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# THE FIRST PERMEABLE REACTIVE BARRIER IN ITALY

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**KEYWORDS**: Permeable reactive barrier (PRB), zerovalent iron (ZVI), biopolymer slurry, guar gum, chlorinated hydrocarbons, groundwater remediation

## 1. ABSTRACT

The aim of this study is to describe the first full scale application of a zerovalent iron permeable reactive barrier in Italy. The PRB was designed and realized to remediate a chlorinated hydrocarbons plume at an old industrial landfill site, in Avigliana, near the city of Torino, in the Piemonte Region.

The dimensioning of the PRB was conducted by means of a three dimensional flux and multispecies contaminant transport model based on column degradation test.

The excavation of the 120 m long, 13 m deep and 0.6 m thick barrier, was performed in just 8 days using a crawler crane equipped with an hydraulic grab and supported by guar gum slurry. After the excavation, the trench was backfilled with 1700 t of iron and the biopolymer degraded using enzymes.

The final configuration of the site will be characterized by a wide car park, a ciclo-cross track and a green capping to prevent the infiltration of water from the ground surface to the shallow aquifer.

## 2. THE CONTAMINATED SITE

The studied area is located between Avigliana and Buttigliera Alta, near the city of Torino, in the north of Italy. This site was used in the past as an industrial landfill for the disposal of wastes coming from metal working factories.

From the geologic point of view the area is characterized by deposits pertaining to both alluvial sequences connected to Late Pleistocene glacial events and to Ancient Holocene. Middle, recent and present alluvial drifts relate to the evolution of the course of the Dora Riparia River. All of these deposits are made of sandy-gravely incoherent materials, middle fine to coarse grained, with remarkable occurrence of fine muddy and clayey-muddy materials.

The most superficial part of the lithostratigraphic sequence contains an unconfined aquifer, whose impermeable bottom layer consists of muddy clayey drifts found under 11-20 m of depth and connected to the surface hydrographic network. The saturated thickness of this aquifer ranges from 9 to 11 m showing a progressive reduction towards the Dora River, thus representing the drainage axis of the groundwater. The average flow direction in the area is SSW-NNE and the hydraulic gradient is 1.1%.

The hydrodynamic characterization of the aquifer was based on constant rate multiwell pumping tests and slug tests (Tab. 1).

Tab. 1: Average hydrogeological and hydrodynamic parameters of the superficial aquifer.

| Parameter | Symbol | Value |
|---|---|---|
| Saturated thickness | b | 10 m |
| Horizontal hydraulic conductivity | k | $1.8 \cdot 10^{-4}$ m/s |
| Effective porosity | $n_e$ | 0.2 |
| Hydraulic gradient | i | 0.011 |

A detailed horizontal and vertical, soil and groundwater, characterization was performed by means of ordinary drilling rigs equipment and direct push system (Geoprobe). The chemical analyses revealed the presence of two contaminated plumes with a concentration of PCE, TCE and daughter products higher than Italian MCLs (Fig. 1 and Tab. 2)

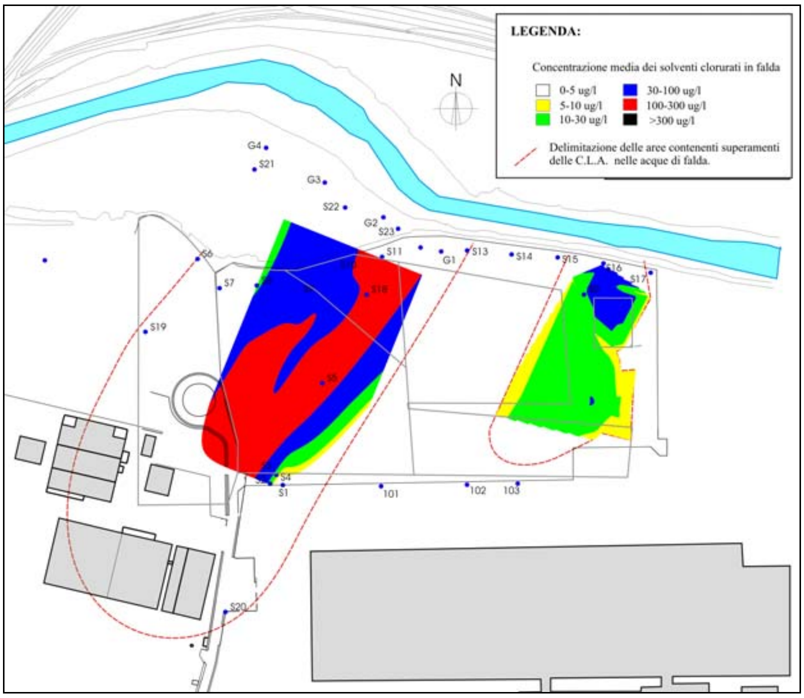


Fig. 1: Delimitation of the contaminated areas.

