implementation of archaeological excavations.
j) Recharge of the lake and calculation of the refilling rate.

3.1 Physical Surveys

Physical surveys have been of an informal nature comprising observations made over six months as part of regular visits to the Mut Sacred Lake. During this period, interviews with long-term security personnel overseeing the lake area and with long term residents of areas adjacent to the Mut Sacred Lake were conducted. These interviews have focused upon the following:

- Observations of wildlife and the history of wildlife at the site, including wildfowl, mammals, vermin and fish.
- Enquiries regarding past human use of the site for festivities, or other incidental use.
- Enquiries regarding the history of water level variations, the history of plant growth around the lake, and the history of nearby land-use which may have had an influence on the lake.

- Enquiries regarding the history of treatment of antiquities resources by the local populace.
- Enquiries regarding the profile of the lake bottom.

3.2 Sample collection and laboratory analysis

Samples of Mut Lake water, sediment and shoreline weed samples were collected and analyzed for various parameters to identify their characteristics before taking any further actions. The sample collection and analysis program was conducted for two main purposes:

a) To determine whether lake water can be safely and legally discharged into the Nile or to a sewer system and;

b) To determine whether the dried lake sediments and vegetation may pose an environmental risk to workers and archaeologists.

A list of the investigated parameters and the results of the chemical water analysis *(See Appendix B*) indicates the water quality is satisfactory for discharge of the lake water into the Nile or to the sewer system.

3.3 Reeds and Vegetation Removal from the Lake Shore

Because dense reeds and other vegetation are considered a potential fire hazard, the project investigated means to eliminate them, or minimize their growth. It was found that jut cutting the reeds is not a solution; reads grow up again, more densely than before. The best way is to spray the area with an effective herbicide. The SCA weed control department suggested the use of the defoliant, "Roundup", one month before removing the weeds. This has the ability to reach the roots and kill the plants.

3.4 Work Schedule

Table 1 shows the time to commence each step.

Tasks	Period by Months														
	2008												2009		
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
Sample and analysis															
Reed removal 1st stage					Removal										
Dewatering (1st stage)															
Reed removal 2nd stage								Spray		Removal					
Dewatering (2nd stage)															

4 Scope of work

The scope of work for the ARCE Luxor East Bank Groundwater Lowering Response Project includes the specified goal of conservation of the Sacred Lake at Mut Temple. As part of its Sacred Lake conservation work, during the 2008/2009 season, the ARCE

project provided technical support to archaeological excavations adjacent to Mut Sacred Lake. This technical support comprised lowering the level of Mut Sacred Lake so excavations could be completed in areas that would otherwise be flooded by the lake water. Other aspects are to document some technical data measured for the first time concerning the following:

- The volume of water in the lake at different elevations.
- The surface area of the lake at different elevations
- Groundwater refilling rate.

5 Planning for the First Dewatering Season (June-July 2008)

- During 2007, the ARCE project staff evaluated the goal of conservation of the Mut Sacred Lake and concluded that active management of lake water levels and water quality were a necessary part of any plan to conserve the lake and maintain it in a condition appropriate for a touristic environment.
- Various strategies for lake conservation were evaluated and a conceptual plan for control of the lake water was drafted. An environmental assessment report for the proposed work was prepared and submitted to USAID. A draft design for the lake water control system was communicated to the SCA. Letters of approval from USAID and the SCA were obtained for the proposed work. ARCE proposed to conduct a test of lowering Mut lake water levels in autumn 2007 or early 2008.
- In response to the ARCE project plan, Johns Hopkins University, an archaeological concession holder at the Mut temple, proposed to coordinate an archaeological dig with ARCE's first test-effort to lower the lake water. The water-lowering tests would, it was proposed, allow archaeological investigations in places where it had previously been too wet for digging.
- The coordination of the Johns Hopkins archaeological excavations with the water-lowering test promised to find new information about the ancient configuration of the lake. Coincidentally, information about the lake's ancient configuration is a key requirement for the ARCE as part of its lake conservation and development plans.

5.1 Activities

As of early June 2008, the ARCE Luxor project has conducted a variety of activities as part of its work for conservation of the Mut sacred lake. The following is a summary list of the main preparation tasks, plus the recent activities in June and July during the excavation project conducted by the Johns Hopkins University team.

5.1.1 Planning Activities

A. Beginning in the middle of 2007 the ARCE project staff began to assemble drawings and an equipment list for the dewatering system. Final drawings were completed in January 2008 and meetings were held with contractors to define the scope of work.

B. Definition of the scope of work in early 2008 enabled ARCE to choose a course of action using subcontractors and equipment to be hired or purchased by ARCE directly, rather than using a general contractor.

C. ARCE's actions to mobilize subcontractors in early March 2008 were delayed by a belated request from the SCA to resubmit plans to an SCA technical committee for review prior to proceeding with implementation.

D. ARCE prepared and submitted the groundwater lowering plans to the SCA, but the local SCA representatives refused permission for ARCE's work plan to proceed.

E. As the archaeological teams arrived in Luxor in early June 2008, it became apparent that the USAID funded archaeological dig was at risk if the lake water level could not be lowered in time. To assist ARCE obtaining a satisfactory point for disposal of lake water, the SCA coordinated ARCE's application to local authorities for a connection to the local municipal sewer system.

5.1.2 Sub-Contractor and Various Activities

1. Weed Removal. ARCE hired a team of laborers to clear reeds from the area adjacent to the planned archaeological excavations. ARCE procured and tested a weed cutting device to be used to clear weeds from the lake area in preparation for future excavations.

2. After various meetings with SCA technical personnel, permission was obtained for temporary disposal of lake water into the Karnak groundwater drainage system. This temporary permission enabled the ARCE project to begin lowering the lake water level just in time to prevent significant delays to the archaeological excavation schedule. During the period of time permitted by the SCA to dispose of water into the groundwater system, ARCE conducted sampling of water entering the system's main pump station. This sampling confirmed that water quality entering the system was satisfactory and did not represent a threat to the groundwater system pumps.

