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Water Resources Management System for Nile River

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***Abstract*— The economic and social importance of ensuring the security of the Nile River against any natural or anthropogenic threats cannot be overemphasized. Egypt, with a population of 76 million in 2007, is experiencing rapid population and urban growth which leads to additional demand on its limited water resources. It is anticipated that by year 2025 Egypt's total population will be about 100 million, thus, increasing the demand for scarce water and arable land and decreasing per capita water share. In view of the above, there existed an urgent need to establish a pilot system in Egypt to monitor its strategic water bodies (the Nile River and its vast network of canals and drains) on a real time basis. The implemented real-time water monitoring and reporting system allows senior water managers to protect the integrity of Egypt's vital water resources, as well as, report the suitability of water for designated beneficial water uses.**

Eight real time water monitoring stations were established on the Nile River (from the Aswan Dam to the Damietta and Rosetta branches) and El-Salam Canal (which runs eastward 261 km from its inlet on the Damietta branch into the Sinai desert). Data was collected on water level, pH, dissolved oxygen, water temperature, conductivity, ammonia and nitrate every 15 minutes beginning in January of 2008. The real time stations were effective at detecting the condition of transboundary water entering Egypt, seasonal variations during high and low flow periods, dam effect, erosion and reservoir stagnation, increased salinity due to irrigation drainage, sudden changes in hydraulic regime affecting quality and quantity, and point source pollution discharges and their timing.

Keywords: Egypt, Nile, El-Salam Canal, real time, water quality

I. WATER RESOURCES OF EGYPT

The history and culture of Egypt and its people is intricately linked with the Nile River. The environmental sustainability of the Nile determines the current and future socio-economic status of the country and region. In Egypt the Nile River is the primary source of water for a multitude of strategically important water uses such as drinking, fishing, industrial, livestock and irrigation. Approximately 85 percent of the Nile River water is used for irrigation, 8 percent for drinking and 7 percent for industrial uses. The water from the Nile is conveyed to users through a vast network of canals. Wastewater and agricultural drainage water from these uses is collected by drains and often returned to the Nile River as inflows.

The economic and social importance of ensuring the security of the Nile River against any natural or anthropogenic threats cannot be overemphasized. Approximately 99 percent of the population of Egypt (total population is approximately 76 million) lives within the Nile Valley and Delta, which constitutes less than 5.5 percent of Egypt's total land area. The area of the Nile Delta itself is about 25,000 km^2 with about 35 million inhabitants. Any disruption or impairment to these from natural or anthropogenic threats cannot be without far reaching economic and social implications.

The water supply-demand situation in Egypt is changing over time with ever increasing demand and shrinking supply due to climate change, increased withdrawals and pollution. Table 1 shows the current water resources in the year 2006 for Egypt. As shown, major portion of water resources originates from the Nile River. Egypt is experiencing rapid population and urban growth which leads to additional demand on its limited water resources [1]. The total population has increased from 33 million in 1965 to 76 million in 2007. It is anticipated that by year 2025 Egypt's total population will be about 100 million, thus, increasing the demand for scarce water and arable land. Based on the analysis of the available data, per capital water share has changed from 1,700 cubic meters per year in 1950 to 1,000 cubic meters per year in 2000.

TABLE 1 : WATER RESOURCES FOR THE YEAR 2006

Water Resources	Billion Cubic Meters (BCM)
River Nile	55.5
Agriculture Drainage water reuse in the delta	5.2
Groundwater in the valley and the delta	4.8
Rainfall and Floods	1.0
Treated Wastewater Reuse	0.7
Groundwater in the deserts and Sinai	0.57
Total	67.77

II. CURRENT STATE OF WATER MONITORING IN EGYPT

Since the construction of High Aswan Dam (HAD) in 1964, the water quality of the Nile became primarily dependent on the water quality and ecosystem characteristics of the Lake Nasser reservoir and less dependent on the water quality of the upper reaches of the Nile. Downstream changes in Nile water quality are primarily due to: (i) the hydrodynamic regime of the river regulated by the different barrages, (ii) agricultural return flow, and (iii) domestic and industrial waste discharges including oil and waste from the river fleet which comprises over 9000 units.

