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Restoration and Development Project of South Lake of Tunis and its Shores

Abstract

This paper describes the development of the South Lake of Tunis which has recently been accomplished by the group LAC SUD 2000 (a consortium of five dredging contractors) at the request of the Tunisian Government. The project is within the framework of the national development programme of the coastal Tunisian lagoons, in an effort to improve the living conditions in this area and to protect the environment against the various forms of pollution which have affected it for more than half a century.

It is amongst the rare projects which introduce viable solutions for limiting the extent of pollution in one of the most eutrophic lagoons in the world. Considering the location of the lake within the heart of the town of Tunis City, the project will offer to Tunis centre an opening onto the sea, giving it a whole different look. The history of the Lake Tunis, its location before the development works, the after-project results and the work volume executed during the project period will also be discussed here.

The works were completed within the contractual period and a programme monitoring water quality will follow the project during a maintenance period of two years and a guarantee period of five years.

For information about the remediation of the North Lake of Tunis see *Terra,* number 49, September 1992.

Introduction

The South Lake of Tunis is a shallow lake located in the north of Tunisia at the east side of Tunis City. Before the works described here were implemented, all rainwater and wastewater of south Tunis City and Ben Arous industrial zone were discharged into this lake. The investigations carried out before the start of the project showed the presence of approximately 2 million m^3 of organic sediment contaminated by heavy metals such as Chrome, Copper, Zinc, Iron, Nickel, Aluminium and Hydrocarbons. Owing to this, the South Lake had reached a high level of pollution and eutrophication. The extreme eutrophication conditions appear in summer with dystrophic crises characterised by red water, bad smells and high mortality of fish life.
In order to solve these pollution conditions, the "Societé d'Etudes et de Promotion de Tunis Sud" (SEPTS) invited LAC SUD 2000 (a consortium of five contractors led by Dredging International) to carry out a large restoration and development programme during a period of three years.

The main objectives of this programme consisted of the creation of a flushing system of seawater by the construction of an inlet and an outlet sluice driven by natural tidal forces, the confinement in a terrestrial zone by a vertical PEHD liner of 1 million m^3 polluted sediments, the removal of a quantity of 12 million m^3 of organic sediments in order to dredge the lake to a depth of 2 m and the extraction of a quantity of 5 million m^3 of sand in order to gain reclamation land on the shores of the lake. Most importantly, however, this project aimed for a total regeneration of the lake including a modification of its shores, its morphology and its topography.

Pre-dredging Studies

At the beginning of the project, detailed studies were carried out by setting up mathematical models for water circulation and water quality. The water circulation has been studied by 2D and 1D models. The 1D model was coupled with an ecological model that was used to predict water quality and the effect of the circulation on the ecosystem. The ecological model, based on site measuring and laboratory tests, describes the nutrient seasonal variation in relation with

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Ben Charrada Rafik

Ben Charrada Rafik was involved with the restoration and development of both the North and South Lakes of Tunis and has extensive experience in management of water and environmental problems. He obtained his Doctorate in Hydraulic Engineering in 1997, basing his thesis on his study of hydrodynamic flows in the Tunisian coastal ecosystem.

the macro algal growth and nutrient release from bottom sediment.

Hydraulic study showed for the retained dredging plan that the water circulation in the lake will be homogenous and the lake water will be regenerated in a short time. The residence time will be from 4 to 7 days as a function of the tide and the wind.

The prediction of water quality carried out by the ecological model showed that the lake can be regenerated with the new flushing system. The nutrient contents in the lake will be comparable to those in the Tunis Gulf, the bottom concentration of macro algae will be reduced and water will be well oxygenated. This will improve the situation of the lake by eliminating red waters and all sources that had negative effects on water quality before the works.

Geographic Situation

The South Lake of Tunis belongs to a Mediterranean lagoon complex including the North Lake and the navigation canal. This complex belongs to the set of the coastal Tunisian lagoons and is located at the bottom of the Gulf of Tunis which is located on the south part of the Sicily-Tunisian canal. The South Lake constitutes the south part of this complex and it is separated from the

Figure 1. Geographic localisation of the South Lake of Tunis.

North Lake by the navigation canal. It is limited by the town of Tunis and its surrounding from the east, the southeast and the south sides (Figure 1).

History

Before the end of the 19th century, the South Lake was part of a more extended lagoon having a surface of 4000 hectares (Figure 2). It was only in 1881, when France colonised Tunisia that this lagoon was divided into two parts by the navigation canal which was dredged to allow the entry of boats up to Tunis harbour. The south part, of about 1500 hectares in surface and 0.80 m in average depth, constitutes the South Lake and is the subject of the present project (Figure 3).

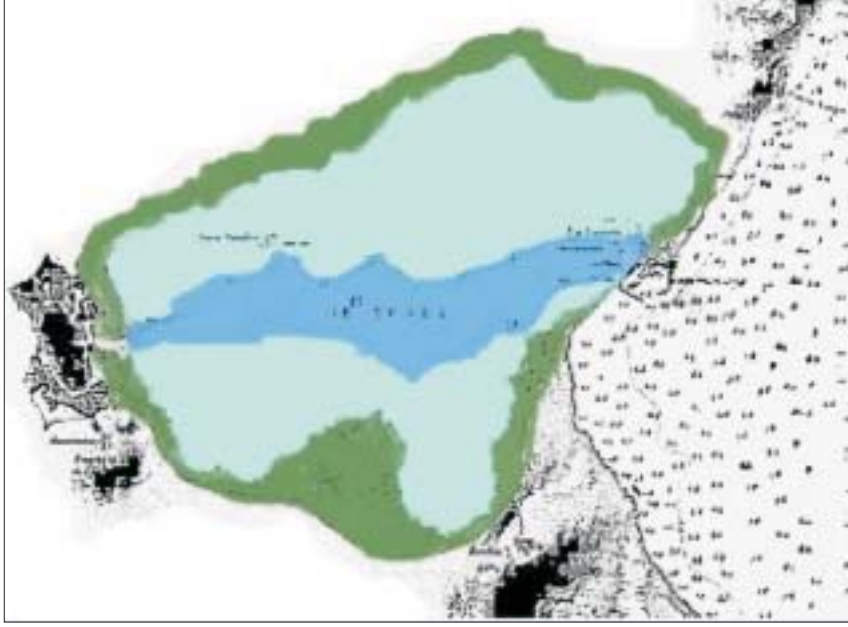


Figure 2. The Lake of Tunis in 1880 before its subdivision. In straight blue: navigation canal yielding to the Port of Tunis in the arsenal zone.

