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# Groundwater resources assessment at a local scale: monitoring of industrial effluents in a wetland

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**Abstract** In general, industrial activities produce a potential pollution hazard for groundwater which depends on the characteristics of both the contaminant load and the receptor body. Bahco Argentina SA, an industrial metallurgy company, has built a wetland for secondary treatment of its effluents with the aim of achieving sustainable environmental management and as a step before the final disposal into a local surface water body. Hydrogeological characterization has developed an understanding of the groundwater flow particularities at regional and local scales. A monitoring programme is currently being carried out to obtain a clear identification of the state of the groundwater and surface systems, taking into account that groundwater supply sources are located near to the industrial plant. The results regarding operation and monitoring of the industrial wetland provide a new perspective on the temporal behaviour of this type of treatment.

**Key words** constructed wetland; groundwater pollution hazard; industrial wetland

## INTRODUCTION

Industrial activities produce a potential groundwater pollution hazard. This hazard depends on the characteristics of both the contaminant load (type, disposal mode, intensity, duration, etc.) and the receptor body (soil, river, aquifer, hydraulic connection, exploitation, etc.). Chemical constituents detected in groundwater contamination plumes from industrial activities usually show a close relation with the industrial type. The management and discharge of effluents is an important problem in relation to groundwater contamination. Industries located near surface water courses frequently discharge their effluents directly into these bodies and sometimes via soil infiltration. These practices always produce a direct or indirect threat to groundwater quality, except when the industry undertakes systematic effluent treatment (Foster *et al*., 2003).

With the aim of providing a sustainable environmental management of its effluents, Bahco Argentina SA, an industrial metallurgy company, has built a wetland (Haberl *et al*., 2003) for secondary treatment and as step before the final disposal into a surface water body (“cava”) which belongs to the same plant. The results obtained from local environmental hydrogeological assessment, hydrogeological evaluation of the pilot wetland and local characterization for the constructed industrial wetland are presented here, together with an assessment of monitoring progress.

