# Scientific and Research Needs for Contaminated Land Management

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Abstract

*This paper identifies major concerns which have been voiced about contaminated land problems in Europe. Research needs are a priority in respect of site characterisation, protection of water resources and bioavailability. The development of theoretical and practical tools to assist in decision-making, use of models, dealing with risks, risk comparison, perception and communication of risks are discussed. Recommendations are made where well-focused and integrated RTD initiatives have been identified and are most urgently needed.*

Key words: problem catalogue, contaminated land, CLARINET, RTD needs

## INTRODUCTION

Integrated, multidisciplinary research activities are essential to provide decision-making tools for the sustainable management of contaminated land in Europe. CLARINET has identified and summarised these research, technological development and demonstration (RTD) priorities. These suggestions have been passed on to the European Commission, DG Research (12) to help the EC Framework 5 RTD Work Programme towards real-world problems and integrated solution approaches. They have also been used to stimulate international collaboration between national R&D Programmes in Europe (see van Veen *et al.*, this issue). The identification of RTD needs was based on a survey of perceived problems with contaminated land for a range of stakeholders. The problems reported were compiled as a 'Problem Catalogue'(available in draft format on the CLARINET website *www.clarinet.at*). This paper identifies major concerns about contaminated land in Europe, and where well-focused and integrated RTD initiatives are urgently needed.

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## BETTER METHODS FOR CONTAMINATED LAND MANAGEMENT

### Risk assessment

Contaminated land risk assessment is still underpinned largely by scientific research carried out for other purposes. The nature of the risk assessment is to a large extent determined by the availability of these more or less useable scientific building blocks. Whether current assessment procedures really address the question of risk in a rigorous, quantitative way is not completely clear. Further development and integration of the building blocks needed for risk assessment is of the utmost importance if assessment is to be more than a mere sequencing of separate disciplines like soil and water sampling, chemical analysis, exposure modelling and toxicology. In a fully integrated approach, choices of toxicological endpoints have consequences for the design of sampling schemes and exposure models, and *vice versa*. Uncertainties at each stage in the assessment should be recognised and may lead to the use of probabilistic or other techniques for dealing with uncertainty. Decision-support systems may provide guidance for risk managers to help balance reduction of uncertainties against the costs of additional investigation. Integrated risk assessment procedures have yet to be fully developed, and progress will depend on research in two main areas:

- the nature of contaminated land; dealing with the identification and analysis of pollution and its impact on human health, water resources and other environmental receptors; and
- the relationship between soil and water contamination and fitness for use; specifying the conditions for sustainable land-use in urban and rural areas, and remediation.

### The nature of contaminated land

This research area encompasses the development of techniques, methods and procedures to assess soil and water pollution (and their relationship) and to establish the scale and intensity of the pollution in such a way that the consequences for land-use and environmental protection can be assessed. Soil and groundwater pollution is dynamic. Pollutants may degrade, disperse and transform with time. Hence, risks may decrease or increase in time, depending on land-use, soil and aquifer characteristics. The dynamic interplay between these factors must be understood in order to predict future impacts, to maintain risk management, and to assess the various options available for remediation. Three interlinked themes for research have been distinguished: site characterisation, protection of water resources and bioavailability.

#### *Site characterisation*

Site investigations should provide much of the data necessary for exposure analysis and risk assessment, and must also quantify the uncertainties associated with site characterisation. The linking of site investigation to exposure analysis and evaluation of uncertainties needs further development in most countries, and requires scientific research in the following areas.

- *Robust and rapid low-cost techniques for investigating potentially contaminated sites*

  Robust and low-cost techniques are needed that are able to provide the necessary and sufficient data. These data need to be collected during investigations for human toxicology, ecological risk assessment, fate and transport analysis and modelling. Better techniques need to be identified, developed and field-tested. Often a phased approach is used in site investigation, so assessment tools must be developed at various levels of sophistication. For preliminary investigation more extensive use of non-intrusive investigation methods is highly desirable. The use of geostatistics and regionalised variable theory should be explored further.