5.1.3 Startup and Dewatering Activities

1. Equipment and material requirements for the dewatering system were procured and assembled including: an electrical control panel, pipes, tubing and connectors, and a 4" diameter submersible pump. *Appendix C*

2. ARCE staff oversaw subcontractors involved in installation of the control panels, electrical power supply, submersible pump, and lake-water transmission lines.

3. After coordination with local authorities, the ARCE project hired a contractor and procured pipeline materials for the connection of the lake-water discharge line to the city sewer system. ARCE personnel then hired additional contractors and personally supervised the repair, cleaning and restoration of road curbs. ARCE provided safety equipment during the night-time excavation and set-up traffic control points until the roadwork was completed.

4. After completion of the connection to the city sewer system, the lake-water disposal system was redirected to the city sewer.

5. Various changes to the pipeline route made as a result of changing the disposal locations resulted in numerous leaks which the ARCE project repaired after brief interruptions to the pumping schedule.

6. The ARCE project employed a survey contractor to survey the bottom of the lake while the water level was at its lowest. The survey of the ground levels across the lake bottom was completed at 5 meter intervals. This activity was initiated to support future lake lowering efforts and as an added service to the archaeological work. *Appendix D.*

7. This survey work enabled us to ascertain the following:
   - the elevation of the bottom of the lake is 69.1 meters above sea level (masl)
   - the average lake water elevation in winter time is about 71.7 masl, as the Nile water level is about 69.5 masl. (Fig.3)
   - the average lake water elevation in summer time 72.5 masl, as the Nile water level is about 72.8 masl. (Fig.3)

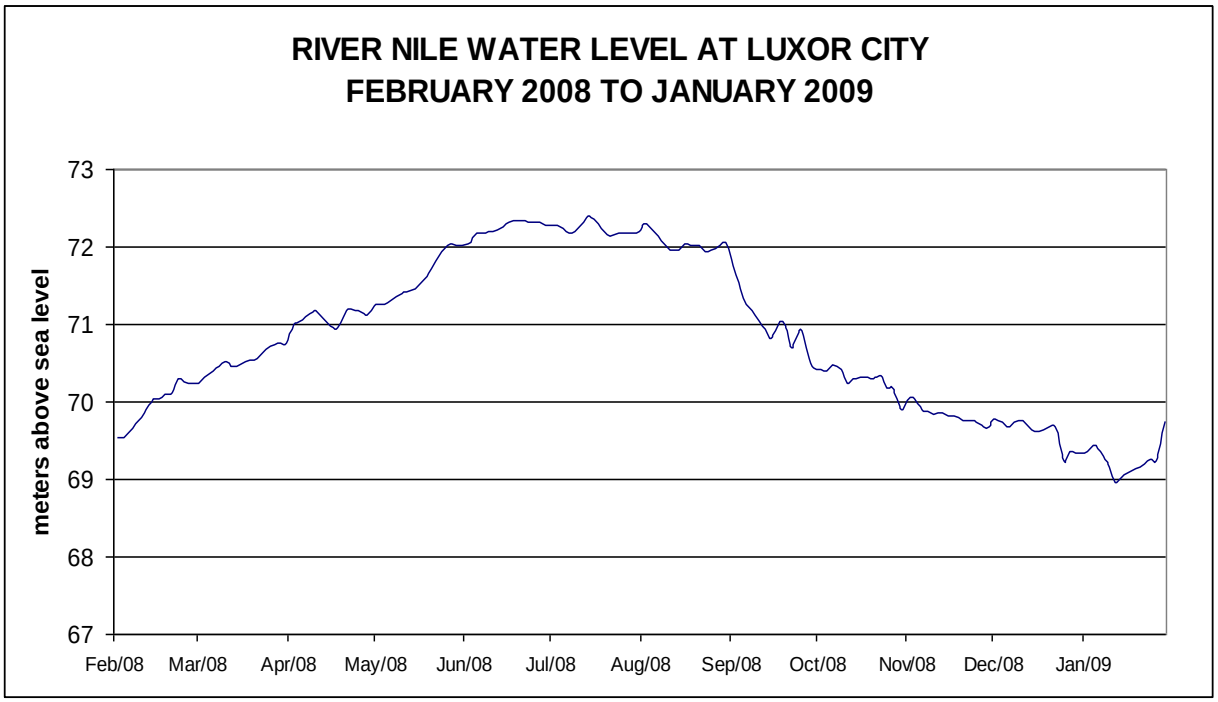

Fig.3 shows the seasonal changes in the Nile water level

8. At the request of the Johns Hopkins Archaeology Director, ARCE's contract surveyor conducted surveys of the new archaeological excavations beside the lake. *Appendix D.*

9. To assist lowering and drying of the lake edges, the ARCE project employed laborers to manually drain small ponds that had formed on the exposed lake shore.

10. The ARCE project constructed an infiltration well adjacent to the archaeological trenches to help drain the excavations. The well's electrical pump drained the groundwater to a depth of approximately 2 meters below grade. The well appeared to provide a supplemental excavation depth of approximately 1 meter.

11. A variety of alterations were made to the main discharge pump intake to keep the pump working effectively as the lake level dropped. A metal-box screen was fabricated to prevent the pump from plugging. A few days later, the box screen was lowered into the lake bottom to enable the water level to be reduced to its lowest point.

12. To support object conservation and screening of organic matter by the archaeological team, the ARCE project constructed a wash-basin with running water and a disposal drain adjacent to the excavation trenches.

13. Sampling of water. The ARCE project collected samples of lake water at different points during the lake-lowering. Conductivity testing showed that water salinity in the lake was reduced to approximately ¼ of the original salinity as a result of infiltration by groundwater. This result confirms the project goal of reducing the salinity of water in contact with ancient temple materials.

14. ARCE staff conducted measurements of water levels during lowering and refilling to identify the rates at which groundwater refilled the lake.

15. A variety of electrical problems were encountered during operation of the lake-water discharge pumps. The problems included accidental "disconnections" by third parties, low voltage (as low as 320 volts when 380 volts was normal), failure of one or more phases (transformer problem), and "thermal-trip" which occurred as a result of the low voltage. These problems resulted in many outages of the discharge pump and contributed to a slower rate of water discharge from the lake. The various failure causes will be evaluated during program design for future dewatering of the lake.

