# A Real Time Water Quality Monitoring Network and Water Quality Indices for River Nile

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## Abstract

The history, culture, current and future socio-economic status, and environmental sustainability of Egypt and its people is intricately linked with the River Nile. The Nile River is the primary source of water for a multitude of strategically important water uses such as drinking, fishing, industrial use, livestock and irrigation and there is a critical need to ensure the security of the Nile River against any natural or anthropogenic threats and to develop an effective Water Resources Management System. This paper outlines the concept behind the environmental monitoring network, its scope, and environmental benefits. The paper discusses the progress made to date. It highlights the challenges encountered in establishing the environmental security and water resources management system. The paper presents the results of the initial application of the Egyptian Water Quality Index including how the challenge of the scarcity of use based water quality guidelines was overcome. The paper also outlines how Egypt plans to expand the index network to address trans-boundary monitoring of Nile River and the monitoring of Groundwater and Drainage Water.

**Abstract Keywords:** Real time water quality monitoring, water quality indices, River Nile, trans-boundary monitoring, index network, integrated water resources management

## 1. Introduction:

The Nile River in Egypt is the primary source of water. It is used for strategically important water uses such as drinking, fishing, industrial use, livestock and irrigation. The water in the Nile in Egypt is intricately managed through an extensive system of dams, barrages and canals. The water from the Nile is conveyed to the users through a vast network of canals. Wastewater and agricultural drainage water from these uses are collected by drains and are often returned to the Nile River as inflows.

Any disruption or impairment to the Nile River from natural or anthropogenic threats can potentially have far reaching economic and social implications. Approximately 99 percent of the population of Egypt (total population is approximately 78 million) lives within the Nile Valley and delta, which constitutes less than four percent of Egypt's total area. The area of the Nile Delta itself is about 25,000 square kilometres and has approximately 35 million inhabitants.

Currently, 69 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 (Abdel-Gawad and Khalil, 2003). These sites are divided between the five main water bodies and the locations as listed in Table 1 (Abdel-Gawad and Khalil, 2003).

**Table 1.** Distribution of Sampling Sites between Five Main Water Body Types

| **Site** | **Number of Locations** |
|---|---|
| Lake Nasser | 4 Locations |
| Nile River | 18 locations |
| Nile Branches | 7 locations |
| Drains | 29 locations |
| Irrigation | 11 locations |

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 in Figure 1. This biannual monitoring program is important for describing the status of water quality in the River Nile. It however can not be used to detect in real time any threat to water quality from either a terrorist source or any event based on environmental pollution.