The current water monitoring network in Egypt comprises of 232 grab sample monitoring stations on Lake Nasser, Nile River, Irrigation Canals and Drainage Canals [2]. Figure 1 shows the location of water monitoring stations. Currently most of the sites along the Nile River are monitored by the Ministry of Water Resources and Irrigation (MWRI) and its research wing – the National Water Research Center (NWRC) for water quality and water quantity on a pre-defined frequency. Four of these sites on the El Salam Canal are under semi continuous water quality monitoring. This system is not conducive to any early warning application and thus cannot set into motion any corrective measures by responsible authorities.

The water quality monitoring locations along the Nile are described by water body or reach. The Nile main stem is divided into four reaches. The first reach is from HAD to Esna Barrage, the second reach from Esna Barrage to Naga Hammadi Barrage, the third reach from Naga Hammadi Barrage to Assiut Barrage and, the fourth reach from Assiut Barrage to Delta Barrage.

The sites on the Lake Nasser, Nile River and Nile Branches are identified by the prefix “NL” in Figure 1. The Drainage and Irrigation locations are identified by the prefixes “DU” and “IU” respectively. This biannual monitoring program is important for describing the status of water quality in the River Nile.

Lake Nasser is the main fresh water reservoir in Egypt. Water quality monitoring on Lake Nasser describes the quality of water entering Egypt. Four locations are included in the national program, which are monitored twice per year. Location NL00, 281 km upstream HAD and about 50 km below the border with Sudan, describes the quality of water entering Egypt. Location NL01, 256 km upstream HAD, describes the quality of water entering the Sheikh Zayed Canal through the Mubarak Pump station. Location NL02 is located 10 km upstream HAD. Location NL03 is located 2 km upstream HAD, and describes the quality of the water being released to the Nile River.

From the water resources management perspective while water data (quantity and quality) is currently collected on a regular basis, appropriate communication tools do not exist to convert raw water data into information and then knowledge (i.e. to convert complex water quality data into scores and rankings that are easy to communicate). There is no exceedance base computation for the different water uses (drinking, fishing, etc.). This sampling regime, while important for studying the Nile River, can not detect in real time any threat to water quality from either a terrorist source or any event based on environmental pollution. This sampling system is also not conducive to any early warning application and cannot be used to set into motion any corrective measures. The conversion of raw water quality data into information and then knowledge is a core component of water resources management and is critical for effective decision making by executive, politicians and the general public.

