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Foreword

Trends in Soil, Sediment and Groundwater Quality Management

Soil, groundwater, surface water and sediment systems play an important role in quality of life. The harmful effects of chemical pollution of such systems have been a concern for politicians, the public and scientists for decades. More than half a century of experience in soil and groundwater quality management gives the opportunity to abstract some interesting trends in societal responses, and how these relate to cost effective research and management approaches (Fig. 1).

1. Early Awareness

Sixty years ago, diffuse pollution of pesticides such as DDT, recalcitrant industrial compounds and metals like Cadmium, Chromium and Mercury generated the first awareness of the harmful effects of chemicals upon entering terrestrial-aquatic ecosystems. Rachel Carson's famous book *Silent Spring* initiated the first calls for environmental protection in 1962. The full extent of chemical soil and water pollution had, at that time, yet to be revealed.

2. Crisis Triggered Response

In the 1970s and 1980s, the problem of soil, sediment and groundwater contamination became clear in Europe and North America by a series of local pollution situations directly affecting the quality of human life. Instances such as Love Canal in New York and Lekkerkerk in The Netherlands are two well-known examples (Glaubinger et al., 1979; Rushbrook et al., 2006). Other cases soon emerged, such as heavy metal pollution around mining and metal production areas, which negatively affects agriculture, fisheries, and human health. Petro-chemical pollution around industrial production areas, energy and transport sites, and at former gas manufacturing plants started to block real estate development and to threaten the quality of groundwater resources, used for drinking water production or other purposes. All these events aroused a strong public awareness, triggering demands for immediate policy and mitigation actions. Regulations needed to be implemented and site remediation programs had to be initiated, however, a mature scientific and technological knowledge base had not yet been developed to support such measures.

3. Science Based Response

North American and European states responded in the 1980s and 1990s by establishing protection policies and extensive soil quality inventory programs. Since then, millions of sites have been identified as polluted, with the estimated remediation costs increasing exponentially with time to hundreds of billions of Euros. The multi-functional remediation goals as demanded by regulators combined with a very limited technology portfolio (pump and treat and excavation coupled to *ex situ* thermal treatment and soil washing), created unmanageable restoration programs requiring budgets too high to be carried by EU-member states and polluted site owners. Research programs were funded to build up a new knowledge base supporting cost-effective solutions and a scientifically schooled community at universities, institutes, ministries, environmental protection agencies, industrial sites and private-sector environmental businesses. These newly formed networks set up two leading international conference series, ConSoil – now AquaConSoil – in Europe and On Site and *in situ* Soil Reclamation of Batelle in the USA, to share among all stakeholders knowledge on and the latest developments in policy, science, technology and management of soil, sediment and groundwater quality. Various networks were created, facilitating interactions within Europe, and between Europe, North America and other parts in the world (Table 1). Transdisciplinary research programs with involvement of stakeholders were established that proved to be essential in finding new optimal solutions.

During the last thirty years, soil and groundwater policies and remediation approaches developed progressively. Policies changed from multi-functional threshold and target value oriented approaches to risk-based receptor-oriented protection. The practice of remediating regardless of the cost started to be questioned (Hamilton and Viscusi, 1999), and remediation alternatives were extended from pump-and-treat and intensive *ex situ* treatment towards *in situ* bioremediation and natural attenuation. A better insight into the potential and limitations of the self-purification capacity of soils, sediments and groundwater systems was established, giving way to scientifically sound application of natural attenuation and in situ bioremediation. Both *ex situ* and *in situ* based mitigations are now equally well accepted. In many countries, environmental regulations and policies now take the functional use of soil and groundwater to frame reclamation measures (Swartjes, 2011).

Additionally, the problem of diffuse pollution as originally described by Carson, (1962), was intensively studied. The ecotoxicological effects of chemicals were coupled to fate and transport assessments. This revealed that many chemicals can affect ecosystem and human health through bio-uptake via food, (drinking) water, inhalation, and ingestion of soil or dust particles. This has led in Europe to the establishment of REACH (Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals) (EU, 2006), to allow industrial and pesticide chemicals only to enter the market when demonstrated to be environmentally safe.

4. Integration and Innovation

Around the year 2000, it became clear that dealing with soil and groundwater pollution in isolation generally does not yield optimal

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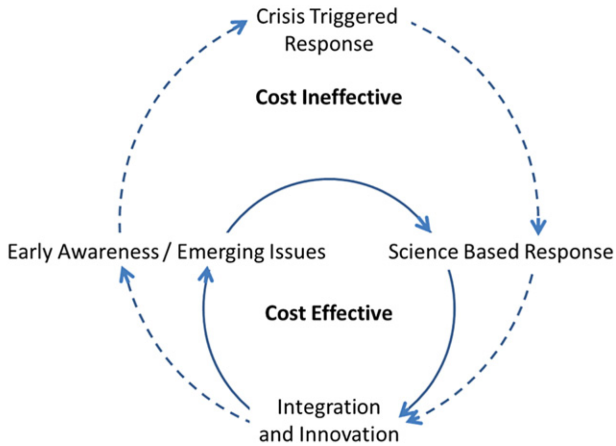

Fig. 1. Responses in Soil and Groundwater Quality Management related to Cost-Effectiveness.

solutions, and wider integrated approaches came into development (Nasiri et al., 2007). In Europe, this was to a great extent triggered by the European Water Framework Directive and the inclusion of groundwater quality in river basin management plans that were established during the last decade. Moreover, in many urban and industrial situations, pollution in soil and groundwater is distributed over larger areas and in complex situations, especially at so called Megasites and Brownfields (Angold et al., 2006; Wedding and Crawford-Brown, 2007; Wycisk et al., 2003). Here, pollution mitigation measures need to be integrated into an overall assessment of surface and groundwater interactions (Petelet-Giraud et al., 2007) and redevelopment plans must adequately revitalize socio-economic and biodiversity functions (De Sousa, 2003). Here, pollution assessment and mitigation needs to be considered in interaction with the renewal of housing, infrastructure, landscape, sustainable water and energy supply, and financial challenges. In Europe, national and European research programs and networks strongly support these integrative approaches (Table 1).