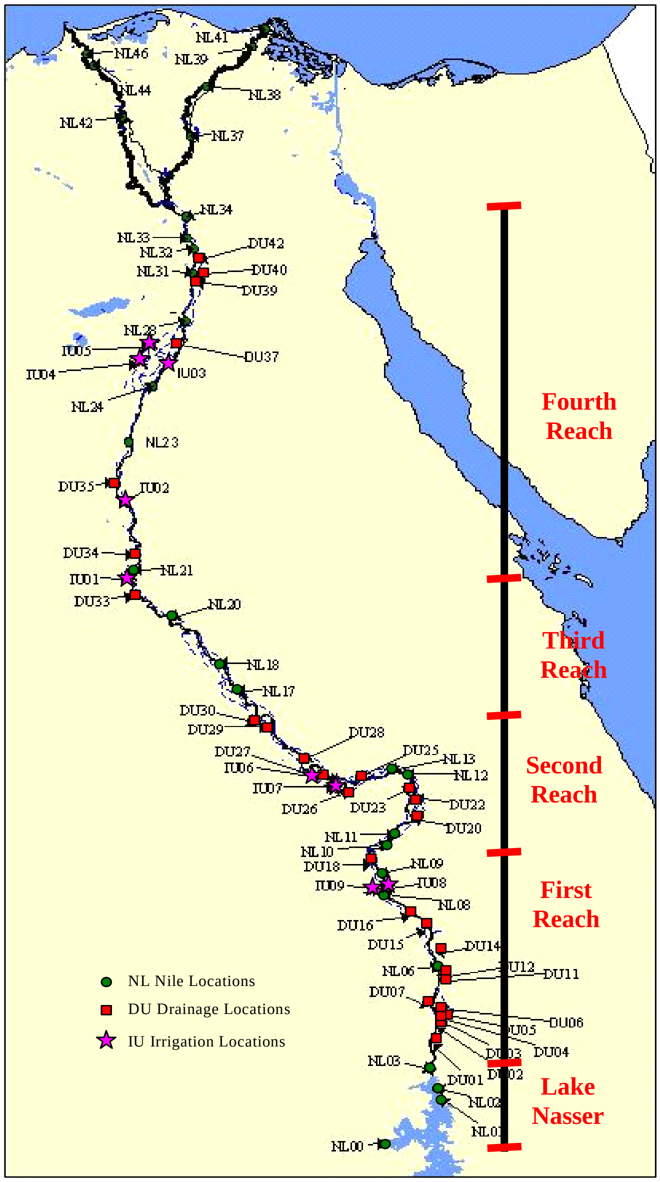


**Figure 1.** Water Quality Monitoring Sites

Concurrently, while the water of the Nile River is used for a wide variety of water uses, the suitability of the Nile River water for the various uses is neither evaluated nor reported. This is primarily due to the absence of tools to evaluate and report on the Nile River water for the various uses. This inability to report on the suitability of Nile River for a variety of uses is not conducive to effective decision making.

Consequently there is a dual need to augment the current national water quality monitoring program with real time water quality (RTWQ) monitoring and to develop a water quality index (WQI) to report the suitability of the Nile River water for various uses.

Addressing this need, a “state of the art” environmental monitoring and sensing system is being implemented for the Nile River in Egypt through a NATO “Science for Peace” Project entitled “An Environmental Security and Water Resources Management System Using Real Time Water Quality Warning and Communication”. The “Science for Peace” project, initiated in July 2007, is setting up for the Nile River an environmental security and water resources management system using RTWQ warning and communication.

## 2. Objective:

The main objective of the project is to research and develop a capability in Egypt to detect and predict adverse changes in water quantity and quality in the Nile River in real time allowing for response to any threat to water quality. In parallel, an Egyptian Water Quality Index (EWQI), a critical tool for water resources management, is to be developed to evaluate and communicate the suitability of water bodies in Egypt for various uses. This project will allow Egypt to ensure environmental security of its water bodies and enhance integrated water resources management.

## 3. Methods:

### 3.1 Real Time Water Quality Network

Real time water quality warning will be provided through a four station RTWQ monitoring index network on the Nile River and a four station RTWQ network on the El-Salam Drainage canal. This eight station network will be complemented with an automated weather station with a central command centre.

The four strategic sites on the Nile River selected for this project were NL03, NL34, NL39 and NL42. However after a site visit site in January 2008, NL03 was changed to a new sampling site downstream of NL03 that will be called NL03A. NL03 was originally selected as it is located just upstream of the Aswan dam and it is the reference point for the quality of water entering the Nile River from Lake Nasser. However after a site visit the site was not deemed to be a safe location for field work due to the depth of water and possible currents from the dam’s turbine intakes.

NLO3A is a new monitoring location on the Nile River just after the Aswan dam but before any drainage inflow into the Nile River (Figure 2). 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, Khour-Elsail drain (DU01), is downstream of this site. The Khour-Elsail drain about 9.9 km downstream High Aswan Dam. This drain carries industrial wastes from Kima and Coca-Cola factories and also treated and untreated sewage from Aswan WWTP. A second 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 economic sustenance of people living in the Nile Delta along both Branches of the Nile River is based on agriculture, fishing and to a lesser extent on aquaculture. 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.

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.