5.2 Observations and findings

1. No live fish were observed during the lowering of the lake. Many fish bones were discovered on the lake bottom when workers entered the lake to make adjustments to the pump.

2. The lake-lowering attracted many birds who fed on the exposed muddy lake bed.

3. The lake had a loose, mucky deposit up to 40 centimeters thick over much of the eastern end of the lake and along the lake shore closest to the central temple location. The outer perimeter of the lake tended to be more solid. The lake bottom along the center portions of the lake appeared to be firm-packed clay with embedded sand.

4. Water infiltration rate appears to be highest at the northern end of the lake. The visiting Johns Hopkins environmental consultant, Dr. Edward Bouwer, suggested this phenomenon may be due to a sand bar in those areas consistent with the suggested formation of the lake of lake in ancient times. Dr. Bouwer visited the site under contract with ARCE to complete a study of environmental and geotechnical issues related to the conservation of the lake.

6 Activities for the Second Dewatering Season (November 2008 - March 2009)

A. Beginning in the middle of November 2008 the ARCE project staff began to repair and fix the dewatering system. The pipeline section located outside the temple was taken apart and re-installed according to the standard installation procedures after getting permission from SCA to dig a trench 1 meter deep and 100 meter long to bury the 6 inch PVC line. This installation protected the pipeline from direct sunlight and high temperature.

B. The pipeline section located inside the temple was re-installed correctly and covered with mud bricks to protect it from direct sunlight and high temperature as digging is not allowed in this area.

C. Two 4 inch submersible pumps were prepared and located in the deepest part of the lake at an elevation of 69.1 m.a.s.l. These pumps were connected to the 6 inch pipeline via long, coiled, flexible pipes.

D. The submersible pumps were powered from one control panel. The control panel was connected to the city 380 volt feeder. Because of the repeated power failures we had during the previous dewatering, a 14 kw standby generator was connected to the control panel to provide alternate power to the dewatering system in case of main power failure.

E. To control the groundwater level in the excavation areas, 22 wells, three meters deep, were dug in different locations and each one provided with a 1 inch submersible pump (Appendix D). When the John Hopkins University archaeological teams arrived in Luxor in early January 2009, the excavation areas were ready and dry enough to excavate.

F. The dewatering of the lake continued for 24 hours per day, 7 days per week until the excavation work stopped (from December 1, 2008 to March 5, 2009). ARCE assigned a night shift to oversee the pumping system and to run the standby generator if needed.

G. After the end of the excavation work, ARCE staff removed all the small pumps from the wells, covered the wells and kept the pumps for future use. One 4 inch pump was removed. The second pump was left in the lake to be operated from time to time to refresh the water for better control of algae growth and to maintain the salinity concentration around the normal value of 500 to 600 mg/l.

H. A water level sensor was set on the bottom of the lake bed before stopping the pumps. The sensor enables a calculation of the rate of increase in the water level against time. This data is used to calculate the lake recharge rate during this time period. *Appendix E*.

7 Weed Removal.

To clear the area around the lake of heavy growing reeds and camel thorn, ARCE cooperated with the SCA Weed Control Team to spray this area with effective systematic defoliant (ROUNDUP) (Appendix F). One month later, as the reeds and camel thorn died off and dried out, ARCE hired a team of laborers to clear reeds from areas adjacent to the planned archaeological excavation. This action was very effective and new weed growth was greatly reduced.

8 Discussion

- Obtaining local SCA permissions for technical work within the Mut precinct will require liaison with SCA officials in Cairo to ensure permissions are sufficiently comprehensive to allow project work to proceed.
- The comparatively high rate of water inflow during summer months, compared to winter months, is due to changes in the Nile water level. Irrigation canals are a very important factor affecting the efficiency of any dewatering system.
- The comparatively high rate of water inflow at the north end of the lake will require special attention and construction of water infiltration wells upslope from proposed archaeological excavation trenches will probably be required.
- Dewatering pumps may be too susceptible to power failures when the lake has been lowered to its lowest levels. If a power failure were to occur, excavations at levels below the lake bottom could rapidly refill with water. ARCE recommends the possibility of using diesel powered pumps, or a diesel emergency backup system to prevent any flooding of trenches.

9 Conclusions

The lake water lowering exercise appears to have been a significant success. The following goals were achieved.

1. Determination of the best months to achieve effective dewatering, (December, January and February, when the Nile water level is lowest.). Fig.3
2. Determination of the pumping capacity needed to lower the lake.
3. Determination of the lake recharge rate. Appendix E.
4. Determination of a means for disposal of lake water.
5. Identification of alternatives for a permanent fresh water supply for the lake.

6. Support for archaeological excavations to a depth of approximately 2 meters below what would otherwise have been possible.
7. Facilitation of the discovery of previously unknown facts related to the ancient temple substructures around the lake.
8. Generally helpful logistical support for the Johns Hopkins archaeological project and its members was achieved.
9. Lowering of the lake level to support excavations below the lake bottom appears feasible within reasonable cost limits.

Prepared by:

Magdy Mokhtar
Project Technical Coordinator

APPENDICES

APPENDIX A

Luxor City Annual Climatic Condition

Table A. 1 Annual climatic condition in Luxor city (Average values)

Month	**Temp. Celsius**		**Rainfall (mm /d)**	**Evaporation (mm /d)**	**Humidity %**	**Sky cover %**
	Min	Max.	monthly			
January	5.4	23	0	5.1	52	0.7
February	6.8	25.4	0.2	6.5	42	0.9
March	10.7	29	0	9.3	34	1.1
April	15.7	34.8	0	13.3	26	0.9
May	20.7	39.3	0.1	16.6	22	1
June	22.6	40.7	0	17.7	22	0.1
July	23.6	40.7	0	17.7	24	0.2
August	23.5	41	0	17.5	26	0.5
Sept	21.5	38.5	0	14.3	32	0.1
October	17.8	35.1	0	10.1	39	0.2
November	12.3	29.6	0.1	7.1	47	0.9
December	7.7	24.8	0.1	5.3	53	1.1
TOTAL ANNUAL			0.5	140.5		
ANNUAL MEAN	15.69	33.49	0.04	11.71	34.92	0.64

APPENDIX B

Lake Water Quality Before Dewatering

Table B.1 List of parameters to be investigated in the collected samples.