- *Improved methods for estimating and interpreting the accuracy and likely variability of the whole sampling and analytical process*

  Two aspects are important here: first, the quantification of accuracy and variability, and second their quality assurance. Quality assurance and quality control are important for all aspects of site characterisation to ensure reliable results. The need to assess variability and accuracy may encourage the use of statistical approaches that do justice to the notion of risk as a probabilistic concept. The value of probabilistic risk modelling may critically depend on the statistical soundness of the results of site investigations.

- *Methods that yield information at spatial scales relevant for exposure assessment*

  At present contaminated land is investigated with methods primarily derived from soil mapping. Although generally considered a useful starting point, these methods do not yield all the information needed for assessing exposure to soil pollution. Depending on the heterogeneity of the soil and the spatial scale at which various exposure routes operate, information may be needed on a more refined scale than current methods seem to provide. Information on the spatial scales most relevant to human and ecological risk is generally lacking, and is of the utmost importance for the development of integrated risk assessment procedures.

- *Characterisation by biosensors and bioassays*

  Current practice in contaminated land risk assessment starts with a chemical characterisation of the site. Biological effects and risks are then assessed by interpreting the chemical data in biological or toxicological terms. The use of bioassays and biosensors may provide a shortcut in this procedure, and may be very cost-effective. Apart from the development of biological test methods or indicators, a frame of reference for the interpretation of bioassay and biosensor results is also lacking. Comparative studies, where biological methods are combined with chemical assessment, might provide such a frame of reference and encourage the use of cost-effective biological methods.

- *Measurement and modelling of gas-phase contaminants in soil and buildings*

  An important exposure mechanism, particularly in connection with the redevelopment of industrial land for housing, is the transport of airborne contaminants (vapour or dust) from soil to indoor air. This topic has been the subject of recent research in The Netherlands, the UK, Australia and the USA but further work is still needed. Specific research needs include the validation of transport models for benzene and particle-bound metals (e.g. lead), the treatment of spatial and temporal variations in these processes, and the control of exposure to airborne contaminants during remediation works.

***Protection of water resources***

In most countries groundwater is protected as a resource that should remain pure, as implied by the EU Groundwater Directive. There may be situations, however, where the application of this principle in environmental groundwater protection has become impossible due to the extent and persistence of contamination. In these situations a more risk-orientated approach may be used. Methods to predict whether soil pollution will in the long run migrate to groundwater, and to what extent groundwater pollution will disperse and affect abstracted or surface water quality, are of the utmost importance. Current practice is mostly based on geohydrological models. A broader scientific basis including geological, geotechnical and probabilistic approaches may yield substantial improvements. In particular, the transport of contaminants in the unsaturated upper layer of the soil and the behaviour of contaminants at the interface between the unsaturated and saturated zones both need further study. The following issues may be addressed:

- *Macropore transport and fate of contaminants in soil*

  Transport of contaminants in soil and groundwater is often calculated based on the assumption of bulk flow through a homogeneous porous medium. However, in many cases the preferential flow pattern is through fractures or other macropores in soil, with the implication of much faster contaminant transport rates. Therefore, there is a need to study the mechanisms governing the fate and transport of contaminants in such macropores, including the importance of colloids, partitioning processes in macropores, bacterial colonisation behaviour, etc. Groundwater flow in fractured aquifers is already the subject of intensive study.

- *Organic carbon as a major factor governing fate and transport*

  Organic carbon in soil is known to play a key role in both transport and fate of organic contaminants in soil and groundwater, e.g. as a medium for sorption, or as a co-substrate for microbial processes. Until recently organic carbon has been looked upon as having the same characteristics in all cases. However, organic carbon may differ substantially in chemical composition and properties, which may have a strong influence on its ability to serve as a co-factor in the fate and transport

processes. Methods to separate, characterise and differentiate between different types and fractions of organic carbon in soil are urgently needed, as is an understanding of the dynamics of organic carbon in contaminated soils.

