A low impact technology chemical oxidation, bioremediation and groundwater reinjection analysed with SiteWise™ and SEFA.

Marco Pagano, cm@ecosurvey.it Claudia Mosangini, Alessia Avantaggiato and Roger Midence, Ecosurvey®, Bologna.

Andrii Oleksandrenko, ISA Lille – Yncréa Hauts-de-France.

Riassunto

È stata eseguita un'analisi comparativa degli impatti ambientali associati a tre diverse tecnologie proposte per il risanamento di una falda acquifera sottostante un sito industriale dell'area di Bologna. L'analisi ha consentito di calcolare gli impatti ambientali delle tre alternative di intervento possibili per il sito: [1] sistema estrazione acque sotterranee, trattamento e re-iniezione [2] biorisanamento riduttivo e [3] ossidazione chimica in situ (ISCO). Gli impatti ambientali sono stati calcolati con due sistemi di calcolo dell'impronta ambientale SiteWise™ e SEFA.

Summary

A comparative analysis of the environmental impacts associated with three different technologies proposed for the remediation of an aquifer below an industrial site in the Bologna area was performed. The analysis made it possible to calculate the environmental impacts of the three possible intervention alternatives for the site: [1] groundwater extraction system, treatment and re-injection [2] reductive bioremediation and [3] in situ chemical oxidation (ISCO). The environmental impacts were calculated using two environmental footprint impacts analysis tools: SiteWise™ and SEFA.

1. Introduction

The Italian environmental legislation allows to the application of the "circular economy" principles in the remediation of contaminated sites [4] [5]. Therefore, there is the opportunity to examine former remediation projects under the "green & sustainable remediation" principles [6].

The main purpose of the present work is to compare the environmental impacts associated to the following 3 different technologies aimed to remediate a multi-layer aquifer contaminated by chlorinated compounds and at a minor level by hydrocarbons (Figure 1):

- pump and treat [1] with water reinjection (PT&R) for UA[1];
- anaerobic biological reduction [2] (Biorem) for UA;
- in situ chemical oxidation [3] (ISCO) for UA;
- pump and treat with water re-use in industrial production for DA[2].

Moreover, environmental footprint analysis related to the different remediation technologies have been calculated with the following assessment tools:

- SiteWise™ [7];
- SEFA [8].

The remediation plants are located in the productive area of a bitumen production plant, which has a surface of about 15 300 m^2 and is located near Bologna, close to the Reno river at an altitude of about 40 m above a sea level. The local litho-stratigraphic scheme until about 40 m below ground surface and the two remediation P&T plants, for upper and deep aquifer, are summarized in Figure 1. The acquirers are part of the same regional surface aquifer [9] and they are separated due the presence of a low permeability soil layer.

