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Dewatering and remediation of the ˝ex Whitehead Motofides˝ area (Pisa, Italy)

Dewatering e bonifica dell' area ˝ex Whitehead Motofides˝ (Pisa, Italia)

Nicola Conti, Roberto Salvadori, Massimo Aiello

Riassunto: Nel 2007 sono stati avviati i lavori di bonifica dell'area "ex stabilimento Whitehead Motofides", in località Marina di Pisa.

Per garantire lo scavo, in condizioni asciutte, dei terreni da bonificare è stato necessario realizzare un sistema di *dewatering* delle acque di falda. Della realizzazione e gestione di questo sistema si è occupata la società Acque Industriali S.r.l.. Le acque prelevate tramite dewatering sono state poi trattate in un impianto adeguato, anche questo realizzato e gestito da Acque Industriali. L'attività di Acque Industriali è iniziata nel 2008. L'impianto di dewatering era costituito da spilli di aspirazione infissi ad una profondità di 5.5 m collegati con collettore di raccordo alla pompa di aspirazione e spinta vuoto assistita che consentiva il rilancio delle acque di falda all'impianto. L'impianto di trattamento delle acque, progettato interamente da Acque Industriali e denominato ITAM (Impianto Trattamento Acque di Falda Mobile), è stato realizzato ed allestito a fine 2008 ed era costituito da una sezione di pretrattamento in elementi prefabbricati in cemento armato e di polmonazione, e da un impianto chimico-fisico a ciclo continuo interamente realizzato su *skid*. L'impianto, con potenzialità massima di 25 m^3/h è stato in grado di rimuovere dall'acqua particelle di materiale sedimentabile o in sospensione, ferro, manganese, sostanze organiche residue quali idrocarburi, solventi clorurati e non, PCB ed in parte metalli pesanti.

Complessivamente sono stati gestiti 98,167 m^3 di acqua di falda in circa 25 mesi di attività. I risultati analitici in ingresso e uscita dall'impianto hanno confermato un'efficienza di rimozione degli inquinanti estremamente elevata, tale da garantire sempre il rispetto dei limiti imposti dalla Normativa.

Parole chiave: bonifica siti contaminati, dewatering, acque sotterranee, policlorobifenili (PCB), Marina di Pisa.

Keywords: *remediation of contaminated land, dewatering, groundwater, Polychlorinated Biphenyls (PCBs), Marina di Pisa.*

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Abstract: *In 2007 the activities for the remediation of the "ex-Whitehead Motofides area" (in Marina di Pisa, Italy) started.*

In order to allow the contaminated soil excavation in dry conditions a dewatering system was necessary. The water pumped through this system was then treated in an adequate plant. Acque Industriali realized and managed the whole system.

The dewatering system was made of suction pins fixed to a depth of 5.5 m, connected by a junction manifold to the suction and booster vacuum assisted pump, which allowed the groundwater release toward the plant. The treatment plant, entirely designed by Acque Industriali and called ITAM (Impianto di Trattamento Acque di Falda Mobile, which means movable groundwater treatment), was realized and set up at the end of 2008. It consisted of a pre-treatment section, made of reinforced concrete, prefabricated nitrogen sweep elements, and a physical chemical treatment plant, in a continuous loop, completely made on skid. The plant, with 25 m^3/h of maximum potential, was able to remove possible sedimentable or in suspension material particles from water, iron, manganese, residual organic substances such as hydrocarbons, solvents (chlorinated and not), PCBs, and partly heavy metals.

Totally, 98,167 m^3 of groundwater were managed in about 25 months of activity. The analytic input and output results confirmed extremely high and satisfactory pollutant removal efficiency. The concentration values of the pollutants, in fact, were always lower than the limits imposed by law.

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Introduction

Soil degradation is a serious problem in Europe. It is driven or exacerbated by human activity such as inadequate agricultural and forestry practices, industrial activities, tourism, urban and industrial sprawl and construction works. These activities have a negative impact, preventing the soil from performing its broad range of functions and services to humans and ecosystems.

Soil degradation has a direct impact on water and air quality, biodiversity, and climate change.

