# ELMAA

***Integrated water management of Mediterranean phosphate mining and local agricultural systems***

# Publishable Final Activity Report

## *September 2005 – April 2009*


Source: BRGM

**Project n° INCO-CT-2005-015410**
**Instrument:** ***Specific targeted Research Project***
**Thematic Priority:** [10]
**Project coordinator organisation name:** ***BRGM, Environment & Process Division***

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# 1. Project general description

The phosphate industry is a major contributor to the economy of some Mediterranean countries (i.e. Morocco, Jordan, Tunisia, etc). Large volumes of water are required by the mining industry from areas where water resources are scarce or limited. Water scarcity may be worsened by a degradation of the water quality after phosphate processing. The pressure on water is liable to hamper the development of phosphate industry and results in competition with other water reliant economic sectors such as agriculture or tourism. The Elmaa project meets these strategic needs: to reduce tensions on water resources (quantity and quality) at regional scale and to consolidate the sustainable development of the phosphate mining industry.

Elmaa focuses in priority on the interface between the mining and the agricultural sectors, given the economic and social importance of the latter sector. The general objectives of Elmaa are:

- to provide technological innovations to reduce the pressure on water resources, in mining (e.g., use of municipal wastewater in phosphate process) and agricultural practices (e.g. use of phosphate process water for irrigation);
- to provide the phosphate industry and the water managers with a methodology for the integrated management of water resources in the zone of influence of the mine sites. This methodology will integrate a customised Decision Support System (DSS) with a realistic representation of water management system integrating technical, economic, social and environmental dimensions.

***Phosphate mining process***

***Train used for phosphate transportation***

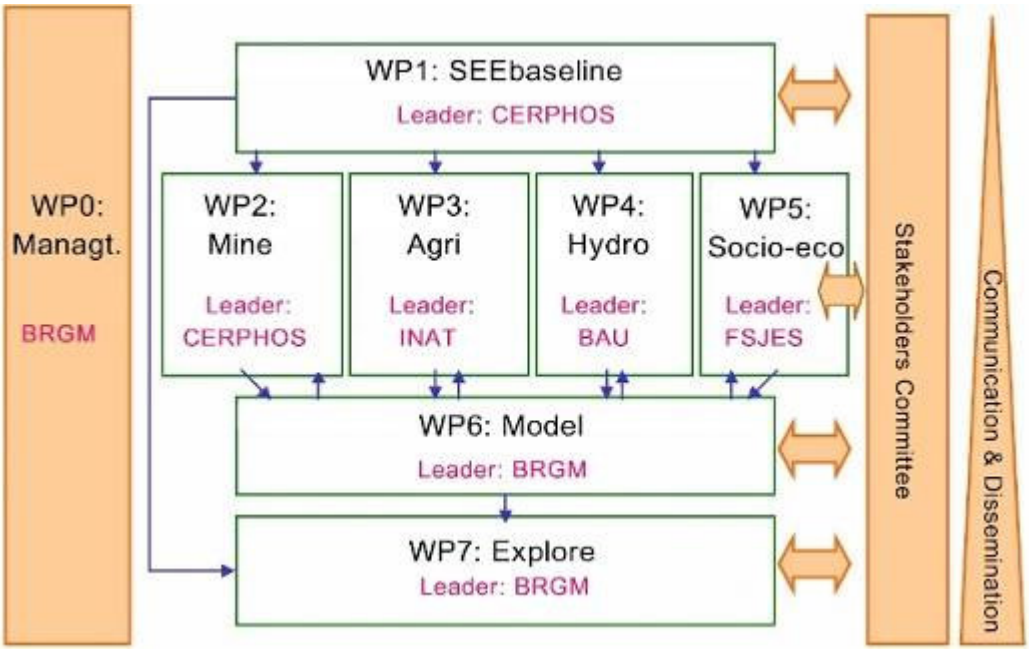
The Elmaa DSS serves:

- to identify and to rank the factors controlling water management and sharing;
- to optimize the water consumption and re-use;
- to measure the potential impact of changes in the mining and agricultural practices related to technological innovations or evolutions in the institutional or regulatory framework.

