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Sustainable management of groundwater resources with regard to contaminated land. RTD needs

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Abstract

Environmental policies for water resources have evolved over time. Some years ago, only emission of hazardous substances into surface waters was controlled. Now, with the enforcement of the Water Framework Directive, water resources are considered as a whole resource that must be protected at catchment scale. The good ecological status of groundwater is a requirement of the Directive, and to address this goal, Member States should implement a programme of measures over the coming years.

The close link between soil and watercycle demands an overall strategy for the management of natural resources. In most industrialised countries brownfields are an origin of groundwater pollution and, in the opposite way, water pollution can be an important source of soil contamination. In order to reach the goal of successfully protecting water resources from point source contamination, some issues should be addressed, like obtaining public awareness of groundwater contamination, permitting activities potentially contaminating, identifying point sources and improving groundwater remediation techniques. Research and technological programmes are vital to achieving groundwater protection. Finally, it is important to involve the stakeholders by means of appropriate, evident and transparent criteria.

1 Introduction

As pointed out, water is the pillar of life. Its quality and quantity determines the quality of our lives and the places where we live, access to clean drinking water is a human right. According to EUROGEOSURVEYS (Eurogeosurveys [1]), of

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the total fresh water amount on Earth (35 x 10^6 km^3), only 0.3% comes from lakes, rivers and swamps. Groundwater is 30.1% of the rest, 69.6% of the remaining water being in the form of ice and snow. Having in mind these figures and taking into account that European countries are facing a significant pollution of groundwater resources caused by former industrial activities, it is easy to understand the increasing awareness of European citizens in relation to water for drinking and bathing, water in rivers, lakes and coastal waters and, in general, water environment.

With the aim of obtaining a sustainable management of groundwater resources effective measures should be taken to prevent and/or reduce the effect of contaminated land on water resources. To date, many industrialised countries have adopted specific legislation to protect groundwater. In the European Union, the Water Framework Directive has come into force on 22 December 2000, and has a strong quantitative component, i.e. a long-term balance between abstraction and natural recharge. On the other hand water pricing will be a major element to conserve adequate supplies (Blöch [2]).

It demands the development of cost effective in-situ treatment technologies. The Member States must prepare a programme of measures to attain good surface water and groundwater status by the end of 2010. To reach this ambitious goal, not only the application of innovative technologies for the remediation of contaminated groundwater must be promoted, but also field demonstrations, bench studies and technology evaluations are needed (Grima and Lopez [3]). Active treatment technologies and passive containment technologies must be investigated for use in cleaning up contaminated groundwater

The Water Framework Directive and future regulations derived from it establishes the necessity of remediation of groundwater masses but, in practice, achieving groundwater cleanup objectives is not possible due to the extent and persistence of contamination. In these situations of technical impracticability even if a cleanup approach is technically feasible, the scale of the operation (EU wide scale) may make it impossible so a more **risk-orientated approach** may be used. In this sense the concept of Risk Based Land Management (CLARINET [4]) was developed as one of the main products of CLARINET Concerted Action (Contaminated Land Rehabilitation Network for Environmental Technologies. The project was funded by DG Research of the European Commission under the 4th Framework Programme for Research and Technological Development, with representation of sixteen European countries.

2 Interdependence water-soil in contamination processes

The environmental problem of polluted sites has been recognised on a European level many years ago. While on the side of water resources, Water Framework Directive has provided a set of principles for the management of water pollution at catchment scale, the EU has not developed a specific soil protection policy (European Commission [5]). Although Water Framework Directive will provide a legislative driver for the remediation of contaminated land (Darmendrail and

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Harris [6]), there is a real need of an integrated assessment for the management of contaminated sites.

In such an assessment land represents a geographical area, and also includes the soil, surface water and groundwater beneath the surface of the land, adding a third dimension to the traditional spatial planning interpretation of land (Vegter [7]), (Kasamas and Vegter [8]). On these broader basis as traditionally used in the context of soil contamination is that arises the concept of Risk Based Land Management as an output form CLARINET. This is in line with the requirements of the Water Framework Directive, as the management of contaminated land can contribute on a long-term basis to the protection of groundwater and superficial water in a sustainable way.

As water is in soil and soil is the receptor of many pollutants, there is a close link between soil and watercycle. It is, therefore, necessary make an integration of groundwater in decision support systems for contaminated land.

