Site-specific ecological risks:
A basic approach to function-specific assessment of soil pollution

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Accountability: In this report a basic approach for the actual, site-specific, ecological risk assessment is presented. It is the result of the meetings of a working group of representatives of a broad cross-section of institutions, involved in the establishment of frame-works for actual ecological risk assessment in The Netherlands. The project was initiated by The Netherlands Integrated Soil Research Programme and carried out in the years 1997-1998. This report is a translation of an earlier report in Dutch in the same series.

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Contents

Preface and outline

In 1996, the first steps were taken towards the establishment of a project for the formulation of a basic philosophy for the assessment of actual ecological risks of pollution in aquatic sediments or soil. A working group consisting of C. Denneman, H. Eijsackers (chair), C. van de Guchte, J. Faber, S. Ouboter, J. Postma, P. de Ruiter, M. Rutgers, M. Scholten, N. van Straalen and J. van Wensem represented a broad cross-section of institutions involved in the establishment of frameworks for actual ecological risk assessment. Four meetings and consultations with a number of people involved in soil use resulted in the “basic approach” presented in this paper. Joint responsibility for the project was in the hands of IBN-DLO (now: Alterra, a division of the Agricultural Research Service), AquaSense (acting on instructions from the Institute for Inland Water Management and Wastewater Treatment (RIZA)) and the National Institute of Public Health and Environment (RIVM).

In the basic approach presented here, a number of basic principles are set out which can be used in the site-specific assessment of ecological risks and in the development of decision-support systems. Important elements are the definition of the desired soil use, the selection of ecological aspects in the light of the site in question and the set of instruments with which ecological damage (effects) - rather than potential risks - can be determined.

This report is based on the concept “ecological aspect”, a selected component or characteristic of the local ecosystem (for example, a desired group of species) or of a higher ecological integration level (for example, life-support functions), given the ecological soil use.

After the introduction and a description of the problem, this paper first sets out the outlines of site-specific ecological risk assessment. The actual determination of ecological damage is then discussed (by contrast with the calculation of potential risks), together with the question of whether or not there is adequate support for the implementation of a system of this kind. Finally, a number of suggestions are made for the selection of the “right” ecological aspects in relation to the desired soil use, as well as for the determination of a suitable set of instruments.

In 1999 the “basic approach” has been tested on three cases. The result is published as volume 29 of this series in Dutch.

Summary

The soil pollution problem in the Netherlands is too extensive to be solved altogether within a reasonable length of time. As the result of changes in the soil policy, a number of options have emerged clearly such as meticulous priority setting through the use of site-specific risk assessment techniques, the implementation of measures (clean-up, soil management) at polluted sites which are adjusted according to the use of the soil, and the adjustment of soil use according to the soil quality.

This paper sets out principles which can be used in the site-specific assessment of *ecological* risks and in the development of decision-support systems. Important elements are:
1. a definition of the soil use;
2. selection of ecological aspects depending on the site, and;
3. a set of instruments with which ecological damage (effects) can be determined rather than potential risks.

The various elements and links between them are worked out in greater detail.

Although ecosystems are characterised by highly complex structures and functions, it is possible to identify sub-elements on which the ecological assessment can be focused. In that sense, ecological risk assessment need not be complex by definition and a simple set of instruments can (depending on the desired level of precision) be deployed for the broad determination of ecological effects. In the case of nature development, for example, an assessment framework can be used in order to arrive at a more optimal development of the area without clean-up being necessary. On the other hand, an assessment framework can be used to determine whether a relatively small intervention can result in a major improvement in ecological soil quality with respect to soil use.

The principles described in this paper for site-specific risk assessment will, in practice, have to be formulated in greater detail. On the basis of a number of representative site studies, a start has been made on the implementation of this basic approach (Rutgers *et al.*, 2000).

Introduction

In the Netherlands, with its high population density, the soil on which we live is a precious good. Good soil quality is essential for the healthy functioning of numerous social activities and processes. This quality, and therefore use by society as a whole, is however threatened by pollutants in the soil. In a very large number of places, the soil (soil and sediments and the deeper layers of the subsoil) is polluted as a result of the emission of pollutants from localised or diffuse sources. A recent survey conducted by the Association of Provincial Authorities (IPO) showed that the number of severe cases of soil pollution (i.e. sites where the intervention value, a Dutch threshold cleanup value, for one or more contaminants is exceeded by a minimum volume of 25 m^3) is estimated at a total of 60,000 (Ouboter *et al.*, 1997). The number of sites where there is mild pollution is probably even higher.

At present there is considerable demand from society as a whole for a framework and set of instruments for risk assessment with respect to soil pollution (set of indicators, parameters, tests and criteria) in order to characterise the ecological risks and effects in the light of site-specific circumstances. This is the result of both an immediate advantage for society as a whole (no limitations in the realisation of the intended soil use in the short and long terms; or an understanding of the limitations) and of more idealistic considerations about the intrinsic value of species and processes in ecosystems. The question is, for example, whether, in a specific case of soil pollution which is considered to be “mild” or “severe” on the basis of generic assessment measures, the use society makes of that soil in the short or long-term is hindered by potential or actual ecological effects (damage). A risk for, or damage to, social interests on the basis of a reduction in soil function in ecological terms is therefore of importance for a more detailed assessment of the pollution. Ecological risks or effects therefore have to be included within the framework of the site-specific (sometimes referred to as 'actual') risk assessment (Nijhof and Koolenbrander, 1998).