It can also impair the health of European citizens, threaten food, and feed safety.

Although soil degradation processes vary considerably from Member State to Member State, with different threats having different degrees of severity, soil degradation is an issue all over the EU (COM (2006) 231).

In this context, the European Commission adepts a Soil Thematic Strategy (COM (2006) 231) with the objective of ensuring sustainable use of soils across the EU and protecting them from a series of key threats such as biodiversity decline, compaction, contamination, and so on (Jones et al., 2012).

As for local soil contamination, in 2011 a total of 2.5 million potentially contaminated sites in the EEA-39 were estimated. About one third of an estimated 342,000 contaminated sites in the EEA-39 have already been identified and about 15% of the estimated totals (58,300) have been remediated (Van Liedekerke et al., 2014).

The distribution of the different contaminants is similar in the liquid and the solid matrices. The main contaminant categories are mineral oils and heavy metals (Van Liedekerke et al., 2014).

Polychlorinated biphenyls (PCBs), synthetic chlorinated aromatic compounds, were widely used throughout the 20th century for a number of industrial purposes. Their production was banned in 1980 because they represent a serious threat to both the environment, as well as animals and humans (Nuzzo et al., 2012).

The extent of PCB contamination worldwide is unknown. In the United States, 350 of the 1,290 Superfund Sites are contaminated with PCB, whereas in Canada there are 148 sites according to Federal Contaminated Sites Inventory. In European countries, an estimate points 5,800 sites, which are contaminated with chlorinated hydrocarbons (Gomes et al., 2013).

This work (remediation of soil and groundwater mainly contaminated by PCB) moves in this context.

Historical background

Business interest in Marina di Pisa area, and especially in the Arno river mouth area (Boccadarno), dates back to the early years of the 20th century. In fact, in 1916 the Gallinari Company of Livorno, which from 1906 dealt with civil and naval ship repair, decided to expand its business by extending it to the construction of wooden seaplanes: right in these years of war, there was a large request of them (Fiorio et al., 2001). Boccadarno, enclosed on two sides by the river and the sea, had indeed all the necessary properties for the production and testing of these new seaplanes. By end of the World War I, production immediately threw into crisis and soon the plant went idle, despite all the efforts made by the company to create a respectable industry in Boccadarno. With the end of the war and the following signing of the peace treaties, some German entrepreneurs were forced to seek abroad the opportunity to continue with their business. There was among them engineer Dornier, who launched the facility for the production of the Dornier-Wal seaplane; it became the first metal hydroplane made in Italy, as well as one of the earliest all over the world: between 1922 and 1932 indeed 129 of them were built, both for military and commercial purposes. The increasing yard's production capacity pushed shareholders to buy neighbouring lands, to increase the surface area of the facility. The importance of this factory in Marina di Pisa for the Italian industry and the forthcoming return of Dornier in Germany drove Fiat to involve itself in this company, and to become its sole shareholder in 1937.

The yard, between 1930 and 1943, was able to keep up with the times, combining hydroplanes production with new wheeled machines one. The war events substantively affected the factory's future. The location, which made it ideal for the construction of seaplanes (the sea a step away, very useful for the tests), showed all its limitations in land-based aircraft testing, which required long runaways and landings. After World War II, it was reconverted towards buses and railway carriage repair, fabrication of electric cookers, furniture, and automotive parts. After a few years of uncertainty, also due to the economic crisis, in 1953 Fiat decided to turn the Marina di Pisa factory into "Fiat-Sezione Officine di Marina di Pisa" (Marina di Pisa Fiat workshops section), providing it with all the necessary facilities for producing car accessories.

Because of the transportation costs, the automotive industry crisis and the now unsuitable location, Fiat group decided to move the processing plant to Torino and to Livorno. It definitively closed down in the mid-eighties, and it was put in abandonment state up to its final demolition, begun on 9th October 2007, using thirty pounds of explosives made of microbursts. This event started the remediation of the whole area.

Acque industriali intervention

The Area of Intervention

The need for environmental and urban restoration in Boccadarno area inevitably passed through soil and groundwater remediation. The bureaucratic process started in 1995 and it definitely ended in 2009.