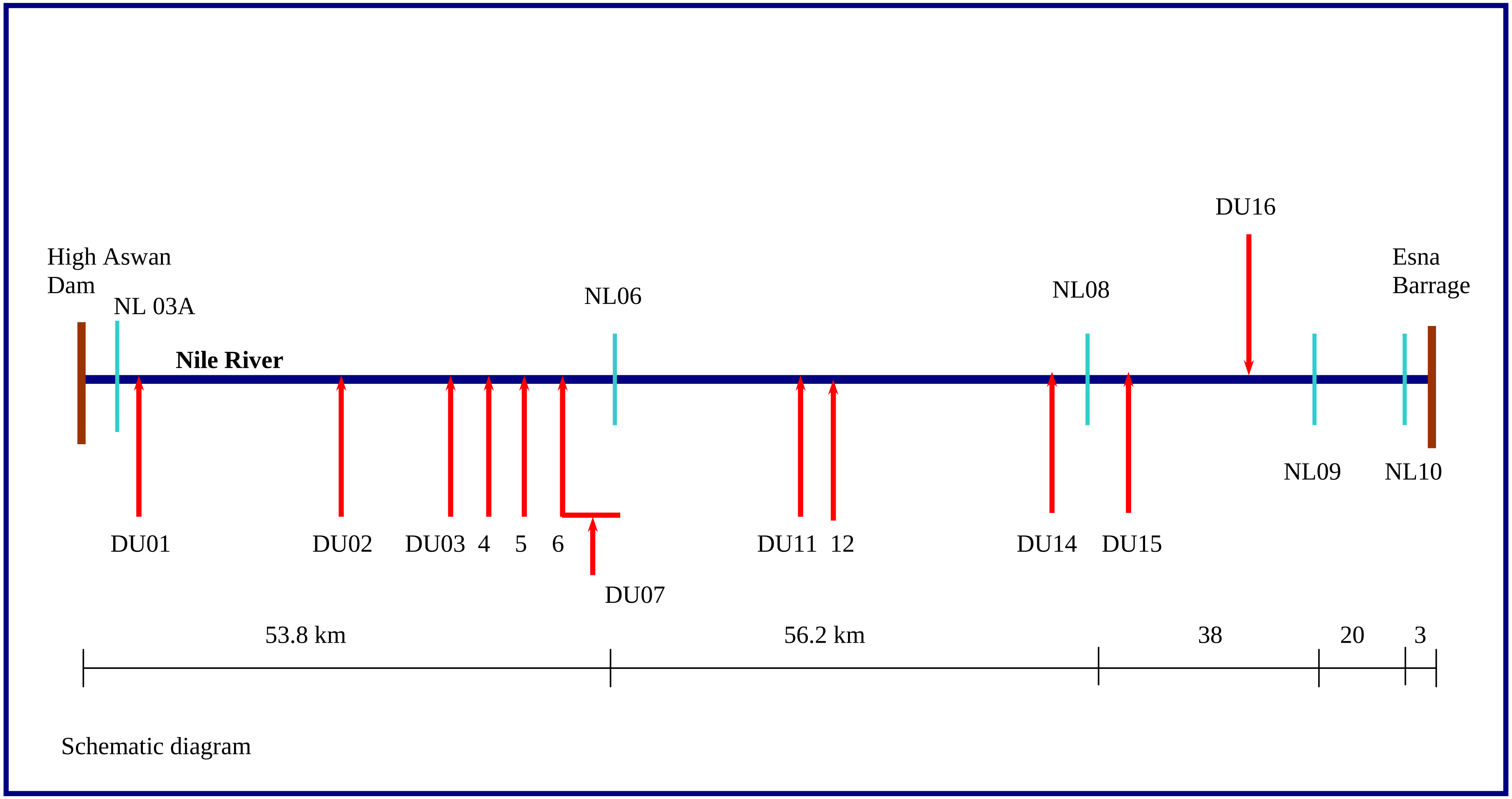


**Figure 2.** Monitoring Locations in the First Reach of the Nile River

In addition to the establishment of the above four RTWQ monitoring sites, there are four existing semi continuous water quality monitoring sites in Egypt. These four sites will be upgraded with communications equipment to enable them to report in real time. These four sites are located on the El Salam canal and measure drainage water quality using individual sensors for pH, conductivity and dissolved oxygen. The Government of Egypt is interested in accessing this data in real time mode in order to ensure the integrity of El Salam Canal water quality and to initiate policy corrective measures to improve quality of drainage discharge into the El Salam Canal.

The communication schema for the RTWQ network is shown in Figure 3. Water depth and seven water quality (water temperature, pH, conductivity, turbidity, dissolved oxygen, ammonium and nitrate) will be measured in real time using a HACH Hydrolab multi-parameter probe. The data will be recorded in a datalogger at the data collection platform every 15 minutes. The data collection platform and all instrumentation will be powered using solar energy. The NWRC control station will poll data from the data collection platforms every hour using both land lines and cellular connections. The data will be processed; converted into graphs; and published on a webpage that can be accessed by users.