Parameter	Water	Soil	Weeds
pH	√		
EC and Salinity	√		
Ca, Mg, Ca, Na, K	√		
Carbonates and Bicarbonates	√		
Chlorides	√		
Sulfates	√		
Nitrates	√		
Ammonia –N	√		
Total- N	√		
Residues of Pesticides and Herbicides	√	√	√
Algae count or Chlorophyll "A"	√		
Parasites count and identification	√		
Total Coliforms	√		
Total count	√		

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مصلحة الكيمياء

ISO 9001/2000

Certificate No: 16075

الإدارة العامة لمعامل الإسكندرية

(I A L)

رقم المعمل : 2007/3394

نوع العينة : مياه

الجهة الوارد منها: المركز الأمريكي للبحوث

Report

The sample submitted by American Research Center give the following Results:

Test	Result
PH	9.55
Ec	14.54
N- NH_4	< 0.0078 PPm
Co_3^{--}	652.326 PPm
Na^{+}	2785.082 PPm
K^{+}	534.189 PPm
Mg^{++}	109.073 PPm
Ca^{++}	18.241 PPm
So_4^{--}	1250 PPm
Po_4^{---}	21 PPm
Cl^{-}	1441.2 PPm
No_3^{-}	1.2 PPm

مدير الإدارة — كبير الكيميائيين — المشرف العام — إعتماد التوقيعات

رئيس الإدارة المركزية

رسوم التحليل : -ر1080 جنيه فقط وقدرة الف وثمانون جنيها لاغير

حصلت الرسوم ضمن الشيك رقم 1030041 بتاريخ 2007/10/3.....

Ministry of Trade & Industry

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وزارة التجارة والصناعة

مصلحة الكيمياء

ISO 9001/2000

Certificate No: 16075

الإدارة العامة لمعامل الإسكندرية

(I A L)

نوع العينة : مياه

رقم المعمل :٢٠٠٧/٣٤٠٦

الجهة الوارد منها: المركز الأمريكي للبحوث

Report

Water Sample submitted by the American Research Center gave the following results:

Test	Result
Herbicides	Not detected

Pesticides Test required 1000 mL of sample in glass Container

مدير الإدارة

كبير الكيميائيين

المشرف العام

إعتماد التوقيعات

رئيس الإدارة المركزية

رسوم التحليل : ١٠٠٠٠ جنيه فقط وقدرة الف جنيها لاغير

حصلت الرسوم ضمن الشيك رقم ١٠٣٠٠٤١ بتاريخ ٢٠٠٧/١٠/٣

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Bacteriological Analysis of a Water Sample

مصلحة الكيمياء

Referance number of sample	03 / 01/ 89 /01	رقم العينة
Source of sample	Lux Mut lake	مصدر العينة
Taken by	مصلحة الكيمياء	أخذت بمعرفة
Sampling date	23/09/2007	تاريخ جمع العينة
Receiving date	24/09/2007	تاريخ الاستلام

Date of Analysis	Requested Test Methods	Actual Count	Specifications	Ref. Test Method
25/09/2007	Number of bacteria growing on agar in 48 hrs at 35 °c	1660		St. METHODS- 21ST Ed. # 9215.B
25/09/2007	Total coliform / 100mL	1000		St. METHODS- 21ST Ed.# 9222 B
25/09/2007	Fecal coliform / 100mL	<1		St. METHODS- 21ST Ed.# 9222 B