The site stratigraphy consists of an average 25 m thick sand layer in the upper strata (hydraulic conductivities ranging from 10^{-4} m/s to 10^{-6} m/s) lying over consolidated clays. The sandy layer hosts a phreatic aquifer.

Following site investigations, pollutants were detected in some areas in soil (unsaturated zone) and groundwater. In particular, heavy metals, heavy and light hydrocarbons (NAPL, both carcinogenic and non-carcinogenic), halogenated aliphatic (especially vinyl chloride) and polycyclic aromatic hydrocarbons (PAH) were detected.

Moreover, although not foreseen in the project hypothesis, concentrations of PCBs higher than those set for the commercial-industrial limit (5 mg/kg; D.Lgs 152/2006), were found. They were situated in crushed on-site bases and sub-foundations, and in some portion of land, which conversely were thought to be re-used on site.

In those sectors where values higher than the ones in B column of DM 471/99 (concentration limits allowed for soil, referred to commercial and industrial land use) or than Concentrazione Soglia di Rischio (risk threshold concentrations; D.Lgs. 152/2006) were detected, remediation took place.

The areas to be remediated were divided into three sectors (Port Area, Green Area, and Camper Area; Figure 1 and Figure 2).

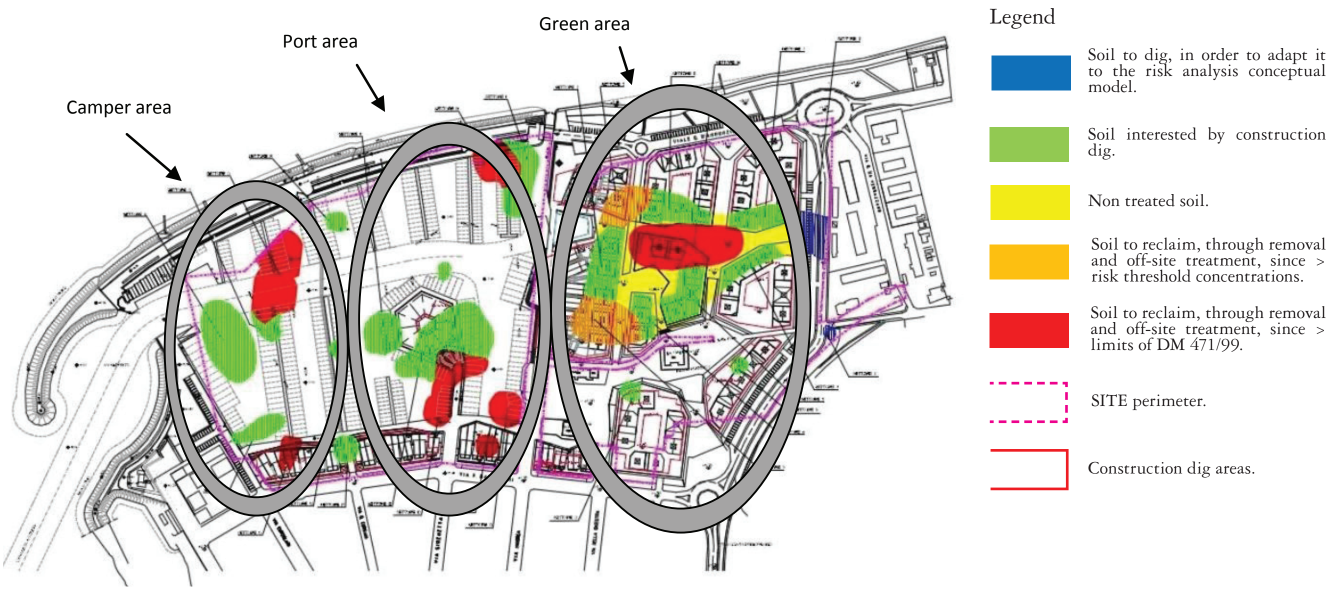

Fig. 1 - The area showing the sectors to remediate.

Fig. 1 - L'area in oggetto con evidenziate le zone coi terreni da bonificare.