Considering their location within the heart of the capital Tunis, the two lagoons constituted the town's only receptacle of wastewater and therefore they deteriorated during the 1970s into a very eutrophic state. This situation pushed the Tunisian government, beginning in 1980, into initiating a large cleanup programme which consisted of treating the crude domestic wastewaters (previously discharged into the North Lake) in treatment plants and, between 1985 and 1988, of executing a project to develop the North Lake.

The South Lake, however, remained in its eutrophic state until the end of the 1990s. Its location at the centre of the urban and industrial section of Tunis south has exerted intensive pressure on the ecosystem, which has worsen its eutrophication state. The only exploitation activities at the South Lake were undertaken by the "Office National de Pèche" to allow fishing at the pass ways with the navigation canal. This exploitation stopped in 1997.

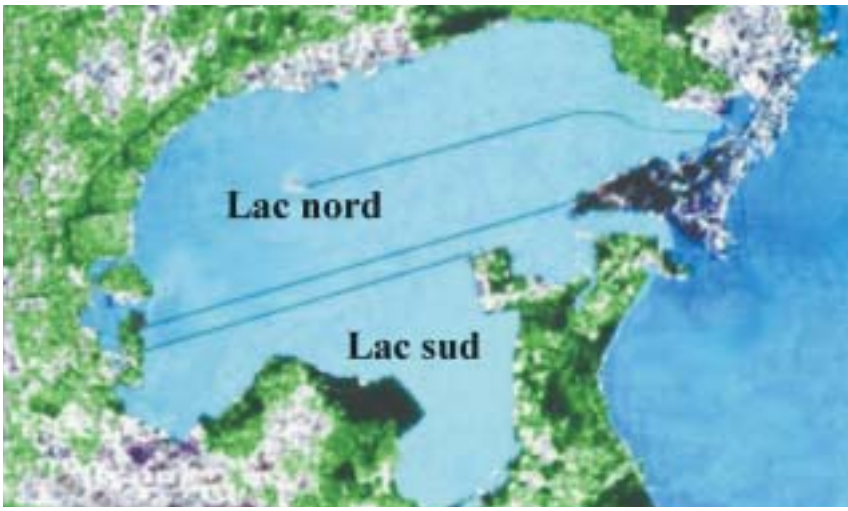


Figure 3. The Lake of Tunis in 1995 (satellite photo). The lagoon complex just before the beginning of the project to restore the North Lake.

SEPTS

With growing consciousness of the significance of the problem, the Tunisian State prepared a development and cleanup programme of the lake in order to stop the pollution which negatively affects the water quality. This programme started in 1989 with a preliminary study executed by the "Ministry of Public Works".

In 1990, the Tunisian company "Société d'Etude et de Promotion de Tunis Sud" (SEPTS) was created in order to promote and develop the South Lake and its shores. Since its creation, SEPTS has co-ordinated different actions with all the interfering parties in the zone and has undertaken several studies in an effort to fight pollution in the south zone of Tunis. In 1997, SEPTS has offered an international bid for the restoration and the development of South Lake and its shores.

In February 1998, the project was awarded to the group LAC SUD 2000 for a work period of three years with a lump sum of 60 000 000 €. The group comprised the following five companies: Dredging International N.V. (leading company); Van Oord ACZ B.V.; Tideway B.V.; Societa Italiana Dragaggi Spa; and Sider Almagia Spa.

The Control Inspection mission of these works has been entrusted to a joint venture of consulting firms STUDI (Tunisian) and SOGREAH (French).

Objectives

The main objectives of the project awarded by SEPTS to the group LAC SUD 2000 were to limit the pollution effects on the city's water quality and to ensure a clean environment which would allow the city of Tunis the opportunity to extend its leisure sites, green parks and residential spaces.

