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Towards a Methodology for a Risk Assessment System for Contaminated Sites

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SUMMARY

This report describes a procedure to develop a risk assessment methodology for contaminated sites with respect to the risk of dispersal in groundwater. The methodology was originally intended for landfills, but is for example also usable for risk assessment of contaminated industrial sites and sludge depots or to determine the priority of remediation.

A Geographic Information System database can be constructed from available databases and preliminary modelling studies, which should then be ranked according to a fuzzy logic system, and incorporated into a Decision Support System. The final product, the Decision Support System, is a flexible instrument for making environmental policy decisions where the available data is vaguely defined and/or incomplete.

SAMENVATTING

Dit rapport beschrijft een procedure om een methodiek te ontwikkelen, waarmee een risico analyse voor verontreinigde locaties uitgevoerd kan worden. De methodiek was oorspronkelijk ontwikkeld voor vuilstortplaatsen, maar is tevens bruikbaar voor bijvoorbeeld de risico-analyse voor gecontamineerde industriële locaties en slib-opslagplaatsen of de urgentiebepaling van saneringen met betrekking tot het risico van verspreiding.

Met behulp van de beschikbare gegevensbestanden en de resultaten van verkennende modelstudies kan een Geografisch Informatiesysteem gegevensbestand worden geconstrueerd. De gegevens kunnen vervolgens worden gerangschikt volgens de regels van de 'fuzzy logic' en worden ingebouwd in een Besluitvorming Ondersteunend Systeem (Decision Support System). Het eindprodukt, het Besluitvorming Ondersteunend Systeem, is een flexibel instrument om milieuhygiënische beleidsbeslissingen op te baseren, in die gevallen waarin sprake is van een beperkt inzicht in de milieuhygiënische karakteristieken van de locatie.

1. INTRODUCTION

Sources of contamination posing a threat to the surface and groundwater resources in the Netherlands are being studied by the RIVM (National Institute for Public Health and Environmental Protection) in connection with the extent and prioritization of the risk. These contamination sources include, among others; landfills, sludge depots, and polluted industrial sites. The predictions made on the basis of the results are to be used in the development of a simple risk-assessment model. Once the risks have been determined, the urgency of the remediation claims can be evaluated to permit prioritization of the known contaminated sites and the potential contamination sources.

More than 4000 landfills exist in the Netherlands today. The physical characteristics of these landfills range from old, closed landfills that have no lining and are sitting atop or within the groundwater to new landfills with sophisticated liners and leachate collections systems. Obviously, the newer landfills are not going to require immediate attention in the remediation schema, but these are few, and the older, closed landfills can pose an immediate threat to the environment.

The most accurate method of determining if a landfill is leaching pollutants to the groundwater is to place monitoring wells along the circumference of the landfill and monitor the groundwater on a regular basis. From an economic standpoint, this is obviously not practical for the number of landfills in the Netherlands. Therefore, some sort of system must be implemented to prioritize these landfills as to concentrate attention on those deemed most likely to cause environmental problems.

Development of such a prioritization scheme is a complicated task. The risk of environmental threat contains a myriad of factors such as the geohydrology of the area, the waste disposed of in the landfill, the land use in the area containing the landfill, and many others. It may be that an old landfill atop a thick clay layer that is leaking toxic chemicals which adsorb strongly to clay (therefore yielding a travel time for the chemical of several hundred years) will have a much lower remediation priority than a newer landfill which is leaking high doses of a much less toxic chemical directly into the groundwater in the vicinity of a groundwater pumping station. The difficulty lies in the classification and ranking of so many vaguely defined, but critical interrelated factors.

Many of these factors must also be taken into account when evaluating polluted industrial sites and sludge depots, of which there are more than 400,000 in the Netherlands. In some cases, remediation can be done easily; for example, a dioxin-contaminated terrain may possibly be remediated simply by removing the contaminated soil, since dioxins are extremely immobile. However, in practice, this is an extremely expensive operation, and may be excluded from the remediation list for economic reasons. In sludge depots, the accumulation of heavy metals may be the most serious environmental threat.

The same prioritization scheme can also be used for planning purposes. If the need for a new landfill is indicated requiring an environmental impact assessment, or if an old industrial site is being considered for a new use, the risk assessment decision support system outlined in this report can be adapted for these uses. To prevent unnecessary wordiness, the description of the system refers only to landfills, although it is adaptable for many other uses.

2. CONCEPT

The development of a risk assessment system to quantify the environmental threat to the surface and groundwater resources from landfill leachate requires a complicated series of modelling simulations to achieve a reliable product. Less effort is needed to *prioritize* the environmental risks of landfills. Nevertheless, several preliminary studies must first be carried out to achieve an adequate classification scheme which can be successfully implemented in a Decision Support System.

The first of the preliminary studies will be to determine the effect of different soil types on the attenuation of the leachate; i.e., under what conditions and which geologic strata different pollutants will travel to the surface water and groundwater. This will be performed with METROPOL and CHARON, following the guidelines given below in Section 3.1.