[1] UA Upper Acquifer
[2] DA Deep Acquifer

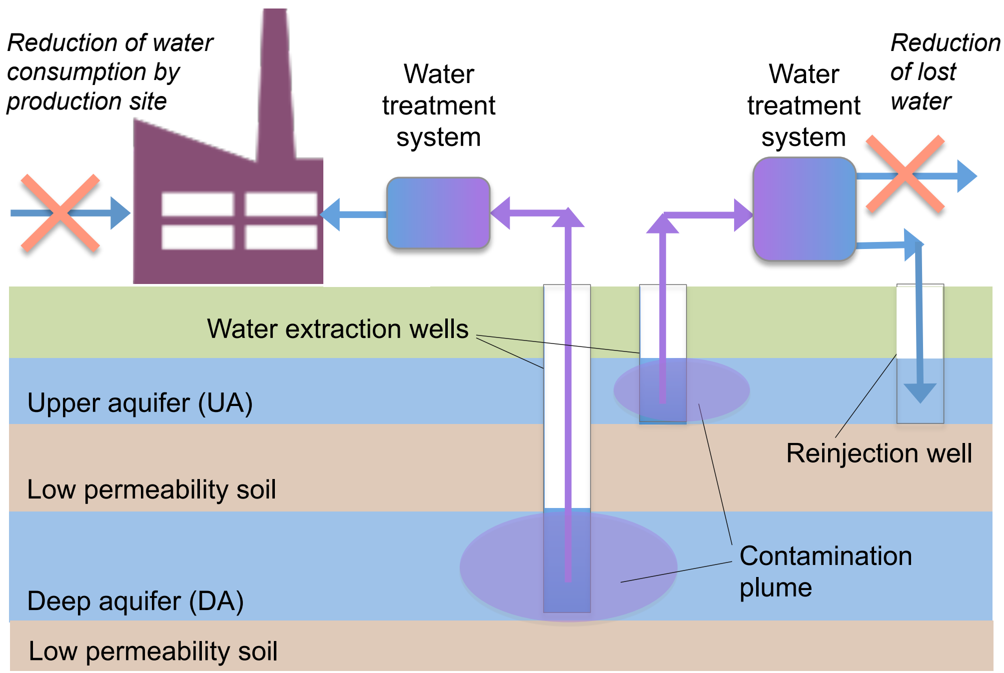

Figure 1 – Scheme of the stratigraphy and PT&R system for the upper and deep aquifers.

2. Activities

According to the site, actual baseline conditions were assumed (Figure 1) and the environmental impacts focused on greenhouse gas emissions, water and energy consumption were calculated for the three remediation options PT&R, Biorem and ISCO for upper aquifer. For the scope of this analysis the deep aquifer was not considered.

The evaluated technologies for the treatment of the upper aquifer are briefly described as follow.

2.1 Pump, Treat and Reinjection (PT&R)

Because chlorinated aliphatic hydrocarbons (CAHs) exist dissolved in groundwater, the extraction of groundwater allows the mass removal of the contaminants. P&T process has been designed to comply with the green remediation principles through the re-injection of the treated water output of the water treatment system (WTS). The configuration of the PT&R system consists on 3 pumping wells that conduct the extracted groundwater to a WTS made by sandy filter units, metals removal units and a set of activated carbon filters for the removal of organic contaminants. Treated water is reinjected in the aquifer through a well instead of discharged to public sewer or to superficial water. The exhausted carbons of the treatment plant are subjected to a regeneration process to avoid waste production.

2.2 Anaerobic biological reduction (Bioremediation)

Because chlorinated aliphatic hydrocarbons (CAHs) exist in an oxidized state, they are generally not susceptible to aerobic oxidation processes. However, oxidized compounds are susceptible to reduction under anaerobic conditions by biotic (biological) processes. Enhanced anaerobic bioremediation is intended to exploit primarily biotic anaerobic processes to degrade CAHs in groundwater [2]. The main on site expected reaction by the injection of the organic enhancer with glycerol (from 45% to 60%), mixed triglycerides and soybean oil (from 3% to 10%) is Direct Anaerobic Reductive De-chlorination. A biological reaction in which bacteria gain energy and grow as one or more chlorine atoms on a CAH molecule are replaced with hydrogen in an anaerobic environment. The chlorinated compound serves as the electron acceptor, and it appears that hydrogen serves as the direct electron donor. Hydrogen used in this reaction is typically supplied by fermentation of organic substrates [10]. The de-chlorination is progressive so that temporary accumulations of compounds with a lower halogenation degree can be observed as indicated in the following path: PCE –TCE-DCE isomers (cis-DCE or trans-DCE)-VC-Ethane.