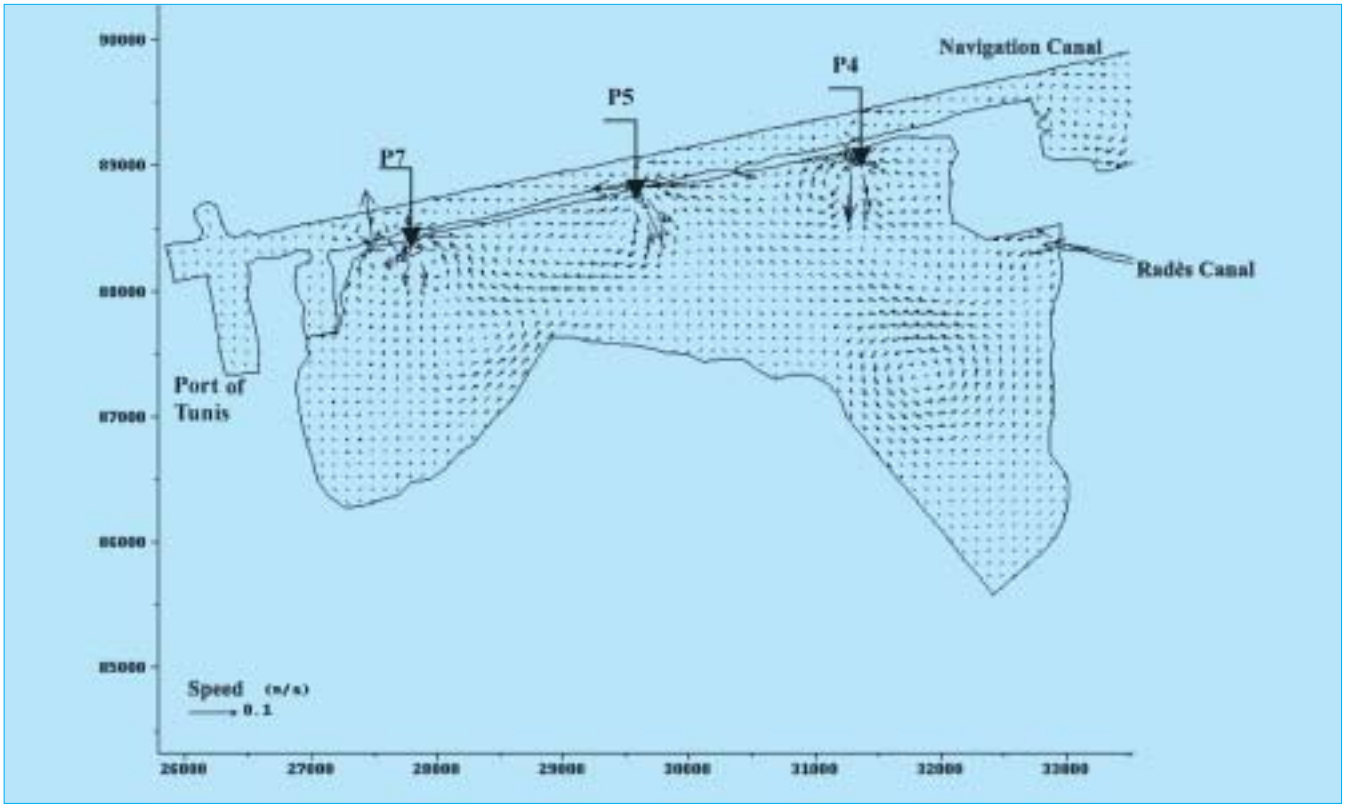


Figure 4. State of the circulation in the South Lake of Tunis just prior to the project.

The project should ensure:
- the elimination of stagnation zones and the renewal of the lake waters in an adequate time period;
- a maximal oligotrophic character, being highly mixed with sea water;
- avoiding the development of short cycle algae (type *Ulva* and *Enteromorpha*-originating from putrefaction and anoxia yielding to eutrophication);
- the elimination of bad odours and their origins; and
- a good physico-chemical quality of the waters, in conformity with certain criteria related to those of the Tunis Gulf.

State of the Lake Before the Project

The development works of the lake were preceded by assessment measures of the site by SEPTS before the project as well as by LAC SUD 2000 during the start-up period of the works. These investigations have concerned:
- the identification of the effluents;
- the hydraulic situation;
- the ecological situation; and
- the sediments quality.

The effluents

The downhill basin of the South Lake has a total area of about 4000 hectares, of which 1500 hectares are occupied by the industrial zones of Ben Arous, Megrine , Bir El Kasaa and Rades, regrouping about 650 industrial units. The rainfall and the industrial waters of these zones are fed into the lake at two different locations:
- the first diverse at the east section using Bir El Kasaa canal; and
- the second at the west by Ben Arous and Megrine channels.

The shoreline of the South Lake is run by a belt canal, which is destined for the drainage of rainfall waters and for the protection of Megrine against water rise. These channels flow into the lake rainfall water during rainy periods and industrial wastewaters during normal times. The industrial waters discharged into the lake come from jeans-washing water factories, various food industry units and others. The industrial flow rates were estimated to be about 3000 m^3/day for the canal of Bir El Kasaa and about 2500 m^3/day for Ben Arous discharge canal.

The investigations undertaken have shown that these waters are polluted with heavy metals such as Chrome, Copper, Zinc, Iron, Nickel, Aluminium and Hydrocarbons. A treatment station under construction will be used to treat such waters. During the lake development works, these waters were deviated via a belt canal towards the Tunis harbour.

Hydraulic situation

Before the project, the lake did not maintain internal circulations and its waters were pseudo-stagnant. It communicated with the sea via the Rades Canal and with the navigation channel by three passes that were called Fisheries P4, P5 and P7. The exchanges with the Gulf of Tunis were very small, however, the exchanges with the navigation channel were relatively more important. The waters were pseudo-stagnant and circulations were only constrained at the area near the passes. Figure 4 represents the circulation state before

the works using a 2D hydrodynamic model executed within the framework of the development project.

Ecological situation of the lake

The effluents in the lake have yielded to very high pollution, which accelerated starting in the 1970s and was getting progressively worse during the 1990s owing to the rapid evolution of urbanism and industrialisation. This situation was a result of a very high eutrophication which was characterised, especially during the summer, by dystrophic crises with the appearance of red water phenomenon and the odours detectable within the whole zone of the south Tunis City.

This phenomenon was the result of the decomposition of large quantities of macro-algae of the type *Ulva rigida* (Figure 5), which was a dominant nitrophile species developing in the lake (concentration could reach 10 kg/m^2). These summer dystrophic crises were characterised by a low rate of dissolved oxygen, a very low pH, high salinity and high contents of phosphorus and nitrogen followed by a massive mortality of fishes (Figure 6).

The investigations undertaken about the physico-chemical quality of the water over a one-year period before the start of the project have revealed values proving a high eutrophication. The organic-nitrogen varied between 1500 and 3237 mgN/l, representing about 80% of the total nitrogen, the remaining account being present in the form of ammoniacal nitrogen.

The total phosphorus was also high and had reached values around 1000 mgP/l. These eutrophication conditions had yielded to a very severe natural selection of the ecosystem populations. At the zoological level, the benthic species were subject to a progressive decline starting from the zones close to the canal of Rades and the fisheries (the side of the navigation canal) of the number of species until the major confinement zones located at the level of the east and west areas.