The ecological risk of soil pollution as such is difficult to determine since the ecosystem which would have to be assessed is too complex for a simple description. In that sense, there are always different risks which are probably not always recognised or measurable: “Ecosystems are not more complex than we think, but more complex than we can think!” (Egler, 1997). Risks, and particularly ecological risks, can seldom be expressed in a one-dimensional assessment framework as was stated by the Health Council (Gezondheidsraad, 1995). Ecological risks should therefore be assessed by means of an integral approach based on a number of complementary measures and criteria.

'State-of-the-art' in ecology and ecotoxicology

Ecotoxicological research focuses on the assessment of environmental risks posed by substances, particularly toxic substances, in a broad sense. The research for the purposes of risk assessment in soils and aquatic sediments in particular has developed rapidly in recent years (Van de Guchte *et al.*, 1996). The foundation has been established for a large number of laboratory results of “toxicity tests” which describe the ecotoxicological properties of individual substances. Much of this basic ecotoxicological data has now been used in the derivation of risk limits and environmental quality objectives which have proved practical in setting general priorities on the national level in a range of substance-oriented policy fields. A great deal of effort then went into laboratory studies of the quantification of potential effects in relation to the biological availability of pollutants. Compensation for biological availability is of major importance in site-specific risk assessment since there are large differences between sites.

The approach sketched out above (“standard toxicity tests”, QSAR and QSSR relationships and equilibrium-partition models) makes use of information about the presence of substances (both generally and site specific) and it therefore provides a substance-driven approach which allows for extrapolation to ecological processes. In order to determine actual ecological effects in the site-specific risk assessment, a supplementary ecology-driven set of measurement instruments is required. For this purpose, ecotoxicological and ecological field data must be collated and ecological processes must be modelled. At present, ecological and ecotoxicological studies are putting a lot of effort into the development and operationalisation of bioassays which will make it possible to obtain information about site-specific toxicity, as well as into the development of a set of instruments for ecological observations in the field (for example: Gezondheidsraad, 1991; Den Besten *et al.*, 1995; Hendriks *et al.*, 1997; Schouten *et al.*, 1997; STOWA/RIZA, 1997).

Currently, the discussion is centred around the development of assessment frameworks for specific, practical situations in which the acquired ecological and ecotoxicological expertise, methods and techniques are implemented. In this report, an approach is presented which can serve as a basis for assessment frameworks of this kind. This basic approach provides a template for a site-specific risk assessment of polluted soils on the basis of ecological aspects and soil use, characterised by a number of elements:

1. presentation of a schematic decision-making procedure with respect to dealing with soil pollution on the basis of ecological risks;
2. the designation of universal clusters of assessment criteria for soil quality;
3. the first step towards the elaboration of ecological aspects differentiated according to soil use, and;
4. the listing of a number of examples of ecotoxicological methods which can be used for site-specific risk assessment.

It should be stated that there is no such thing as “*the ecological risk*” of soil pollution. Depending on local soil use and soil use in the immediate surroundings, there will be different, specific ecological risks. The functioning of the local ecosystem is threatened in such a way that the use of that particular soil by society as a whole will not be done full justice in terms of the ecology. When disturbances of the ecosystem of this kind can be determined by means of measurements of ecological processes or other ecological characteristics, one is justified in saying that there is an effect (damage).

One of the assumptions used in this report is the concept of "*ecological aspect*", a selected component or characteristic of a local ecosystem (for example, a desired species) or of a higher ecological integration level (for example, life-support functions), given the ecological soil use. An initial step is then taken towards the definition of a set of instruments appropriate for the ecological aspects which will make it possible to evaluate the ecological risks of soil pollution. A set of instruments consists of a set of measurable or calculable indicators and ecological parameters for soil quality (criteria) in relation to soil use (see also Faber, 1997; Van Hesteren *et al.*, 1998). Examples are given of a set of ecotoxicological measurement instruments which make it possible to establish a picture through site-specific research of site-specific risks (including future effects) and effects which actually occur.

Outlines of a site-specific ecological risk assessment

Figure 1 provides a diagrammatic overview of a basic approach to ecological risk assessment which can be used generally for both aquatic sediments and terrestrial soils. The nature of the problem of soil pollution is the same for both terrestrial soils and aquatic sediments and a single site can contain both types of soils at the same time (for example, in the case of dredging sludge left on the edge of the water). Upon further elaboration, the distinction between types of soil use and aquatic sediment use, emerges as a result of the selection of the ecological aspects or indicators (see below). In effect, a three-stage process is proposed as a basic approach:

Stage I. During the decision-making process relating to spatial planning in cases of soil pollution, administrators, planners, landowners and experts define the intended soil use (first stage in figure 1). In addition to the functional properties of the soil (VROM, 1986), the focus is upon user functions which can be assigned to the soil. In addition to the general and ever present soil functions (general ecological function and groundwater reservoir function) which apply to almost every soil, the more specific soil functions are determined by the current or future use by society as a whole: the "*soil use*". For example, the Association of Netherlands Municipalities (VNG from the Dutch abbreviation) uses a classification into industrial area/infrastructure, urban or rural residential area, agricultural area, recreational/nature area (VNG, 1992). A further sub-classification on the basis of specific use or objectives for a specific site is possible. In this discussion document, it has been proposed for reasons of practical implementation that this broad classification should be adopted (see also table 1). In the general description of an assessment framework, a breakdown into an excessive number of types of use should be avoided. During the site-specific risk assessment, soil use can then be elaborated in a more detailed fashion so that matters such as type of landscape, wider appreciation for the landscape from society as a whole, sensitivity and rarity are described and will have an influence on the ecological aspects to be selected. These aspects must be based on ecological functioning within the context of soil use for humans which has been designated by spatial planning. It could therefore emerge during the later elaboration of this topic that the classification used by the

VNG (which fits in well with the derivation of human risks) is not optimal from an ecological point of view.

