TOWARDS A LAKE NASSER MANAGEMENT PLAN: RESULTS OF A PILOT TEST ON INTEGRATED WATER RESOURCES MANAGEMENT

S. S. Zaghloul[1], N. Pacini[2], Karl Schwaiger[3], Pierre Henry de Villeneuve[4]

[1] Sohair Saad Zaghloul National Water Research Center, Egypt
[2]Nic Pacini, Department of Ecology, University of Calabria, Italy
[3]Karl Schwaiger, International Water Policy, Ministry of Environment, Austria
[4]Pierre Henry de Villeneuve, Office International de l'Eau, France

ABSTRACT

Lake Nasser is of key strategic importance for sustaining Egypt's water demand and it is essential that its water quality is protected from pollution. Rapid development is taking place in all parts of the catchment and may spread equally to Lake Nasser area in the near future, as foreseen by the Aswan Governorate "Lake Nasser Development Plan" (2002). In 2009-2010, a Pilot Test was performed to implement integrated water resources management (IWRM) approaches and methodologies based on the EU Water Framework Directive (Directive 2000/60 EC) through the definition of reasoned objectives, applied methodologies and standard procedural planning steps inspired to the main principles of the Directive.

To achieve IWRM objectives in Lake Nasser, integrated planning is required including a broad set of information ranging from an analysis of competent authorities in place and their responsibilities, a description of relevant waterbody characteristics, an analysis of potential pressures and impacts, and finally a tailored programme of measures. A set of indicators is defined to follow the evolution of water quality status and to identify main trends in environmental changes that could impact water quality in the proximity of the reservoir. Major potential drivers for change have been identified, as well as some key parameters and locations, within the reservoir, that need to be closely followed up to refine the interpretation of potential impacts. Finally, a broad range of management recommendations could be derived to ensure a sustainable healthy future for Egypt's most important water resource.

Currently Lake Nasser enjoys high water quality and faces no threat of degradation due to local sources. The preliminary observations provided by the Pilot Study represent a valuable step towards the definition of a management plan specific to Lake Nasser and illustrate how a reasoned integration of information derived from different disciplines can support progress in water resources management practices in Egypt and can represent and incentive and guidance for targeted capacity development in competent institutions. The IWRM Pilot Test was conducted in the frame of a EU-Twinning Project on Water Quality Management.

Keywords: Water quality assessment and protection, Monitoring, Nutrient loading, Pressure and impact assessment, EU Water Framework Directive.

1. INTRODUCTION

This exercise provided a unique opportunity to test on the ground in Egypt the implementation of methodologies recently developed in Europe; water resources management made important progress since the introduction of specific requirements concerning IWRM made by the European Water Framework Directive (2000). Testing the IWRM approach under Egyptian situation also aimed at stimulating Egyptian authorities and stakeholders to work more closely together and to develop opportunities that only integrated management approach can produce, in terms of better informed and more generally shared resource planning.

Large team of experts, each responsible for a special portion of the overall outcome, contributed to this research study working side by side with Egyptian officials in the High Aswan Dam Authority (HADA) and in collaboration mainly with the Lake Nasser Development Authority (LNDA) and with the National Water Research Council (NWRC). This joint work served as a demonstration of how specialists from different disciplines can unite their skills and produce a multi-faceted management plan by combining competences including: policy assessment, chemical and biological monitoring, chemical analysis, data management, data interpretation, impacts and pressures analysis, nutrient load modelling, GIS and the design of a Programme of Measures.

The Pilot Test focused on estimating the potential contribution of local human activities, present mainly in the northern and along the western shore of the reservoir, to incoming nutrient and pollutants' loads, and their effect on water quality.

Currently, the management of Lake Nasser is under the main responsibility of HADA, under the Ministry of Water Resources and Irrigation. Presidential Decree 203 of 2002 provides general guidelines restricting human activities around the reservoir to avoid potential impacts. Information is available on some of the potential pressures that exist in proximity of the shoreline, but there have been no attempts at assessing their cumulative impact on water quality. In 2002, Aswan Governorate issued a "Lake Nasser Development Plan" [1] including the description of the potential status of human activity in 2022. This document has been taken as reference to provide an estimate of potential future pressures on water quality.