From the scientific side to assess the risk of groundwater pollution particular attention should be paid to pollutant transfer from soil to groundwater. Due to the complexity of the processes involved many idealisations and simplifications are usually required (Fergusson, et al [9]). It means that there are many scientific and technical uncertainties in contaminated land decision making. Managing these uncertainties means not only the introduction of concepts like probabilistic approaches, but also involving stakeholders in the management of risks.

Finally, a number of issues have close relation with contaminated land business and may affect management and decision support systems. Relevant topics include the following:

- Intensive agricultural land use practices can be the origin of diffuse contamination (mainly due to nitrates) and lead to high levels of consumption. It may originate the drinking water not to meet the standards and eutrophication of surface waters (Kasamas, et al [10])
- Erosion can lead to desertification and so affect the quality of soil
- Overexploitation of groundwater can produce seawater intrusion in coastal aquifers, especially in Mediterranean countries
- Rising groundwater levels in urban areas may originate an interaction of groundwater with overlaying urban contaminated lands. It sometimes produces a flushing effect as well as physical-chemical changes that mobilises contaminants
- Interaction of seawater with contaminated soils. Some immobile or scarce-mobile contaminants, such as heavy metals, may mobilise as a consequence of salinity changes in the physical medium

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3 Legal framework

The approval of the Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control (IPPC) [11] and the Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy or, in a short way, the EU Water Framework Directive [12] published in the Official Journal (OJ L 327) on 22 December 2000, expresses the significant efforts that the European Union is facing up to prevent and control the industrial contamination and to ensure the good quality and quantity of water.

The purpose of the IPPC Directive is to achieve integrated prevention and control of pollution arising from industrial activities listed in Annex I of same. The way to tackle it is summarised as follows:

1. Integrated proceedings of permits, granting authorisation to operate all or part of an installation, subject to certain conditions, which guarantee that the installation complies with the requirements of the Directive
2. Establishment of emission limit values expressed in terms of certain specific parameters, concentration and/or level of an emission, which may not be exceeded during one or more periods of time
3. Transparency of the proceedings through the access to information and public participation in the permit procedure
4. Exchange of information between Member States and the industries concerned on best available techniques, associated monitoring, and developments in them.

With regard to the new authorisations or integrated permits, above point 1, the emission limit values of contaminant substances specially those listed in Annex III, should be specified. These new authorisations should also include the prescriptions to guarantee soil and groundwater protection.

The main goal of the EU Water Framework Directive (WFD) is the establishment of a protection framework of continental groundwater and superficial water, as well as coastal and estuary water in the European Union, through several objectives like: drinking water and other economical needs supply; environmental protection; diminishing the effects of drought and floods. Some of the principles in which the WFD is based on to achieve this objective, also in agreement with the IPPC Directive, are the following:

1. Expanding the scope of water protection to all waters, surface waters and groundwater. The protection of human health, water resources and natural ecosystems has a priority status
2. Achieving "good status" for all waters by a set deadline
3. Water management based on river basins
4. "Combined approach" of emission limit values and quality standards
5. Getting the prices right
6. Getting the citizen involved more closely
7. Streamlining legislation

From the above paragraphs it may be inferred that the aim of the environmental legal framework in the EU is clearly focused on protecting the quality and

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quantity of water resources in order to ensure human and economical supply, as well as obtaining a high quality status for all the masses of water in the EU. Other key subject is also the effort to generate a transparent legal framework through easy access and exchange of information, and the involvement in awareness of the citizens in the environmental problems.

However, no new emission limits of contaminants have been established in these two Directives, and it seems to be one of the main goals where the future legislative efforts should be focused on. Until that date, the applied limits will those specified in the Directives listed in the Annex II of the IPPC Directive.

Within this framework, the sustainable management of water resources and already contaminated lands appears to be one of the most powerful tools in the future environmental policy of the European Union.