Stage II. After the soil use has been defined, it is the task of experts (ecologists/ ecotoxicologists) to select ecological aspects which follow from the soil use and which are related to ecological functioning (second stage in figure 1; see also table 1). No measurements are yet made but the final test should take place in accordance with the ecological aspects chosen during this stage using a set of indicators (measurable units and parameters) and associated criteria for soil quality. A set of standard ecological aspects can be linked to the standard set of soil use categories. The working group is of the opinion that, for example, a minimum level of quality has to be guaranteed in all cases, with at least micro-organisms and species responsible for certain processes potentially serving a role as ecological aspect ("*life-support functions*"; Schouten *et al.*, 1997).
Detailed ecological aspects will be different for every site and soil pollution, with elements such as rarity or appreciation of the type of landscape - as described in soil use, target nature types, target species - and requirements for basic ecological quality possibly playing a role. In this way, it can be supposed that ecological aspects for dwellings with gardens in urban areas will be different from those in rural areas since specific requirements relating to characteristic vegetation also have an effect. In general, areas of natural beauty impose the strictest demands on basic ecological quality (in other words, the presence of sensitive species and key organisms must be possible), but they provide, on the other hand, few points of departures for guidelines which can be used generally (each ecosystem has specific characteristics). It should be clear here that less demanding "nature" can have good prospects, even on severely polluted soil. What matters is not so much what is actually present in terms of flora, fauna and micro-organisms but what is *no longer* present or what has been affected.

Stage III. In the third and most labour-intensive stage of risk assessment, a set of instruments (indicators, parameters, models and/or criteria) are deployed in order to test the ecological aspects which are associated with the intended soil use. This set of instruments can include measurements, estimates, derivations and other approaches. Examples of site-specific indicators are:

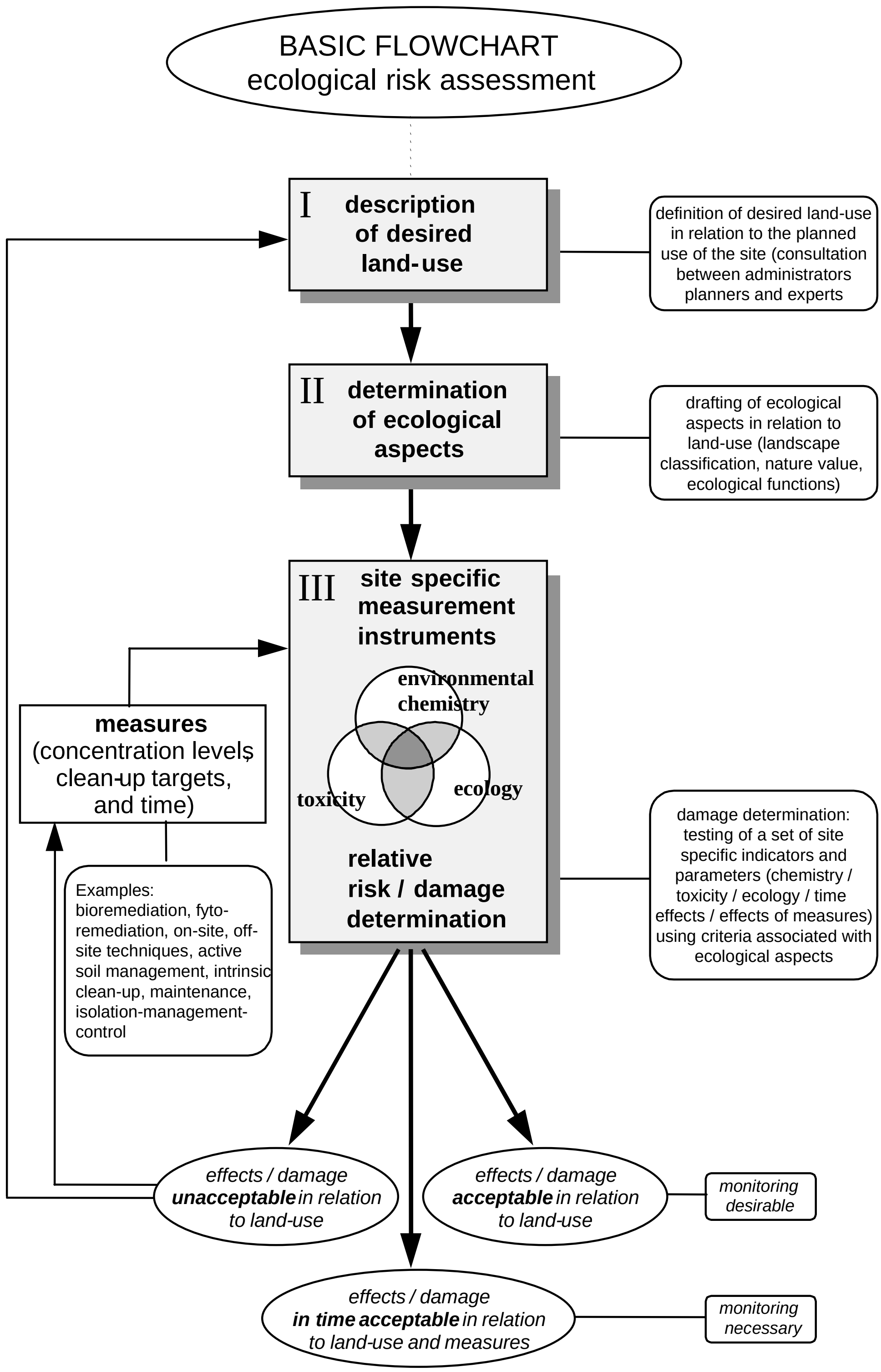

Figure 1. Proposal for a basic structure for a decision tree for site-specific ecological risk assessment. See text for further explanation.

- the chemical concentrations of substances in the soil and biota;
- the mobility of substances within the site and outside the boundaries of the site, for example:
  1. chemical mobility (sorption, partition, availability, exposure);
  2. biological mobility (secondary poisoning, bioaccumulation, biodegradation);
  3. physical mobility (wind erosion, facilitation, earth/soil water transport);
- estimates or measurements of effects on ecological receptors (key species, structure of the ecosystem, system processes, community tolerance, food webs *etc.*);
- effects of mixtures of substances, unknown substances and other stress factors;
- site-specific toxicity (bioassays, field toxicity measurements, biomarkers);
- functional redundancy in ecological processes and the recovery potential of processes and structures;
- time scale for exposure and for ecological effects;
- prediction of ecological benefit and effects of proposed measures (sanitation, phytoremediation, soil management);
- appreciation for, and perception of the ecosystem (rarity, type of landscape, species diversity).

When a site-specific set of instruments is deployed, criteria should be drawn up for interpretation in order to determine whether a specific level of soil quality should be considered to be adequate or inadequate for the intended soil use. Reference data are of major importance here.

There are three possible results of site-specific ecological risk assessment (figure 1):

1. The intended soil use can, on the basis of the risk assessment and taking into account the extent and severity of the soil pollution, be achieved without unacceptable effects on the ecosystem. In this case, one should always be wary of "*type 2 errors*", in other words the incorrect assumption on the basis of the risk assessment that there are no major effects on the ecosystem. The reduction of the risk of type 2 errors means that greater efforts have to be made in terms of testing since repeated testing is necessary or more sensitive measurements or methods are required. The reduction of the risk of type 2 errors increases the risk of type 1 errors at the same time, in other words the incorrect rejection of the intended soil use on the basis of the tests carried out since the observed effects are not significant. This can result in unnecessary action being taken;
2. The intended soil use can, on the basis of the risk assessment, not be achieved without unacceptable risks for, or effects on, the ecosystem. In this case, there are two options:
   i) action is taken (clean-up, adapted soil management *etc.*), or
   ii) a less demanding type of soil use is chosen. Using a new set of ecological aspects and associated instruments, the risk for the ecosystem at that site is characterised again.

Table 1. *Examples of soil use, ecological aspects to be selected and indicators and parameters to be used. Soil use and the ecological aspects are determined further by specific characteristics of the site. The selection of indicators and parameters will depend on the desired precision of the assessment. Direct testing of ecological aspects will usually not be possible so that the representativity of the indicators will have to be determined by experts. The table is primarily based on biological information; chemical information (such as substance concentrations and bioavailability) has been left aside but can also play a role as indicators or parameters.*

Stage 1 SOIL USE (indicative)	Stage 2 ECOLOGICAL ASPECTS (examples)	Stage 3 INDICATORS and PARAMETERS (examples)
nature	target type: key species target species top predators interspecific relationships system processes	jaw deformation mosquito larvae, structure sediment and macro-fauna, bird densities, bioaccumul-ation in fish and sediment fauna, bioaccumulation in soil fauna and small mammals, litter decom-position, structure nematode community, nitrification, food webs
agricultural practice	sensitive crop plants and cattle natural attenuation mycorrhiza litter degradation groundwater	bioaccumulation metals (earthworm), biodegradation rate, maturity index nematodes, spiders, food webs, functional groups of mites, groundwater organisms
recreation green space	plant species (determine nature of area) nutrient cycles specific fauna	maturity index nematodes, germination tests, microbial diversity
dwellings with vegetable gardens allotments	most sensitive crop plants nutrient cycles natural attenuation pets	maturity index nematodes, germination tests, resistance and substrate diversity micro-organisms
dwellings with gardens	plant growth (ornamental plants) nutrient cycles natural attenuation pets	maturity index nematodes, germination tests, substrate diversity micro-organisms, bioaccumulation metals (earthworm, wood lice), PAH (soil fauna)
dwellings without gardens, traffic, work, social/cultural	plants in green amenities and verge vegetation natural attenuation groundwater	bioaccumulation metals (wood lice), biodegradation rate, substrate diversity micro-organisms, bioassay groundwater organisms

When consideration is being given to active soil management or clean-up measures, the benefits and the effects of those measures should be determined using risk assessment. Particularly in the case of far-reaching (off-site) clean-up in which the vegetation is sacrificed, this will have a negative influence on the result of the risk assessment. If recovery processes are given enough opportunity (for example, the vegetation is given the opportunity to grow "old" and valuable fauna is reintroduced), complete clean-up will often be the best option;

3. With function-based clean-up, soil management adapted to the polluted site, or the presence of natural intrinsic recovery processes, a third result is possible, namely that ecological risks will only drop to an acceptable level after a period of time given the intended soil use. When this is the result of the risk assessment, it will be necessary to initiate a monitoring programme in order to determine whether, and when, that period of time has elapsed and the ecological risks and effects have been reduced to an acceptable level.