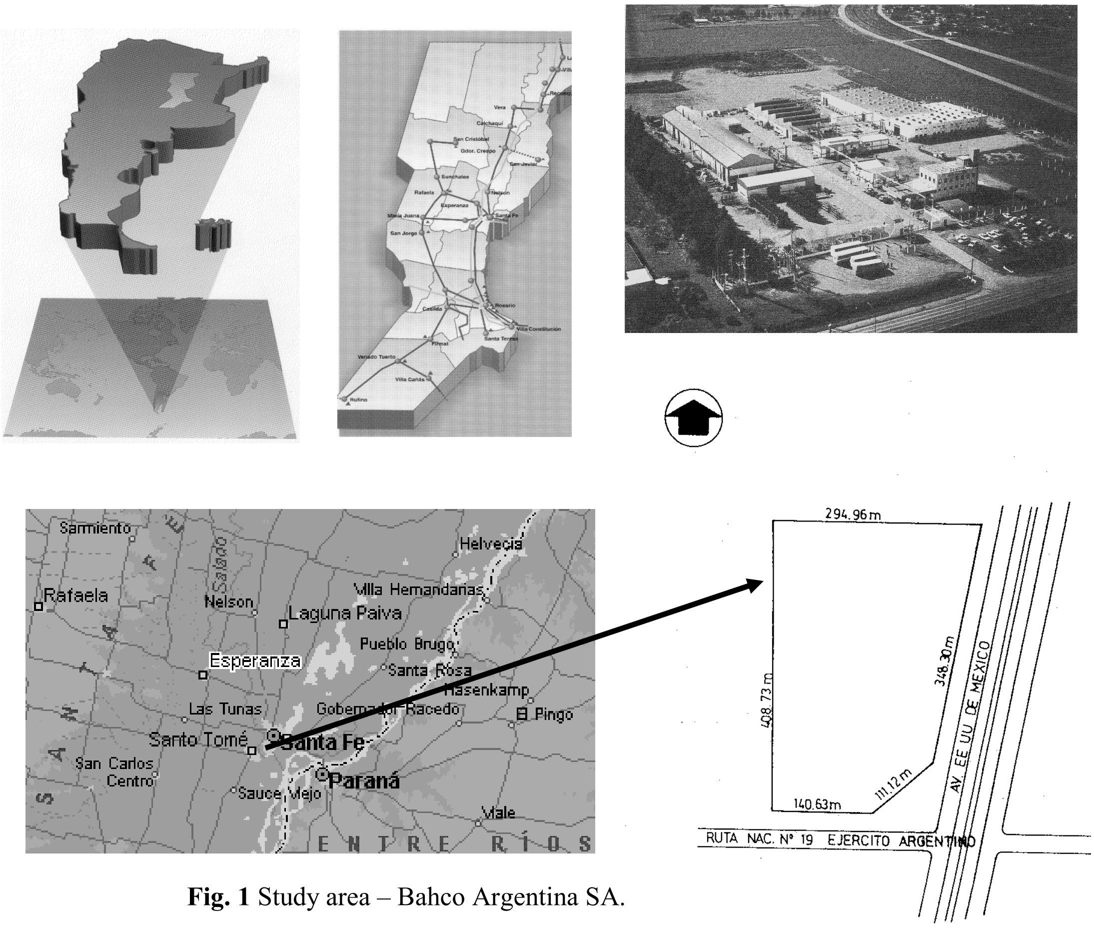


**Fig. 1** Study area – Bahco Argentina SA.

## STUDY AREA

The Bahco Argentina SA industrial plant (100 000 $m^2$) comprises the study area. It is located in Santo Tomé, Provincia de Santa Fe, Argentina (Fig. 1) and produces metal tools. Its liquid effluents are subjected to a primary treatment that reduces the total content of chromium, nickel and zinc by about 95%.

## DATA AND METHODS

Lithological profiles and the physical design of water supply wells belonging to Bahco, Santo Tome city and to private owners, geotechnical profiles, infiltration and hydraulic conductivity test data, results of soil studies, and climatic data constitute the main background information to the present study.

For the environmental hydrogeological assessment, undertaken in 2000, 17 wells (total depth = 7m) were drilled to measure the water level, to take water and soil samples from different strata and to test the hydraulic conductivity (Fig. 2). Principal anions and cations, copper, nickel, iron, PAHs, total carbon TOC (%), total hydrocarbons, greases and oils were analysed in water and soil samples. In 2002, new wells were constructed for hydrogeological evaluation of the pilot wetland and for local characterization to guide construction of the industrial wetland (Fig. 3).

The aquifer vulnerability and potential for contaminant load generation were carried out according to GOD and POSH methods, respectively (Foster *et al.*, 2003). This allowed groundwater pollution hazard in the area to be defined.

Water samples in monitoring wells and soil samples between 2 and 2.5 m depth were taken during the present monitoring work in order to assess the impact of the industrial wetland according to its size and hydraulic charge. Analytical results are not available yet.

## RESULTS

The average annual precipitation is 900 mm with a rainy season between October and April. Higher temperatures are registered between November and March (up to 20ºC). The relative humidity reaches its maximum value between April and July (80%). The maximum values of wind speed are recorded from July to November (up to 12 km $h^{-1}$) with SE and NE being the more frequent directions.