- *Methods to assess the natural potential of soil and the unsaturated zone to attenuate contaminants, and techniques to monitor the process*

  Knowledge of biodegradation of contaminants is substantially based on research performed under controlled conditions in the laboratory. Experience with contaminated land suggests that many biodegradable substances may be much more persistent in the real world. On the other hand, some substances that appear to be persistent in the laboratory have turned out to degrade slowly in nature. The potential for soils and rocks to biodegrade certain substances depends on the specific characteristics of the site. It is not a characteristic of the pollutant alone. As natural attenuation is both pollutant dependent and site dependent, its outcome is difficult to predict. Yet such predictions are of great importance in risk assessment, especially with regard to the way risks change with time, and for remediation strategies. The practical feasibility of using extensive and low-cost biological remediation also depends on the availability of reliable risk assessment methods for gradual environmental procedures.

- *Modelling interactive metabolism of contaminants*

  Modelling of contaminant mobilisation, in most cases, addresses biodegradation only at one point, as a function of a number of geochemical, geological and hydrogeological parameters. However, in many cases the different contaminants are degraded sequentially as a result of redox gradients down the flow path or due to variable degradability of the contaminants under the prevailing environmental conditions, including co-metabolic dependencies, etc. To better reflect field situations models must be able to handle a higher degree of complexity than is currently possible.

- *The interaction and general fate of contaminant mixtures*

  In current risk assessment practice each polluting substance is usually considered in isolation. In toxicology it is well appreciated that one toxic substance may increase or reduce the effect of other substances. Similarly, contaminants might also interact in the environment, influencing each other's fate and transport. Interaction between contaminants, especially for transport and fate of complex mixtures like petroleum hydrocarbons, is an important subject for further research.

- *Free phase fate and transport*

  Most research has dealt with fate and transport of contaminants in solute form. Classical methods for the prediction of contaminant migration fail when pollutants do not mix with groundwater but exist as floating or sinking layers of free phase liquid, i.e. the LNAPLs (light non-aqueous phase liquids) and DNAPLs (dense non-aqueous phase liquids). Special methods must be developed to help characterise these products in the subsurface and to predict future behaviour. A better understanding of how free-phase products affect soil processes must also be achieved. One topic is the solubilisation kinetics of free-phase liquids as a possible factor governing their fate and transport. Another topic is the biodegradation of free-phase contamination, including the microbial toxicity of free phase and the colonisation of microbial populations on free-phase surfaces.

- *Improved techniques to investigate and estimate mobile contaminants along a plume under aspects of mass flow analysis*

  Approaches to plume assessment are typically focused on the comparison of concentrations with accepted quality standards. Owing to the large variety of hydrogeological features and the heterogeneity of aquifers, concentration and distribution of contaminants in a plume may vary to a large extent. It would be valuable to integrate aspects of mass flow analysis to the assessment of plumes to better assess the total amount of migrating contaminants, perhaps even to develop new techniques for plume assessment able to integrate the principles of mass balancing.

- *Techniques for risk comparison of different types and mixtures of contaminants, e.g. to compare the effect of diffuse agricultural impacts with the effect of impacts from point sources*

  The Framework Directive for water policies operates *at* the level of protection and restoration of water resources within catchment areas (river basins). Within one river basin, several different impacts affect the status of aquatic ecosystems. To prevent further deterioration, and to protect and enhance the status of aquatic ecosystems, it is important that any programmes of management measures should be established at a *regional* level – such as within river basin management plans. In addition, it would be important to develop tools for a 'relative' assessment to weigh different impacts against each other, and identify the relative importance of these different impacts, as a basis for a staged programme of measures within a river basin. Such an approach might also identify the effectiveness of possible measures for diffuse and point sources with a combined approach.

- *Methods to assess the contribution of soil, aquifer and underlying groundwater contamination in determining surface water quality*

  Techniques should be developed to assist in understanding the groundwater-surface water-land quality relationships. It is becoming increasingly clear that the quality of our surface water systems, particularly in urban areas where there has been industrial development, could be highly influenced by groundwater quality where this groundwater is an important input to surface water flows. This groundwater qual-

ity is in turn influenced by the overlying soils and land pollution. The Water Framework Directive could be highly influential in driving remediation policies, depending on the ultimate impact of the various point and diffuse sources of land contamination on surface water quality (see also point above).