Potential risks, effects and damage

When taking decisions about the future use of a polluted soil, spatial planning and other matters, the ecological consequences of pollution should be balanced against the socio-economic and/or financial issues. Given the fact that the term "damage" can be used easily and clearly in the economic/financial sense, the required balancing process could get stuck in a comparison of "financial consequences" with "the possibility of certain ecological risks". On the basis of this consideration, it is therefore advisable, when determining ecological consequences, not just to talk about opportunities and chances but also to determine the actual or anticipated ecological damage (both in the long and short terms). This paper does not make any more precise distinction between the ecological effects and ecological damage. The question of whether ecological effects of soil pollution must be considered unacceptable and result in ecological damage seen from the point of view of society as a whole is of importance for the setting of criteria.

It will also remain necessary to estimate risks because ecological effects are sometimes difficult to establish or they can only be established at high cost. The risks of secondary poisoning for organisms higher in the food chain when there are substances which accumulate slowly such as PCBs are a good example of this.

Recently, ecological risk assessment has started on the integrated appraisal of a range of types of supplementary information flows, for example using the TRIADE approach (Chapman, 1986; STOWA/RIZA, 1997; Maas *et al.*, 1993). This approach is based on the simultaneous and integrated deployment of site-specific chemical, toxical and ecological information in risk assessment. A major assumption here is that an integrated approach will lead to more precise answers than an approach which is solely based on, for example, the concentrations of pollutants at the site, thereby linking up better with the concept of damage. An important factor in a risk assessment is the availability of good reference data; the results of the site-specific ecological measurements or calculations are compared to this data. If there is inadequate reference information, effects can only be determined in relative terms by comparison with other sites. This is usually adequate for determining the degree of urgency and further prioritisation of clean-up work or the choice of site in the context of spatial planning and the development of areas of natural beauty. The possible elaboration of this issue is discussed in the "set of instruments" chapter.

Support for ecological risk assessment and measures

Severe cases of soil pollution must, according to the prevailing Soil Protection Act, be assessed in terms of the site-specific ecological and human risks and the risks of dispersion. On the basis of these risks, the urgency of clean-up work is determined (Koolenbrander, 1995; Nijhof and Koolenbrander, 1998). Sites with an increased ecological risk can be broken down broadly into four categories which are relevant for this paper (figure 2):

1. There are cases of soil pollution which are so extensive that the physical and social efforts required are too great to clean up these sites fully. Examples of this are the pollution in the Kempen site, the former landfill in the Volgermeer polder and the filled-in ditches in the Krimpenerwaard. The financial resources for tackling these cases of soil pollution are always inadequate and ways have to be sought to deploy them efficiently in a more limited area. In the case of a limited deployment of this kind, a site-specific ecological risk assessment can provide prioritisation, direction and support so that backing from society as a whole will perhaps be obtained;
2. There are polluted sites where financial resources which are adequate to cover the costs of clean-up are present ("rich sites"). Here, the main question is how the financial resources can be deployed as efficiently as possible in order to make the intended soil use possible. At the sites, clean-up is an option which is clearly in the picture. In addition to a risk assessment in the light of the planned soil use, an important factor with these sites is the expected effect of clean-up methods on the ecological risks and what soil quality has to be achieved by clean-up in order to safeguard the intended soil use;
3. On the same scale, there are also sites where the financial possibilities for clean-up are inadequate ("poor sites"). These are locations for which clear land redevelopment plans are present ("something has to be done") but where the financial resources are limited or where the need for the implementation of an ecological risk assessment has little support for other reasons. An example is maintenance dredging work where keeping open a navigation channel is of decisive importance and where, as a result, a large quantity of polluted sludge has to be dealt with. Another example is the removal of the top layer of turf in nature areas (what is to be done with "polluted" sods?). In nature development projects, a question which often has to be addressed is what specific soil use (for example, which target types are possible) is promising given the limited quality of the soil. In these cases, ecological risk assessment is useful as a support for decision-making;
4. Finally, there are also sites which are severely polluted but where there is no support for an ecological risk assessment, for example because there is no land redevelopment plan or because the intended development has little visible ecological value. Examples of

this are leftover sections of industrial areas, or inaccessible and unused leftover areas in rural settings. Clean-up is not an option for these sites and the solution can be sought in less demanding soil use (for example, nature and recreational functions at the Diemerzeedijk site near Amsterdam). In order to determine the possibilities for soil use when pollution has resulted in a reduction in quality, a site-specific risk assessment is very useful. The IMC clean-up option (isolate, manage, control) has primarily focused in the recent past on the reduction of risks of dispersion and human exposure. The reduction of this type of risk does not necessarily have to result in a reduction of ecological risks at the location in question. The IMC option will also be embedded in the more complete management system of "active soil management" (Ouboter *et al.*, 1997).