These general objectives of the El'Maa project are broken down as follows:

- The scientific analysis of the various components involved in water management (mine site, agricultural sector, social and economic component) and their relationships.
- The investigation of different technological routes for a better use of the water. These technological innovations aim at reducing the pressure on water resources (particularly in mining and agricultural sectors) and at limiting the environmental impact of phosphate mining:
  - in the mining sector: modification of the process to reduce water consumption and to optimise water recycling, use of municipal waste waters as alternative water resources, …
  - in the agricultural sector: evaluation of the use of the mining water for irrigation and of the slimes as amendment taking into account water quality parameters, assessment of wastewater treatment method in case further treatment is required, …

- The assessment of various scenarios of water management and the identification of the most promising ones which could be further developed (action plan).
- The development of a Decision Support System (DSS) dedicated to water management at the scale of a phosphate mining district in close collaboration with the stakeholders. This tool aims to provide a simplified but realistic representation of water management at the interface between mining and farming activities, integrating technical, economic, social and environmental dimensions.
- The exploitation and dissemination of the results.




## ELMAA Partners

**BRGM – Geosciences for a sustainable Earth**
BRGM – Project coordinator & WP6/7 leader - France

**Research Center for Studies on Mineral Phosphates**
CERPHOS – WP1/2 leader – Morocco

**Faculty of Law, Economics and Social Sciences**
FSJES – WP5 leader – Morocco

**National Agronomic Institute of Tunisia**
INAT – WP3 leader – Tunisia

**Al-Balqa' Applied University**
BAU – WP4 leader – Jordan

**Vrije Universiteit Brussel**
VUB – Belgium

**Agricultural University of Athens**
AUA – Greece

**Water Resources and Technologies Center**
CERTE - Tunisia

## ELMAA Stakeholders

Stakeholders are not contractors in the project but are representative of the major players involved in water management in the influence zone of mining industry.

Their strong involvement during the entire project meets three convergent objectives:

- guarantee that the project meets the expectation of MPCs,
- effective appropriation and use of the results after the project completion,
- wide dissemination of the results beyond the scientific community.

Stakeholders represent interests of both the mining industry and local/national authorities: major phosphate operators and representatives of the national/regional authorities in charge of water management and agricultural development in Morocco, Tunisia and Jordan. Their participation in the project has been the opportunity to initiate and facilitate new dialogue practices between the actors involved in water management.

## GENERAL INFORMATION

**Funded by the European Commission 6th Framework Program**
Duration: **44 months (start date 1st September 2005)**
Total Budget: **2.1 M€ (EC 1.6 M€)**
Partnership: **8 Partners/ 3 European countries and 5 Mediterranean countries**
Reporting: **15 technical reports, 5 models, 1 GIS database, 1 Decision Support System – 1 Workshop on water management in phosphate industry in Morocco**

## FOR MORE INFORMATION

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# 2. Major achievements

## 2.1. WATER-RELATED TECHNOLOGICAL INNOVATIONS IN MINING PRACTICES

Two approaches were adopted in order to reduce the pressure on water resources for the mining sector:

- development of technological innovations to improve the water recovery through the optimisation of the solid/liquid separation stages in the phosphate washing plant and in the tailing ponds,
- use of non-conventional water resources, namely treated municipal wastewaters, as an alternative to the use of fresh water resources.

This work was carried out on two case studies: the Khouribga mines in Morocco and the Gafsa mines in Tunisia.

### 2.1.1. Development of technological innovations to improve the water recovery around the washing plant

At the beginning of the project, the water recycling rate was nearly 80% for the Moroccan washing plant and around 55% for the Tunisian one. Therefore, there was a potential to increase water recovery and then to reduce fresh water consumption. The development of technological innovations was focused on two main compartments of the mine, namely the beneficiation plant which separates the phosphate enriched concentrate from the slimes (final clayey residues) and the tailing ponds in which the slimes are transferred.

***Beneficiation plant in Morocco***

***Slimes impoundment area in Tunisia***

Regarding the phosphate washing plant, the most promising technologies tested at the laboratory and pilot scale are the following:

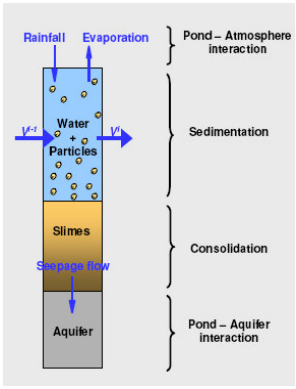
- Micro-hydrocyclones combined with a deflocculating reagent: tests performed in Morocco on micro-hydrocyclone showed that the use of a deflocculating reagent can enhance the hydroclassification performances at high concentration level (340 to 360 g/l). The cut size (D50) varies between 115 µm without deflocculating reagent to 27 µm with the optimal dose of deflocculating reagent. Water recovery varies respectively between 84.8 % and 81.7 but the yield of coarse fractions of the slimes (underflow), which do not contain clays and then can settle easily, moves from 25 % to 51%.
- Lamella type clarifier: the water recovery was increased by a factor 4 on Tunisian process.
- Press filter: the dryness of the filter cake obtained by the Moroccan team varied between 77.3 % and 78.7 % and the water recuperation rate was between 88.8% and 89.8 % for the high concentration level (355 to 360 g/l).
- CERPHOS patented process (Argiphos process) to recover specific clayey fractions which can be further used for an agricultural purpose: the yield of coarse fractions of the slimes (underflow) varied from 41% to 63.9%. The optimal weight recovery of clayey fractions was 36% using deflocculating reagent which corresponds to a water recuperation rate of 83.7%.

***Micro-hydrocyclones***

***Lamella type clarifier***

***Press filter***

The optimization of slimes ponds design is an alternative to improve slimes and residual associated water management. Simulation works using a dedicated modelling tool revealed that the addition of a sand draining layer at the bottom of the ponds improves the slimes consolidation and correlatively the water recovery. This improvement depends on the pond design but also on the slimes behaviour. Water recycling can be improved up to 62%.




***Schematic of processes occurring in a slimes pond***

### 2.1.2. Use of non-conventional water resources: the treated municipal wastewaters

The use of municipal wastewaters for phosphate beneficiation was experimented through laboratory and semi-industrial scale tests. Those tests showed that it is necessary to add one or two more steps to the usual wastewaters treatment process in order to reach water quality level (residual pollution) which meets the phosphate industry requirements.

In Tunisia, two types of treatment were studied due to their performance and their economic and environmental impact: infiltration-percolation process and advanced oxidation processes such as solar photocatalysis with suspended photocatalyst ($TiO_2$).

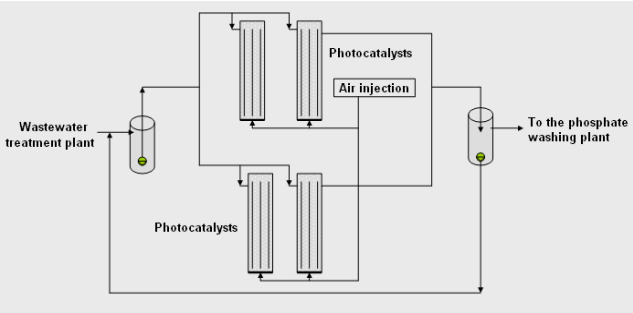



***Diagram of solar photocatalysis of treated wastewaters for a use in the washing plant***

In Morocco, the best performances of water treatment were obtained by using either lagooning followed by phosphates infiltration percolation or by using activated sludge combined with infiltration percolation. Tests performed gave very promising results. Therefore these technological innovations were implemented for the building of a new wastewaters treatment plant which will be operated from November 2009 and will then allow reusing treated wastewaters in the washing plant.

***Wastewater treatment plant***

## 2.2. TECHNOLOGICAL INNOVATIONS IN AGRICULTURAL PRACTICES

Development of technological innovations in agriculture practices focused on the use of the phosphate slimes with their associated residual water as amendment and on the use of phosphate washing water for irrigation. These elements contain potential pollutants (mainly fluor, cadmium and radionucleides). A specific attention was paid on the fate of these pollutants in the soil and their uptake by the crops.

Works were carried out in two phases:

- Laboratory and field scale studies,
- Computer simulations (use of the software Hydrus 1D) to evaluate the potential risk of soil and groundwater contamination.

### 2.2.1. Use of phosphate slimes as amendment

Application of phosphate slimes as amendments to agricultural soils is considered as very beneficial, because they can provide phosphorus and they can also improve the structure of the soils. However, the slimes generally contain a large amount of heavy metals; as a consequence, their extensive application in agricultural land could potentially cause the accumulation of heavy metals in soils and possibly their transport to the groundwater.