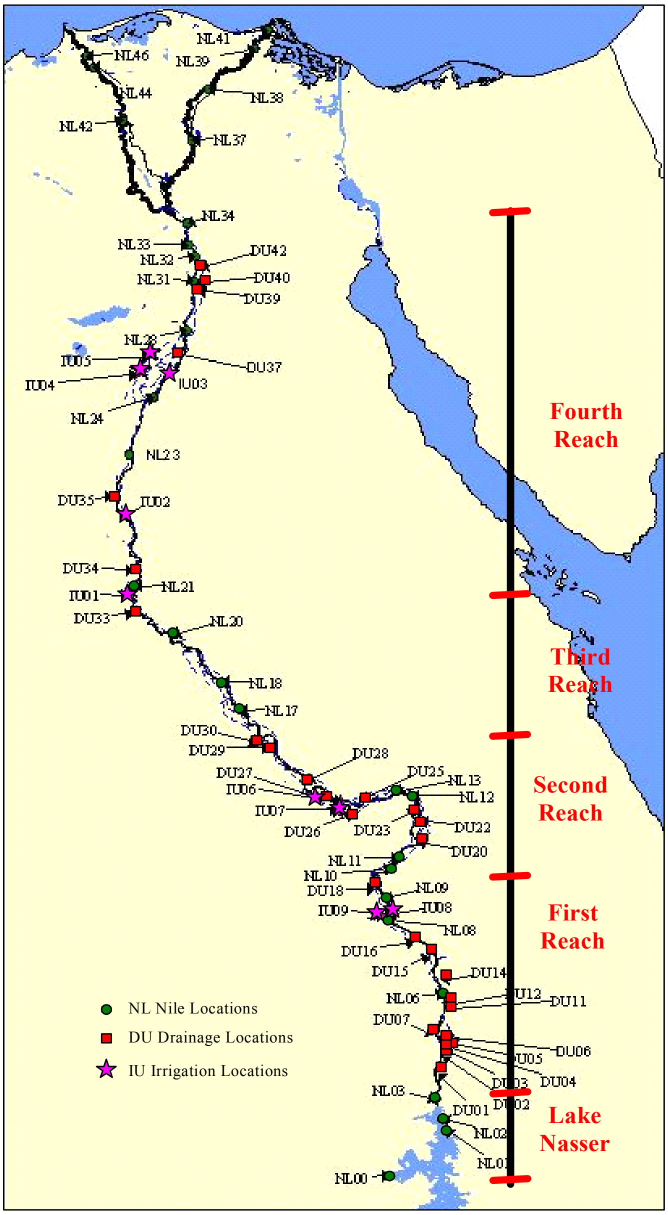

FIGURE 1: WATER QUALITY MONITORING SITES

Currently, 69 surface water sites along the Nile River are monitored by the Ministry of Water Resources and Irrigation and its research wing – the National Water Research Center (NWRC) for water quality on a biannual basis [2]. These sites as summarized in TABLE 2 are divided between the five main types of water bodies as listed in the following table. The balance of monitoring sites is comprised of groundwater wells.

TABLE 2: DISTRIBUTION OF SAMPLING SITES BETWEEN SIX MAIN WATER BODY TYPES

Site	Number of Locations
Lake Nasser	4

Nile River	18
Nile Branches	7
Drains	29
Irrigation	11
Groundwater	163

III. POINT SOURCES OF POLLUTION ALONG THE NILE RIVER IN EGYPT

While drainage inputs provide inflow back into the Nile River, they also act as point sources of pollution. The main types of point source pollution input from the drains include agricultural runoff, sewage and industrial effluent. Monitoring near major point source inputs can help in the overall management of Nile River water quality. There are 97 identified drains discharging into the Nile River in Egypt, the majority of which are agricultural drains as indicated in Figure 2.

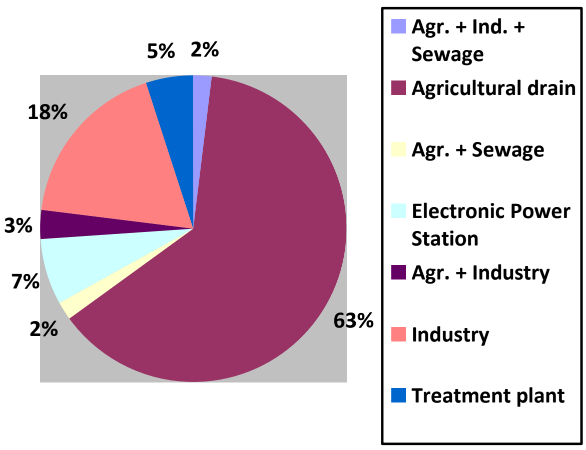

FIGURE 2 TYPE OF DRAIN DISCHARGING TO NILE RIVER

IV. REAL TIME WATER MONITORING NETWORK IN EGYPT

The newly completed real time water monitoring and reporting network funded by the North Atlantic Treaty Organization's (NATO) Science for Peace Program comprises of four real-time water monitoring stations, one automated weather station, four upgraded water monitoring stations on the El Salam Canal, and a data collection and reporting command centre. The new network will allow the management of Egypt's water resources using a real-time pro-active approach.

NL03A is a new monitoring location on the Nile River just after the Aswan dam but before any drainage inflow into the Nile River. This site is of strategic importance as downstream water uses include drinking water use, irrigation, livestock, fishing, tourism and navigation. The first point source of pollution in the Nile after the High Aswan Dam and downstream of site NL03A is the Khour-Elsail drain (DU01), located approximately 9.9 km downstream of HAD. This drain carries industrial wastes from Kima and Coca-Cola factories and also treated and untreated sewage from the Aswan WWTP. A second nearby drain, the El-Berba drain (DU06), carries industrial wastes from Kom-Ombo Sugar factory, sewage from urban areas around the factory, and agricultural drainage water.

NL34 is located on the Nile River at the intake of the Ismailia Canal next to the NWRC about 15 km upstream above where the Nile divides into its two branches, Damietta and Rosetta. The Nile width at NL34 is about 500 m, and water depth ranges from 3.5 m at the west point of the section to 7.0 m at the east point. NL34 is considered the reference point for the water quality entering the two Nile branches along which 35 million inhabitants live. The Ismailia Canal is used as the principal drinking water supply for the Cities of Cairo, Ismailia, Port Said and Suez. The Sharkaweia Canal intake is about three km downstream of NL34. Many water related activities are downstream of NL34 such as the intensive urban areas of Shobra El-Khima on the east bank and agricultural areas on the west bank. Any threat to water quality at this point will have severe human health and socio-economic implications. This point also reflects the cumulative impacts of all the drainage water inflows, industrial water inflows, wastewater discharges into the Nile River, and instream water uses of navigation, tourism, and fishing between Lake Nasser and Cairo. Also of strategic importance is that this location represents a reference point from where water is distributed for the whole of the Nile Delta (along the Rossetta and Damietta Branches). The site at NL34 is complemented by a Real Time Weather Station that is needed to interpret water quality data being reported by the RTWQ stations.