In addition to the categories referred to above, there are other factors which can have an effect on the support for ecological risk assessment. Examples are:

- specific ecological values (for example, rarity and beauty) of the area in question, examples being certain types of up-stream forest landscape, particular valley formations, specific river bank vegetation in watery areas or the last remnants of living moorland;
- the perception and appreciation from society as a whole for the type of landscape, such as river areas, rural and urban areas *etc.*;
- appreciation for general ecological processes which are needed to guarantee a basic level of quality for soil use, even in industrial areas.

Suggestions for the selection of ecological aspects in relation to soil use

If ecological risk assessment is useful and desirable, and if the soil use has been defined as an initial step in this direction, experts (ecologists/ecotoxicologists) should select site-specific ecological aspects. An appraisal should be carried out beforehand to determine whether the intended soil use fits in with the site and whether there is enough differentiation within the standard set of land-use functions. When there is both severe acidification and pollution at the site, it makes no sense to characterise the soil pollution on the basis of acid-sensitive ecological aspects (using for example as an indicator the presence of a nematode population or vegetation which is sensitive to acidification). The appraisal of whether the definition of soil use is realistic is a matter which is outside the scope of this report but possible avenues in this direction are described by, for example, Lijzen *et al.* (1997), Latour *et al.* (1997) and Hendriks *et al.* (1997).

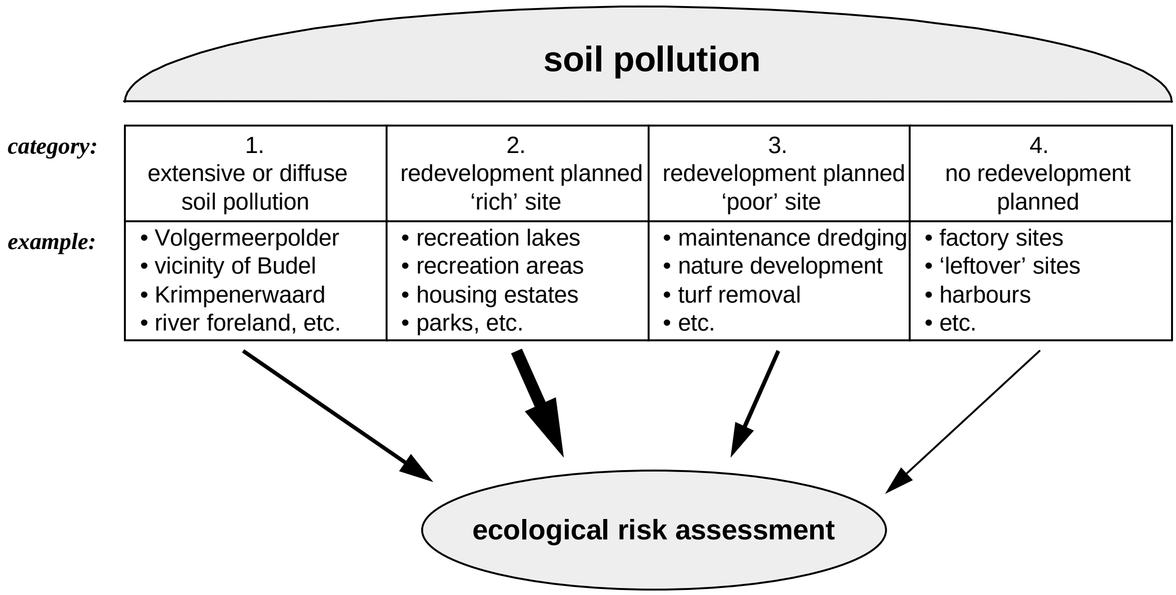

Figure 2. Rough classification of categories of soil pollution in relation to soil use and the expected support from society as a whole (thickness of the arrows) for an ecological risk assessment. The term "redevelopment" has a broad meaning in this figure; it also covers activities such as maintenance dredging work; "rich" or "poor" mean that financial funds are or are not present.

Examples of general parameters for arriving at a justifiable selection of ecological aspects are stated below:

A. Certain ecological aspects follow automatically from the soil use which has been chosen. For example, given the choice for a certain type of nature, a number of target and/or key species are determined immediately which the ecological aspects to be used must match subsequently. The indicator with which the appraisal can be conducted to determine whether the ecological aspects are met can also be directly derived from the choice in question. In the case of rural green areas, ecological aspects can be chosen by selecting key species and system processes using the same system which was used to determine target species or on the basis of sensitivity.
   - Example 1: *The target nature type "river forest landscape in free-flowing river course" has, in addition to a number of animal species, also a large number of higher plants as target species, examples being the E. palustris Crantz and Fritillarea meleagris. The parameter which could link up to this aspect is, for example, a growth and/or germination experiment with a plant which can be assumed to be sufficiently representative for the target species in question. In this way, it is possible to make an appraisal of whether the pollution present involves a certain risk;*

- Example 2: *For the same target type, the badger and the otter have been referred to as target species. If the ecological aspect includes valid populations of top predators of the kind, the parameter to be used could consist of bioaccumulation tests with earthworms or mosquito larvae respectively or of comparable field research. In this way, it is possible to make an assessment of whether the bioaccumulation of persistent pollution constitutes a risk.*

B. The choice of a particular soil use also imposes secondary requirements on soil quality, for example with respect to the incidence of diseases and plagues and the "health" of the ecosystem. Here also, ecological parameters can be used.
   - Example: *If, after land development activities, a particular site is to be used for agricultural purposes, certain types of crop will belong to the "primary" species. Many of these crops grow better if there is a certain concentration of mycorrhiza present in the soil. For a good harvest, a high concentration of the mycorrhiza fungus on the plant root can serve as an ecological aspect and the intended indicator could consist of a certain type of fungus test.*