Results of studies performed in the Elmaa project showed that:

- The impact of heavy metal on soil and groundwater was not significant.
- The addition of slimes increased the humidity of soil. For example, in Tunisia it led to a water saving of about 10 and 78 $m^3$/ha for a dose of 10 and 120 T/ha. The amount of saved water is low but it could be appreciable in arid areas.
- The tested crops did not show a significant accumulation of heavy metals under the particular soil and climatic conditions (Diamantopoulos et ***al.***, 2008; Stefopoulou et ***al.***, 2008).

***Agricultural tests in pots in Morocco***

***Field agricultural experiments in Jordan***

### 2.2.2. Use of phosphate washing water for irrigation

The use of phosphate washing water was evaluated for forage crops irrigation. The laboratory and field tests led to positive results with no significant contamination of soil, groundwater and plants under the particular soil and climatic conditions.

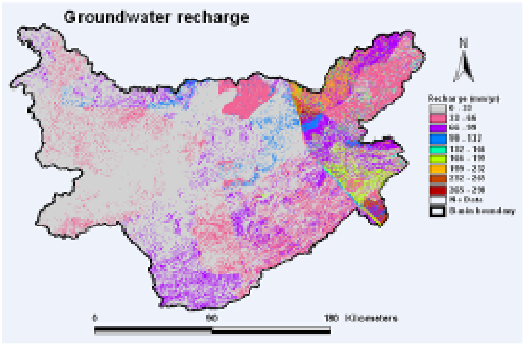
Therefore, mine washing waters can be used for forage crops irrigation in the phosphate mining area with no significant risk of pollution. This will allow reducing competition for water resources between the agricultural and mining sectors, especially in areas where mining wastewaters can not be treated for further water recovery inside the mining process, like in the Jordan case study.

***Around the Jordan mines***

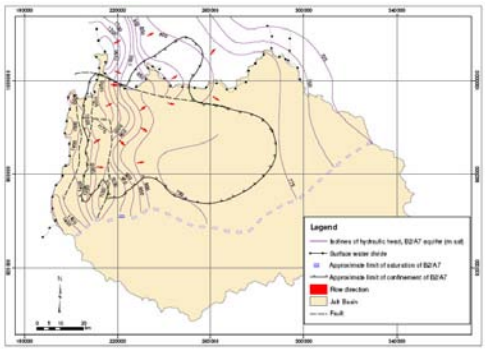
## 2.3. EVALUATION OF THE WATER RESOURCES

In order to have a better understanding of the main hydrological processes in the regions under study, GIS databases and thematic maps were produced. The main components of the water resources (groundwater, surface water) were then identified, characterized and simulations were performed to investigate their evolution over time for different climatic scenarios:

- A climatic scenario consists in 25 years-long sequences of daily precipitation and evapotranspiration which show the same statistical properties.
- Groundwater recharge, surface runoff and evapotranspiration were calculated with WetSpass, a physically based water balance model [Batelaan and De Smedt, 2001]. Indeed, the applicability of WetSpass to arid regions, initially designed to be used on European regions, was demonstrated in the Elmaa project.
- Goundwaters and interactions with surface waters (rivers) were simulated with MODFLOW, the well-known USGS hydrogeological model [Merritt and Konikow, 2000].




***Groundwater recharge for the Moroccan studied area (WetSpass results)***




***Groundwater flow pattern for the Jordan studied area (MODFLOW results)***

## 2.4. CHARACTERISATION OF THE WATER DEMAND

Water is mainly used for mining activity, irrigated agriculture and drinking water. The importance of each sector depends on the case study but mining industry is by far the highest consumer. The water demand was characterized and quantified with the support of stakeholders. This characterization went through an analysis of the socio economic context of the areas. Parameters that are determinant in the evolution of water demand were identified (phosphate production, water recovery in the washing plants, population and its distribution, needs per household, yields of networks, irrigated land and cropping patterns, irrigation techniques, etc.). This enabled to construct a water demand model which aims at calculating the future (2025 or 2030) water demand.