Quality of the sediments

The South Lake sediments were also subject to different investigations in 1997 and 1998. The samples, collected at 26 sampling stations distributed over the whole lake, had revealed contamination by heavy metals such as Chrome, Copper, Zinc, Iron, Nickel, Aluminium and by Hydrocarbons at the two discharge eastern and western coves. The heavy metal pollution concerns mainly the sediments at the superior level (0.25 m) in the eastern cove, whereas within, the western cove, the pollution was found over a surface layer of 50 cm.
Figure 7 shows the spatial distribution of this pollution. Table I presents the contaminated sediments quantities

Studies

The development project entrusted to the LAC SUD 2000 group has included, besides the works, preparation of studies during the first phase of the project. These studies concern topics related to the hydrodynamic, water quality and contaminated sediments. The hydrodynamic and water quality were studied by Aveco BV with the collaboration of HR Wallingford and the NIOO Institute.

Hydrodynamics

The solution adopted consisted of introducing a flushing system which could allow a continuous

Figure 5. Ulva rigida: the dominant macroalgae species in the South Lake before the works.

Figure 6. Fish deaths at the South Lake shores during the summer dystrophic crisis.

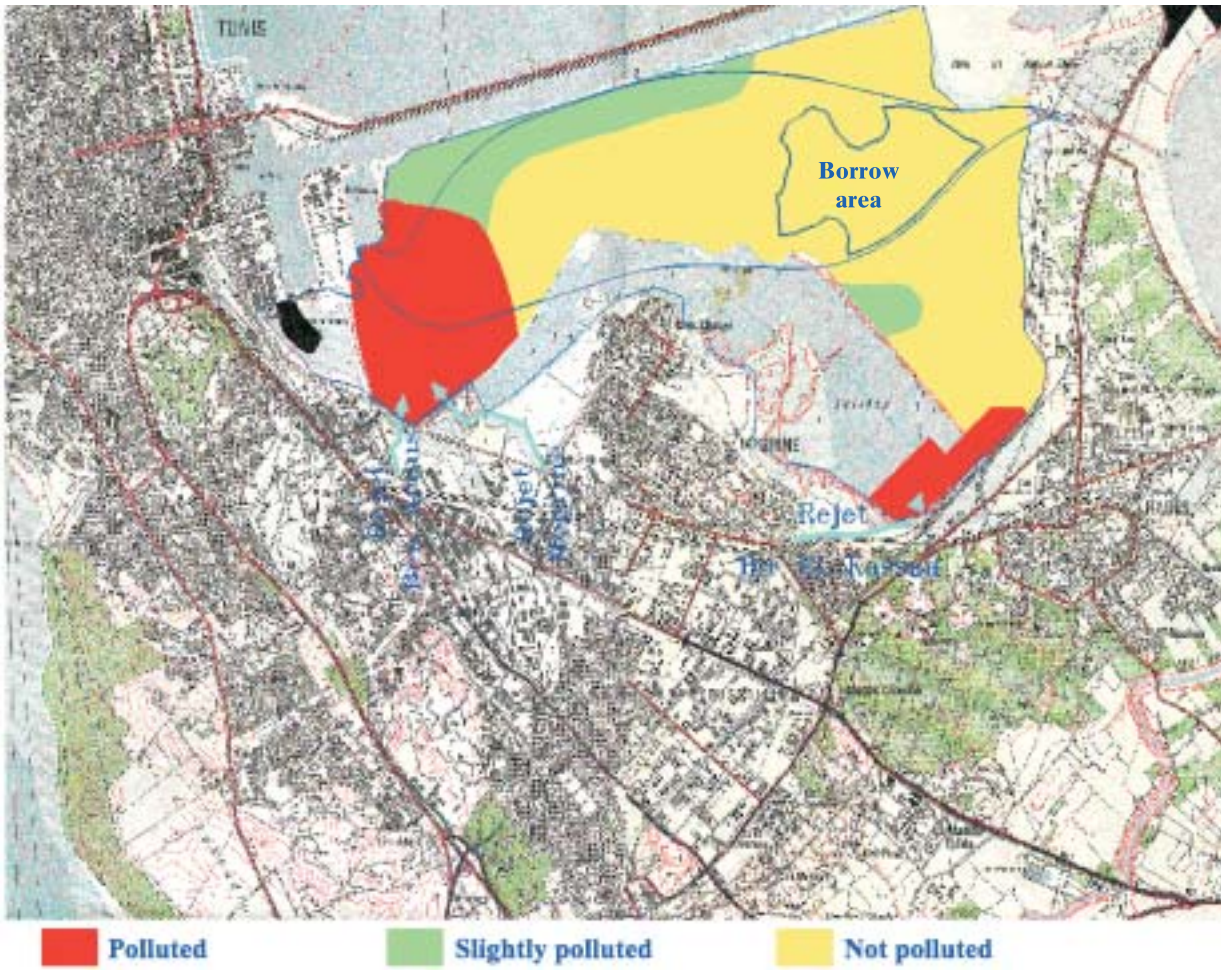


Figure 7. Distribution of the pollution within the sediments and localisation of the effluent points in the lake just before the project.

Table I. Estimated quantities of the contaminated sediments in the South Lake.

Zone	Polluted surfaces (m^2)	Thickness of polluted sediments (m)	Quantity (m^3)
Zone 1a (Effluent of Bir El Kassaâ)	180 000	0.25	45 000
Zone 1b (Effluent of Bir El Kassaâ)	300 000	0.25	75 000
Zone 5a (Effluent of Ben Arous)	850 000	0.50	425 000
Lake zone, west side (Effluent of Ben Arous)	1 000 000	0.50	500 000
Zone 4 (west side of the lake)	150 000	0.50	75 000
Total	2 460 000		1 120 000

regeneration of the lake waters without allowing them to be stagnant within the sites. This solution was ensured by the two following actions:

- The construction of two sluices, driven by the tidal forces. The first, located in Rades, represents the inlet sluice and it allows the entrance of seawater into the lake during high tides. The second one (the outlet sluice) is placed in Tunis and permits the lake waters to exit towards the navigation canal during low tides.
- The use of a geometric shape particular to the lake allowing a homogeneous circulation without local stagnation. This was ensured by the reduction of the lake surface from 1500 to 710 hectares, therefore avoiding the east and west coves which constituted the two major stagnation zones.