In addition new legislation in relation to management of soil and water resources is being developed in the E.U. Examples of it are:

- EC Draft Directive [13] on prevention and restoration of significant environmental damage (environmental liability). Fault-based liability is also proposed for any other activities, which cause damage that affects the favourable conservation status of biodiversity
- A daughter Directive on quality of groundwater and the standards to be set is being drafted in 2002
- A Soil Directive is being designed. As a first step, a Commission Communication on soil issues is expected to be developed until mid 2002

4 Technological development in groundwater protection and remediation

A coherent RTD strategy is needed in order to obtain cost-effective methods and improve sustainability of groundwater remediation. The remediation time frame for a groundwater remedy should be kept within reasonable limits. The right application of the existing techniques, as well as the development of new ones to be applied on problematic aquifers (low permeability, fractured formations, high depths), is shown to be a main goal for future investigation programmes. Comparative studies to determine the effectiveness of multi-technique sequences where biological, chemical and physical methods are combined are also lacking.

4.1 Development of new technologies

Before a specific remedial technology has been selected, some investigation must be carried out, to determine the extent of the contamination and pollutant fate and transport. In this context the relationship between surface water and groundwater is an important issue to be studied. The following issues may be addressed:

- Development of simple (non-intrusive) methods of site investigation.

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- Methods to asses the natural potential of soil and the unsaturated zone to attenuate contaminants, and techniques to monitor the processes.
- Key processes controlling the quality of groundwater/surface water and their interactions.
- Interactive metabolism of contaminants in aquifers.
- Free phase fate and transport.
- Modelling of aquifers paying special attention to fractured and non-homogeneous ones.

4.2 Improving groundwater remediation techniques

We are far from having a set of techniques able to decontaminate every kind of aquifer in a sustainable way (Arctander [14]). In this regard, research needs for improving the effectiveness of groundwater remediation techniques have been short-listed.

- Remediation in low permeability formations and those aquifers where low hydraulic conductivity hinder the use of classic techniques. Low hydraulic conductivity does allow neither air nor solutions injection as well as hinder contaminated groundwater removal
- Influence of rising groundwater tables in urban areas where there is a land contamination.
- Methods to assess interaction of seawater with contaminated soil in coastal aquifers.
- Remediation techniques for inorganic substances and compounds, since most of modern day techniques are specific for organic contamination.
- Genetic information needed by specialised microbes to produce the required enzymes in order to degrade specific contaminant substances, as well as effectiveness of genetically manipulated organisms.
- Vulnerability of microbes to certain substances that produces inhibition of bioremediation techniques.
- Toxicity of by-products generated by the application of remediation techniques.
- Development of new non aggressive methods in order to increase the solubility of contaminants to enhance their movement and removal, avoiding the destruction of the basic aquifer structure as well as the undesirable presence of residual reagents.
- Improvement of methods for dissolving heavy metals in their metallic state, present in the pores of aquifers.
- Optimisation of remediation multitechnique sequences.
- Analysis of geochemical stability systems in order to determinate the dissolution / precipitation potential of metals according to the Eh-pH changes produced in aquifers during the application of remediation techniques.
- Degradation processes of contaminated vapours in the vadose zone, as sub-products of remediation.

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- Investigation on new plants with potential phytoremediation application, as well as genetic engineering to improve their natural capabilities.
- Determination of processes of accumulation and degradation through plant metabolism, in order to determinate the enzymes that breakdown complex organic molecule into simpler $C0_2$ and H_2O ones. The goal of this investigation should be the synthesis of those enzymes.
- Recovery of metals from enriched plant material in phytoremediation techniques, intended for their removal from the environment and / or the food chain.

4.3 Monitoring of remedial performance

It is essential to verify success of aquifer cleanup operations as well as to detect changes in environmental conditions, control the presence of toxic transformation product and verify possible undesired spreading of the plume. A facility should monitor until the groundwater cleanup levels are met at the point of compliance for both protection (new pollution) and remediation of water resources (past pollution). Furthermore, to evaluate data and support decision-making, statistical methods should be also improved.

Basically, systems of groundwater quality control are focused in the definition of a monitoring network, and precise detection techniques of pollutants. For a proper definition of a control network hydraulic and hydrogeological characteristics of the aquifer should be determined prior to remedial activities, so concentration, distribution and movement parameters of contamination in the subsurface can be modelled. To achieve this goal, new investigation programmes on hydrogeology and aquifer modelling should be carried out.

Once the monitoring network has been designed and performed, sufficiently accurate analytical detection techniques should be employed in order to detect small concentration changes. Development of new techniques and improvement of previous ones should be achieved.