Remark: The report is concerning only the sample(s) handeled by the client

APPENDIX C

Fig C.1 Section A of the pipeline – from the manhole to the wall of Mut temple

PLAN VIEW

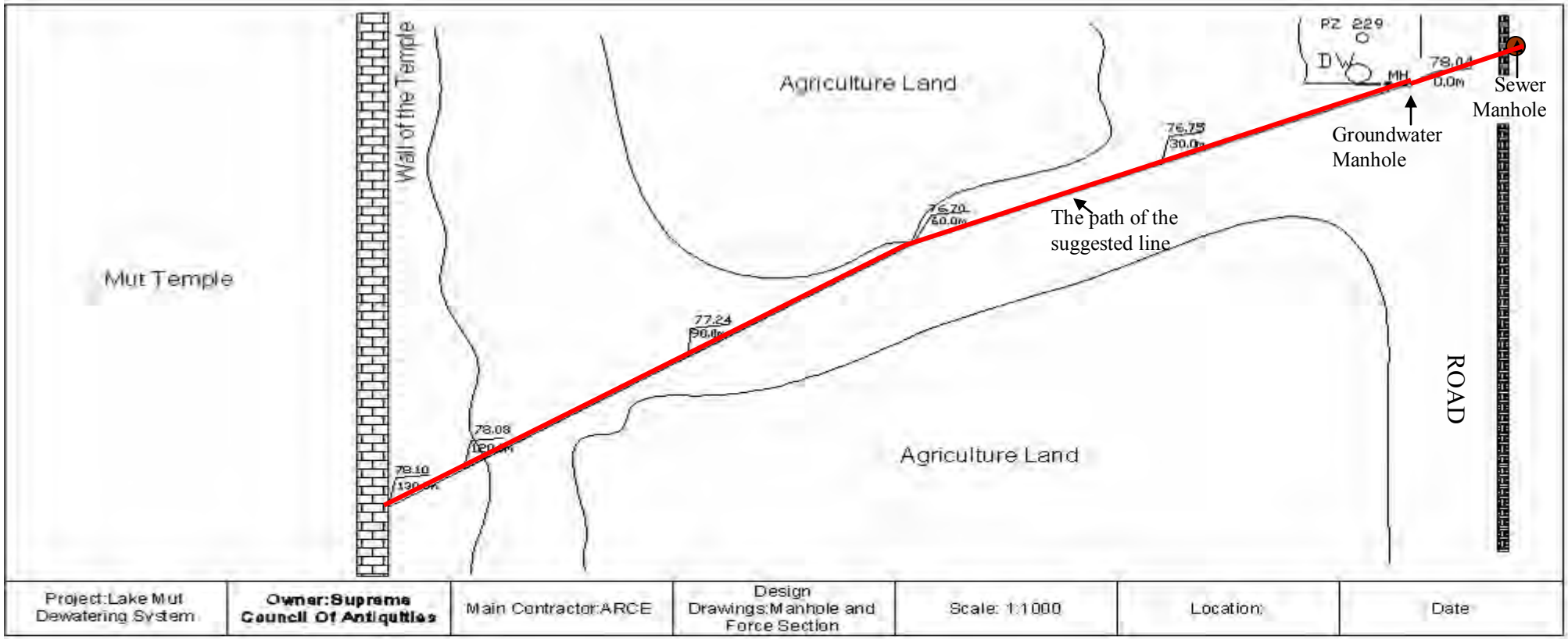
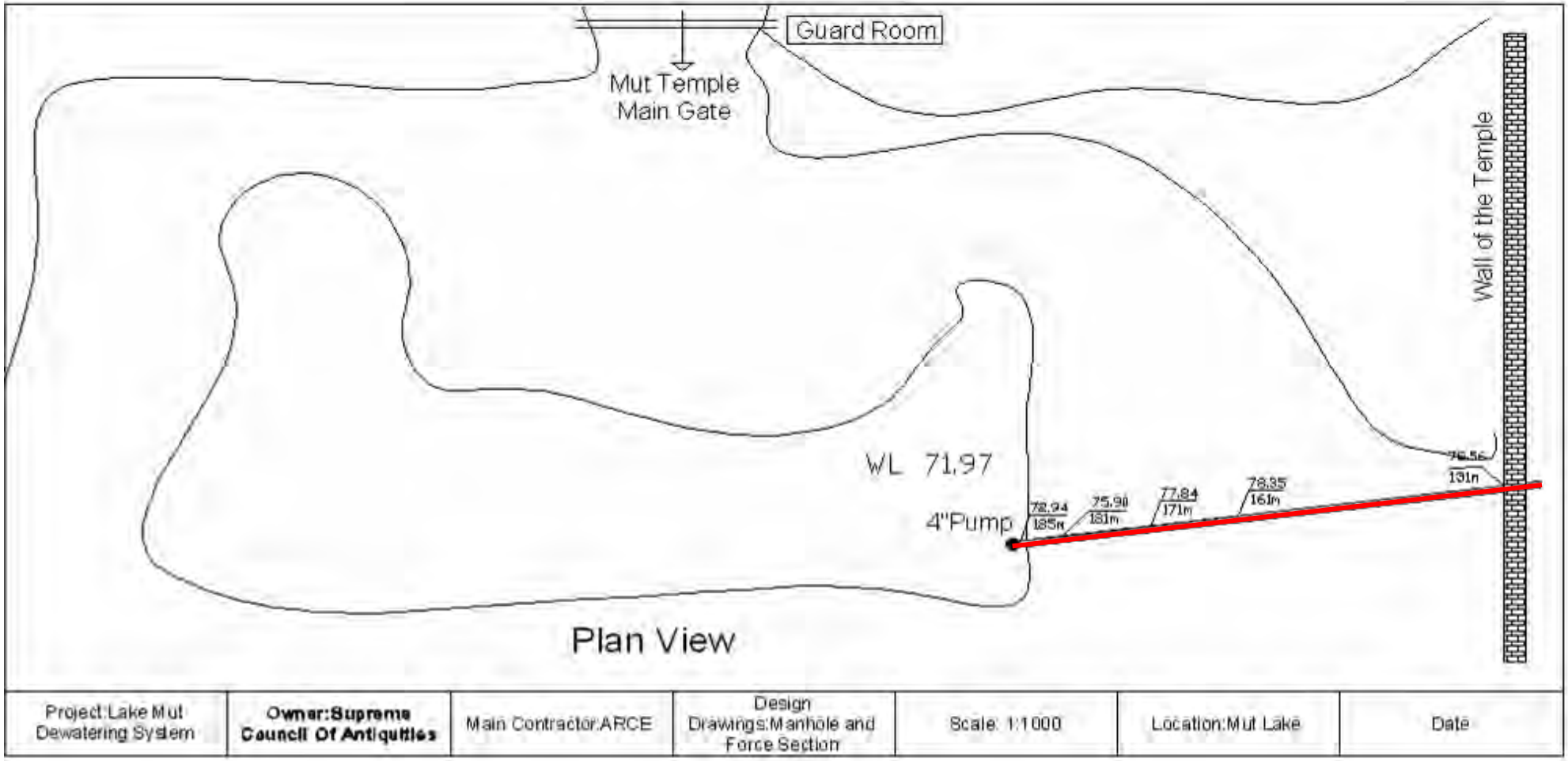


Fig C.2 Section B of the pipeline – from the wall of Mut temple to the Lake

PLAN VIEW



Dewatering System Installation

First stage dewatering, June 2008
Photos show the pipeline installation over the ground per instructions from SCA.

Below- A photo shows the installation of the 4 inch pipe inside the lake (*to the left*) and the flow discharged to the sewer manhole. (*to the right*)

The lake and some of the trenches before the dewatering

The lake and same trenches after starting the dewatering

<u>Second stage dewatering, December 2008</u>
Photos show the pipeline installation in the trenches according to standard installation methods.
Below- A photo show the installation of the 6" pipeline inside the temple over the ground. (*To the right*) and the pipes covered with mud bricks. (*To the right*)

The subcontractor's crew using an auger (locally manufactured) to drill a hole to fix a perforated pipe to make a 3 meter deep well.

A series of wells provided with 1" submersible pumps connected to a main header to discharge the water to the 4" pump in the lake.