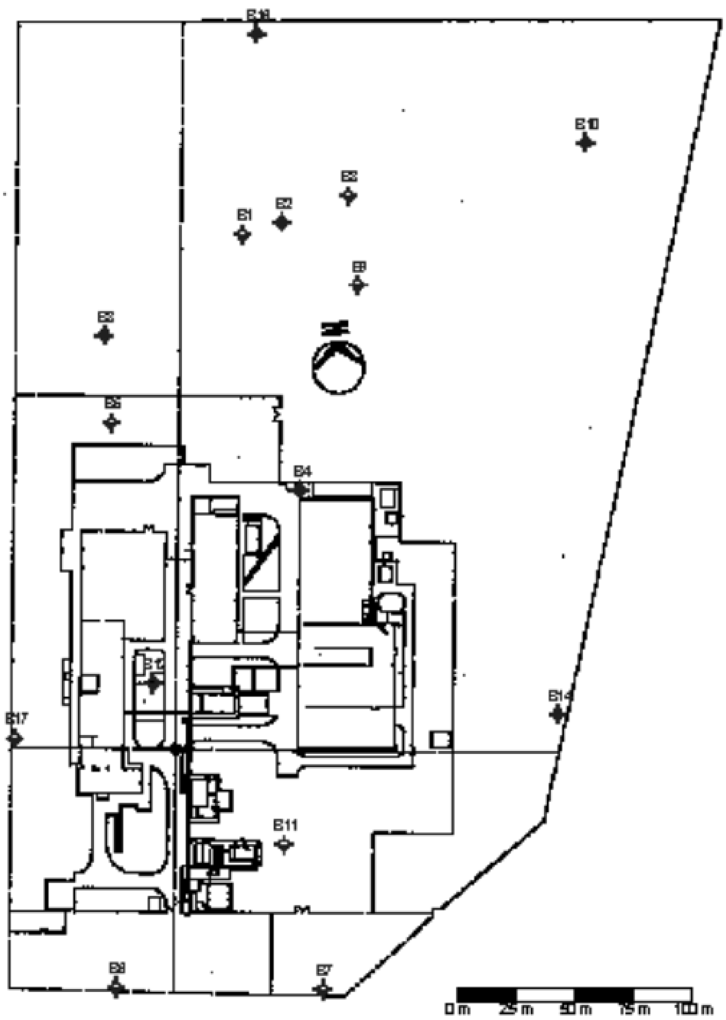


**Fig 2** Location of wells for environmental hydrogeological assessment (2000).

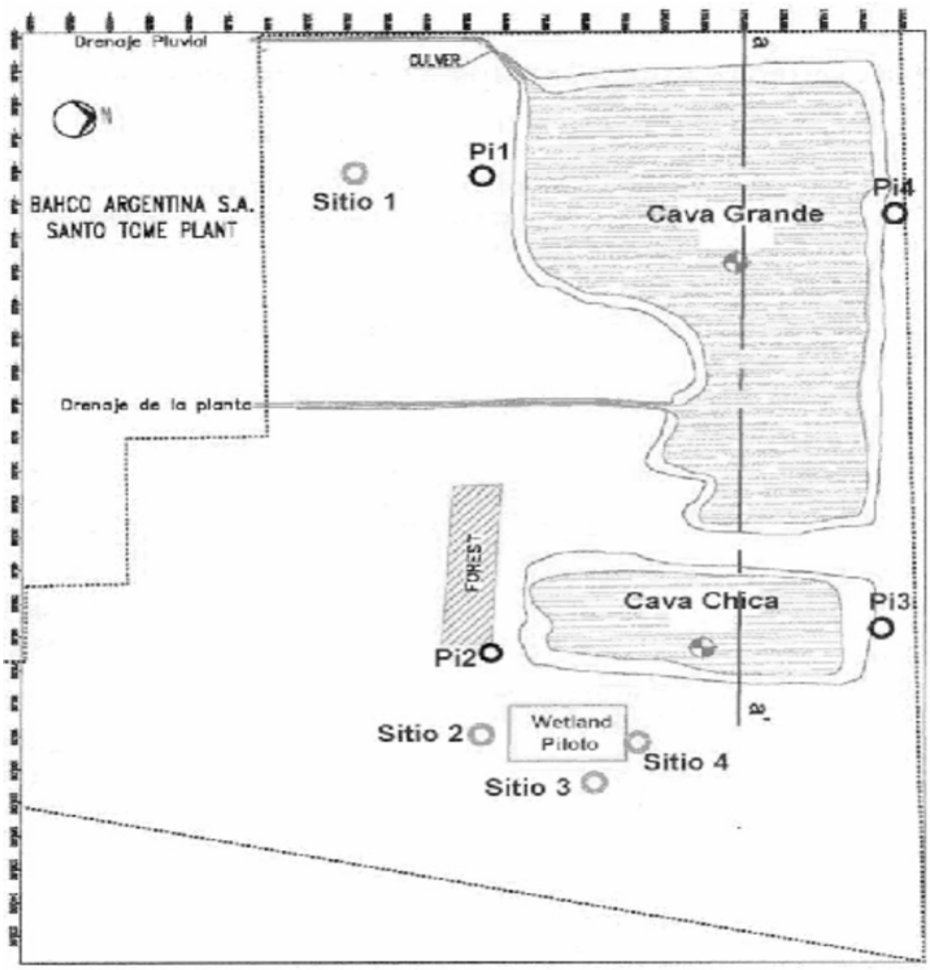


**Fig. 3** Monitoring wells (Pi) and sampling wells (Sitio) used for pilot wetland hydrogeological evaluation and for local characterization for construction of the industrial wetland (2002).

In the area, soils are poorly drained and belong to the Río Salado Serie (INTA, 1991) "Natracualf tipico" type which is developed in the flood plain areas close to the river. This agrees with the lithological description observed in the upper 2 m in the drilled wells.

The regional flow direction is W–E (Bahco Argentina, 2000) (Fig. 4). The analysis of the lithological and hydrogeological information has indicated the presence of a multi-layer aquifer. This aquifer is formed by a unit of Quaternary sediments 10 m in thickness (unconfined aquifer) and is underlain by a semi-confined unit of Pliocene and Pleistocene sediments of 24 m thickness (Fig. 5). The latter unit has good water quality and is the water supply source for Santo Tome city. It is important to note that 200 m NE of the industrial plant there are some wells for exploiting this source.

The depth of the hydraulic connection between the unconfined and semi-confined aquifers varies between 4 and 8 m. Analysis of the temporal piezometric information allowed the relation between the unconfined aquifer and the local hydrological cycle, and the hydraulic relation between the "cavas" and the unconfined aquifer to be qualitatively estimated.