C. In addition to specific species, the choice of a certain type of soil use also imposes requirements on a number of general system processes ("life-support functions").
   - Example: *If the intended soil use relates to allotments and/or vegetable gardens or agricultural use, processes such as the decomposition and nutrient cycles can be looked at. The parameter to be used for the assessment can consist of an inventory of specific groups of soil fauna, litter decomposers such as wood lice, orbited mites, spring tails and nematodes, or of the key groups of micro-organisms immediately responsible and the associated criteria.*

D. Ecological aspects will depend very much upon site-specific, physical-chemical and hydrological conditions. An important aspect is the dispersion related to the groundwater flow and dispersion by wind or biota and bioavailability. In addition, these processes can also provide possible solutions (a reduction in mobility can reduce bioavailability; biodegradation processes and phytoremediation reduce the bioavailable and mobile fraction) or actually result in problems (toxic metabolites).
   - Example 1: *If, as a result of a combination of a particular soil type and a particular position of a site, the chance of the pollution being dispersed by the wind (for example as a result of the formation of dust) could be considerable, the ecological aspect will perhaps have to be focused on the flora in place. It is possible that, if ground-covering plants thrive at the site in question, this will limit the risks of dispersion;*
   - Example 2: *In certain situations, the choice of a certain type of plant can be used in an attempt to absorb as much of the pollution as possible in the parts of the plant above the ground, after which the plants can be removed by chopping them down or mowing. Monitoring of this process produces a picture of the possibility of realising a different type of soil use in time (for example, a meadow where cows can graze at the appropriate time). This technique still has to be proven;*

- Example 3: *In other situations, the intended soil use can mean that a terrestrial site can be covered with water or that it will acidify further (in time). In a situation of this kind, major changes can be expected in bioavailability which should be expressed in the selection of the ecological aspects. An indicator which links up to this aspect is an experiment in which the situation is simulated, after which the water sample obtained can be subjected to toxicity experiments with, for example, water fleas or mosquito larvae;*
- Example 4: *Organic pollution can be broken down by means of biological processes to produce harmless compounds. The measurement or calculation of biodegradation can be used as an indicator. In conjunction with the modelling of degradation processes, soil management can be directed at the maximum stimulation of these processes (intrinsic and/or extensive clean-up, for example the encouragement of good aeration, nutrition or pH level of the soil) so that the soil quality can become acceptable in time.*

E. The time horizon, specific research area and desired precision of the answer can play an important role in the selection of the ecological aspects and indicators to be used.
   - Example 1: *If the assessment is primarily conducted in order to determine the priority of the clean-up work to be carried out, the focus will initially be on a number of fairly simple aspects and/or parameters (for example, "quick" bioassays). On the other hand, if the objective of the study is focused more on the estimate of the potential long-term effects, the ecological aspects and the parameters to be used will have to be adjusted accordingly;*
   - Example 2: *If a site with a special type of ecosystem has to be characterised (specific ecological values), extensive site studies with a specific range of tools can constitute a part of the effect assessment.*

Instruments

As stated above, a shift in the assessment system will have to take place so that site-specific circumstances can be taken into account more than previously, examples being site-specific exposure to mixtures of substances and ecological receptors. The "*state-of-the-art*" of site-specific ecological risk assessment can be found in a number of publications which survey the field (for example: Gaudet *et al.*, 1995; Suter, 1998; Den Besten *et al.*, 1995; STOWA/RIZA, 1997). A possibility which should be taken more into account with ecological effects is the application of the TRIADE, in which use is made of an integrated appraisal of several supplementary sources of information (Chapman, 1986; Maas *et al.*, 1993; STOWA/RIZA, 1997). With respect to a system based on potential risks derived from the chemical presence of pollutants and substance properties such as NOEC values, an approach of this kind also provides more opportunities to link up with specific ecological aspects and function-based clean-up. Finally, it will also have to be possible to make an estimate of how risks change if the intended soil use is changed and what will be the ecological effects and benefits from measures taken (for example clean-up, soil management).

When several forms of severe soil pollution are present at the same time, site-specific risk assessment can be used to indicate the priority of clean-up work for the different cases. In situations of this kind, in which a range of contaminants can be found in high concentrations, stage 1 of the assessment is the conducting of short laboratory tests. Here, standard test organisms are exposed to field samples and the toxic effects on these organisms are measured. If ecological data are also desired, exploratory ecological studies, for example, should be conducted at the site. In principle, this approach will yield enough information to determine the priority of clean-up at various sites, so that the deployment of a limited and small-scale study suffices. However, this also means that the scope of a study of this kind is limited.

If a precise answer is required (for example, if the first stage does not result in an unequivocal answer or in the case of the development of “valuable” areas of natural beauty), one can proceed to stage 2: longer tests, bioaccumulation studies and field studies. Surveys of tests of this kind with standard organisms in the laboratory (including sensitivity for various substance groups) are available (for example, Van Straalen and Van Gestel, 1993; Van de Guchte *et al.*, 1996; Gezondheidsraad, 1991; STOWA/RIZA, 1997). When there are problems with the sensitivity or specificity of various methods, multivariate analysis techniques can provide a solution (for example: Van Wijngaarden *et al.*, 1995). The results must be used for a function-based assessment in which tests are carried out on site-specific ecological aspects. To do this, the soil use and the selected ecological aspects must be known; what groups of organisms or ecological processes are affected given the soil use at the site in question?