The area east of the temple where a quay is located was the site of JHU last summer, and here they will continue to work. Wells have been placed both inside and out of the trenches due to the high volume of ground water in this area.

The western quay - three wells have been placed to facilitate JHU excavation work

A view of the rear (southern) portion of the lake shows how well the dewatering system is working.

Pumps control panel and the standby generator

APPENDIX D

Fig D.1 Mut Lake Elevations

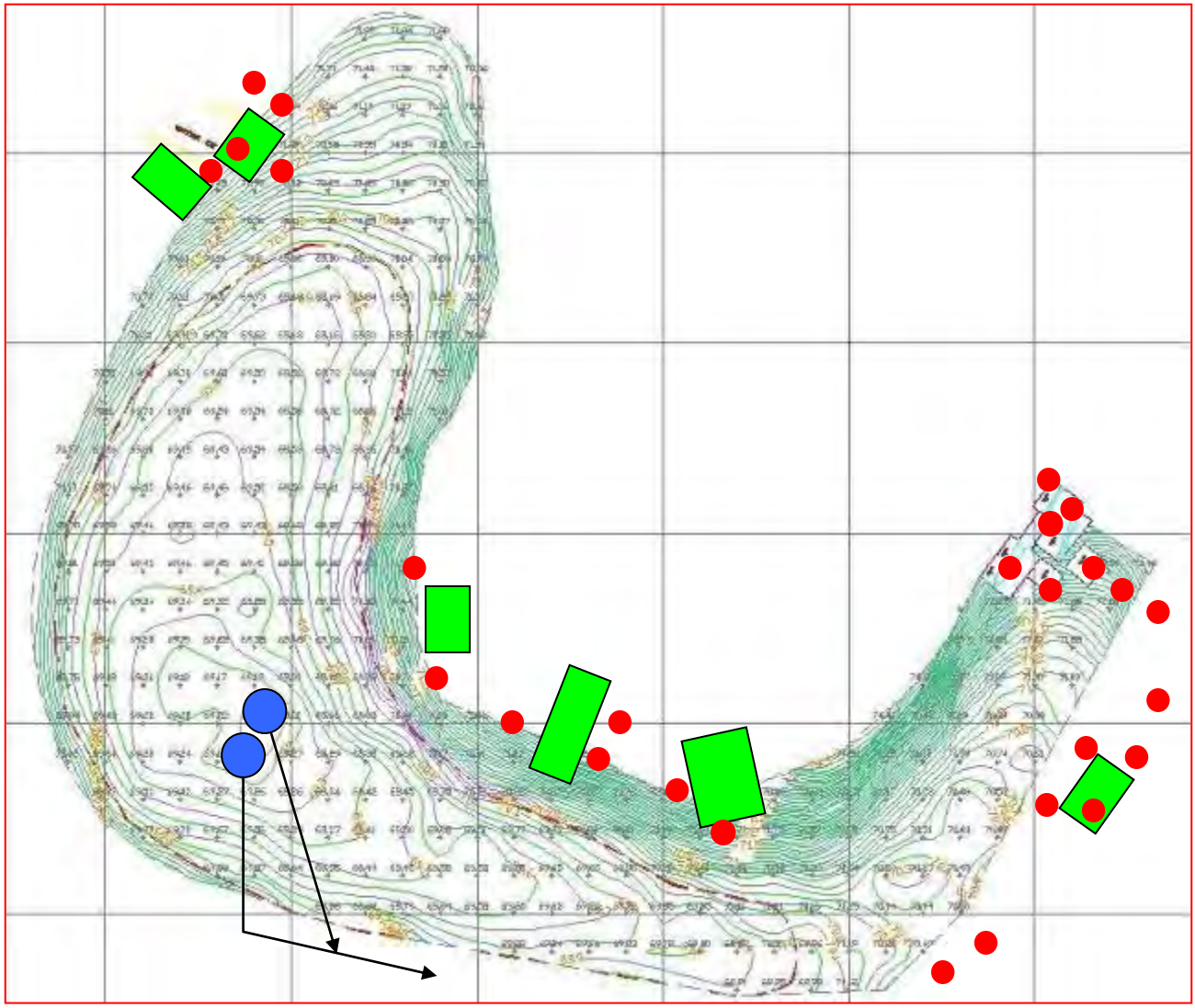
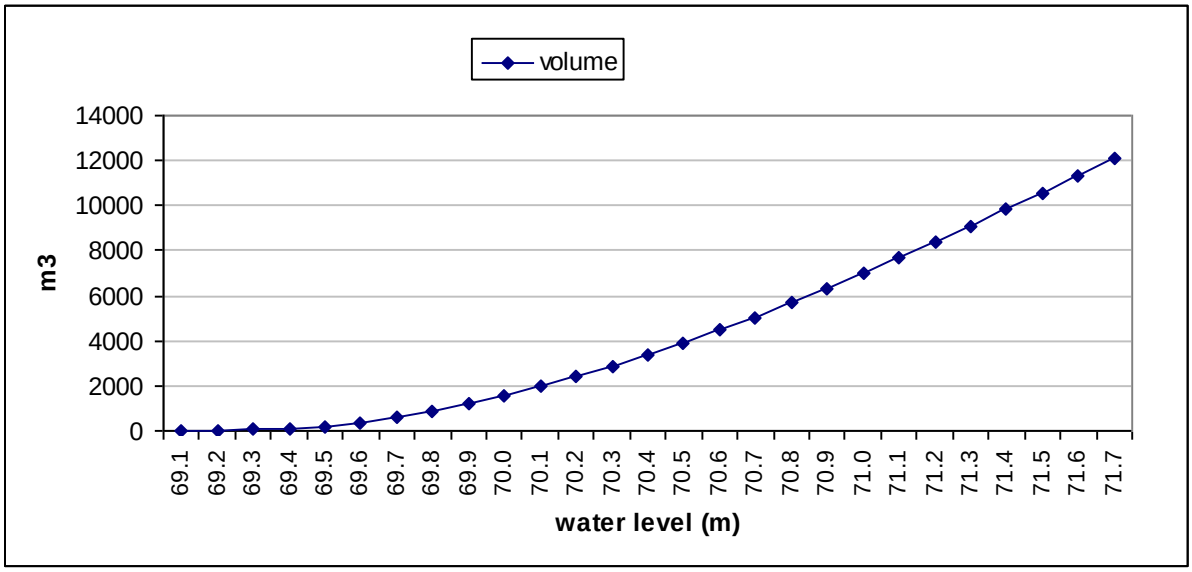


Illustration shows the contour map of the lake and the location of the dewatering wells (red) and the two 4 inch pumps (blue). It also shows the excavation areas (green).