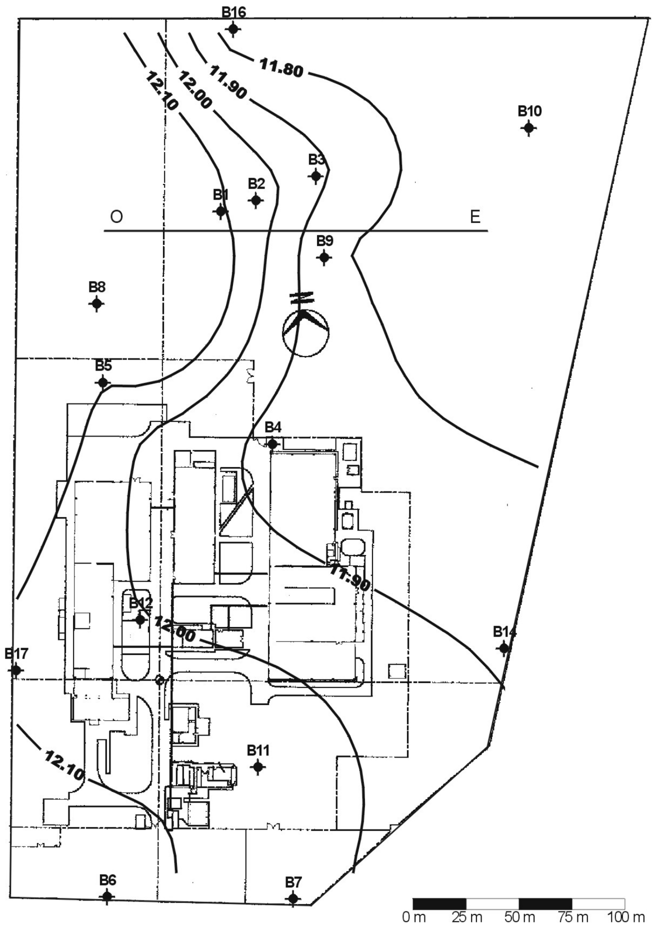


**Fig 4.** Groundwater flow direction in the study area.

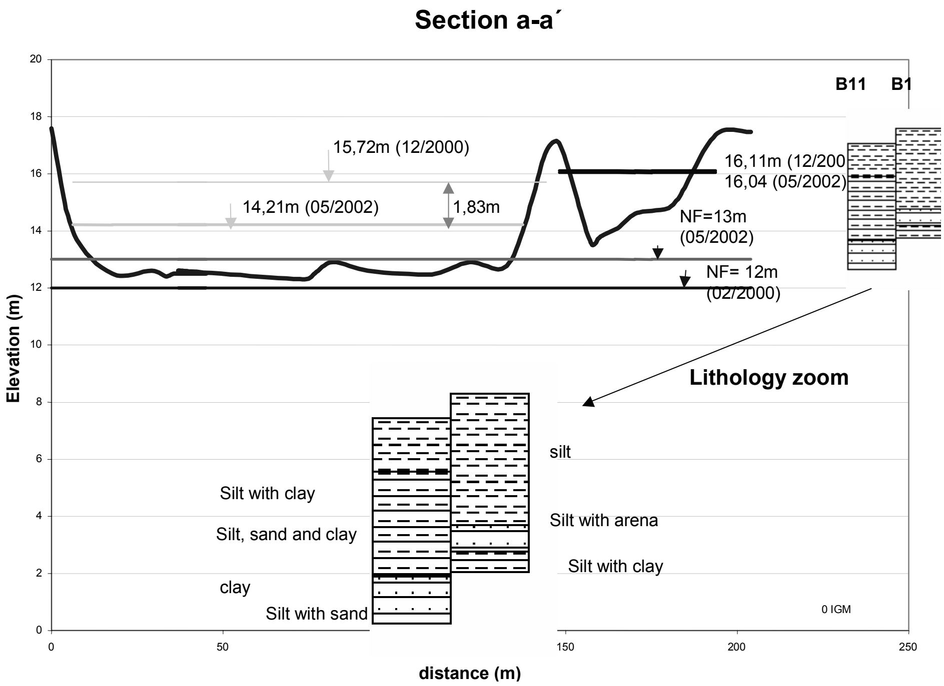


**Fig. 5** Cross section (W–E) in the study area.

According to the lithology, water level depth and the aquifer type, the GOD index is 0.35. It suggests that the groundwater system has a *moderate* vulnerability, while in relation to the solid waste disposal and the industrial type, the potential of contaminant load generation is *elevated.* Both define a *high* groundwater pollution hazard that requires important action levels to protect and control supply sources against contamination.

The regional hydrochemical characteristics previously evaluated only relate to major ions and some minor chemical elements and hydrocarbons in water from the Santo Tomé supply wells (total depth = 30 m, semi-confined aquifer). The present study is the first that includes determination and analysis of heavy metals and trace elements in soils and in the unconfined aquifer.

As a result of the field work carried out in 2000, some chemical concentrations (chromium, copper and nickel) from groundwater samples of the drilled wells were shown to be higher than the drinking water limits (Provincial Law 11220 and National Law 24051) whereas the more frequent values reflect fresh groundwater in a natural state (Förstner & Whitmann, 1979) (Fig. 6). In the soil samples, the contents obtained by leaching were lower than the guideline values and, in most of the cases, lower than the analytical detection limit.