A set of criteria for the quantitative interpretation of research results associated with a set of site-specific minimum instruments can indeed be established but it will include relatively large areas of uncertainty when reference data are lacking. This is related to the complexity of ecosystems in general, and the lack of an accepted framework for the level at which ecological processes have to be protected in relation to a particular (ecological) soil use. Research in this direction is still at an exploratory stage (Faber, 1997; Van Hesteren *et al.*, 1998). Things are simpler if different sites can be compared to each other or when enough reference material is available. In that case, experts can make an assessment of whether a certain level of ecological damage as a result of the presence of soil pollution is acceptable or not. Support for measures for the protection of ecosystems and development for the purposes of nature is still indispensable for the successful deployment of site-specific ecological risk assessment.

The encouragement of research which will act as support for the assessment of whether damage is unacceptable or whether the effects are inevitable but acceptable is, incidentally, highly desirable. Experience can be acquired with the system by testing the basic approach in practical situations at a number of characteristic sites. This experience can then be used to apply ecological risk assessment on a larger scale. In 1999 this testing has successfully been done at three sites to a limited extent, but further testing is necessary (see: Rutgers *et al.*, 2000).

Conclusions and recommendations

- Before the implementation of site-specific ecological risk assessment, the intended soil use should be defined, including information about the valuation and characteristics of the intended ecosystem at the site;
- In an assessment framework for site-specific ecological risks, less use should be made of the usual substance-specific approach and more direct use should be made of ecological and/or ecotoxicological site-specific information;
- Depending upon the nature of the research area in a specific case which is being characterised, an assessment system can be constructed on a modular basis, moving from global to more specific assessments. It should be possible to implement the global part with little effort. The specific part consists of a large number of techniques ("toolkit") from which the expert will make a selection;
- The assessment system not only indicates what the ecological risks are in a particular situation but also the level to which improvements should be made in order to make a specific soil use possible;
- The assessment system must (in addition to the assessment of risks) focus on the determination of actual ecological effects;
- Surveys have been, or are being, drawn up of bioassays which are to be used and which are operational in the Netherlands, together with the available knowledge about specific sensitivities. The drafting of a comparable list with tests based on ecological aspects is fraught with uncertainties, for example with respect to the question of whether the various tests are operational or not;
- Consensus about the way in which an assessment system should be constructed would appear to be possible in the relatively short term. For a system which can be implemented in practice, energy needs to be invested in cost effectiveness, in support from society as a whole and the scientific community, and in the degree to which the results are comprehensible and usable for third parties or non-specialists (transferability);
- It is always useful to monitor ecological effects at the site, but this becomes indispensable if the desired soil quality can only be achieved after a period of time;
- With site-specific risk assessment, a great deal of attention must still be devoted to practicable and comparable studies of benchmark and reference sites;
- The basic approach should preferably be tested for a number of characteristic site studies.

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Annex 1: Glossary

actual ecological risk: term used in priority system for site-specific ecological risk, i.e. site-specific possibility of the occurrence of negative effects (or actual damage) as a result of soil pollution on ecological structures or functions

bioassay: assessment of an environmental sample in terms of the presence of toxic substances with respect to a standard test organism or biological test system

ecological criterion: assessment measure within quantitative measure for ecological indicators for the purposes of risk assessment and monitoring

ecological damage: see ecological effect; actual reduction in ecological functioning with respect to use of soil by society

ecological effect: consequence of the presence of soil pollution which has been actually determined, estimated or calculated (margins of uncertainty should be indicated) with respect to a reference situation

ecological aspect: selected feature (structural or process-related, temporary or permanent, rare or dominant, *etc.*) or characteristic (at a higher integration level) of the local ecosystem, adjusted for the ecological soil use; qualitative

ecosystem: a volume (land/care/water) with a stable natural border which is primarily determined by landscape properties and climatological factors. Ecosystems include, in addition to organisms, a collection of ecological and anthropogenic processes which function in an embedded system of sub-volumes

ecotoxicology: multidisciplinary science which integrates toxicology, environmental chemistry and ecology

environmental-chemical: composition and concentrations of substances in environmental samples; often in relation to standards and/or potential toxicity and/or potential ecological effects

function-based: based on actual or intended use of the soil at the site in question

generic: on the basis of sample from all potential ecological aspects; general (by contrast with site-specific)

indicator: quantifiable parameter for ecological aspect (can also be used qualitatively)

integral approach: approach in which different, complementary elements are seen as parts of a whole (by contrast with reductionist)

intrinsic value: inherent value, particular value (not economic)

site-specific: taking into account the information relating to the site in question; this involves ignoring generic information or specifying that information in greater detail

QSAR/QSSR/partition model: models which can be used for estimating potential effects of known substances on the functioning of ecosystems

set of instruments: set of indicators, parameters, tests, models and/or criteria

soil pollution: presence of substances of human origin in the soil or aquatic sediment; sometimes limited to the list of priority substances in concentrations in excess of the target value

soil use: the social function of the soil to be determined by society as a whole

substance-based: argued on the basis of the presence of substances

test: measurement protocol

toxicity test: test of the toxicity of substance (or of several substances) in a defined medium, with standard test organisms or processes

NB: Dutch organisations have retained their Dutch abbreviations.