- *The influence of rising groundwater tables in urban areas where there is land contamination*

  There has been a substantial decrease in abstraction from groundwater beneath urban areas in Western industrialised countries, due to the demise of heavy manufacturing industry and the use of water. Drinking water is also now procured from outside urban areas and so the fall in water table levels experienced under cities over 100 years is reversing. Examples in the UK are beneath London, Birmingham and Liverpool. The implications for surface water quality as the rising water tables flush out pollutants in the unsaturated zone are unknown. Management strategies to deal with the problem that might arise also require investigation.

- *The development of simple (non-intrusive) methods of site investigation*

  The site investigation process is increasingly being seen as a process that should take place in phases. In most cases a conceptual model, based on the data available, is used to gain an understanding of site contamination problems. This is then refined with the acquisition of more data. However the collection of data is very expensive and needs to be carefully targeted. Simple cheap/non-intrusive techniques could help to target more detailed investigation work and save costs. More research and development is needed to develop such simple exploratory tools.

- *Methods to assess interaction of seawater with contaminated soil in coastal aquifers*

  Aquifers in the Mediterranean area may be locally subject to overexploitation in certain areas, because of scarcity of surface water for irrigation, industrial and domestic use. In coastal areas abstraction may cause pollution of groundwater by seawater, drawn inland by pumping wells. This phenomenon may add to contamination from diffuse or point sources on land and generate complex flow and physico-chemical problems to assess and to solve.

- *Methods to assess (eco)toxicological risk of contaminated river/coastal/marine sediments*

  Methods to assess ecotoxicological risks for different uses and functions of sediments are generally needed. Sediments are a substratum that is critical for many ecosystems. With respect to sediments direct human exposure is more limited than in comparison with overall ecological exposure. Research into ecological risk assessment and the development of a framework for its assessment urgently need development.

### *Bioavailability of contaminants in soil and groundwater*

Bioavailability is a function of the interaction between organisms (soil fauna, bacteria, plants) and their chemical environment. Soil characteristics partly determine bioavailability for organisms, and organisms in turn create their own environment by influencing soil properties. Current bioavailability research has been too focused on abiotic aspects. Organisms are often modelled as a special form of soil organic matter which is exposed to water in the pore spaces of soil, and which does not respond to changes in the environment. Future research should critically test the applicability of simple abiotic bioavailability modelling and should consider the biology of the organisms involved more explicitly.

Another aspect that is not fully appreciated is that bioavailability may change with time. More research on ageing processes of polluted soils and on time dependence of bioavailability should be encouraged. Progress in this field should also be made on the development of cost-effective procedures for determining bioavailability of compounds as they exist in the environment.

### Fitness for use and remediation

#### *Human health risks*

A primary need among contaminated land risk assessors in the determination of 'fitness for use' is for human toxicity data that adequately reflect the chemical forms, modes of delivery, exposure conditions and bioavailability found in the context of contaminated sites. However, the quality and relevance of fundamental epidemiological and toxicological data are severely constrained by both cost and ethical considerations. Realistic research needs are therefore summarised below.

- *Development of the theoretical basis and practical tools (decision-support systems) necessary to allow relative risk contributions to be taken into account when setting target values for soil contaminants*

  There is a need to test and demonstrate with specific examples how a methodology and decision-support system can be used to develop soil target values that take into account the relative contributions of soil and non-soil as well as site and non-site sources to total exposure. In the UK, for example, this approach has already been used in the derivation of the draft soil guideline values for lead. These values have been derived such that any required reduction in soil-lead values is proportional to the contribution that soil makes to total lead uptake in two-year-old children living in urban environments.