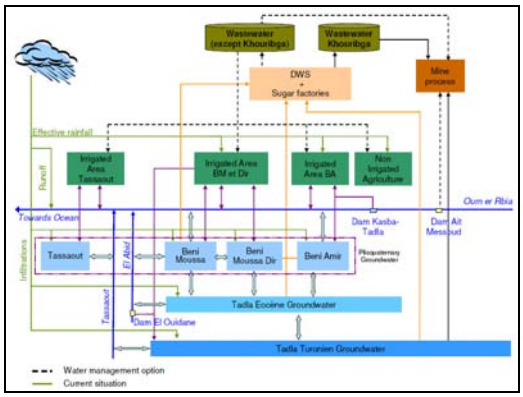
## 2.5. INVENTORY AND SELECTION OF WATER MANAGEMENT OPTIONS

The inventory and the selection of realistic water management options in order to solve, at least partly, the problem of water scarcity were performed. These options aim at either increasing resources (i.e. the offer) or reducing the demand (for instance with technological innovations that save water in the mining, agricultural or drinking water supply sectors). In close collaboration with the Elmaa partners and stakeholders, a methodology describing environmental, economic, social and sanitary impact of management options was developed. A cost-efficiency analysis was also performed to compare all selected options under the cost and water savings potential.

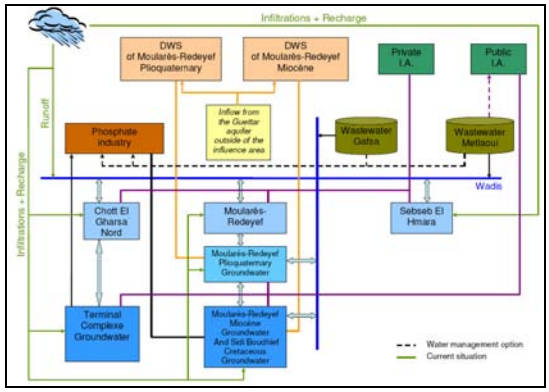
## 2.6. DEVELOPMENT OF A METHODOLOGY FOR THE INTEGRATED MANAGEMENT OF WATER RESOURCES IN THE INFLUENCE ZONE OF THE MINING SITES

In the Elmaa project, a customised numeric tool (Decision Support System or DSS) was developed to help decision-makers to identify problems regarding water management and to define the most pertinent solutions. This DSS building was carried out with the support of stakeholders who are representative of the major water users in the studied zones, namely mine, agriculture, drinking water and sanitation.

Integrated water management involves evaluating the evolution of the water resources and the satisfaction of the water demand in the studied area for the next years taking into account technical, social, environmental and economic dimensions. A first step to the DSS implementation was then to build a simplified but realistic representation of the socio-hydrosystem of the studied area. This conceptual model identifies and describes water resources, water demands and the water flow transfers between them.




***Conceptual model of the Moroccan case study***

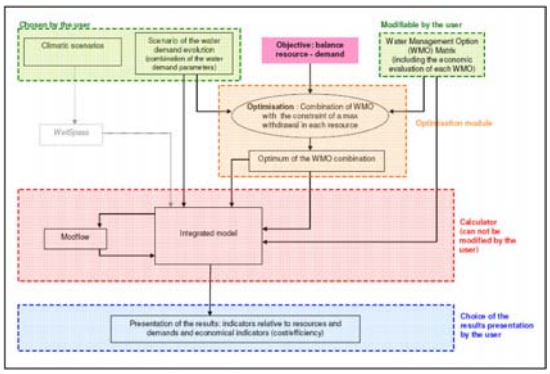



***Conceptual model of the Tunisian case study***

A specific methodology was developed to implement the DSS. This methodology was detailed during the 4th International Congress on Environmental Modelling and

Software held in august 2008 [Bru et ***al.***, 2008]. Exploration of the impacts of a given scenario needs the following steps:

1) The user chooses a scenario (defined for the next 25 years). Each scenario takes into account a climatic evolution, a water demand evolution and a combination of water management options (WMO). A specific routine, based on a cost-efficiency approach, was developed to optimize the choice of WMOs.

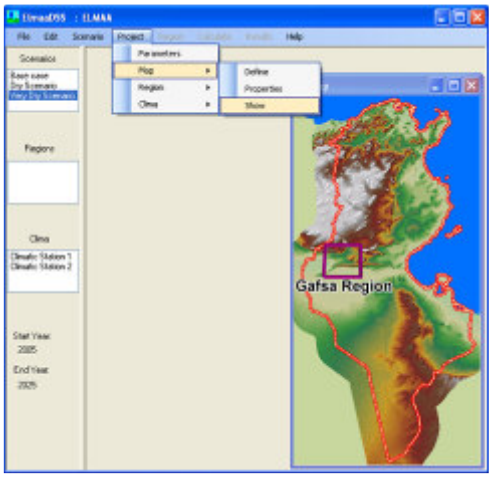



***Schematic of the DSS use***

2) Calculations of water balances and indicators are performed in the integrated model which is the heart of the DSS. In particular, the evolution of groundwater and flows to the rivers are simulated through a dynamic link to a groundwater flow model developed with MODFLOW [Merritt and Konikow, 2000].