Tab. 2: Groundwater contaminant concentrations and Italian MCLs.

| Groundwater concentrations | Area 1 µg/l | Area 2 µg/l | MCLs µg/l |
|---|---|---|---|
| PCE | 0,46 | **56** | 1,1 |
| TCE | **130** | **36** | 1,5 |
| cDCE | **135** | 0,3 | 60 |
| VC | - | 0,1 | 0,5 |

The most suitable technologies to remediate the contaminated plumes were found to be a zerovalent iron permeable reactive barrier (ZVI PRB) for the first area and a capping and MNA for the second and less contaminated zone.

A detailed risk assessment analysis (tier 3) was performed leading to a remediation goal of 30 µg/l of total carcinogenic chlorinated aliphatic compounds.

## 3. DESIGN OF THE PRB

The dimensioning phase required the definition of the configuration, position, orientation, capture area, geometry (height, length, width) of the PRB in order to assess the amount of ZVI needed to achieve the target concentration. The design phase was supported by numerical flow, particle tracking and multispecies contaminant transport simulations implemented in Visual Modflow Pro v.3.1 environment by means of the MODFLOW, MODPATH and RT3D engines.

The site assessment, the flow and particle tracking simulations lead to the choice of a 120 m long continuous reactive barrier configuration (Fig. 2). This solution is not only the less expensive and easiest to implement but also the one that ensures the lowest impact on the groundwater flow. The reactive barrier was designed to penetrate the loamy-clayey bottom of 0.6 m, thus the average depth of the excavation is 13 m, whereas the average reactive height is 10.5 m.

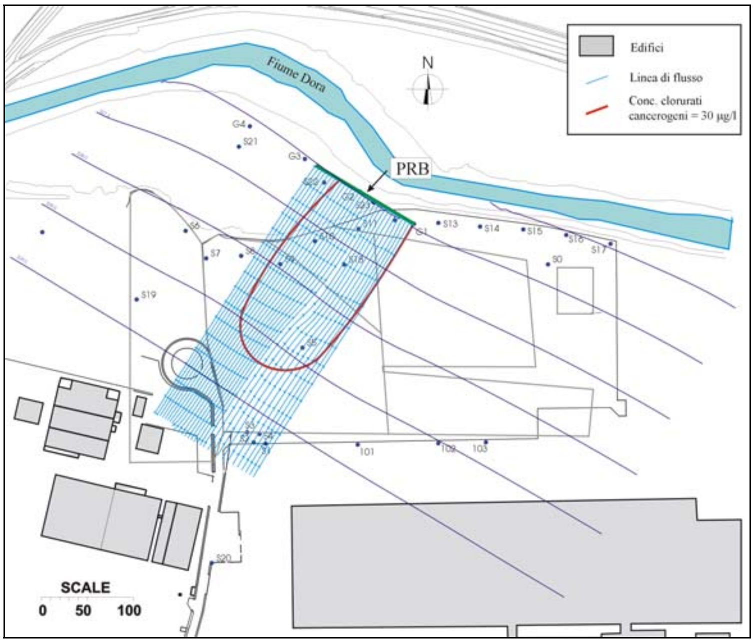


Fig. 2: Final position, orientation and capture area of the permeable reactive barrier.