The specific objectives of the IWRM Pilot Test are:

1. To provide legal and organisational support for an improved and better informed water governance framework for Lake Nasser;
2. To provide support in data management, interpretation, design of GIS;
3. To promote stakeholder participation (use of a participative approach for the preparation of a management plan) stemming from competent authorities that supervise human activities on the reservoir and in its immediate proximity;
4. To propose indicators for a preliminary quantification of the pressures caused by human activities in and around the reservoir;

5. To establish potential impacts on water quality by providing estimates of pollutants' loading;
6. To issue recommendations aimed at enhancing monitoring and further assessments that need to be made to control trends of increase in current impacts;
7. To estimate pressures and impacts according to a year 2022 scenario;
8. To design a draft Programme of Measures to provide suggestions on how to reduce the potential impact of major pressures identified in proximity of the reservoir.

2. CHARACTERISATION

To achieve an adequate site-specific perspective, some key characteristics relating to the main legislation, the institutional set-up, the physical setting and some key water quality parameters were collected an analysed.

2.1 Competent authorities, roles and responsibilities

A large number of actors holds responsibilities at the national as well as the local management level that influence the status of potential pressures influence the reservoir water quality. Cooperation across sectors is of the utmost importance, as no single authority can solve on its own the water quality issue. That is precisely why the coordination of major policy makers in each sector has to be organised through IWRM. The following list provides an impression of the challenge that needs to be faced to coordinate among a large number of actors.

Administrations holding responsibilities related to human activities in and around the reservoir:

1. Ministry of Water Resources and Irrigation (MWRI)
   - Local actor: High Aswan Dam Authority (HADA)
2. Ministry of Agriculture and Land Reclamation (MALR)
   - Local actor: Lake Nasser Development Authority (LNDA)
3. Ministry of Housing, Utilities and Urban Development (MHUUD)
   - Local actor: Aswan Holding Company for Water and Wastewater
4. Ministry of State for Environmental Affairs
   - Local actor: Egyptian Environmental Affairs Agency, Aswan branch (EEAA-Aswan)
5. Ministry of Health and Population (MoHP)
6. Ministry of Industry (MoI)
7. Ministry of Transportation (MoT)
8. Ministry of Local Development (MoLD)
9. Ministry of Planning (MoP)
10. Ministry of Finance (MoF)
11. Ministry of Tourism (MoT)
    - Local Actor: Tourism Authority, Aswan branch

2.2 Environmental setting

Lake Nasser is the second largest man-made lake in the world (480 km long), situated in a desert area with extremely low precipitation and very high evaporation. In the Egyptian portion of the Lake Nasser basin population is low, human activities are strictly regulated and their impact is not expected to be cause of concern for the water quality.

2.2.1 Climate and geology

The climate of the area is continental with marked variations between summer and winter temperatures as well as daytime and night time temperatures. July and August are the hottest months with average minimum / maximum temperatures of 24 and 39.7 °C, respectively. In the coolest months of December and January temperatures fall to minimum / maximum temperatures of 10 and 21.7 °C. Average humidity varies between 13% in summer and 34% in winter. Rainfall is rare, although rain in the eastern desert occasionally causes flash flooding in the wadis on the eastern bank of Lake Nasser and of the River Nile.

There are three main geological units: the basement complex, the Nubian sandstone and the limestone plateau. The basement complex presents intrusions of igneous masses from the Red Sea range in the Eastern Desert. Various different kinds of rocks became folded, fractured and metamorphosed and then eroded into a huge irregular plateau. Above the basement complex a succession of layers of Nubian sandstone were laid down cemented by lime or silica. The Nubian sandstone thickness varies. Phosphate beds and limestone deposits are the most recent deposits consisting of limestone, sandstone, shale and conglomerate.