### 3.2 Egyptian Water Quality Index

In parallel, an Egyptian Water Quality Index, a critical tool for water resources management, will be developed to evaluate and communicate the suitability of water bodies in Egypt for various uses such as drinking, irrigation, livestock, aquatic life and recreation.

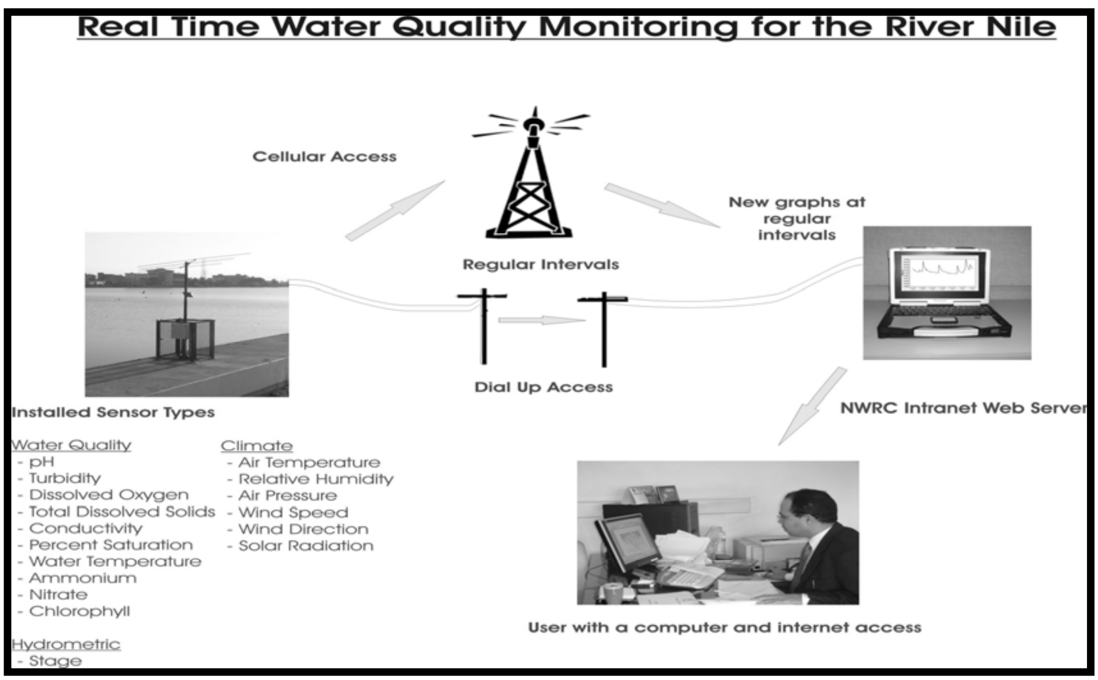


**Figure 3.** Real Time Water Quality Communication Schema

.The Egyptian Water Quality Index will provide an easy to use and scientifically defensible methodology for evaluating water quality based on its intended use and for converting water quality data into information and then into knowledge.

In December 2007 a beta version of the Egyptian Water Quality Index (EWQI), based on the Canadian Council of Minsters of the Environment (CCME) Water Quality Index (WQI) was developed.

The CCME WQI provides a measure of the deviation of water quality from water quality guidelines. The CCME WQI model consists of three measures of variance from selected water quality objectives (Scope; Frequency; Amplitude). These three measures of variance combine to produce a value between 0 and 100 that represents the overall water quality. The CCME WQI values are then converted into rankings by using an index categorization schema that can be customized to reflect expert opinion by users. The detailed formulation of the WQI is described in the Canadian Water Quality Index 1.0 – Technical Report (CCME 2001).

The detailed formulation of the WQI is described in the Canadian Water Quality Index 1.0 – Technical Report (CCME 2001). It consists of three measures which are described as follows:

***Scope, $F_1$***

The measure for scope is $F_1$. This represents the extent of water quality guideline non-compliance over the time period of interest.

$$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right) \text{ X } 100 \qquad (1)$$

***Frequency, $F_2$***

The measure for frequency is $F_2$. This represents the percentage of individual tests that do not meet objectives (“failed tests”).

$$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right) \text{ X } 100 \qquad (2)$$

***Amplitude, $F_3$***

The measure for amplitude is $F_3$. This represents the amount by which failed tests do not meet their objectives. This is calculated in three steps:

<u>Step 1- Calculation of Excursion</u>: Excursion is the number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective. When the test value must not exceed the objective:

$$\text{excursion}_i = \left(\frac{\text{Failed Test Value }_i}{\text{Objective }_j}\right) - 1 \qquad (3)$$

When the test value must not fall below the objective:

$$\text{excursion}_i = \left( \frac{\text{Objective}_j}{\text{Failed Test Value}_i} \right) - 1 \qquad (4)$$

Step 2- Calculation of Normalized Sum of Excursions: The normalized sum of excursions, *nse*, is the collective amount by which individual tests are out of compliance. This is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives).

$$nse = \frac{\sum_{i=1}^{n} \text{excursion}_i}{\text{Number of tests}} \qquad (5)$$

Step 3-Calculation of $F_3$: $F_3$ is calculated by an asymptotic function that scales the normalized sum of the excursions from objectives to yield a range from 0 to 100.

$$F_3 = \left( \frac{nse}{0.01nse + 0.01} \right) \qquad (6)$$

The WQI is then calculated as:

$$\text{WQI} = 100 - \left( \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right) \qquad (7)$$

The WQI values are then converted into rankings by using the categorization schema presented in Table 2. By this process the CCME WQI converts raw water quality data into information (how many variables exceeded the guidelines, how frequently and by what amplitude) and then into knowledge (the water is Excellent, Good, Fair or Poor for drinking water use etc.).

The CCME WQI formulation has been automated in various spreadsheet programs. CCME WQI calculators are available from CCME (http://www.ccme.ca) and the Newfoundland and Labrador Department of Environment and Conservation (http://www.gov.nl.ca) web sites. The NL calculator uses the same formulation as the CCME calculator but it includes additional features and tools that improve its user friendliness.

The index is based on water quality guidelines so it is able to evaluate water quality based on the intended use of the water (i.e. drinking water guidelines are used for evaluating drinking water use; irrigation water guidelines are used for evaluating irrigation water use, etc) and is not restricted by the number of variables. This allows all relevant variables for each designated water use to be included in the computation. The index uses a vector based mathematical function to compute the WQI scores. This allows one to exactly identify what is causing a water body to score poorly. This clarity allows the index to be used as a simple and effective communication tool.

**Table 2.** CCME WQI Categorization Schema

| Rank | WQI Value | Description |
|---|---|---|
| Excellent | 95-100 | Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels; these index values can only be obtained if all measurements are within objectives virtually all of the time |
| Good | 80-94 | Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels. |
| Fair | 65-79 | Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels |
| Marginal | 45-64 | Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels |
| Poor | 0-44 | Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels |

## 4. Results

### 4.1 Real Time Water Quality Network Implementation

In January 2008, RTWQ stations were successfully installed at NL34, NL39 and NL42. A Real Time Weather Station was also installed at NL34. The control centre was set up and data was successfully retrieved from the station at Site NL34 using both a landline and a cellular connection and using just cellular connections from the stations at Sites NL39 and NL42. An Automated Data Retrieval System (ADRS) was also setup to retrieve water quality data from the three stations every hour; to copy the data to a central network drive; to plot the data in the form of 30 day rolling graphs for each water quality variable; and to publish the 30 day rolling graphs to an internal web page. Installation of a RTWQ station at NL03 and the upgrade of the four existing semi continuous water quality monitoring sites on the El-Salam canal are scheduled for August 2008.

### 4.2 Egyptian Water Quality Index Implementation

In January 2008, initial testing of the EWQI was carried out using four years of biannual water quality data from sites NL03, NL34, NL39 and NL42. The results are presented in Tables 3, 4, 5 and 6 respectively. The drinking water quality WQI scores were computed using Egyptian guidelines for drinking water use (EHCW, 1995) but WQI scores for protection of aquatic life, irrigation use and livestock were computed using Canadian water quality guidelines (CCME, 2003) since Egyptian guidelines for these uses had not been sourced as of the writing of this paper.