3) The user chooses the display format of the results (tables, charts…)

The ELMAA DSS is developed using Visual Studio .NET and is based on Object Oriented Programming Techniques.
It consists of calculation and optimization routines, an easy to use Graphical User Interface, a database containing input data, parameters, results and a knowledge base containing key information for the operation of the DSS.


***Example of the Graphical User Interface to visualize the map of the studied area***


***Example of the Graphical User Interface to present results***

Simulations performed with the ELMAA DSS confirmed that most groundwater bodies will be overexploited in 2025 if no specific management option is engaged during this period. The potential benefits resulting from the implementation of water management options were demonstrated.

The ELMAA DSS is then a valuable tool to explore various water management scenarios and to improve water management in the studied areas. It also encourages discussions between stakeholders from different sectors. This existing tool will be further refined and used by the Mediterranean partners beyond project completion.

***O. Batelaan and F. De Smedt (2001) - WetSpass: a flexible, GIS based, distributed recharge methodology for regional groundwater modelling. In: Sixth International Association of Hydrological Sciences (IAHS) Scientific Assembly, IAHS, Maastricht, The Netherlands, 2001.***

***S. Diamantopoulos, N.Dercas, K.Soulis, S.Jellali and A. Stefopoulou (2008) - Investigation of groundwater pollution risk from phosphate water and slime utilization in agriculture using hydrodynamic modelling. In: International Conference HAICTA 2008, Athens, pp 56-64.***

***M.L. Merritt and L.F. Konikow (200) - Documentation of a computer program to simulate lake-aquifer interaction using the MODFLOW ground-water flow model and the MOC3D solute-transport model, Water-Resources Investigations Report 00-4167, 146 p.***

***A. Stefopoulou, N. Dercas, S. Diamantopoulos, S.Jellali and K. Soulis (2008) - Investigation on the environmental risk from phosphate slime disposal using hydrodynamic modelling. In: 8th International Hydrogeological Congress of Greece, Athens, pp 379-388.***

# 3. Dissemination of Elmaa outcomes

The dissemination of the results, methodologies and tools developed in Elmaa is a key step to achieve their effective appropriation by the Mediterranean phosphate industry but also by all the stakeholders faced with the management of water resources.

## 3.1. DISSEMINATION AT A LOCAL SCALE THROUGH STAKEHOLDERS INVOLVEMENT

The stakeholders are not contractors in the project but are representative of the major players involved in the water management in the influence zone of mine industry. They represent interests of both the mining industry (« Office Chérifien des Phosphates » in Morocco; « Compagnie des Phosphates de Gafsa » in Tunisia) and national/regional authorities in charge of water management and agricultural development in Morocco, Tunisia and Jordan.

Stakeholders were involved from the early stages of the project in order to create and to keep a permanent link between research consortium and local water management actors. Three types of consultations were organized:

1) Participation in the consortium meetings
2) Individual consultation in order to collect their point of view and to select the relevant indicators for water management, these indicators being a major component of the DSS.
3) Dedicated national workshops in order to stimulate discussions around management options.

***Progress meeting in Jordan with stakeholders***

Stakeholders from Morocco, Tunisia and Jordan showed a big interest in the Elmaa project. For instance, discussions between the Jordan scientific team, stakeholders and the decision makers led to the following benefits:

- the King ordered the government to give high attention to Elmaa results,
- the Minister of Municipal Affairs promised to utilize the Elmaa results for developing the mining area,
- the Ministry of Water and Irrigation required the hydrogeological MODFLOW model be used for better groundwater resources management in the Jordan phosphate mine basin,
- Badia Research and Study Center asked for the results of ELMAA project to adopt agricultural practices for local Bedouins,
- Jordanian Environmental Society (NGO) had always suffered from mining activities as a source of pollution. They are now convinced to be a productive area through the use of the phosphate washing wastewaters for irrigation.