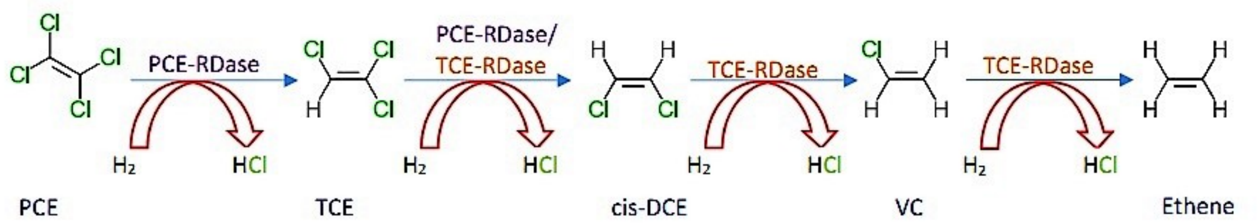

Figure 2 – Anaerobic de-chlorination of CAHs pathway, sequential transformation

2.3 In situ chemical oxidation (ISCO)

In situ chemical oxidation (ISCO) involves the introduction of a chemical oxidizer into the subsoil in order to transform contaminants into less harmful chemical species. There are several forms of oxidants that have been used for ISCO; the four most commonly used oxidants are Permanganate (MnO_4^{2-}), Hydrogen peroxide (H_2O_2) and iron (Fe^{2+}) (oxidation derived from Fenton or H_2O_2), Persulphate ($S_2O_8^{2-}$) and ozone (O_3). The type and physical form of the oxidant indicate the general requirements for materials handling and injection. The persistence of the oxidant in the subsoil is a relevant parameter because it influences the contact time for the transport, advances and diffusion of the oxidant in the subsoil. For example, the permanganate persists for long periods of time which allows a greater diffusion even in materials with low permeability [3]. The ISCO process has been designed considering Potassium permanganate as oxidant.

3. Results (SiteWise^{TM} vs. SEFA)

The comparison analysis was performed using two assessment tools for environmental footprint analysis for the evaluation of the environmental impacts of the remediation project. The tools are SiteWise^{TM} and SEFA which are classified at maximum level of methodologies suggested in Figure 3. This approach requires a high level of the data acquisition (input) and a high level of accuracy of the impact analysis (output) [11], as indicated in Figure 3.

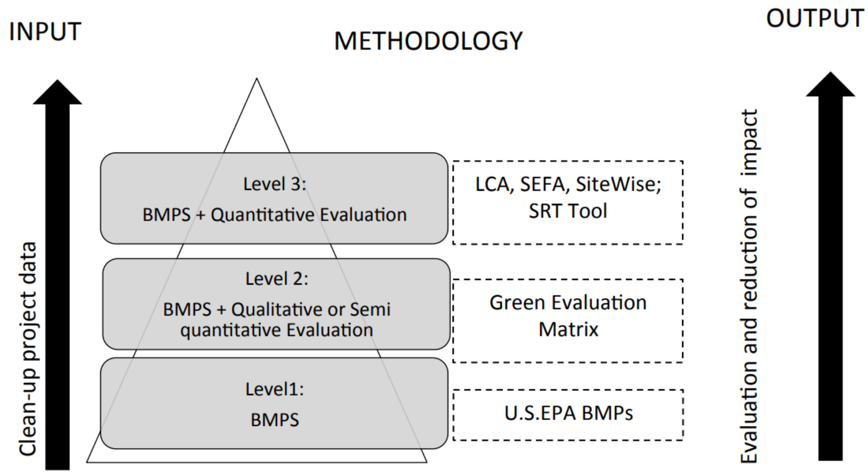

Figure 3 – Comparison of different impacts analysis tools

The SiteWise^{TM} tool is developed by US Navy (NAVFAC), Army Corps of Engineers, US Army and Battelle. The SEFA Spreadsheets for Environmental Footprint Analysis tool is developed by US EPA (Environmental Protection Agency).

Both tools are Excel-based capable to analyse the following main component: material production, transportation, equipment use and residual handling for clean-up activities.

The following table indicates a summary of the calculated environmental impacts, for each remediation option: PT&R, ISCO and bioremediation, projected for one year provided as output for each software. The parameter GHG indicates the sum of the concentration of CO_2, NOx, SOx and PM_{10} emissions.

Parameter	Technology	SiteWise	SEFA
GHG [metric tons]	P&T and reinjection	30	55
	ISCO	40	64
	BIOREM	22	36
Water consumption [m^3]	PT&R	106	-
	ISCO	24	-
	BIOREM	50	-
Energy use [MMBTU]	PT&R	603	908
	ISCO	788	1 558
	BIOREM	438	866

Table 1 Summary output of the one year environmental impact by categories

For this specific site application, the following main differences between the tools have been observed:

- The GHG and Energy used values calculates by SiteWise are lower than those calculated with SEFA. For example, GHG calculated for PT&R by SiteWise are about 45% lower than those calculated with SEFA and for Bioremediation they are about 39% lower;
- SiteWise allows to input consumption water data related to potable water treatment facility, wastewater treatment facility and water resource lost (groundwater or surface water);
- SiteWise output total water consumption due to all activities related to remediation (equipment use due to electricity production, wells perforation, groundwater extraction, filters cleaning etc.);
- SEFA allows to input the water consumption related to Public Water Supply, extracted groundwater, surface water, reclaimed water, collected/diverted storm water and other water resource;
- SEFA provides default footprint conversion factors for energy and air emissions only for "Public Water" and do not output total water consumption;
- SiteWise allows to quantify the accident risk and SEFA not.
- SiteWise allows to compare 4 remediation alternatives and SEFA 6.
- SiteWise output the data in 5 categories (consumables, transportation-personnel, transportation-equipment, equipment use and misc, residual handling) and SEFA in 4 (On-site, Transportation, Grid electricity generation, Other off-site). For example SiteWise divide the impacts for personnel and equipment transportation and SEFA output only the impacts for total transportation.

4. Conclusions

For this specific site application, the following main results have been observed comparing the environmental impacts for the 3 remediation options. The analysis is provided with two environmental footprint analysis tools for the evaluation of the environmental impacts of the remediation projects evaluated.

- Both tools for GHG considering the same period of time show Bioremediation to have less impacts compared to ISCO and PT&R.
- Both tools confirmed bioremediation option as alternative solutions for ISCO and PT&R given the lower levels of environmental impacts.
- For both tools ISCO technology shows higher environmental impacts compared to PT&R and bioremediation mainly cause by the need of the general frequent multiple injection events with Potassium Permanganate in contrast with the general single injection performed with bioremediation.

References

[1] **Cohen Robert M., Mercer James W., Greenwald Robert M., and Beljin Milovan S**. Design Guidelines for Conventional Pump-and-Treat Systems. EPA/540/S-97/504, 1997.

[2] The Parsons Corporation. Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents. AFCEE, NFEC, ESTCP 457 pp, August 2004.

[3] USEPA. Office of Research and Development. 2016a. Pilot-scale demostration of In situ Chemical Oxidation Involving Chlorinated Volatile Organic Compounds. Design and Deployment guidelines EPA 600/R-16-383. https://www.epa.gov/researc

[4] Legge 9 agosto 2013, n. 98. Conversione, con modificazioni, del decreto-legge 21 giugno 2013, n. 69. Disposizioni urgenti per il rilancio dell'economia. G.U. n. 194 del 20 agosto 2013.

[5] Decreto legislativo 3 aprile 2006, n. 152. Norme in materia ambientale. G.U. n. 88 del 14 aprile 2006.

[6] USEPA. Green and sustainable remediation (gsr) guidance document – EPA Region 2 “Clean and Green Policy”, Att. B: Region 2 “Green Checklist”

[7] SiteWise - http://www.sustainableremediation.org/news/2013/10/24/sitewise-version-3-now-available.html. SiteWiseTM develloped in the collaboration of US Navy (NAVFAC), Army Corps of Engineers, US Army and Battelle

[8] SEFA - https://clu-in.org/greenremediation/methodology/#SEFA. SEFA – “Spreadsheets for Environmental Footprint Analysis”, developed by US EPA (Environmental Protection Agency

[9] **Severi P., Bonzi L.** Gli acquiferi dell’Emilia Romagna, 2014. In: Esperienze e prospettive nel monitoraggio delle acque sotterranee. Il contributo dell’Emilia Romagna (Farina M., Marcaccio M., Zavatti A.). Pitagora ed. Bologna, 19-45. (ISBN 88-371-1859-7).

[10] USEPA. Office of Solid Waste and Emergency Response. 2000a. Engineered Approaches to In Situ Bioremediation of Chlorinated Solvents: Fundamentals and Field Applications. Division of Solid Waste and Emergency Response. EPA 542-R-00-008. http://www.epa.gov/clu-in.org.

[11] **R. Baciocchi, G. Costa, C. Di Mambro, F. Polli** (2016) University of Rome “Tor Vergata”, Italy Comparison of different tools for evaluating the environmental footprint of different clean-up options.