Tab. 3: Laboratory and field half lives determined for the uncoupled multispecies contaminant model from lab test results.

| | $t_{1/2}$ lab (h) | $t_{1/2}$ field (h) |
|---|---|---|
| TCE | 0,74 | 2,2 |
| cDCE | 8,4 | 25,2 |
| 1,1-DCE | 1,5 | 4,5 |
| VC | 8,2 | 24,6 |

The calculation of the width of the barrier was performed by means of a 3D multispecies uncoupled and coupled (network) contaminant transport model. The CAHs degradation kinetics were derived from a column test performed by University of Tubingen (I.M.E.S., 2004) on contaminated water sampled from the site and Gotthart Maier Metallpulver iron. The half-lives calculated during laboratory tests were corrected by a factor of three to account of the temperature differences among laboratory and field conditions (Tab. 3). Both the uncoupled and coupled multispecies simulation, performed by implementing an RT3D (Clement, 1997) user defined module, lead to similar results (Sethi, 2004) and to width of 0.5 m of ZVI.

The final width of the barrier was chosen as 0.6 m, due to the standard dimensions of commercial excavation grabs. The volume gap in the trench was planned to be filled by a suitable amount of iron-sand mix.

# 4. CONSTRUCTION OF THE PRB

The construction of the PRB began with several site preparation activities including the flatting of the area and the construction of a concrete crub to guide the digger.

The phase of excavation was performed in November 2004 and lasted just 8 days. The excavation was realized using a crawler crane equipped with an hydraulic grab and supported by guar gum slurry until the backfill with ZVI.

The construction of the 120 m long and 13 m deep permeable reactive barrier (Tab. 4) was performed by means of 17 panels whose average length was 7 m. The choice of proceeding by panels was a safety measure in the case biopolymers would have degraded prematurely thus compromising the trench stability.

Tab. 4: Geometrical characteristics of the PRB.

| Parameter | Symbol | Value |
|---|---|---|
| Length | L | 120.37 m |
| Width | W | 0.6 m |
| Height | H | 11.90 – 13.80 m |
| Reactive height | RH | 9.70 – 11.80 m |

The phases undertaken during excavation can be roughly summarized as follows (Fig. 3):

- excavation of a panel supporting the trench with biopolymers;
- positioning of a steel separating tube (t.s.p.) in order to avoid fluid exchange between neighbouring panels;
- positioning of a screened PVC tube (t.r.e.) in the middle of the panel for enzymes recirculation;
- displacement of the slurry with zerovalent iron and sand mix;
- breaking of the bioslurry with enzymes;
- filling the top of the barrier with sand and three layers of compacted clay of 20 cm each.

The materials used, the preparation of the slurry, the constructive sequences and the quality controls will be examined in the following paragraphs.

## 4.1 Zerovalent Iron (ZVI)

The zerovalent iron was supplied by the Gotthart Maier Metallpulver GmbH (Rheinfelden, Germany) in the quantity of 1700 t.

The material, free from oils and other impurities was characterized by an iron content higher than 90% in weight and a carbon content lower than 4%. The 85% of the iron had a granulometry in the range 0.25-3 mm and all the material was below 5 mm.

The other characteristic parameters of the iron, such as porosity, hydraulic conductivity, bulk density, specific surface area, have been determined and certified by I.M.E.S (2004) and are reported in Tab. 5.

Tab. 5: Average parameters of the zerovalent iron used to backfill the trench.

| **Parameter** | **Symbol** | **Value** |
|---|---|---|
| Total porosity | $\varepsilon_\tau$ | 0.61-0.66 |
| Hydraulic conductivity | $k_g$ | $3.4 \div 7.9 \cdot 10^{-3}$ m s$^{-1}$ |
| Bulk density | $\rho_b$ | $2.6 \cdot 10^3$ kg m$^{-3}$ |
| Specific surface | $S_s$ | 0.56-0.70 m$^2$/g |