2.2.2 Hydrology and physico-chemical characteristics

Limnologically the reservoir can be subdivided into a riverine, a transitional and a lacustrine zone, which exhibit significant differences in physico-chemical and biological features, and whose boundaries tend to change seasonally. The incoming Nile River has an annual mean discharge of about 2,900 $m^3 s^{-1}$, of which 20% gets lost through evaporation. Lake Nasser has a retention time in excess of 1 year. Seasonal flow variation is high, and strongly regulated downstream of Aswan. Annual water level fluctuations reach 10 m vertically, and hundreds of ha in terms of surface area. Water temperature varies between 11 and 36.1 °C. Lake Nasser is warm monolithic, with differences of more than 10 °C between surface and bottom during summer, and homothermous conditions during winter. Dissolved oxygen concentrations are moderate to high at the surface, but decrease strongly below 8–10 m in the North and below 20 m in the South during late summer. Transparency can reach values of more than 4.5 m near the High Dam. Total dissolved solids increase from South to North and decrease with depth during spring. The reservoir is well buffered, with pH values comprised between 7.12 and 8.88 [2]; electric conductivity varies between 203 and 261 µS cm–1 (data provided by HADA).

2.2.3 Nutrients

Nitrogen and phosphorus concentrations undergo a pronounced seasonal and vertical variation (stratification). The N:P ratios indicate phosphorus limitation, however, co-limitation with nitrogen can be assumed in certain periods of the year. Chlorophyll "a" varies between 1.8 and 13.1 μg L^{-1} among different sites [3] indicating that the reservoir can be considered oligo-mesotrophic, with pronounced seasonal variation linked to the arrival of the Nile floods from upstream.
In spite of much information available in public reports and scientific papers, data are scattered and do not allow to describe long-term trends of key water quality parameters that should be regarded as a key purpose of management-oriented to water quality monitoring. Open questions concerning the reservoir's carrying capacity point to the correlation between sediment load and nutrients, and the role of sediment diagenesis in nutrient cycling.

2.3 Protected areas

A "buffer zone" of 2 km is established around the reservoir by Decree 203/2002, where no agricultural, touristic and industrial activities are allowed to take place. Under Law 102/1983, Wadi Alaqi is recognised as a Biosphere Reserve of international importance that should remain free of any development, disturbance and changes in land-use or activity that may degrade the natural interest of the site.

3. PRESSURE & IMPACT ASSESSMENT

3.1 Definition of potential pollution coefficients

A quantification of current pressures was realised by defining pollution coefficients specific to each single human activity, following data extracted from literature sources and experts advice. The main objective was to estimate the total contribution of different pollution sources and to establish whether they can upset the reservoir's nutrient balance and lead to the development of eutrophication. More precise pressure coefficient can be defined following targeted research on the impact of single sectors of human activity. The Pilot Test provided a general framework and also recommendations on how these estimates could be refined further [4].

For the quantification of activities, characteristic figures/indicators were employed

(See Table 1).

Table 1. Impact indicators based upon a quantification of pressures

Sector	Characteristic figure used
Domestic wastewater	Number of inhabitants
Agriculture	Number and type of cattle
	Surrounded cultivated area "feddans"
Fishery practices	Number of fishermen
	Weight of fish production in cages " t"
Navigation	Number of passenger vessels "day"
Aquaculture	Area of surface aquatic plants and percentage of submerged &suspeded

This model-based approach was applied to the current situation and to 'Scenario 2022' to estimate the load of pollution generated following the development estimates described in the Aswan Governorate's LNDP [1]. An important uncertainty remains the effective transfer of the identified pressures to the reservoir and their translation into impacts. In the case of passenger vessels and aquaculture, discharge effluents reach directly the lake waters; in the case of agriculture and urban wastewater impacts are not entirely direct because only a minor portion of these pressures produces effluents that could be drained into the reservoir. A careful assessment of transfer factors that can influence the pressure/impact relationship is particularly relevant in the case of agriculture, as this pressure represents the greatest potential pollution source.

3.2 Calculating "in-lake" concentrations

The sum of the individual loads generated by the different sectors can be divided by the theoretical outflow of the reservoir at Aswan (150,000,000 m^3 d^{-1}). This calculation implies that no pollutant abatement takes place in the reservoir. The estimates presented in Table 2 represent the contribution, in terms of nutrient and pollutant loads, derived from anthropogenic activities in the immediate proximity of the reservoir. The Table illustrates the theoretical effect that pollution loads could have on "in-lake" concentrations.