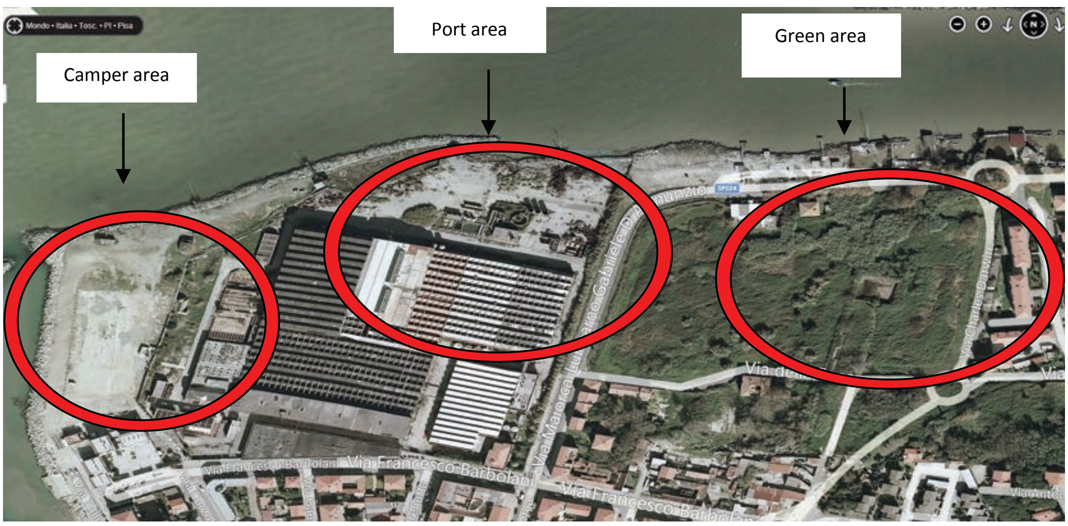

Fig. 2 - Aerial view of the pre-intervention area.

Fig. 2 - Vista aerea dell'area pre-intervento.

Each sector (Port Area, Green Area, and Camper Area) was in turn divided into contaminated sub-sectors, each one affected by excavation to remove and treat off-site (recovery, soil washing or landfill) the contaminated soil, for a total movement of more than 91,000 tons of soil (Mossa Verre, 2010) (Figure 3).

Following site remediation, in Port and Camper Areas a reservoir for 400 berths was created, with docks, port commercial and receptive services; the Green Area will be converted in the near future in a residential area, with houses, recreational and accommodation touristic facilities and boating services (Figure 4 and 5).

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Fig. 3 - Aerial view of the area during the intervention.

Fig. 3 - Vista aerea dell'area durante l'intervento.

Fig. 4 - Aerial view of the area after the intervention.

Fig. 4 - Vista aerea dell'area dopo l'intervento.

Fig. 5 - Aerial view render of the definitive area state. In the foreground, the Green Area, followed by the Port Area and the Camper Area

Fig. 5 - Vista aerea del render dello stato definitivo dell'area. In primo piano l'Area Verde, a seguire l'Area Porto e l'Area Camper.

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The Groundwater Dewatering System

At the end of 2008, Acque Industriali (a company that works in the fields of wastewater treatment, sewage sludge disposal, and remediation of contaminated sites) began its intervention, concerning the remediation of the ex-Motofides area. The objective of the company was to ensure the excavation operations in remediation up to depth of project (5.5 m) in dry conditions, by lowering the water table, and especially to remediate contaminated groundwater.

The plant consisted of a pumping well-point system for groundwater dewatering within the sheet piling polluted sectors, and a subsequent chemical-physical movable treatment system, before discharging into the Arno river. The whole treatment plant was designed, realized, and managed directly by Acque Industriali.

The groundwater dewatering system was designed and realized according to geological and hydrogeological data, obtained from the remediation detailed plan.