Table D.1 shows the water volume and the surface area of the lake at different elevations.

Level of water (m)	Volume (m^3)	Area (m^2)
69.1	1	25
69.2	10	204
69.3	44	462
69.4	106	796
69.5	213	1331
69.6	375	1924
69.7	592	2432
69.8	859	2908
69.9	1177	3410
70.0	1547	3831
70.1	1959	4143
70.2	2403	4397
70.3	2874	4645
70.4	3371	4901
70.5	3900	5205
70.6	4463	5436
70.7	5053	5644
70.8	5670	5845
70.9	6312	6019
71.0	6976	6181
71.1	7662	6346
71.2	8366	6494
71.3	9087	6642
71.4	9825	6781
71.5	10580	6914
71.6	11349	7044
71.7	12133	7172



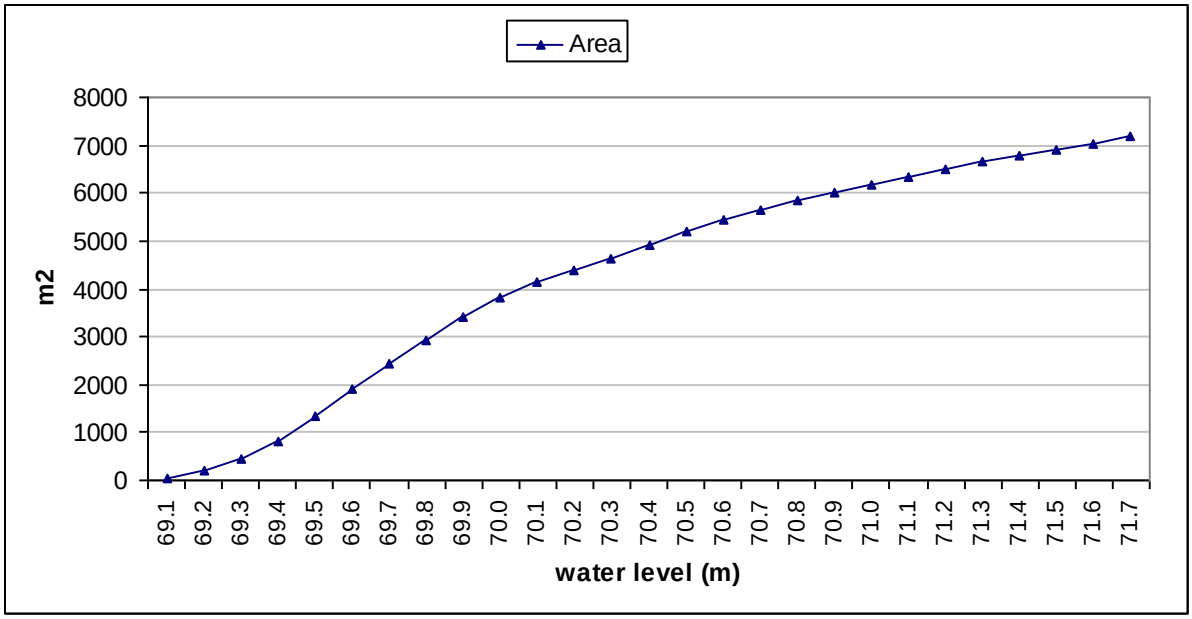


Fig D 2 Graphs show the water volume and the surface area of the lake at different elevations.

APPENDIX E

Water Level Measurements

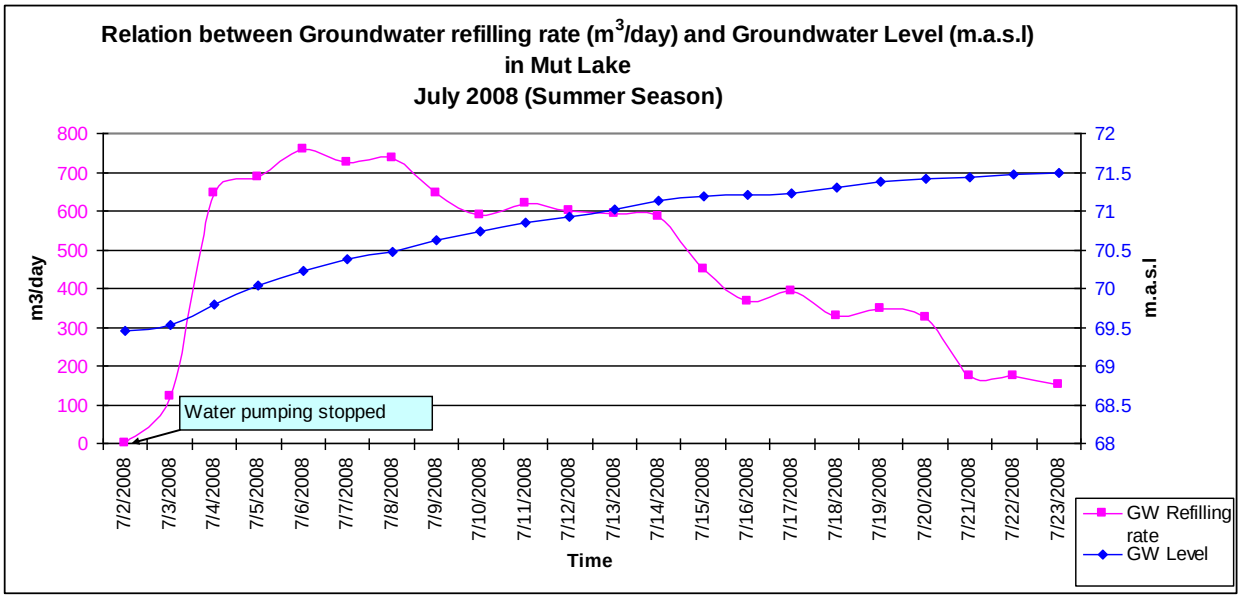
Fig E.1 The water level sensor - *MadgeTech 2.00, Level 1000*- used to measure the water level during the dewatering and during the refilling phase.