Table 2. Pollutant'loads and estimated "in-lake" concentrations

Pollutant	Pollution load ($kg\ d^{-1}$)		Concentration ($mg\ L^{-1}$)	
	Today	2022	Today	2022
Suspended solids	1 701	4 611	0.011	0.03
Organic matter	999	2 755	0.006	0.018
BOD	2 259	6 068	0.015	0.04
Nitrogen	3 837	30 698	0.025	0.2
Phosphorus	1 015	2 411	0.0067	0.016

The pollution coefficients are expressed in g per day ($g\ d^{-1}$) representing an average pollutants' export during a normal activity day. The main approximations used to define the coefficients are based on expert advice and studies extrapolated from the international literature. A similar approach conducted in France in particular for the calculation of an ear-marked tariff imposed on the discharge of polluting effluents produced by different water users. Details can be found in the reports submitted to MWRI under the Twinning Project Water Quality Management [4].

The first column [Pollution load/2010] provides sum of the estimated loads for each parameter. By dividing these figures by the average theoretical flow at Aswan (150 million $m^3\ d^{-1}$), it is possible to calculate a theoretical contribution of human activities of in-lake pollutants' concentrations [Concentration/Today]. A similar calculation has been carried out for the year 2022 estimates, based upon estimates of future development provided by the Aswan Governorate [1]. The 2022 in-lake concentrations appear significantly higher.

Based on the scenario outlined above, nitrogen loading would increase from 3,837 to 30,698 kg (by 700%), while phosphorous loading would increase only from 1,015 to 2,411 kg (by 137%). The striking difference between the two nutrients is due to the fact that, as documented in the sectoral approach analysis, more than 90% of nitrogen and phosphorus are generated by agriculture, which is likely to apply more nitrogen than phosphorus due to current fertilization practices. In both cases, our estimates suggest that the potential increase in nutrient loading due to local human activities could bear a significant impact on in-lake concentrations by 2022. For nitrogen, the contribution of local pressures to in-lake concentrations increases 8 times (0.025 to 0.2 $mg\ L^{-1}$) while phosphorus is above 2 (0.0067 to 0.016 $mg\ L^{-1}$). As a primary approximation, these impacts could be significantly judged in the potential trophic status change of the lake.

The increase in Organic matter and BOD are potentially significant, but represent relatively negligible impacts for the water quality of the reservoir as a whole. A similar consideration can be made in the case of suspended solids. The calculations illustrate a potential increase in loading from 1,701 to 4,611 kg (by 171%). This order of magnitude appears entirely negligible compared to the estimated yearly deposition of about 134 million tonnes of sediment provided by Saad [5], based on an average yearly inflow of 84 km^3.

3.3 Estimating the contribution of local nutrient sources in relation to the overall load

The relative importance of local pressures must be assessed in relation to the overall nutrient loading in the reservoir. No precisely quantified estimates exist at the moment. However by applying the Vollenweider Model (Table 3) to the average measured total phosphorus concentration it is possible to obtain an approximate estimate of the total phosphorus loading coming into Lake Nasser. No simple model can be applied to estimate nitrogen loading, due to the complex biogeochemical interactions that characterise the behaviour of this nutrient.

Table 3. The Vollenweider model equations

Parameter	Equation
Hydraulic residence time (T) “ days”	$T = \frac{VOL}{Q}$
Surface overflow rate (QS) “m3/d”	$QS = \frac{Z}{T}$
Areal phosphorus load (LP) “mg/l”	$LP = \frac{LOAD\_TP}{SUR}$
Mean depth (Z) in m	$Z = \frac{VOL}{SUR}$
Phosphorus concentration prediction (TP) “mg/l”	$TP = \left(\frac{Lp}{QS}\right)\left(\frac{1}{1+\sqrt{\left(\frac{Z}{QS}\right)}}\right)$

Considering the data provided mainly in [6], it could be estimated that the average total phosphorus concentration during the overturn period (desertification) could be approximated to 20 µg L^{-1}. The application of the Vollenweider Model provides the results illustrated in Table 4.

Table4. Phosphorus loading from local sources and total phosphorus loading

Current status “2010”	phosphorus load	12,000 kg d^{-1}
	load due to local pressures	1,015 kg d^{-1} (= 8% of total)
Estimated status “2022”	load due to local pressures	2,411 kg d^{-1}
	total phosphorus load	13,396 kg d^{-1} (= 18% of total)

This calculation indicates that even if the ambitious Development Plan illustrated in Aswan Governorate's document [1] will come true, the contribution of local phosphorus sources to the overall phosphorus loading will reach at most 18% of the total.