Large and small scale site specific solutions also triggered innovations in new technologies and concepts. During the last three AquaConSoil conferences, many of such topics were presented in this field, including functional and ecosystem services based site redevelopment, green remediation, subsurface energy storage combined with groundwater remediation, zero-valent iron nanoparticles for *in situ* bioreactive barriers, and biphasic remediation (*in situ* Chemical Oxidation followed by Biological Remediation), among many other examples. These approaches also require novel technological innovations in soil and water quality assessment and monitoring, for instance based on non-invasive site characterization methods. Another promising development is the use of molecular techniques to assess microbial populations in soils and groundwater, and natural biological and geochemical capacities for self-purification and engineered chemical or biological remediation (Sutton et al., 2014). These approaches may prove to be very important for new types of chemicals, categorized as organic micropollutants, recently discovered in surface water and groundwater systems, for which their environmental effects are largely unknown (Luo et al., 2014).

5. Cost Effectiveness

A significant change was accomplished in policy and mitigation of soil and groundwater quality from the time of the first discoveries of polluted

Table 1
International Networks on Soil and Groundwater Quality Management since 1980.

Network	Initiation	Partners and Thematic Orientation
Superfund US EPA	1980*	Superfund is technically called the Comprehensive, Environmental Response, Compensation, and Liability Act (CERCLA), enacted in 1980 with authority with the EPA, that first published the Hazard Ranking System (HRS) in 1981 to identify hazardous sites requiring remediation. The National Priorities List (NPL) was first published by the EPA in 1982, giving a list of sites eligible for long-term remediation under the Superfund program. This list continues to be used and updated.
AquaConSoil	1985*	AquaConSoil is organized by Helmholtz Centre for Environmental Research UFZ (Germany) and the Netherlands Research Institute Deltares and is Europe´s largest conference on applied-knowledge of management of quality of soil-water systems. It was originally started under the name ConSoil by TNO (The Netherlands Organisation for applied scientific research) and Karlsruhe Nuclear Research Centre (KfK later FZK).
NATO/CCMS Pilot Studies	1986*	The Committee for Challenges to Modern Society (CCMS), is oriented at transfer of technological and scientific solutions and experiences among NATO member and other nations. The Pilot Study series examined soil and groundwater remediation technologies and management approaches.
NISRP-NOBIS-SKB	1986*	Netherlands Integrated Soil and Sediment Research Program (NISRP), later followed by Netherlands Research program on In Situ Bioremediation (NOBIS) and Soil and Groundwater Knowledge Transfer Network (SKB) for remediation practitioners.
In Situ and On Site Bioreclamation	1991*	Batelle Memorial Institute (USA) initiated a series of International symposia on soil, groundwater and sediment bio-reclamation, and later also specific series on chlorinated and petroleum hydrocarbons.
EUROSOL	1992	EUROSOL conference on soil quality management, initiated by the NISRP in collaboration with other EU member state soil research programs.
IWGCL/FAO-OECD	1993	Ad Hoc International Working Group for Contaminated Land: Environmental agencies from 20 different countries worldwide and FAO and OECD.
Common Forum	1994*	The Common Forum for Contaminated Land in the European Union: Member States, the European Commission and the European Environmental Agency (EEA).
ITRC USA	1994*	Interstate Technology and Regulatory Council in the USA was formed to reduce barriers to the application of innovative remediation environmental technologies by improving regulatory acceptance of new approaches and remediation and knowledge transfer.
CARACAS	1996	Concerted Action on Risk Assessment for Contaminated Sites in Europe
NICOLE	1996*	Network for Industrially Contaminated Land in Europe, consisting of Industrial End Users, Service Providers and Scientists
EEA European Topic Centre on Soil (ETC./S)	1996*	The European Environment Agency (EEA) initiated the ETC./S as part of its strategy to collect, generate and provide objective, reliable and comparable information and data on environmental issues in Europe.
CLARINET	1998	Contaminated Land Rehabilitation Network for Environmental Technologies
SAFIRA	2000	Regional Contaminated Groundwater Research Programs and Network Mid-Eastern part of Germany coordinated by UFZ
EUROSOIL	2000*	EUROSOIL is an international pedologic conference which was realized for the first time in Reading, Great Britain in 2000.
SedNet	2002*	SedNet was funded by EC DG-Research under the 5th RTD Framework Programme in the field of 'assessment of fate and impact of contaminants in sediment and dredged material and at sustainable solutions for their management and treatment'
SNOWMAN	2003*	Started as ERA-NET under the 6th Framework Program from the EU: EU member state joint funding for collaborative research on soil and groundwater management.

*) Network still active