**Table 3.** WQI Scores and Rankings for Nile River Site NL-03

| Data Summary | Drinking | Aquatic | Irrigation | Livestock |
|---|---|---|---|---|
| **WQI** | **95** | **39** | **95** | **100** |
| **Categorization** | **Excellent** | **Poor** | **Excellent** | **Excellent** |
| **F1 (Scope)** | 9 | 64 | 8 | 0 |
| **F2 (Frequency)** | 1 | 31 | 1 | 0 |
| **F3 (Amplitude)** | 1 | 78 | 4 | 0 |

**Table 4.** WQI Scores and Rankings for Nile River Site NL-34

| Data Summary | Drinking | Aquatic | Irrigation | Livestock |
|---|---|---|---|---|
| **WQI** | **65** | **26** | **83** | **88** |
| **Categorization** | **Fair** | **Poor** | **Good** | **Good** |
| **F1 (Scope)** | 36 | 73 | 25 | 8 |
| **F2 (Frequency)** | 20 | 41 | 7 | 4 |
| **F3 (Amplitude)** | 43 | 97 | 13 | 19 |

**Table 5.** WQI Scores and Rankings for Nile River Site NL-39

| Data Summary | Drinking | Aquatic | Irrigation | Livestock |
|---|---|---|---|---|
| **WQI** | **84** | **37** | **79** | **100** |
| **Categorization** | **Good** | **Poor** | **Fair** | **Excellent** |
| **F1 (Scope)** | 27 | 64 | 33 | 0 |
| **F2 (Frequency)** | 3 | 33 | 7 | 0 |
| **F3 (Amplitude)** | 7 | 82 | 13 | 0 |

**Table 6 .** WQI Scores and Rankings for Nile River Site NL-42

| Data Summary | Drinking | Aquatic | Irrigation | Livestock |
|---|---|---|---|---|
| **WQI** | **79** | **30** | **79** | **100** |
| **Categorization** | **Fair** | **Poor** | **Fair** | **Excellent** |
| **F1 (Scope)** | 27 | 73 | 33 | 0 |
| **F2 (Frequency)** | 12 | 40 | 6 | 0 |
| **F3 (Amplitude)** | 21 | 88 | 14 | 0 |

The guidelines are summarized in Table 7. By August 2008, all available Egyptian water quality guidelines will be compiled and EWQI scores will be computed for all of the Nile River water quality monitoring sites identified earlier in Figure 1. In August 2008, an Egyptian expert panel will evaluate the scores to develop an index categorization schema, like the one presented in Table 2, to reflect Egyptian expert opinion. The Egyptian index categorization scheme will be used to convert the EWQI scores into rankings that reflect Egyptian expert opinion.

The EWQI requires water use based water quality guidelines to compute WQI scores and ranking for each intended use of water. If Egyptian water quality guidelines are not available for Protection of Aquatic life, interim water quality guidelines based on representative background concentrations will be derived. The derivation of water quality guidelines using background concentrations and its implementation in a WQI calculator are explained in detail by Khan et al (2005).

## 5. Challenges

Some of the challenges encountered in establishing the environmental security and water resources management system were:

1. The equipment had to be sourced, assembled as a system and tested in Canada. Then equipment was used to train two young Egyptian scientists in Canada and then repackaged and shipped to Egypt.

2. While all components of the RTWQ and weather station were tested to work as a system in Canada prior to shipping to Egypt, the cellular GSM modems to be used for communication could not be tested due to the difference in GSM cellular frequencies between Canada and Egypt. The GSM cellular modems were sourced separately from England and were tested for the first time during the field installation. This resulted in delays as various modem configurations had to be tested in the field until communication was achieved.

3. Despite the testing in Canada an error was discovered in the datalogger programming upon installation in Egypt. The programming had to be corrected on all three dataloggers.

4. As it was not financially possible for the Canadian team to help in installing all the RTWQ stations, a core team of Egyptian young scientists were trained to the installation. A “train the trainer” approach was adopted whereby four young scientists were trained in Canada in different aspects of the installation and operation and then these four young scientists trained the remaining young scientists in Egypt under the supervision of the Canadian team.

## 6. Conclusions and Path Forward:

While the stations being set up under the NATO Science for Peace project are monitoring surface water in the Nile river and the El-Salaam canal, the same stations can be used for monitoring groundwater. When used for monitoring groundwater the Hydrolab Series 5 probes is replaced with a Hydrolab Quanta probe which is designed with a smaller diameter so that that it can be used in groundwater wells.

On successful installation of all RTWQ stations, a network expansion plan will be developed for extended deployment of the RTWQ monitoring stations at other strategic sites on the Nile River, irrigation canals, drainage canals and groundwater monitoring sites.