- *Identification of areas where significant improvements in epidemiological and toxicological understanding can be achieved at a realistic cost*

  There is a need to understand better how contaminant-matrix interactions affect the bioavailability of contaminants after entering the human body, how to predict the availability of pollutants within the human body, and how to distinguish the difference between intake and uptake. In order to arrive at a realistic description of human toxicity the availability of contaminants in soil

relative to the availability in the animal experiments used to derive reference values (e.g. TDI) must be taken into account.

- *Development of better and more consistent ways of interpreting currently available toxicological and epidemiological data, and dealing with the associated uncertainties*

  Dealing with combined exposure to mixtures, and finding a more scientifically defensible basis for uncertainty factors are important risk assessment R&D needs. These needs are common to all toxicologists, not just those working in the context of contaminated land. It would be beneficial to develop a more consistent decision-support methodology among participating countries (and, indeed, world-wide).

- *Improve the predictive power of exposure models and specify human risks in space and time*

  Validation of models for various exposure pathways is important in view of their impact on contaminated land decision-making. Although risk assessment procedures cannot usually be tested empirically as a whole, testing of specific parts is still possible. Further studies of exposure pathways from soil to humans will also yield information on the appropriate spatial scale for human exposure. This is important for the design of soil sampling schemes. For better risk assessments it will also be necessary to consider the appropriate time frame for risks in view of the choice of exposure period and averaging period, and degradation of pollutants.

***Risk comparison***

Many of the above research needs identified relate to the issue of risk comparison. Research in this area may be seen as a key step in addressing the basic question: how significant are the risks associated with contaminated sites in relation to other risks, and on what factors do these judgements of significance depend? This area of research requires an innovative integration of scientific risk assessment methodologies and those of the social and behavioural sciences.

The valuation of risks and risk management options is a multidisciplinary field involving many areas of risk study, including remediation economics, insurance, law, ethics and policy. An important task here is to complement traditional cost-benefit and risk-benefit analyses with modern multi-criteria decision methods.

***Ecological risk assessment***

Whereas human health risks concern the health of an individual, ecological risk has to address the health of populations of a multitude of species and ecosystems. Ecological risk is largely based on the no observed effect concentration (NOEC) concept and results of toxicity testing in the laboratory. Yet, there is at present no ecosystem theory that can serve as a framework for interpretation of NOEC data. In contrast, human health risk assessment is also largely based on laboratory experiments with animals, but does have a framework for interpretation in medicine, sociology and psychology. This is lacking in the ecological approach.

Many forms of land-use by humans also need a certain level of ecological function in soils, sometimes referred to as the ‘life support system’. In the derivation of land-use based remediation goals, discussions about human toxicity have dominated and the requirements of the life support system as a whole have been neglected. More ecological research should be devoted to investigating this ‘life support system’ concept.

Another neglected ecological field is groundwater ecology. Groundwater reserves are under pressure from over-exploitation, and in some countries water shortages are already occurring. At present groundwater is protected as a source of drinking water. The ecological consequences of groundwater pollution are still poorly understood and would provide additional motives for groundwater protection.

The main topics for research in the field of ecological risk assessment are:

- impact of a site on the surrounding environment;
- ecological recovery at the site;
- changes in community structure caused by pollution-induced tolerance versus classical ecotoxicological endpoints;
- biomagnification risk and adverse effect on food chains;
- ecological soil and groundwater quality requirements related to human land-use.

***Models for risk assessment***

Models are powerful tools for integrating the various elements in a risk assessment, e.g. site characterisation, fate and transport of contaminants, exposure assessment and risk estimation. They may be used as tools for site-specific assessment of a given contaminated site, or to derive generic screening or guideline values. Models, however, are abstract representations of complex systems, and are based on numerous assumptions. It is therefore of the utmost importance that models and submodels should be validated and tested in real-world situations, both in regular contaminated land risk assessments and in special research projects. Field-testing and validation of models raises important questions about the precision and accuracy of model predictions. In particular, can we expect accurate estimates from the overall assessment in view of the many uncertainties in source characterisation, in exposure assessment and in the toxicological basis for tolerable daily intakes?