NL39 is on the Damietta Branch of the Nile River at the intake of the strategically and socio-economically important El Salam Canal. It is located about two km upstream of the Farasqur dam, where the Damiette Branch discharges into the ocean. The branch width at NL39 is about 220 m and water depths range from 5.25 m at the west point to 11 m at the east point of the section. Agricultural areas are evident on the west bank and at EL-Adleya city which is located on the east bank at NL39. From a water resources management perspective, this point represents the cumulative impact of several drainage inputs along the Damietta Branch and is a site used for fishing. NL39 is located about 53 km downstream of the El-Serw drain outlet. It also represents the starting water quality of the El Salam Canal which is the primary source of irrigation water for agriculture in the Sinai Peninsula. The El Salam Canal itself is also used for fishing and aquaculture. NL39 describes the quality of the water being released to the El-Salam canal.

NL42 is a strategically important site on the Rossetta Branch that is located at the drinking water intake of the town of Benowar. It is located 123 km downstream of the Delta Barrage. The Rosetta branch width is about 550 m at NL42 and the water depth ranges from 2 m at the east point to 7 m at the west point of the section. Five agricultural drains discharge directly to Rossetta Branch along these 123 km. Agricultural areas are evident on the west bank, while Kafr El-Zayat city is located at the east bank. NL42 is located about 2.5 km downstream of the Maleya factory for chemicals and fertilizers and is about 100 m upstream of a Salt and Soda Factory which are located on the east bank. There are drinking water intakes of other small communities located downstream of this site. There are almost annual incidents of fish kills reported in this segment of the Rossetta branch between NL 34 and NL 42. This point is also important from a water resources management perspective in that it represents the cumulative impact of several drainage inputs along the Rossetta Branch.

In addition to the establishment of the above four RTWQ monitoring sites, there are four existing semi-continuous water quality monitoring sites in Egypt located on the El Salam canal that have been upgraded to real time water monitoring stations as part of this project. The 261 km El Salam canal runs eastward from its inlet on the Damietta branch of the Nile into the Sinai desert, even crossing under the Suez Canal. The canal was officially opened in 2002 and is of strategic importance in adding approximately 1680 km^2 of farmland to a country mostly comprised of desert. Water has to be pumped into the canal through a series of lift stations, and inputs also come from agricultural drainage.

The Government of Egypt is interested in monitoring water quality in the El Salam Canal in real time in order to ensure the integrity of the canal and to initiate policy corrective measures to improve the quality of drainage discharge into the canal.

V. REAL TIME DATA COMMUNICATION

Water quality is measured in real time using a Hach Hydrolab multi-parameter probe that measures pH, dissolved oxygen, water temperature, conductivity, ammonia and nitrate. Water level is be measured by a stand alone potentiometer. The automated weather station collects weather related data such as air temperature, relative humidity, air pressure, precipitation, wind speed and direction. The data is recorded in a datalogger at the data collection platform every 15 minutes. The data collection platform and all instrumentation are powered using solar energy. An Automated Data Retrieval System (ADRS) was setup for the NWRC at the control station to retrieve water quality data from the real time stations every hour using both land lines and cellular connections. The data is copied to a central network drive, processed, and converted to 30 day rolling graphs for each water quality variable which are published to an internal web page that can then be accessed by users. Any unusual activity within the sites will be indicated by extreme values on the graphs. From the internal real time water monitoring web site, users are able to select a particular station and view the data graphically in (near) real time.

VI. REAL TIME WATER QUALITY STATION DATA ANALYSIS

At site NL03A, just downstream of the Aswan Dam, the analysis of data indicates that water temperature increased over the period of record as expected [3]. Total dissolved solids (TDS) and specific conductivity showed a gradual decrease over the period of record. It is expected that these parameters are affected by seasonal flow variation, becoming more concentrated during low flows around February and more dilute during higher flows in summer. For the observed period of record pH was above the guideline of 8.5. Dissolved oxygen (DO) decreases gradually with increasing water temperature as expected. Levels appear to be within acceptable limits. The maximum range of the turbidity sensor is 3000 NTU. During the period of record this maximum level was reached for a significant amount of time. This could either indicate extremely turbid water coming from the Aswan dam, or dam effect erosion.