The studies were undertaken by using 2D and 1D hydrodynamic modelling. The results showed that the lake waters can be auto-regenerated in 4 to 7 days with

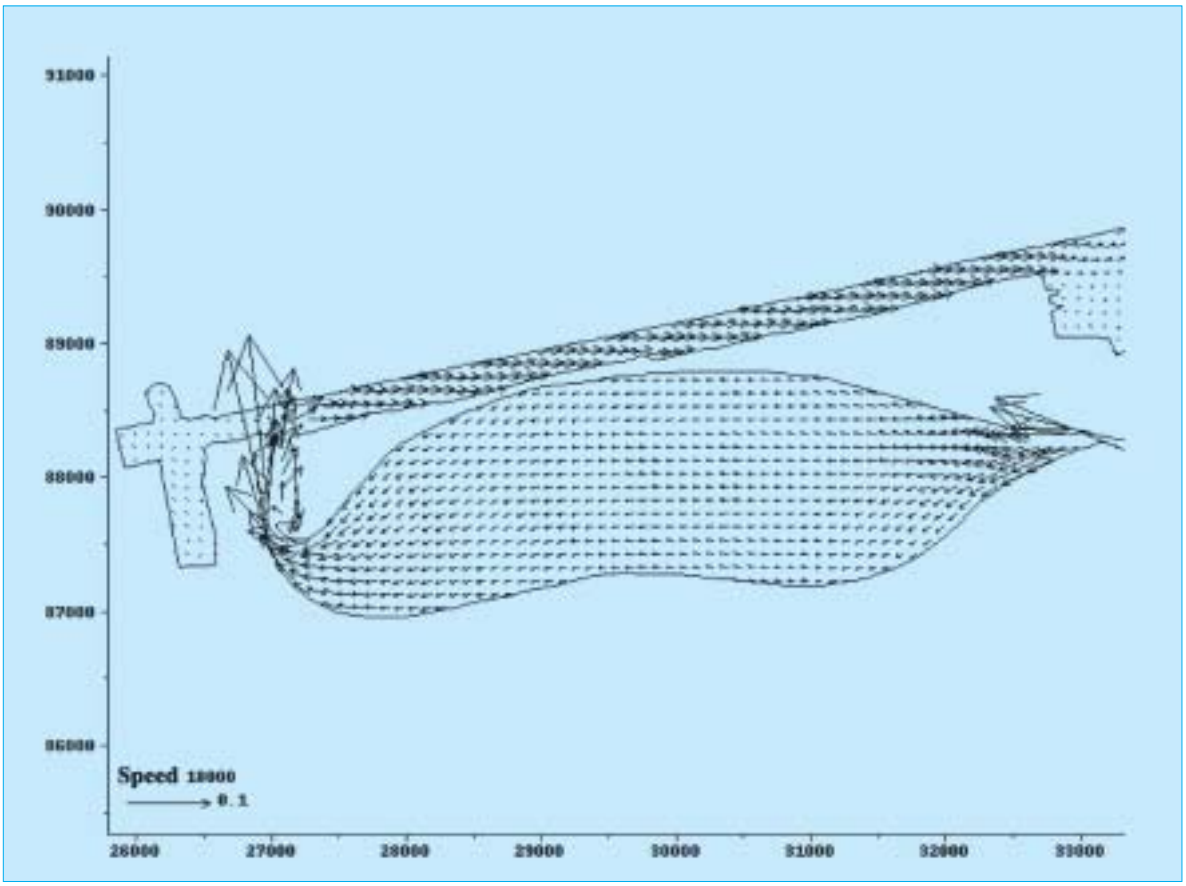


Figure 8. Expected circulation within the lake after the development project.

a daily rate varying as a function of the tides from 2.5 to 3.5 millions m^3/day. Figure 8 presents the expected circulation in the lake after the execution of the project.

Ecology and water quality

The water quality was simulated using a hydro-ecological model (ECO) that represents a combination of hydraulic and ecological processes. It describes the variation of few state parameters such as macro algae, phytoplankton, phanerogams, phosphorus, nitrogen, the pH and dissolved oxygen as a function of the hydro-dynamic, the benthic sediments release and other hydrologic parameters such as temperature, sunlight, salinity and so on. These parameters are calculated in three compartments of the lake with a time step of 1 hour. The variation processes are presented in Figure 9.

The predictions given by this model showed that the designed circulation system could regenerate the lake towards a high oligotrophy with seawater of Tunis Gulf.

The nutrient level will be comparable to that of the Gulf and the water will be well oxygenated during the entire year, which will help avoid anoxic periods that created all the pollution phenomena that affected the ecosystem prior to the restoration project (Figure 10).

A specific study about the future of bird life around the lake was carried out with the collaboration of the Dutch Reporting Commission of Environmental Impact. The solution given by this study was to create a reserve for these birds in a permanent wetlands area on the western side of the lake with a surface of 43 hectares (see Figure 12).

Contaminated sediments

The presence of a quantity of 1.12 million m^3 of sediment contaminated with heavy metals required special treatment different from that adopted for other types of sediments (categories II and III). Despite the fact that this topic was not included within the bid initially entrusted to the LAC SUD 2000, it was studied during the work period conforming to Tunisian legislation (law 96 – 41 of June 1996 relating to the treatment of polluted solid waste). A number of alternatives were studied concerning the confinement mode on land over the lake shores and in the aquatic area placement pit.