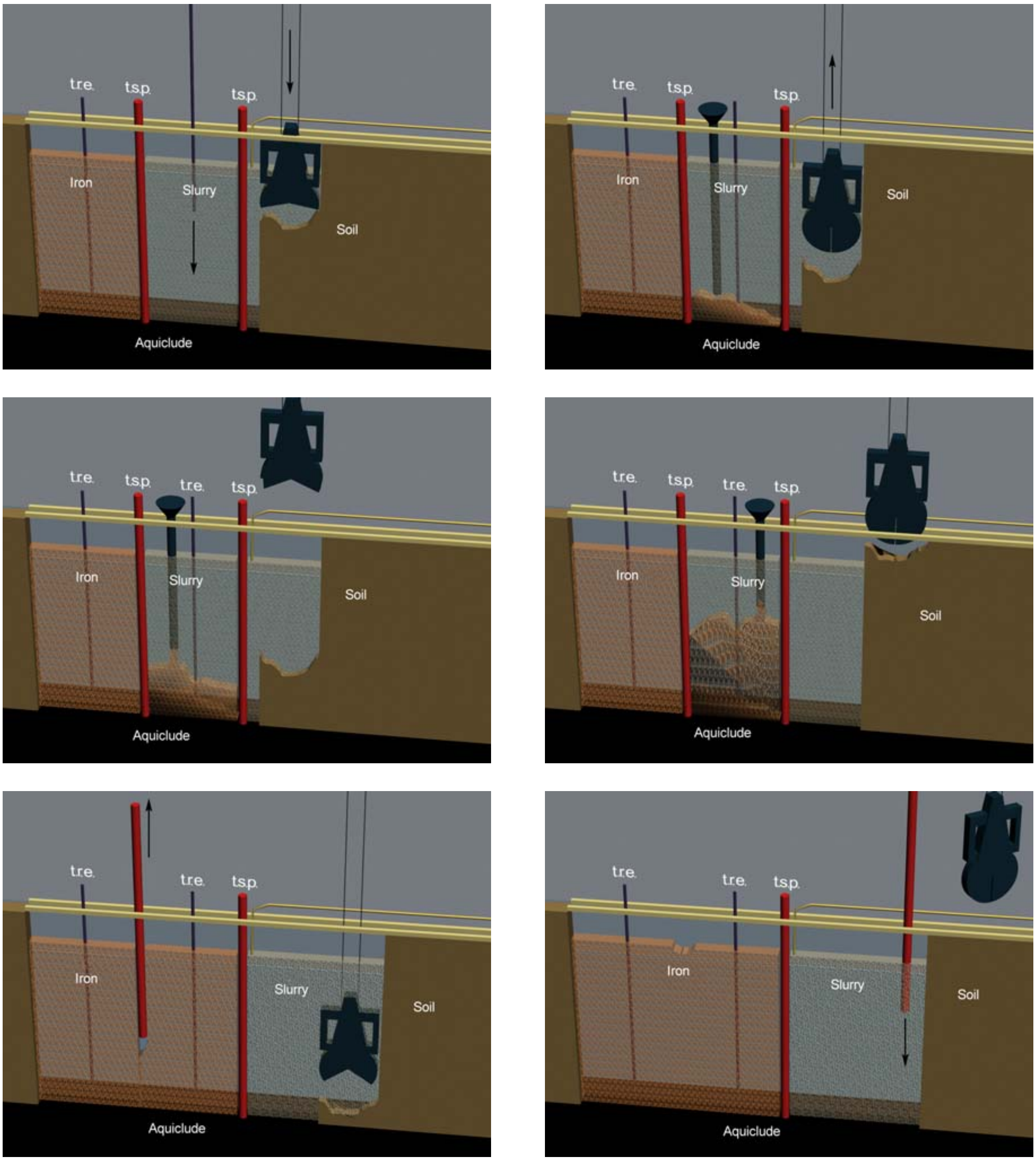


Fig. 3: PRB construction's phases.

## 4.2 Biopolymers and slurry preparation

Biopolymers are biodegradable compounds (i.e. guar gum, xanthan gum, polyacrylamide, carboxymethyl cellulose) that mixed with water form a slurry able to support the excavation walls. The slurry mantains its properties for a time ranging from 1 to 30 days depending on the type, the temperature, the microbial activity and on the quantity of preservatives.

The biopolymer slurry was prepared in a batch mixing plant made up of an hopper for the solids and a dispenser for the liquids (Fig. 4). Each batch was prepared using 3500 l of tap water, 22.5 kg of guar gum and preserved with 2.5 kg of lime stone and 0.2 kg of biocide each time (Marconetto, 2004, Tab. 6). After mixing, the ready made slurry, was stored in recirculated cilindrical tanks. The biopolymer preparation was supervised by Steve Day from Geo-Solutions Inc.