3.4 Assessment of the effect of increased nutrient loading

By calculating the Vollenweider formula backwards, it is possible to estimate the "in-lake" total phosphorus concentration that will result from the increased loading estimated for 2022. The calculation indicates this to be comprised between 21 and 22 $\mu g\ L^{-1}$. The difference between the current (20 $\mu g\ L^{-1}$) and the future average in-lake phosphorus concentration (21-22 $\mu g\ L^{-1}$) is below the detection limits for the analysis of total phosphorus, therefore this increase will not be detectable by standard monitoring procedures.

4. EUTROPHICATION PROGNOSIS FOR LAKE NASSER

Based upon the calculation of the potential contribution of local human activities to the load of pollutants entering Lake Nasser, and on the other hand upon calculations performed using data extracted from scientific literature, it can be concluded that currently the reservoir does not face a serious risk of undergoing eutrophication/degradation of water quality due to excessive nutrient inputs from local anthropogenic sources.

The current contribution of local pressures to the phosphorus load is <10% of the overall phosphorus loading, while >90% is most likely to come from the Nile River upstream. In the near future, local phosphorus loading could increase to a maximum value of 20% by 2022; however this increase is likely to result in a marginal increase in "in-lake" concentrations because most of the incoming load will be buffered by the self-purification capacity of the reservoir itself (complication, sedimentation and digenesis). The application of the Vollenweider Model indicates that the increase in "in-lake" concentration will be only marginal and undetectable to standard monitoring practices. A similar fate is expected to be common also to nitrogen loading, however no quantified estimate can be given at present. This uncertainty should be addressed by a specific assessment programme, given the great potential relevance of nitrogen in limiting primary production in Lake Nasser.

Despite these reassuring results, it should be stressed that the Pilot Study had no means to estimate current trends of increase in nutrient and pollutants' loads coming from upstream. Given their current large predominance, it is expected that the evolution of these loadings could be determinant for the reservoir's water quality status.

5. PROGRAMME OF MEASURES

To keep under control the potential impact of local human activities on reservoir eutrophication, targeted policy lines and measures, specific to each sector were suggested. This included non-structural measures in support of the implementation of structural ones and of their follow-up. Some of these will help refining the overall understanding of critical factors that influence the transfer functions linking pressures and impacts under the specific conditions realised in the case of Lake Nasser.

The following list resumes the principal sectors and objectives under which measures were proposed to keep under control human activities in the Egyptian portion of Lake Nasser. A more detailed table presenting the programme of measures is available as part of the results of the recently concluded EU “Water Quality Management” Twinning Project 2008-2011 [4].

Urban/rural wastewater management:

1. Define a strategy for the management and planning of current sanitation facilities and define a local sanitation Master Plan
2. Develop further sanitation facilities
3. Improve management of the secondary effects of domestic sanitation, i.e. sludge in particular, side-effects of wastewater disinfection with chlorine and treated wastewater and sludge reuse
4. Improve monitoring of urban sanitation

Agriculture:

5. Develop and disseminate standards and guidelines concerning treated wastewater reuse in irrigation, and the reuse of drainage water
6. Define and disseminate standards for establishing the exact needs in terms of fertilisers, pesticides, etc, of single crops, assessed in a site-specific context.
7. Establish a Code of good practices with the participation of farmers’ representatives
8. Develop activities to improve knowledge of the potential impact of agriculture on water quality under site-specific conditions

Navigation:

8. Adapt the command/control system to reach a fleet of passenger vessels operating on Lake Nasser with “zero emissions”
9. Create a network of dedicated shore reception facilities for solid waste as well as wastewater generated aboard vessels
10. Restructure institutional attributions in order to enforce regulations more efficiently

Fishery sector:

11. Improve the institutional and organizational framework to better control fishery practices in Lake Nasser
12. Promote fish productivity keeping a reduced pollution load discharge

While the measures above address economic activities, a number of concrete recommendations was illustrated concerning updating and refocusing water quality monitoring activities, through a redefinition of mutual responsibilities among local administrations and the establishment of a more regular assessment of the incoming nutrients and pollutants loads coming from upstream.

Targeted recommendations and intervention measures were defined also for accidental pollution control, including a proposal for an oil spill contingency plan as well as specific actions to enhance preparedness, rapid response capacity and transboundary cooperation.