The final option was chosen with the collaboration of the Tunisian government represented by the "Agence Nationale de Protection de l'Environnement".

This option, which was applied, includes the following confinement modes:

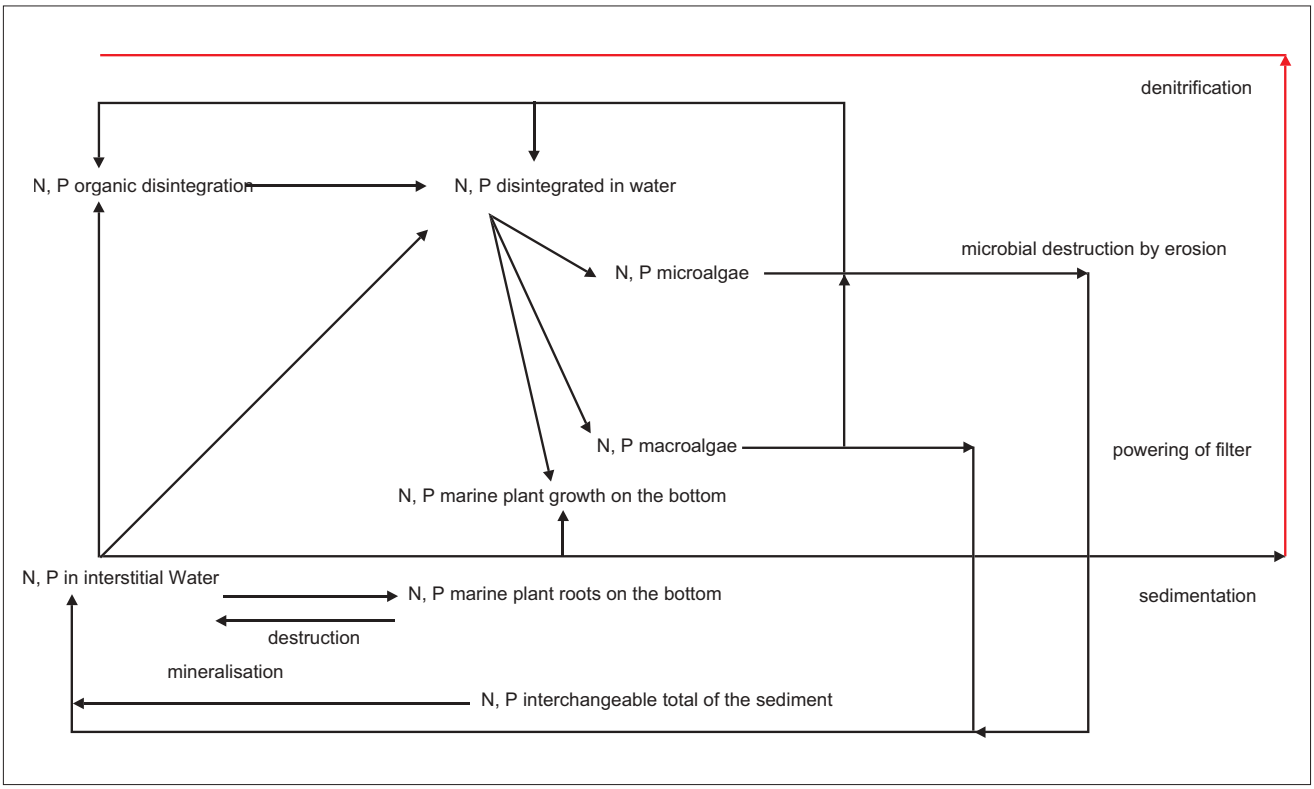
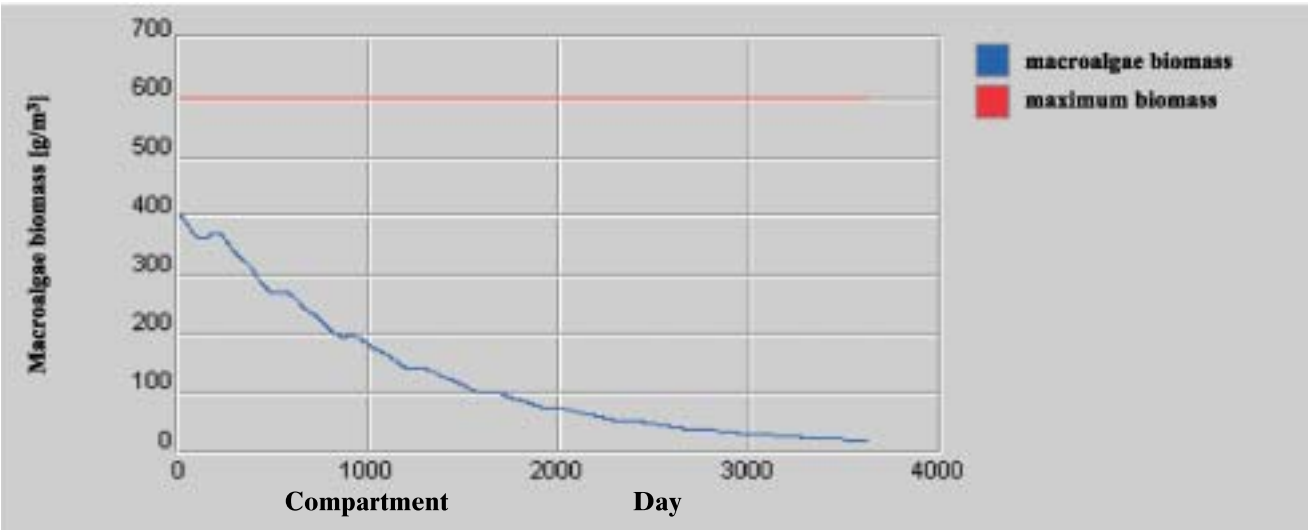


Figure 9. Adopted ecological processes within the hydro-ecological model.

Figure 10. Expected evaluation of the macroalgae after the development.