The second of the preliminary studies consists of the calculation of travel times and streamlines for each of the landfill locations in the dataset available from the LAE (Laboratory for Waste Materials and Emissions) at the RIVM. This series of calculations will result in a classification of landfills by the time required for a particle to travel from the underside of the landfill to the surface, or to a groundwater abstraction well. Much of the geohydrological data is already available in the database of the GIS for the RIVM National Groundwater Model (LGM).

Further data classifications need to be made in order to set up the datasets necessary for the Decision Support System. Some of these may include:

- separating landfill data into construction type; i.e., whether or not liners are present, or capping, or neither, year of construction, etc.;
- separating landfill data into content type; domestic, industrial, etc., including possible leachate composition (this data can be obtained from the literature);
- separating landfill data into land use categories based on the land use of the area in which the landfill is located;
- separating landfill data as to geologic strata and hydrogeological characteristics.

Once the preliminary results have resulted in a series of Datasets, these will be entered into a prioritizing schema using fuzzy logic software which will be incorporated into an interactive Decision Support System (DSS). Figure 1 schematizes the approach, where the Datasets mentioned above have been incorporated in the Decision Support System (Multiple Datasets). A dataset with the travel times of the pollutant, calculated with the LGM, is an example of such a Multiple Dataset.

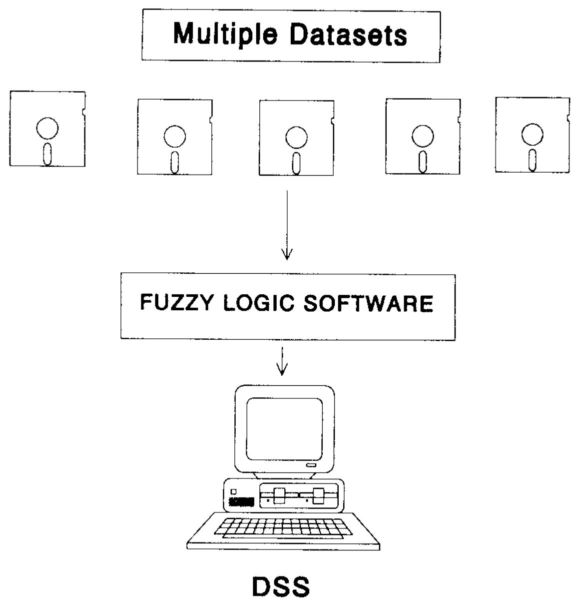

Figure 1: Approach of the Decision Support System (DSS)

Figure 2 represents some of the decision making criteria which could be, if translated into Datasets, incorporated into the DSS.

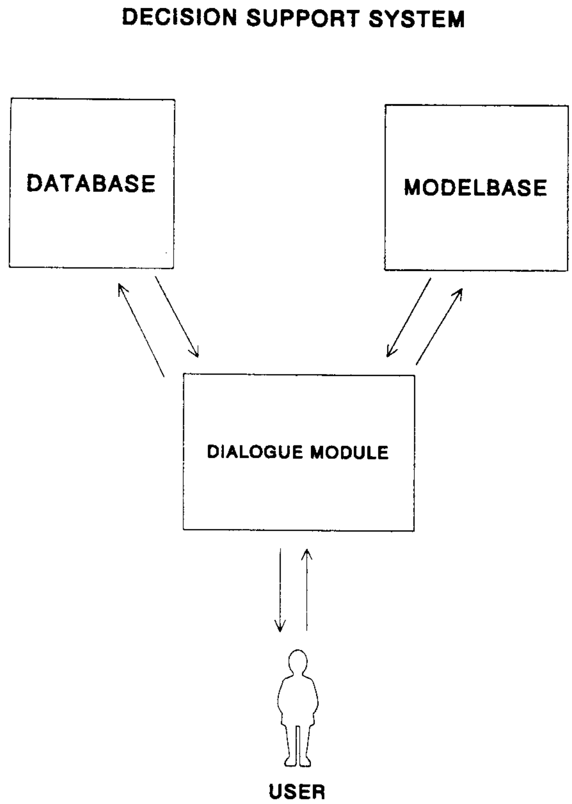

Figure 2: An overview of the decision making criteria which could be incorporated into the Decision Support System.

3. MODELS

The following section contains brief descriptions of all the models to be used in both the preliminary and main studies. References are included for more detailed information.

3.1 Preliminary modelling studies

The two studies outlined below are necessary to obtain a measure of the sensitivity of the parameters in the decision support system. The first, a combination of METROPOL (groundwater flow) and CHARON (chemical equilibrium and transport), explores the different processes which occur as leachate moves through different soil types or combinations of soil types. The second study, using the LGM (RIVM National Groundwater Model), is to determine travel times and streamlines for the different landfills.

3.1.1 METROPOL and CHARON

This study is designed to determine the sensitivity of the chemical transport parameters. A landfill evolves through four separate phases of chemical development; the aerobic acidic, anaerobic acidic, instable methanogenic and stable methanogenic (Beker, 1992). It is not possible to give an exact time scale to any of these phases, only a relative time scale. The purpose of this preliminary study is to model leachates from two different phases (acidic and methanogenic; Beker, 1992) of landfill development as they percolate through different sediment types, or a combination of sediment types. For example, infiltration could be modeled as a column experiment with a column of "pure" clay or sand, or a standard Dutch soil profile. Two different landfill phases are chosen because several of the leachate components vary significantly with phase.