6. CONCLUSIONS

Despite the paucity of reliable data, the application of IWRM principles and methods to the Lake Nasser situation is useful to highlight critical issues and draw some general conclusions about the likely evolution of the reservoir's ecology.

- It cannot be over-emphasised that trends of change in nutrient loading should be followed with particular care by the managing authorities.
- Potential increase in nutrient loading regarded as more or less insignificant for water quality in rivers, may trigger the development of eutrophication in a reservoir such as Lake Nasser, which should be regarded as potentially sensitive to these effects due to its very large drainage basin.
- These concerns should be carefully considered within the context of the ongoing extension of irrigated areas, the ongoing urbanisation, industrialisation and intensification of agriculture in the catchment around the reservoir and also further upstream of Lake Nasser.
- Experiences made in Europe with regard to fighting eutrophication in Lake Constance, in the North Sea, in the Baltic Sea and in the Danube Delta indicate that it is never too soon for taking adequate precautions to prevent water quality deterioration.
- The results of the assessment presented here indicate that local human activities bear a limited influence on the overall transfer of nutrient loading into the reservoir.
- It should be stressed that more consistent data need to be produced, collected and ordered in a validated water quality database, to improve the reliability of the results that are presented here.
- A number of implementation measures should nevertheless be introduced to control the potential impact of different human activities at local (Egyptian) level and to guide further development on the shores of Lake Nasser towards sustainable resource management.
- To provide these operational measures, it is paramount that local management authorities as well as central ministries may define specific agreements, and share information concerning their activities in relation to water quality monitoring as well as to the monitoring of the evolution of human activities around the reservoir.

- Special care should be dedicated to assess localised effects of pollution; depending on their individual location, *khors* have lower flow velocities than the Lake, thus an even more reduced potential of mixing of local effluent discharges and thus an enhanced potential vulnerability to local impacts.
- Lower current flow, low depth, higher temperatures and more intense nutrient exchanges fuelling higher primary production contribute to create ideal conditions in the *khors* for fish spawning. This in turn attracts a lot of bird life and fishermen can exploit this resource.
- *Khors* represent the most accessible portion of the lake for a range of human activities (fishing, washing, pumping water for irrigation, extraction of sediment for land reclamation) and are therefore increasingly threatened by local pollution sources. Some of the more exposed *khors* should thus be object of more regular monitoring.
- The current good water quality status of Lake Nasser and the low impact due to local (Egyptian) sources indicate that the future water quality status of the reservoir is dependent mainly on potential impacts that could come from the Nile inflow upstream.
- A targeted monitoring scheme should be put in place to follow more closely incoming loads as well as their evolution over time, taking into account the large variations in nutrient concentrations that accompany seasonal changes triggered by the Nile floods.

ACKNOWLEDGMENTS

This IWRM Pilot Test was conducted in the frame of a EU-Twinning Project on Water Quality Management EG/07/AA/EN09.

REFERENCES

[1] Aswan Governorate (2002) Lake Nasser Development Plan.

[2] NAWQAM (2008). Component National Water Quality and Availability Management (NAWQAM), National Water Quality Monitoring Component - Component 1000, Final Technical Report, Report n. WQ-TE-0812-023-FN, December 2008.

[3] Mohamed I.O. (2000). Average changes in the distribution of phytoplankton chlorophyll a in the euphotic zone in the main channel. In: Craig JF [ed.], Sustainable Fish Production in Lake Nasser: Ecological Basis and Management Policy. ICLARM Conf. Proc. 61, Penang, Malaysia, pp. 57-58.

[4] EU-Twinning Project “Water Quality Management” EG/07/AA/EN09 Reports and documents deposited in the offices of the Planning Sector of MWRI, Cairo.

[5] Saad M.B.A. (2000) Conflicts between users. In: Craig JF [ed.], Sustainable Fish Production in Lake Nasser: Ecological Basis and Management Policy. ICLARM Conf. Proc. 61, Penang, Malaysia, pp. 7-9.

[6] Goma R.H. (2000). Seasonal and spatial variation of nutrients. In: Craig JF [ed.], Sustainable Fish Production in Lake Nasser: Ecological Basis and Management Policy. ICLARM Conf. Proc. 61, Penang, Malaysia, pp. 33-38.