- The contaminated sediments of the east cove, representing the effluent zone of Bir El Kassaa, were left on site (on land) and covered with an inert material layer.
- The sediments of the west part of the lake were removed and taken to the terrestrial zone 5a, located on the western shores, over the locally contaminated sediments and were then covered by a non-polluted material layer. This zone was isolated from the lake by cavalier of sand that is made impermeable by using a vertical PEHD liner over a total depth of 8 m (Figure 11).

The risk study, using underground modelling, showed that the pollutants would be stopped in this terrestrial confinement zone and that Cadmium, being the most

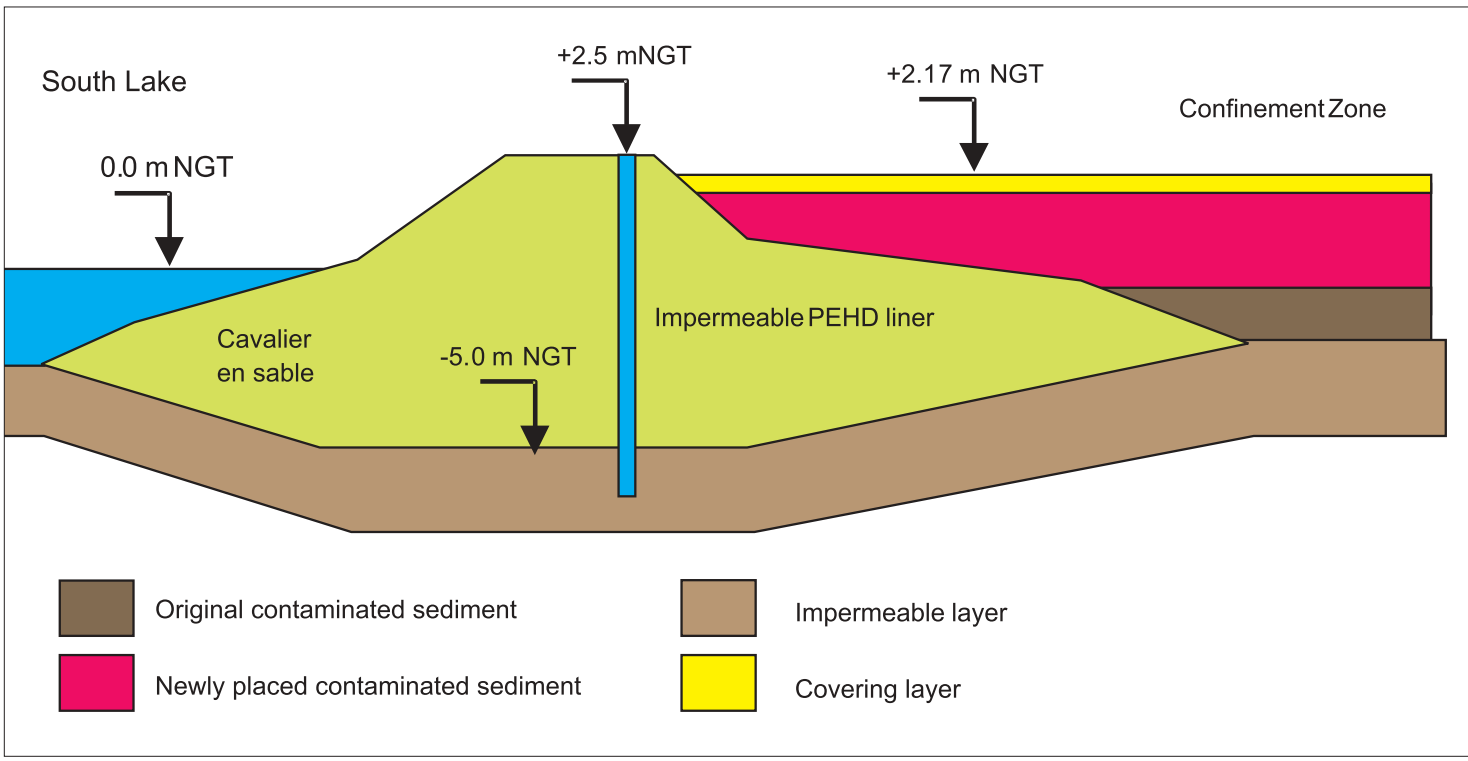


Figure 11. Confinement system installed over the west shores of the lake.

mobile pollutant, would be displaced by a few centimetres within a time period of 50 years.

The Executed Works

Taking into account the objectives of the project as well as the results of the studies undertaken within the framework of this project, the following activities have been executed:

- the dredging of a quantity of 5 million m^3 of sand category I from the lake, in an effort to create land reclamation site appropriate for housing;
- the dredging of a quantity of approximately 12 million m^3 of organic sediment categories II and III, in order to deepen the lake at a homogeneous level of –2 m NGT;
- the development of about 873 hectares of reclaimed land over the lake shores, including 350 hectares by sand category I and the rest by sediments categories II and III;
- the development of 13 200 m of cavaliers protected by rip raps extracted from Tunisian stone quarries;
- the installation of 2 100 m of PEHD liner (8 m deep) along the cavalier in order to confine the contaminated sediments in the terrestrial zone 5a;
- the development of a seawater feeding canal of 2 100 m in average length and 50 m in average width. This canal includes a section going into the sea of 765 m in length made by two dikes of large rocks of which the northern one is protected by the accropodes from the waves;
- the development of two bridges located over the canal of Rades, in an effort to maintain a hydraulic section sufficient to ensure a seawater inlet to the lake;
- the construction of an inlet sluice to Rades and an outlet one to Tunis marine. Each sluice is made of 8 compartments, separated by vertical concrete walls spaced by 9 m, including a pair of one-way metallic gates; and
- the development of two targets, in Tunis marine, of 1800 mm diameter and equipped by one-way valves in order to improve the circulation in Tunis harbour:

The South Lake, that previously had an area of 1500 hectares, now extends over an area of 710 hectares and includes a new shoreline of over 13 200 m in length and an overage depth of 2 m. Figure 12 shows the new configuration of the South Lake as well as the land reclamation on its shores.