From a general methodological point of view an important area for research might be to study how risks estimated from site-specific exposure modelling differ from those estimated using generic criteria. It could be investigated whether exceeding a toxicological reference intake or soil screening level relates to the probability of human health or ecological effects occurring. From a risk characterisation point of view it is important to know how accurate one could hope to be on the probability of an effect occurring, as well as on the magnitude of the

effect. This in turn would influence risk communication.

***Risk perception and communication***

Use of the results of scientific risk assessment in environmental decision-making must take into account the perception of various risks and other social issues. The development of coherent risk dialogue strategies to communicate the results of risk assessment and the choice of a solution to those who are or feel themselves to be at risk as a consequence from (potentially) contaminated land is an important issue. Some stakeholders may have perceptions very different from those of the risk assessors and decision-makers; the challenge is to engage in a constructive dialogue with them to address such issues as:

- The relative importance of a negative effect which is unlikely but has very significant consequences, as opposed to one which is more likely but has minor consequences. (Is this always a site-specific judgement or could a general framework for deciding on relative importance be established?)
- The development of a general measurement scale for the importance of adverse effects and for acceptable or tolerable probabilities of occurrence in view of the differences in perception between the general public and those who might suffer the adverse effect.
- The discussion of whether risks at contaminated sites caused by human activity are more or less acceptable than naturally occurring risks.

**Risk management**

Effort on the RTD catalogue has so far focused on risk assessment issues. Work on risk management RTD needs is in progress. Some preliminary suggestions follow.

- *Development of criteria to assess the environmental merit of remediation activities*

  There is a need for the identification of meaningful criteria to assess and compare various remediation options with regard to the environmental impacts of (secondary) emissions and (energy) resources involved in the remediation processes. This should enable sustainability issues to be considered in the decision-making process as well as a purely financial comparison between different remediation options.

- *Development of criteria to assess the benefits of remediation activities considering environmental, economic and social aspects*

  Multi-criteria analysis should be developed to evaluate remediation activities to take into consideration the broader impacts for affected communities. Such impacts could include, for example, the environmental impacts of canal restoration, the effects on local employment of regeneration programmes and improvements in the appearance of an area.

- *Evaluation of long-term efficiency of enclosure systems and permeable reactive barriers*

  The long-term performance of containment barriers must be quantitatively predicted both for soil and groundwater contaminants. Containment and isolation of pollutants, as an alternative solution to removal, must follow analogous risk assessment requirements to show that any dispersion of pollution, by accidental or routine leaks, would not result in any unacceptable human health or ecological risks according to site use.

- *Development of remediation technologies for contaminated fractured, heterogeneous and/or low permeability soils and aquifers*

  Soil and groundwater remediation technologies generally show a higher performance with permeable soil matrices. Better methods are needed to cope with less permeable materials or with heterogeneous alluvial soils where sand lenses may alternate with clay strata which are characterised by different pollution patterns and contaminant flow chemistry and dynamics. In addition, contaminant flow follows discrete patterns in fractured rock strata rather than the currently used porous fate and transport dynamics.

## DISCUSSION

Risk assessment for contaminated sites is a rather loose assemblage of concepts and methods borrowed from various disciplines. Until recently, the research community seems to have had little interest in studying fundamental issues related to integrating the various building blocks of contaminated land risk assessment. Developments in this area are being driven by regulators who need better decision-support systems. The limitations of toxicological reference values, exposure modelling and soil and groundwater sampling are not widely understood, especially by the generalist scientist or engineer who is often the person involved in site investigation and risk assessment.

Risk assessment is not yet recognised as a coherent scientific discipline. Further integration of the building blocks will be achieved under pressure from environmental policy makers with the support of industry. International co-operation is important in this for a number of reasons:

- to avoid unnecessary duplication;
- to provide a wider basis for scientific peer review;
- to provide a common database for physico-chemical and other basic data;
- to promote international co-operation on the assessment of toxicity of substances in soil and groundwater;
- to promote mutual understanding of the way science is put to work in developing and delivering national policies.