Each of the above-mentioned sub-sectors was enclosed by "Larssen 704" sheet piles at 16 m depth. They were anchored to the "impermeable" layer in order to create a sort of "almost" watertight container, to lower the water table up to about 1 m from the excavation floor. Around every sheet piling a steel manifold has been laid and wired. It was provided with couplings having a 150 mm diameter, with suction pipes directly connected through 2" flexible pipes to the suction pins, having a 1" ¼ diameter, fixed to a depth of 5.5 m. An electric vacuum assisted pump was installed on each manifold head; this allowed to pump the groundwater and to push it towards the first section of the treatment plant. The suction tips, equipped with a sand filter, were fixed at a mutual distance of about 150 cm, in other words a tip every two sheet piles, in order to ensure a homogeneous and distributed lowering over the entire area of interest (Figure 6).

The flow rate pumped with the described system allowed successful lowering of the water table. In the largest sub-sector 210 well-point tips, divided into two manifolds, with a total length of about 345 m, were installed. In order to reach deeper depths (about 6 - 7 m from ground surface) another suction ring to pump the groundwater at an average depth of 8 m, was created within the already existing one. This guaranteed the dewatering at the required depth

Fig. 6 - Groundwater dewatering system.

Fig. 6 - Il sistema di *dewatering* delle acque di falda

The Groundwater Treatment Plant

The groundwater mobile treatment plant, called ITAM (Impianto di Trattamento Acque di Falda Mobile, movable groundwater treatment plant), was designed, set up and wired on site from November 24th to December 3rd, 2008 by Acque Industriali (Fig. 7).The plant was fully funded by the Company.

Water, pumped through the dewatering system above described, flowed directly inside the treatment plant, consisting of the following sections:

- **Sedimentation – flotation**: it was achieved by a prefabricated reinforced concrete tank, with a volume of 55 m^3. In this rectangular cross-section unit, water underwent a quieting and a uniform flow distribution, in order to allow the sedimentation to the heaviest particles (sand and mud). In the same tank, the separation of the floating substances (any traces of oil and insoluble hydrocarbons) took place using the principle of gravity. The lightest particles, floating on the surface, were hold back by a deflector blade, while the water flew down from an outlet hole on the opposite side.
- **Accumulation – homogenization**: this section consisted of three tanks in prefabricated reinforced concrete, working in parallel, and each having a volume of 55 m3. This section had the function to dampen the hydraulic load peaks (nitrogen sweep) and to uniform the quality of the water sent to the treatment plant (homogenization). This accumulation also allowed a strict control of water during start-up, before their final discharge. Indeed, this volume has been used both as a lung in crude water and as an accumulation of treated water.
- **Filtration on quartz sand**: it was made of two carbon steel filters, having a 1,400 mm diameter, a 2,000 kg (2 tons) filter material per unit, a 1.50 m^2 area, and a total height of 2,500 mm. Their function was to hold the solid particles present in water. Filters worked in parallel.
- **Filtration on activated carbon**: it consisted in two carbon steel filters, having a 1,500 mm diameter, a 1,800 l filtering mass, a 1.50 m^2 area and a total height of 2,500 mm. Their function was to absorb the principle groundwater pollutants (in particular chlorinated organic solvents and PCBs). They could work both in series and in parallel, to be able to provide a higher managerial flexibility. Upstream the activated carbon filters, there was the chance to dose the sodium hypochlorite through a dedicated dosing pump, in order to preserve the carbon by unwanted bacterial proliferation, which would significantly reduce the filter efficiency itself, and its lifetime. Once the activated carbon was exhausted, it was replaced

and disposed as waste (Code EWC 19 09 04; Commission Decision 2000/532/EC). The activated carbon used was of mineral type, having a 0.6 to 2.4 mm grain size (8x30 mesh) and 450 g/l bulk density.

- **Filtration on selective resins**: consist of two bisphenolic resin columns with a 1,000 mm diameter, working in series. This extra finishing was planned in cases the water quality, coming out from the first stage, would not have been within the limits according to the legislation in force. It could be activated in case there was need of further refinement towards load peaks, soluble metals, or the ones refractory to other treatments (mercury, arsenic, etc.).

Fig. 7 - The movable groundwater treatment plant.

Fig. 7 - L'impianto di trattamento acque di falda mobile.