The Monitoring Programme

The development works of the South Lake have been executed within the predicted due date of 3 years. The bid predicted a guarantee of the water quality, including the following parameters and criteria:

Dissolved oxygen	Tolerated minimum level: 30% of saturation
Total N and P	Tolerated maximum concentration for annual average: twice

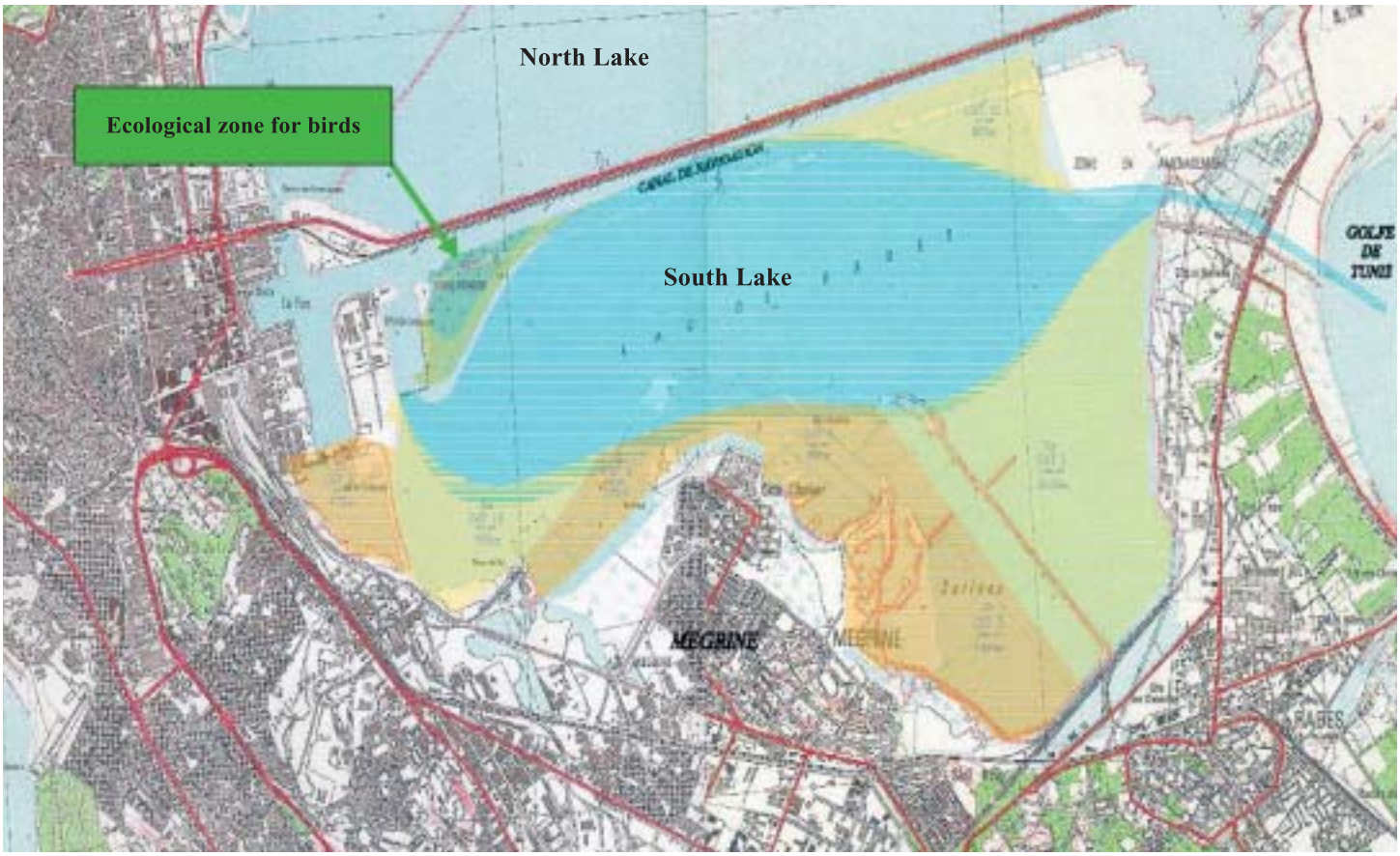


Figure 12. The new configuration of the South Lake after the restoration works.

	that of the gulf water for the east site and three times for the west side of the lake
Chlorophyll a	Tolerated maximum concentration for annual average: 10 mg/l
PH	Must be between 7 and 9 at any time
Transparency	Must be higher that 2 m in calm weather
Algae	Absence of accumulation of floating algae on the water surface
Macro algae biomass	Tolerated maximum bottom concentration: 0.6 kg/m^2 in dry weight.

The work period will be followed by a maintenance period of 2 years and a guarantee period of 5 years during which a monitoring programme maintaining the above parameters will be executed. A chemical laboratory was installed on-site to this purpose.

Conclusion: Technology Transfer

The aim of this project for a total regeneration of the lake including a modification of its shores, its morphology and its topography seems to have succeeded.

Moreover, the development project of the South Lake has allowed the transfer of new technologies to Tunisia. This transfer includes hydro-ecological modelling, management of lagoon water quality and management of dredged polluted sediments.

The group LAC SUD 2000, with the collaboration of the Dutch firm Aveco BV, has organised a training week on hydro-ecological modelling in order to allow the SEPTS engineers to explore and use software for the hydro-ecological provision and the management of the lake water quality. This software was supplied and installed within the terms of the project for SEPTS in two versions: one version, being based on exploitation and calibrated for the sake of the project, and a second study version which could be calibrated upon future changes within the lake. A new technique relating to the confinement of contaminated sea sediments was also adopted and constituted the first of its kind in Tunisia.