It is also important that remediation is considered in the broader context of sustainable development. This encompasses economic, social and environmental aspects, and points to their consideration in a holistic way. While cost benefit analyses and risk perception are increasingly part of contaminated land RTD activities, the importance of an integrated approach to all of these considerations has only been recently begun to be recognised.

Contaminated land RTD is applied not only directly to problem solving, but must also inform policy and decision-making; increasingly the technical basis for policy and decisions is being sought at an international level.

International co-operation in environmental science and policy is at present considered necessary to solve large-scale problems. Some people feel that soil and groundwater problems are local problems and therefore international co-operation is not so important. This is perhaps a rather naive point of view. Global problems evidently need political solutions at an international level. Local problems need solutions that reflect local needs and circumstances, but this does not mean that international exchange of ideas about how to tackle these problems is of limited value. Reinventing solutions for soil and groundwater problems in each country is simply a waste of time and money. Common political solutions may not be necessary or desirable, but exchange of technical and scientific approaches between countries is extremely valuable.

Improving risk assessment for contaminated sites depends not only on the results of research projects. Other requirements have to be met, of which the most important are:

- training of risk assessors and decision-makers;
- networks for communicating new approaches and practical experiences;
- linking fundamental science to real-world problems.

*Training of risk assessors and decision-makers*

The science behind risk assessment has to be applied in a local decision-making context. This means that local decision-makers need to have sufficient grasp of the scientific basis and/or be able to manage the input from specialist consultants. In most countries there is a substantial need for training local contaminated land risk managers and others involved in decision-making. This is especially so in the light of the many variables, uncertainties and other methodological pitfalls in current risk assessment approaches.

Risk assessment only leads to defensible decisions if its limitations are recognised. Sometimes the risk assessment cannot provide all the answers, and decisions may have to be taken without a high level of certainty of the outcome. This is not new in environmental policy, at least at the national level. However, the decisions relating to soil and groundwater pollution are often taken by local authorities with limited expertise to draw on. Training of local authority personnel is therefore very important.

*Network for communication of new approaches and practical experiences*

Even the best-trained personnel have to maintain and update their knowledge. They will also gain practical experience with various forms of risk assessment in different situations. These experiences may be very beneficial to others. The perspectives for dealing effectively with contaminated land are broader if they are based on shared knowledge and do not entirely depend on the experience of an individual assessor. Most countries also need a platform for sharing information, developing case studies, disseminating new approaches and identifying research priorities. In view of the many scientific questions in risk assessment, and the fact that present day science is performed in an international context, an international network for the scientific aspects of contaminated land risk assessment brings great potential benefits.

*Linking fundamental science to real-world problems*

Fundamental science traditionally aims at establishing general theories that are tested against observations under controlled and defined circumstances. Very often, theories are difficult to apply directly in complex areas like soils and ecosystems. A long period of applied research is needed before most products of fundamental science can be used effectively in real-world problems such as the assessment of risks from contaminated land.

A more promising strategy is not to wait until contaminated land problems catch the attention of the fundamental scientist, and the outputs of fundamental scientists catch the attention of the applied scientist, but to find ways of bringing all types of scientist together in the context of contaminated soil and groundwater risk assessment. The solutions generated may be less fundamental and universal than the products of fundamental sciences, but they may be more directly applicable. Generalities and new scientific theory may evolve as practical experience with contaminated land accumulates. One of the best ways to improve risk assessment is to link fundamental and applied RTD projects with specific contaminated land problems.

## CONCLUSION

There are many areas where significant improvements in the science base would greatly reduce the cost and increase the certainty of risk-based land management.

The results will be important to us all for providing:

- a safe and attractive environment;
- sustainable reuse of former industrial areas for homes, businesses and leisure areas etc.; and
- effective and timely solutions at a viable cost to society.

**NOTE**

Comments on this article are welcome and can be directed to Paul Bardos, UK manager for CLARINET (e-mail paul@r3 environmental.co.uk, by 31 January 2001).