The plant (Figure 8) was designed and realized to ensure an automatic (continuous loop) groundwater treatment, with 25 m^3/h of maximum potential without interruptions (thanks also to the installation of a 60 kW emergency electric generator). Furthermore, the specific plant conformation (having the filtration system entirely made on removable skids) allowed its movement several times within the remediation area. This to facilitate the far-reaching water dewatering and to clear the short-term occupied area for the subsequent realization of the marina.

Treatment plant and dewatering management

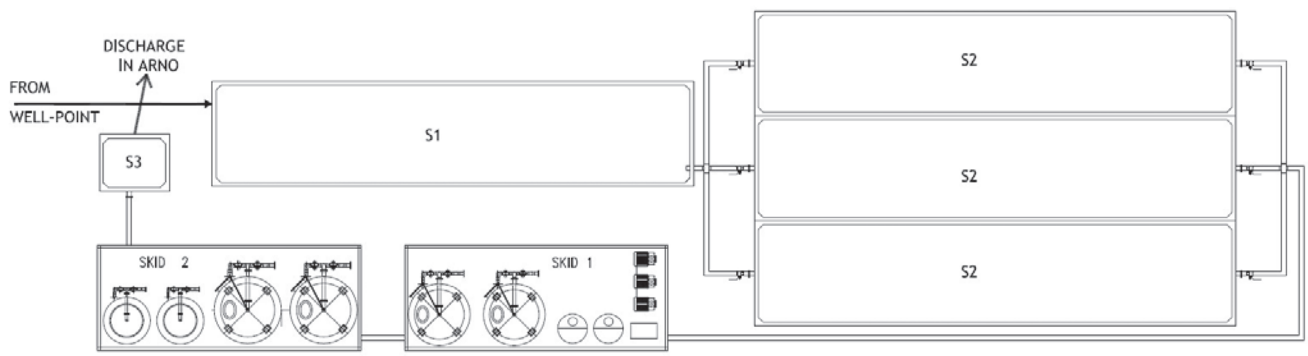
The first well-point ring set up took place on January 27th, 2009. Before routinely operations began, a plant test was performed. With the supervision of proper authorities it was possible to certify, by means of treated wastewater chemical-physical analysis, the determination of the pollutants to be monitored, and the conformity of the water discharged quality characteristics. Only after a positive check, it was possible to put the plant in operation. The activity began on February 4th, 2009.

In total, during Acque Industriali intervention, an amount of 98,167 m^3 groundwater were managed in about 26 months of continuous activity, during which there were also long plant shutdown periods, due to the normal management in remediation (fixing sheet piles, waiting for analysis results, etc.). Rainwater also was included in this volume: it was stored and decanted in appropriate tanks in the land-storage bay area (Green Area), and decanted into Acque Industriali treatment plant through purging (1,360 m^3).

After obtaining the approval from proper authorities (Municipality of Pisa), the discharge of treated water took place directly into the Arno river, in accordance to the authorization limits provided in Table 3, Annex 5, to the third part of D.Lgs 152/2006 (discharging into surface water; Table 1).

Both internal and external controls (from accredited laboratory and from the Regional Environmental Protection Agency) have been conducted.

Regarding Pb, Cd, Cr, Zn, Cu, Hg, total hydrocarbons, and chlorinated organic solvents, they never entailed risks of exceeding law limits. It's the Authors opinion that the main



Legend:

S1	Sedimentation – flotation
S2	Accumulation – homogenization
S3	cockpit of discharge
SKID 1	Filtration on quartz sand, group pumps and switchboard
SKID 2	Filtration on activated carbon and selective resins

Fig. 8 - Planimetria dell'impianto di trattamento acque.

Fig. 8 - Risultati della indagine *Direct Push* basata su uno *slug test* multilivello al punto 10.

reason for this lies in the fact that the choice of a slow and steady dewatering, allowed the already contaminated soil to serve as a natural filter, in the maximum physically possible way (as in Chiesa, 1991, and Boni et al., 2010). In addition, the plant allowed to reach pollutant concentrations down to values often below the instrumental detection. Important heavy metal concentrations were found in sand and mud, accumulated, and disposed here by the sediment filter in the first section of the plant.