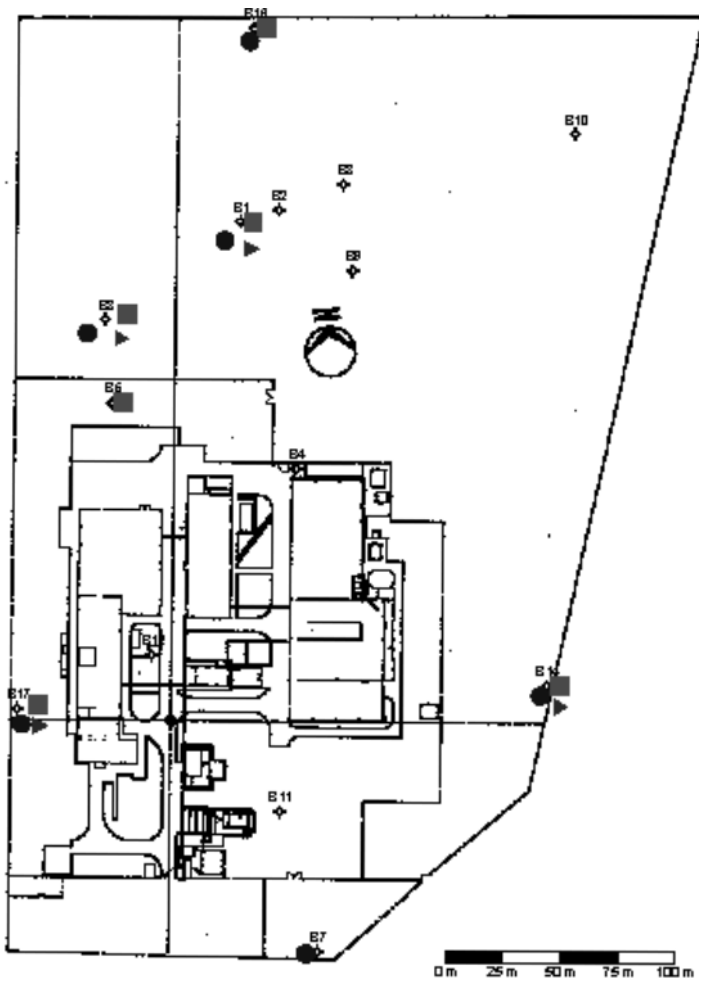


**Fig. 6** Places with values greater than the guidelines values Nickel ●, Chromium ■, Copper ▲.

Physico-chemical characteristics of the surface water measured in this study show high values for pH, major ions and minor elements, especially in the little "cava". According to the hydraulic behaviour of the aquifer, these surface water bodies should be considered as providing a high pollution hazard for groundwater.

As regards the irrigation water in the area, which is derived from the primary treatment plant, the results show that iron and nickel concentrations are higher than the guideline values and the concentrations of sulphate, salinity, pH and TOC are also high. Therefore, it was necessary to test a final effluent treatment in an environmentally controlled way. The company therefore developed a small-scale project—the pilot wetland—for evaluation as a secondary effluent treatment system. It is important to note that due to the efficiency of the primary treatment plant (95%), the heavy metal concentrations in the effluents entering the wetland are low. However, 81% of the total chromium, 69% of the nickel and 8% of the zinc are retained (Bahco Argentina, 2001, 2002). Table 1 presents some results from the studies of water, sediments and plants (Maine *et al.*, 2002).

Chromium, copper, lead and zinc concentrations in soil samples obtained in locations near to the pilot wetland (see Fig. 3, sitios 2 to 4) show a uniform behaviour in the first 2 m of the soil profile, and were lower than the maximum limit defined by

**Table 1** Cr, Ni and Zn concentrations obtained for the pilot wetland.

| | Cr (mg $L^{-1}$) | | | Ni (mg $L^{-1}$) | | | Zn (mg $L^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|
| **Water** | Average | Min. | Max. | Average | Min. | Max. | Average | Min. | Max. |
| Inlet effluent | 0.112 | 0.0048 | 0.478 | 0.247 | 0.0258 | 0.75 | 0.0675 | 0.0021 | 0.12 |
| Outlet effluent | 0.02147 | 0.0018 | 0.105 | 0.06724 | 0.0035 | 0.19 | 0.062 | 0.055 | 0.069 |
| | Cr (μg $g^{-1}$) | | | Ni (μg $g^{-1}$) | | | Zn (μg $g^{-1}$) | | |
| **Sediment** | Initial | 60 day | | Initial | 60 day | | Initial | 60 day | |
| Inlet | 6.32 | 83.6 | | 5.21 | 107.9 | | 30.3 | 96.5 | |
| Outlet | 6.32 | 25.9 | | 5.21 | 58.5 | | 30.3 | 42.0 | |
| | Cr (μg $g^{-1}$) | | | Ni (μg $g^{-1}$) | | | Zn (μg $g^{-1}$) | | |
| **Plants** | Initial | 60 day | | Initial | 60 day | | Initial | 60 day | |
| *Thypa dominguensis* (totora) (*) | 0.092 | 11.1 | | 1.14 | 18.9 | | 6.1 | 13.9 | |

* as an example.