Tab. 6: Products used in each batch of slurry.

| Product | Quantity |
|---|---|
| Tap water | 3.500 l |
| Guar gum | 22.5 kg |
| Biocide | 0.2 kg |
| Lime stone | 2.5 kg |

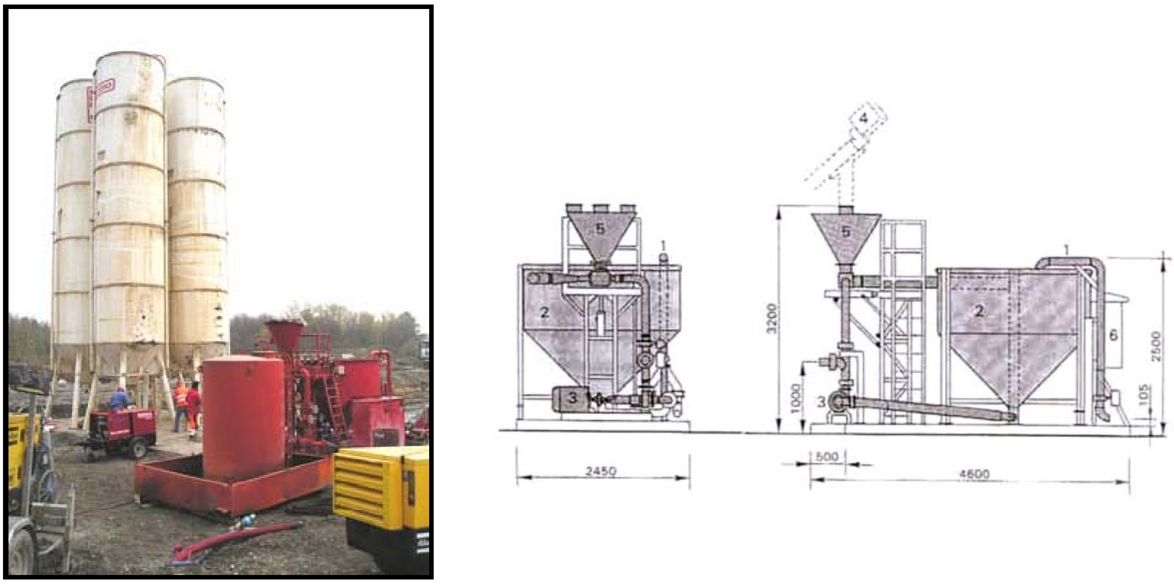


Fig. 4: Storage and slurry mixing plant.

## 4.3 Excavation of the PRB

The trench excavation was executed by Trevi S.p.A. by means of a Link Belt LS338 crawler crane equipped with a Casagrande K4000 hydraulic grab (Fig. 5). The grab was 0.6 m wide, 4 m long and with a volumetric load capacity of 1 $m^3$.

Due to the length of each of the 17 panels, each ranging from 6.00 to 9.65 m, the excavation of every section was performed in two or three operations. At the beginning the lateral portion of the panels were excavated and than, eventually, the central part was removed. The excavation of each panel was extended of 1 meter in the neighbouring panel in order to leave enough room for the insertion of the separation tube (t.s.p.) and to avoid scraping with the grab.

The hydraulic separation of the panels was achieved by inserting, through the concerete crub into the subsoil and till the aquiclude, steel cylindrical separation tubes (t.s.p.). The separation tubes were 15 m long and 0.6 m in diameter provided with two later ribs. After the excavation of the panel and before filling with iron-sand, a slotted PVC tube for the enzymes recirculation (t.r.e.) was inserted.

The iron-sand mix was prepared in two parallel hoppers, loaded on concrete mixers and than placed into the trench trough a tremie pipe.