At site NL34, upstream of where the Nile branches, the analysis of data indicates that water temperature ranged from around 15-28 ºC. TDS and specific conductivity showed a gradual decrease with a more significant drop from around Sept to Nov. This could be due to dilution caused by the Nile flood wave during the period of maximum flow. Of interest is the fact that these measures of salinity are higher than at the upstream station NL03A, probably due to irrigation drainage inputs. pH shows annual variation, with a trend of slightly higher values in the beginning of the year and lower values June to Dec. Values exceeded the maximum guideline of 8.5 on four separate occasions. DO values seemed reasonable until mid-July averaging around 10 mg/L. This is higher than at the upstream station at NL03A and could be due to aeration in the river, versus stagnation in Lake Nasser. Turbidity values seem to indicate a baseline value of approximately 75 NTU with several significant spikes, one of which reaches the maximum range of the turbidity sensor of 3000 NTU. Turbidity show no particular seasonal variation and observed spikes are most likely due to specific discharge events upstream.

At site NL39, on the Damietta Branch of the Nile River at the intake of the El Salam Canal, the analysis of data indicates that water temperature showed expected annual variation, with a minimum water temperature around 13 ºC and a maximum of approximately 35 ºC, significantly higher than observed at the upstream station of NL34. TDS and specific conductance showed a similar annual pattern of slightly higher values during the period of minimum flow and lower values during the period of maximum flow. Both parameters indicated an increase in salinity from the upstream station of NL34 most likely due to irrigation drainage inputs. pH was relatively stable from Jan-Jun followed by a period of 5 distinct step increases or decreases indicating significant changes in water quality most likely due to sudden change hydraulic regime (ie. discharges and withdrawals from drains and canals, holding back of water at dam gates). pH had three distinct periods above the guideline value of 8.5. Turbidity values again reached the maximum range of the turbidity sensor of 3000 NTU at this site. Values were either baseline at around 50 NTU, or highly variable. Turbidity show no particular seasonal variation and observed spikes are most likely due to specific discharge events upstream.

At site NL42, on the Rossetta Branch that is located at the drinking water intake of the town of Benowar, the analysis of data indicates that water temperature showed expected annual variation, with a minimum water temperature around 13 ºC and a maximum of approximately

31ºC, slightly higher than observed at the upstream station of NL34, but less than at NL39. TDS showed a similar annual pattern of slightly higher values during the low flow period and lower values during the high flow period. TDS indicated an increase in salinity from the upstream station of NL34 most likely due to irrigation drainage inputs. pH was relatively stable from Jan-Aug8 and below the maximum pH guideline of 8.5, followed by a period of increased and prolonged variability in pH, including a spike of almost 12. This branch of the Nile experience frequent fish kills, which could be explained by observed spikes in pH. Something, possibly a new industrial discharge, seems to have had a significant affect on pH at this site. Dissolved oxygen appears to have been fairly stable at around a baseline of approximately 4 mg/L from Jan-Jul. From this point onward the sensor appears to be malfunctioning. These DO values are lower than for either NL34 or NL39. Turbidity readings were highly variable from Jan to Aug with several spikes reaching the maximum range of the turbidity sensor of 3000 NTU. From this point onwards readings flat line at around 90 NTU with little variation. There appears to be no seasonal link to the observed turbidity values at this site, meaning observed values are most likely due to industrial, municipal or other drainage inputs.

VII. CONCLUSION

The old axiom "you can't manage what you can't measure" takes on even greater meaning when the resource you are trying to manage is a limited and shrinking under extreme pressure from multiple fronts. Increasing water demand, population pressure, water pollution and climate variability are all taking their toll on the Nile River water quantity and quality. The real time water monitoring set up as a part of this project will be useful for the proactive management of the Nile River water.

The key outcome of this project is that the Egyptians have assumed the ownership of the modern water monitoring network. Data is continuing to be collected from existing stations, calibration is occurring more frequently, summary reports are being drafted, and most importantly, the Egyptians are set to expand the use of real time water monitoring introduced as part of this project using internal funding.

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