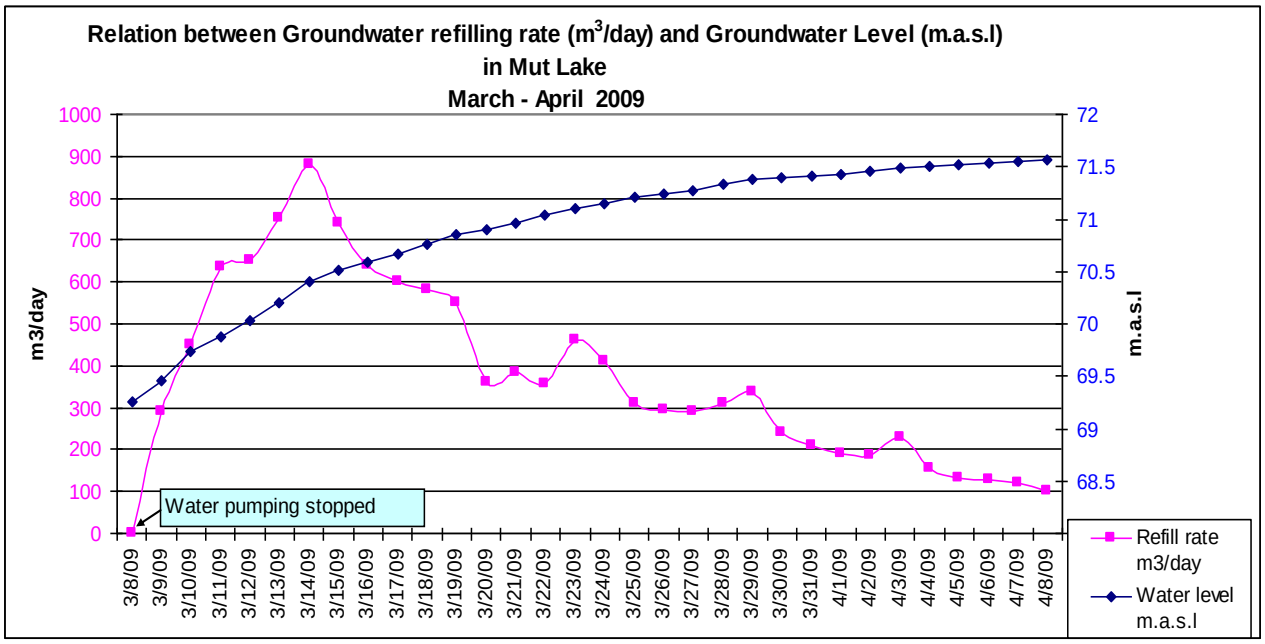
Table E.1 presents the rise in the lake water level as the pump stopped and the estimated refill rate calculated by using the data in table D.1. This data collected during July 08.

Date	Water level m.a.s.l	Refill rate m3/day
7/2/2008	69.45	0
7/3/2008	69.52	120
7/4/2008	69.80	644
7/5/2008	70.04	688
7/6/2008	70.23	760
7/7/2008	70.38	724
7/8/2008	70.48	735
7/9/2008	70.62	644
7/10/2008	70.73	590
7/11/2008	70.84	617
7/12/2008	70.93	600
7/13/2008	71.01	592
7/14/2008	71.13	584
7/15/2008	71.19	450
7/16/2008	71.20	366
7/17/2008	71.22	394
7/18/2008	71.30	327
7/19/2008	71.37	346
7/20/2008	71.41	325
7/21/2008	71.44	175
7/22/2008	71.48	173
7/23/2008	71.50	151
min		**120**
max		**760**
Average		**455**

Table E.2 presents the rise in the lake water level as the pump stopped and the estimated refill rate calculated by using the data in table D.1. This data collected during March - April 09.

Date	Water level m.a.s.l	Refill rate m3/day
3/8/09	69.25	0
3/9/09	69.45	291
3/10/09	69.74	451
3/11/09	69.88	637
3/12/09	70.03	650
3/13/09	70.20	753
3/14/09	70.40	880
3/15/09	70.51	740
3/16/09	70.59	640
3/17/09	70.67	600
3/18/09	70.76	580
3/19/09	70.85	551
3/20/09	70.90	360
3/21/09	70.96	383
3/22/09	71.03	356
3/23/09	71.11	461
3/24/09	71.15	409
3/25/09	71.21	312
3/26/09	71.24	296
3/27/09	71.28	291
3/28/09	71.33	312
3/29/09	71.38	337
3/30/09	71.39	240
3/31/09	71.42	211
4/1/09	71.43	191
4/2/09	71.46	186
4/3/09	71.49	227
4/4/09	71.51	156
4/5/09	71.52	131
4/6/09	71.54	126
4/7/09	71.55	120
4/8/09	71.57	100
min		**100**
max		**880**
Average		**386**


Relation between Groundwater refilling rate (m3/day) and Groundwater Level (m.a.s.l)
in Mut Lake
July 2008 (Summer Season)
m3/day
m.a.s.l
Water pumping stopped
Time
GW Refilling rate
GW Level


Relation between Groundwater refilling rate (m3/day) and Groundwater Level (m.a.s.l)
in Mut Lake
March - April 2009
m3/day
m.a.s.l
Water pumping stopped
Refill rate m3/day
Water level m.a.s.l

APPENDIX F

Weed Removal

Photos show the dense weeds around the lake (top) and the weed control staff spraying the weeds with Roundup (bottom).