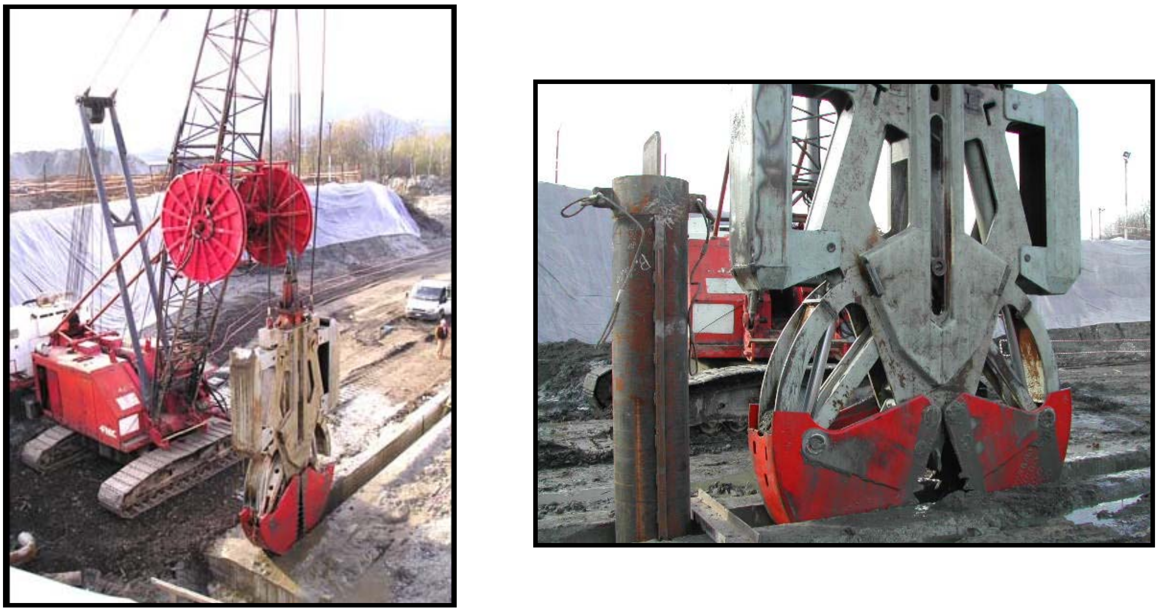

Fig. 5: Crawler crane equipped and hydraulic grab used in the excavation.

The excavation of the barrier using crane digger equipped with hydraulic crab had been so fast that it was possible to realize 3 panels in just 12 hours.

Breakdown of guar gum was initiated by injecting a water solution with 60 l of LGB-10 Apex enzymes into the recirculation tubes (t.r.e.) as shown in Fig. 6. Air lifting was used to pump the enzymes solution inside the barrier and protracted up to 2 PV of water were recirculated. Meanwhile, the chemical bonds of the polysaccharide broke to form soluble oligosaccharides and a small amount of insoluble residue. Breakdown of these residues by microbes results in products of carbon dioxide, water and biomass. At the end of this operation Marsh Funnel viscosity was less than 30 s.

A sand layer and than an impermeable three layered clayey cap was placed on the top of the permeable reactive barrier to provent oxidation of the iron.

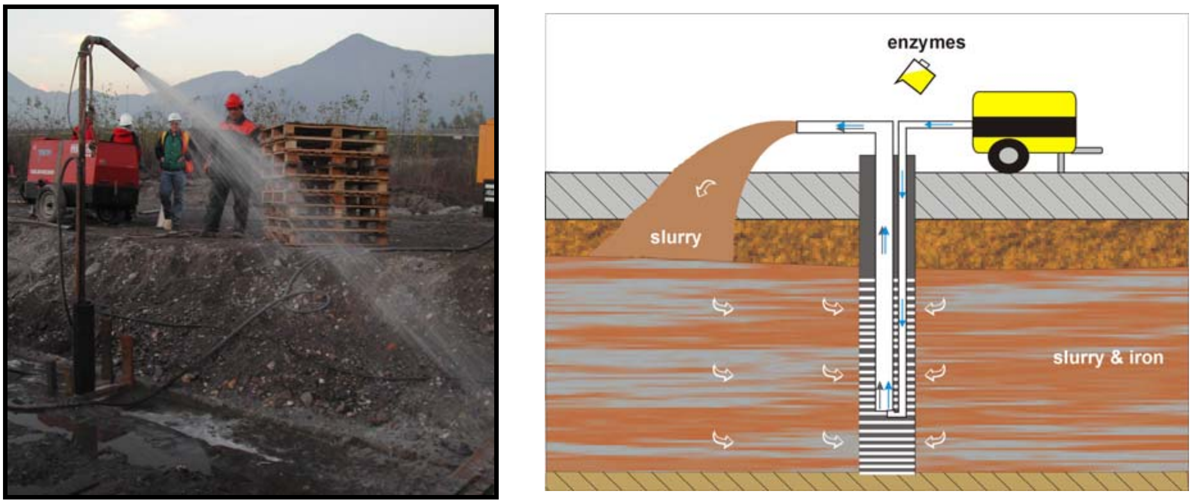


Fig. 6: Degradation of the biopolymer by enzymes recirculation.