In Morocco and in Tunisia, the dialogues between the scientific teams and the decision makers led to similar benefits.

***Jordan team in a field visit***

***Meeting with Rana Hajaya, mayor of the Al-Hisa municipality (Jordan)***

## 3.2. DISSEMINATION AT NATIONAL AND INTERNATIONAL SCALE

One of the main actions for disseminating the project results consisted in organising an international workshop dedicated to water management in the phosphate mining industry. This workshop was held in Marrakech (Morocco) on 19th March 2009 during the COVAPHOS III Conference, the third International Conference on the Valorization of Phosphates and Phosphorus Compounds.

Moreover, the consortium participants undertook the dissemination of the scientific and technical results through submittal of papers to technical and scientific journals, presentations in conferences and seminars, and creation of a dedicated web site. The main figures regarding the dissemination of the Elmaa results are presented below.

| Categories | Number |
|---|---|
| International workshop | 1 |
| Publications (see list below) | 7 |
| Participation to conferences as a key note speaker | 1 |
| Number of participations in conferences | 16 |
| Website (French and English version) http://elmaa.brgm.fr | 1 |
| Flyer | 5 |

### 3.2.1. Elmaa website (http://elmaa.brgm.fr)


### 3.2.2. Peer review publications list

Mohamed Bizi and Hervé Gaboriau (2008) - Flocculation analysis and control system by laser diffractometry at industrial scale. AIChE, 54, pp. 132-137.

Mohamed Bizi (2008) - Filtration characteristics of a mineral mud with regard to turbulent shearing. Journal of Membrane Science, 320, pp. 533-540.

Fatma Karaouli, Sarra Touzi, Jamila Tarhouni and Latifa Bousselmi (2008) – Improvement potential of the integrated water resources management in the mining basin of Gafsa. Desalination, 248, pp. 157-163.

Kathy Bru, Anne-Gwenaelle Guézennec, Sandra Lanini, Nina Graveline, Konstantinos Soulis, Fatma Karaouli and Anis Guesmi (2008) - Model development for integrated water management in the influence area of phosphate mines. In: iEMSs 2008: International Congress on Environmental Modelling and Software, 7-10 July, 2008, 8 p.

Fatma Karaouli, Mounira Zammouri, Jamila Tarhouni and Younes Hamed (2008) - Hydrogeological study and impact of exploitation intensification on groundwater quality of the Moulares-Redeyef basin (Southwestern Tunisia). Sécheresse, 19, pp. 61-65.

Omar Rimawi, Anwar Jiries, Yasin Zubi and Ali El-Naqa (2008) - Reuse of mining wastewater in agricultural activities in Jordan. Environment, Development and Sustainability, In Press.

Submission for publication of an article about the “Groundwater Modeling in the Shidiya Phosphate Mining Area, Southern Jordan”.

Submission for publication in the journal Environment, Development and Sustainability of the following article: “Municipal wastewater recycling in phosphate beneficiation plant using sand bed amended with discharged slimes”

# 4. Elmaa key outcomes

- ***Technological innovations for mining and agricultural practices***. Tests were performed at the laboratory and pilot/field scale. Some innovations have been implemented at a full scale:
    - use of treated municipal wastewater in the phosphate washing plant in Morocco,
    - use of phosphate washing water for fodder irrigation in Jordan; in particular, it was demonstrated that there is no significant risk of soil, groundwater and crops contamination with potential pollutants contained in this water.

- ***Collection and update of information about the phosphate mining areas*** (i.e. mining and agricultural practices in term of water management, hydrogeological and socio-economic data, etc.)

- ***Scientific progress and knowledge transfer within Elmaa consortium***.

- ***Development of an integrated model and of a Decision Support System (DSS).***

- ***Commitment of stakeholders.***

- ***Communication and dissemination of Elmaa results,*** in particular with the organisation of an international Elmaa workshop in the framework of the COVAPHOS conference

ELMAA is recognised as an important project for the studied regions with direct impacts not only on the preservation and the management of the water resources, but also on the economic situation. The Elmaa project has played the role of a facilitator to initiate new dialogue practices in phosphate mining areas. It has also been the opportunity to strengthen durable Euro-med partnerships. Last but not least, the Elmaa project has initiated new fields of research and has paved the way for future refinements and developments:

Elmaa project (015410): Integrated water management of Mediterranean phosphate mining and local agricultural systems

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