For PCBs, however, the case is different. As already said above, they resulted to be the most insidious and persistent pollutants among all ones. While the static monitoring, executed through the piezometer network installed in the remediation area, showed an occasional presence of PCBs, during the handling of land and underpinnings PCBs concentrations significantly increased.

As shown in Table 1 the legislation does not define a limit value for the discharge of PCB in surface waters. This led to a specific act by the Municipality of Pisa, which, in accordance with the Regional Environmental Protection Agency and other Authorities, set some ad hoc measures about PCBs, including an adequate limit for discharging into surface water, equal to 1 µg/l.

Tab. 1 - Concentration limits for discharge in surface water (D. Lgs 152/2006).

Tab. 1 - Valori limite di emissione in acque superficiali (D. Lgs 152/2006).

Parameter		Limit (mg/l)
heavy metals	Pb	≤ 0.2
	Cd	≤ 0.02
	Cr	≤ 2
	Zn	≤ 0.5
	Cu	≤ 0.1
	Hg	≤ 0.005
Hydrocarbons		≤ 5
chlorinated solvents		≤ 1
PCBs		No limits

A series of management and plant precautions were adopted in order to achieve the appropriate PCBs concentration value. First, there was the need to replace the activated carbon within the filters by materials having specific sorption characteristics so to be more effective in removing the pollutant. In addition, a more intense input-output flow analysis, and a more accurate control of the activated carbon state were planned. Thanks to those actions, the limit value of 1 µg/l have never been exceeded, rather often a concentration of PCBs below 0.1 µg/l has been found.

The percentage of abatement reached a maximum of 98%, with a 79.8% average, surely depending on the input concentration value.

In Figure 9 a graphic elaboration concerning the intervention in Port Area and Green Area is shown.

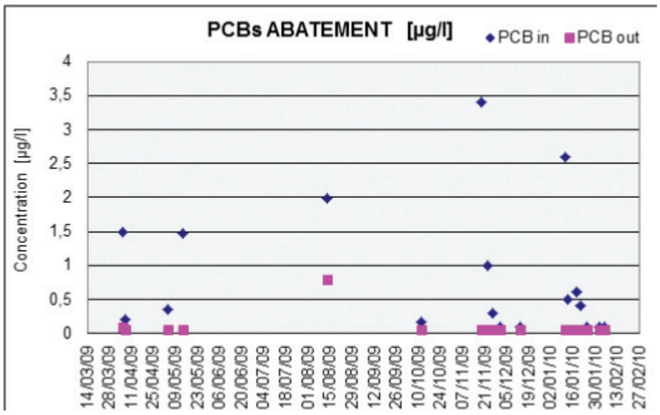


Fig. 9 - PCBs input-output system concentration monitoring.

Fig. 9 - Monitoraggio della concentrazione PCB ingresso-uscita impianto.

Conclusions

The area of the ex-Whitehead Motofides in Marina di Pisa (Pisa, Italy) has been abandoned for a long time (circa 30 years). In October 2007, the remediation of the area started.

Acque Industriali intervention regarded mainly the groundwater treatment. The water was contaminated by Pb, Cd, Cr, Zn, Cu, Hg, total hydrocarbons, and chlorinated organic solvents. Moreover, a not expected pollutant was found: PCB.

Acque Industriali activities consisted in the dewatering of the groundwater and the realization and the management of the water treatment plant (that treated the groundwater pumped through the dewatering system, before discharging it in the Arno river).

The analysis, conducted in input and output flows, showed an efficiency of treatment: the concentration values of the pollutants were always lower than the concentration limits imposed by the Municipality of Pisa (for PCBs) or by the D.Lgs 152/2006 (for the other pollutants). In particular the efficiency of PCB removal reached the maximum percentage of 98.5%.

Part of the remediated area has now been converted into a marina. The remaining is going to be converted into a residential area. Therefore, the intervention is not only a good example of remediation, but also a good example of revaluation of abandoned environment.

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