## 5. MONITORING NETWORK

The monitoring network of the site is nearly complete and will be made up of 15 new piezometers that will add to the 28 already existing for a total number of 33. In order to monitor the concentration near the barrier, 4 piezometers upstreams, 4 inside, 4 downstream and 2 on the side of the barrier have

been planned. These monitoring wells will be equipped with small diameter centrifugal submersible pumps or with bladder pumps depending on the distance from the barrier.
Chemical sampling from the piezometers was not performed because of the limited amount of time elapsed from the excavation and bioslurry break down.

## 6. COSTS

The total cost of the zerovalent iron PRB installation is about 1.4 M€ and includes:

- supply of zerovalent iron, guar gum, additives and enzymes: 889.500 €;
- construction of the PRB including preparation of the area, excavation and biopolymer preparation: 293.600 €;
- license fee costs paid to E.T.I. and I.M.E.S.: 154.000 €;
- construction of the monitoring network of the PRB: 63.700 €.

The calculation doesn't include the costs due to site characterization and design phases.

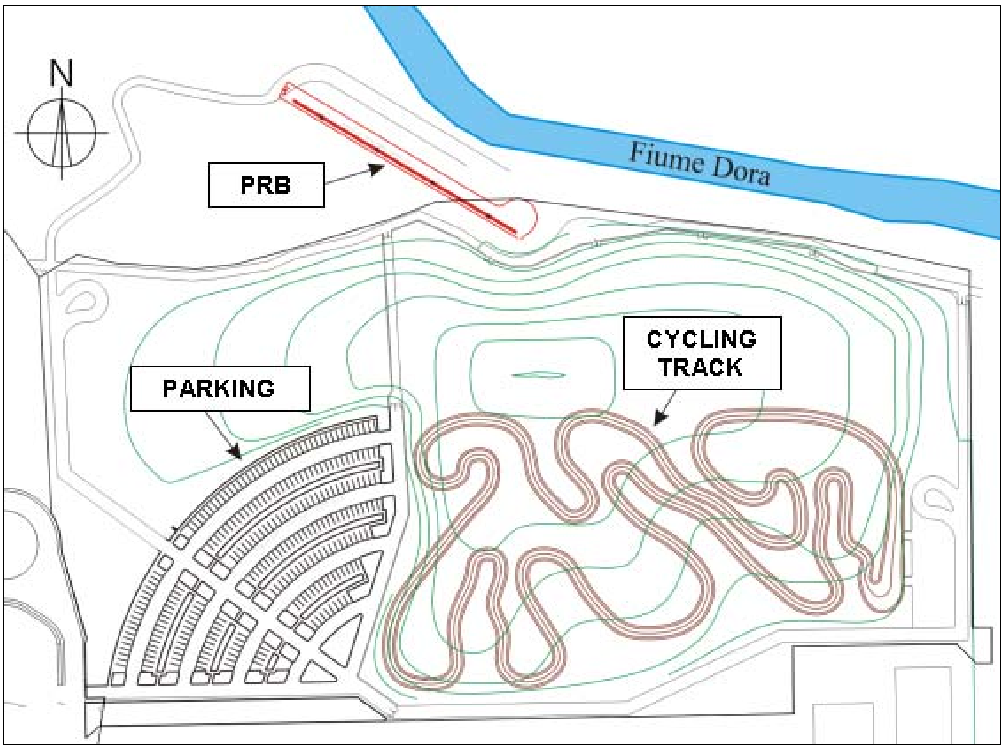


Fig. 7: Final configuration of the area.

## 7. CONCLUSIONS

The construction of the first PRB in Italy by means of a crawler crane equipped with an hydraulic grab showed an oustanding performance compared to the use of stick excavators. In just 8 days it was possible to excavate and backfill a 120 m long and 13 m deep trench with a precision much higher than common excavators can reach. The accuracy of the excavation was also due to the use of a concrete crub to guide the digger.

The final configuration of the site (Fig. 7) will be characterized by a wide car park, a ciclo-cross track and a green capping to prevent the infiltration of water from the ground surface to the shallow aquifer.

The monitoring phase will confirm the effectiveness of the PRB in lowering contaminant concentrations to target levels.

## 8. ACKNOWLEDGEMENTS

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