**Table 2** Soil chemical analysis for "sitio 4".

| Sample<br>Law 24051 – limits | Depth (m) | Cr (mg $L^{-1}$)<br>5 mg $L^{-1}$ | Cu (mg $L^{-1}$)<br>100 mg $L^{-1}$ | Pb (mg $L^{-1}$)<br>1 mg $L^{-1}$ | Ni (mg $L^{-1}$)<br>1.34 mg $L^{-1}$ | Fe (mg $L^{-1}$)<br>20 mg $L^{-1}$ | Zn (mg $L^{-1}$)<br>500 mg $L^{-1}$ | pH<br>6–8 | Organic carbon (%) |
|---|---|---|---|---|---|---|---|---|---|
| M4-1 | 0.00–0.30 | <2 | <3 | <4 | 3.8 | 1.3 | <0.05 | 6.16 | 0.9 |
| M4-2 | 0.30–0.60 | <2 | <3 | <4 | 7.6 | 0.21 | <0.05 | 5.96 | 0.4 |
| M4-3 | 0.60–1.00 | <2 | <3 | <4 | <3 | <0.2 | <0.05 | 6.11 | 0.3 |
| M4-4 | 1.00–1.30 | <2 | <3 | <4 | 3.7 | 0.21 | <0.05 | 6.42 | 0.2 |
| M4-5 | 1.30–1.60 | <2 | <3 | <4 | <3 | 0.21 | <0.05 | 6.47 | 0.2 |
| M4-6 | 1.60–2.00 | <2 | <3 | <4 | <3 | 0.23 | <0.05 | 7.12 | <0.1 |

National Law 24051. In contrast, nickel does not exhibit a uniform behaviour (Table 2). The isolation of the pilot wetland bottom was done using plastic material which was broken by the plants roots.

The hydraulic conductivity tests conducted in the industrial plant show low values of approx. $5 \times 10^{-3}$ m day$^{-1}$. According to the infiltration and/or leakage possibilities that these soils offer, a maximum design depth for the industrial project of 2 m was indicated. In addition, a very good compression of the natural land with a clay addition was required.

## MONITORING

Water management indicators are an important tool in the development of water policies, the setting of targets and goals and in relation to monitoring performance. The appropriate combination of indicators helps to show how well objectives are being met, and if necessary, can provide a tool to help reformulate policies and programmes including monitoring (GWP, 2003).

Taking into account the results presented above and with the purpose of providing secondary treatment for its effluents in order to reduce the potential for pollution, Bahco Argentina SA built a wetland in 2002 (Fig. 7). This system began to operate in 2003 and nowadays it is controlled according to an *offensive monitoring scheme* (Foster *et al*., 2003) which was designed on the basis of specific hydrogeological knowledge, the hydrodynamical behaviour of the aquifer at the local scale and its relationship with the surface water bodies ("cavas"), and the design characteristics of the wetland. The monitoring includes collection of water samples and field determination (electrical conductivity, pH, temperature) in the monitoring wells (see Fig. 3), "cavas" and other new exploitation wells in the industrial plant; soil sampling at different depths near the wetland and water level measurement. Major ions and heavy metals (chromium, copper, nickel and zinc) are analysed in the samples.

**Fig. 7** Industrial wetland in 2002.

This work will allow environmental sustainability indicators of the treatment system management (wetland) to be obtained, and evaluated in relation to the water supply sources and the aquifer with a coordinated land use and according to groundwater quality protection requirements, and the integrated water resource management. Analytical results are not available yet.

## FINAL CONSIDERATIONS

An understanding of the regional groundwater flow and its particularities at the local scale have allowed site characterization for both the construction of the industrial wetland and the monitoring design and operation.

Taking into account the high groundwater pollution hazard produced by the activities developed and the close proximity of the water supply source, it is very important to continue the hydrodynamic and hydrochemical assessment of the aquifer and the monitoring of the wetland. This assessment will generate the indicators to guide environmentally sustainable management and to consider other protection policies that could include relocation of the water supply source.

Few specialized studies have been published concerning the development, operation and monitoring of industrial wetlands and so it is hoped the present investigation will provide a valuable background to this subject.

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