**Table 7.** Water Quality Guidelines Used in WQI Computations

| Variables | Units | Drinking[1] Lower | Drinking[1] Upper | Aquatic[2] Lower | Aquatic[2] Upper | Irrigation[2] Lower | Irrigation[2] Upper | Livestock[2] Lower | Livestock[2] Upper |
|---|---|---|---|---|---|---|---|---|---|
| Temperature | oC | | | | | | | | |
| Conductivity | uS/cm | | | | | | | | |
| Color | TCU | | | | | | | | 15 |
| **Turbidity** | NTU | | 5 | | | | | | |
| Dissolved Oxygen | mg/L | | | 9.5 | | | | | |
| pH | | | | 6.5 | 9 | | | | |
| Total Alkalinity | mg/L | | | | | | | | |
| Calcium | mg/L | | 200 | | | | | | 1000 |
| Sodium | mg/L | | | | | | | | |
| Magnesium | mg/L | | | | | | | | |
| Potassium | mg/L | | | | | | | | |
| Sulphate | mg/L | | 400 | | | | | | 1000 |
| Chloride | mg/L | | | | | | 110 | | |
| **Fluoride** | mg/L | | 0.08 | | 1.2 | | 1 | | 1 |
| Diss Org Carbon | mg/L | | | | | | | | |
| Phosphorus | mg/L | | | | | | | | |
| **Nitrate(ite),(Nitrite)** | mg/L | | | | | | | | 100 |
| Nitrogen | mg/L | | | | | | | | |
| Silicon Dioxide | mg/L | | | | | | | | |
| Aluminium | mg/L | | 0.2 | | 0.005 | | 5 | | 5 |
| **Arsenic** | mg/L | | 0.05 | | 0.005 | | 0.1 | | 0.025 |
| **Barium** | mg/L | | | | | | | | |
| Beryllium | ug/L | | | | | | | | |
| **Cadmium** | mg/L | | 0.005 | | | | 0.0051 | | 0.08 |
| Cobalt | mg/L | | | | | | | | |
| **Chromium** | mg/L | | 0.05 | | 0.001 | | 0.0049 | | 0.05 |
| Copper | mg/L | | 1 | | 0.002 | | 0.2 | | 0.5 |
| Iron | mg/L | | | | 0.3 | | 5 | | |
| **Mercury** | ug/L | | 0.001 | | 0.1 | | | | 0.003 |
| Lithium | mg/L | | | | | | | | |
| Manganese | mg/L | | | | | | 0.2 | | |
| Molybdenum | mg/L | | | | 0.073 | | | | |
| Nickel | mg/L | | | | 0.025 | | 0.2 | | 1 |
| **Lead** | mg/L | | 0.05 | | 0.001 | | 0.2 | | 0.1 |
| **Selenium** | mg/L | | 0.01 | | 0.001 | | 0.02 | | 0.05 |
| Strontium | mg/L | | | | | | | | |
| Vanadium | mg/L | | | | | | | | |
| Zinc | mg/L | | 5 | | 0.03 | | 1 | | 50 |

[1]EHCW - Egyptian Higher Committee of Water (1995), [2]CCME (2003)

The plan will include prioritisation of sites for further expansion. A number of scenarios for future development will be simulated and, based on multi-criteria analysis, the most efficient scenarios will be derived.  The network expansion plan will serve as a blue print for further implementation of the RTWQ network to both the Nile River, irrigation canals, drainage canals and groundwater monitoring sites.

The RTWQ network can be used to address trans-boundary monitoring of Nile River by extending the network to site NL00 and other sites further south of NL00. NL00 is located a few kilometres north of the border between Egypt and Sudan. And it describes the quality of the water entering Egypt. The High Aswan Dam Authority has established an environmental buoy at NL00 (Figure 4), Hydrolabs can be installed on this buoy to measure water quality at different depths and to communicate the data to the central command centre in real time. This buoy earlier had a Hydrolab on it but the Hydrolab was not set up for RTWQ reporting and did not have sensor wipers. It consequently was subject to considerable fouling and had to be eventually removed. The new Hydrolab Series 5 probes are equipped with sensor wipers and a more robust sensor for measuring dissolved oxygen.

Upon successful testing and customisation of the EWQI, an implementation plan will be developed for the use of the EWQI for data management and reporting and to use the derived information and knowledge for integrated water resources management.


Figure 4. Environmental Buoy at NL00

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