5 Implementation of risk based land management

During last decades pressures in land use have strongly increased. In the European Environment Agency report, the Dobris Assessment, it is mentioned in its chapter on soil degradation, that data on contaminated sites are not suitable for aggregation in a consistent manner. In addition, European countries have different legislative and procedural approaches to the problems of groundwater protection and remediation of groundwater contamination (Darmendrail [6]). On the other hand, there exist a number of similarities in the management of contaminated land in most European countries. For example, management is handled at a regional level. Moreover, Water Directive provides a common legal framework for European countries and can be a driver for the remediation of contaminated land. Implementation requires an integration of differences and consideration of environmental and spatial planning perspectives. The former is

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focussed on the impact on contamination on human health and environmental quality, and the latter deals with the management of impact on contaminated land on the way land is used, for example regenerating industrial areas, or increasing agriculture use, or for creating a nature area.

For the protection and remediation of groundwater quality in relation to contaminated land sites risk assessment approaches are used in most European countries. The main principles that underlay risk assessment are the definition of the sustainability of the resources, prevention of new pollution and remediation of past pollution if necessary to protect human health or the environment (Darmendrail and Harris [6]) (Ferguson [15]).

Related to the implementation process itself, some conditions must be fulfilled for the legislation to have the desired effect. First, the legislation must be appropriate for the protection and remediation of water resources. Secondly, responsible authorities must be capable of driving the process, and finally, financial instruments must be provided. As stated by the Ad Hoc International Working Group on Contaminated Land (Ad Hoc International Working Group on Contaminated Land [16]):

> "Most industrialised countries have developed laws on the protection of groundwater. Following the principle of precaution, most of these laws require the maintenance of the multifunctionality of all groundwaters. These requirements are mostly very stringent, but their implementation pose enormous financial problems, as complete decontamination and the aftercare measures to ensure continued effectiveness of the long-term in cases of only partial decontamination or containment of the contaminants are very expensive. It is therefore necessary to examine these laws from the point of view of the contaminated sites management and to consider another philosophy of groundwater protection"

This philosophy must consider longer time perspective of sustainable environmental management, and can be characterised by three elements (Vegter [7]):

- Suitability for use. It focuses on the quality of the land for uses and functions. In relation with water resources Water Framework Directive considered groundwater as a resource to be protected from any change. In fact, one of the goals is achieving a good ecological status of groundwater masses.
- Protection of the environment. Environmental protection of soil and water resources with the aim of preserve, protect and improve their ecological quality and to establish a sustainable way on utilisation of these natural resources
- Long-term care. Reduction of aftercare is needed in order to avoid solutions that need control and maintenance during long periods of time.

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Taking account of these factors brings up a requirement to improve the ideas on to date contaminated sites clean up and to improve risk management strategies. Natural Attenuation is not a new strategy (Müller [17]) and, moreover, it is not a "do nothing" approach. Hopefully, evolution of remediation techniques will bring new procedures to define acceptable levels of residual pollution and remediation objectives on a site-specific basis.

6 Conclusions

Interaction between water and soil is an important environmental problem, so successful implementation of Water Framework Directive has to involve land management. Although Water Framework Directive will provide a legislative driver for the remediation of contaminated land, there is a real need of an integrated assessment for the management of contaminated sites. In such an assessment land represents a geographical area, and also includes the soil, surface water and groundwater beneath the surface of the land.

The Water Framework Directive is highly precautionary in its approach to preventing new pollution and issues the need of remediation of damaged groundwater masses to attain good quality status by the end of 2010. Reaching those groundwater cleanup objectives in time is fairly unattainable due to technical and scale impossibilities. However an orientated approach may be achieved, developing new remediation technologies, optimising the application of existing ones and using proper monitoring techniques. Natural Attenuation although not widely accepted must be investigated as the only viable remediation option in many cases.

Investigation should be focused, among other, on problematic aquifers where present day applied techniques have failed due to their heterogeneous hydraulic behaviour or high operating depths, as well as the application of new technologies such as genetic engineering in order to improve bio and phytoremediation techniques. Typifying proper remediation multitechnique sequences shows to be a main objective in orders to optimise the existing techniques.

It is likewise important to improve the Knowledge State of aquifers to be cleaned up, by mean of hydrogeological investigation and modelling, prior to the application of remedial activities and the establishment of monitoring networks. The latter is essential to verify the success of cleanup operations, and therefore extra effort should be carried out to improve the design, the data processing and the analytical pollutant detection techniques.

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