It is not intended that this combination of models be used to model every landfill, and every geological formation that is found in the Netherlands. Several representative soil types should be modeled with both leachates for the purpose of forming a generalized geological prioritization based on the results. This database only needs to be set up once, then used 'as is' for the rest of the system.

How the leachate changes in chemical composition as it moves through differing soil/sediment layers is not known. It is expected that adsorption, decomposition of organic components and chemical precipitation would be the major factors that may influence the chemical composition. Density effects should also not be neglected, but may be difficult to incorporate into this particular study.

METROPOL

In order to make predictions about the leaching of components from a landfill, a modelling code is necessary that encompasses three-dimensional groundwater flow through porous media as well as geochemical transport and adsorption, both in transient and equilibrium conditions.

METROPOL (**ME**thod for **TR**ansport **O**f **POL**lutants) which simulates the three dimensional flow of groundwater is based on the finite element method. The model consists of a package of computer programs for preprocessing, simulation and postprocessing. The preprocessing package includes programs for mesh generation and refinement and data distribution over a given mesh. The simulation package contains programs for steady state and transient groundwater flow with constant density or transient flow with transport of dissolved salt or adsorbing and decaying species at low (tracer) concentrations. The postprocessing package includes programs for particle tracking and the generation of contour plots in two-dimensional cuts.

Typically, this report does not contain detailed information about the physical and mathematical background of the equations and numerical methods on which the programs are based. For more detailed information on these subjects, the reader is referred to Hassanizadeh (1986a); Hassanizadeh (1986b); Hassanizadeh and Leijnse (1988); Sauter et al. (1990) and Sauter et al. (1993).

METROPOL-1 is the steady-state groundwater flow program which will generate a flow field to be used in CHARON. At this point, a coupling between CHARON and METROPOL-1 has not yet been accomplished. METROPOL-3 was developed for use with salt solutions, and calculates transport of dissolved salt with a strongly varying liquid density and viscosity in transient groundwater flow field. This does not include chemical reactions. METROPOL-4 calculates geochemical transport, adsorption and dispersion with liquid density and viscosity independent of concentrations.

CHARON

CHARON has been developed at the Waterloopkundig Laboratorium ('Delft Hydraulics'; De rooij and Kroot, 1991), in connection with aquatic system modelling for surface and groundwater. It incorporates convective and dispersive transport and with equilibrium and/or non-equilibrium chemistry, and uses a groundwater velocity field generated by one of several other models (in this case, Metropol 1). CHARON can predict solute concentrations as a function of time and space, for a number of species. It would, therefore, be possible to predict the changes that occur with slow acidification or sulfurization of the groundwater. An advantage of CHARON is that the end products (species) can be specified and CHARON can reconstruct the original components of the system. This can be quite useful in combination with the reverse particle tracking program in the METROPOL family to estimate point-source pollution. In landfills, particularly, the exact composition of the contents and the degree of decomposition is very rarely known.

CHARON uses both mass balance and mass action equations which are solved per element to calculate flux and equilibrium. Each mesh element is considered to be a homogeneous unit. The chemical equilibrium module solves by the minimization of Gibbs free energies (mass action law). For further information, see de Rooij and Kroot, 1991.

3.2 Preliminary Study 2: LGM

The LGM (RIVM National Groundwater Model), is a groundwater model whose domain is the entire country of the Netherlands. It divides the Netherlands into 4 aquifers, 3 aquitards, a surface layer and a geological base. The database is in a Geographic Information System (ARC/INFO), and the calculations are performed with the AQ-FEM computer code. This preliminary study concerns all the landfills in the Netherlands whose x,y coordinates are contained in the LAE (Laboratory for Waste Materials and Emissions) database. Travel times and streamlines will be calculated, and spatial information such as land use area will also be determined for each of the landfills.

3.2.1 ARC/INFO (GIS) database

Most of the hydrological preliminary results will be calculated with the LGM, which is a GIS (ARC-INFO) based groundwater flow model. The GIS database for the LGM already contains much of the specific geohydrological data for the Netherlands, such as the polder heads, surface layer, permeabilities for the permeable layers, depth of the top of the semi-permeable layers, and many others (see Lieste and Verlouw, 1993). There is also a dataset for the x,y coordinates, approximate age, contents and conditions for all of the landfills in the Netherlands which is available at LAE. This needs to be incorporated into the database for the LGM.

The files that are present in the LGM database (although they should be corrected for local models) include the following;

- depth and thickness of the aquitards
- permeability of the aquifers
- polder water level
- groundwater abstraction data
- groundwater level monitoring filters
- rivers
- soil type
- land use
- precipitation
- open water evaporation

These files were obtained from IGG-TNO. Due to the fact that these files cover the entire country and the data are sometimes interpolated over large areas, these files should be corrected for local modelling.

The x,y coordinates of the landfills will be spatially correlated with several of the files in the LGM, resulting in datasets for each landfill of the land use in the area, hydrology, soil type, and underlying geologic strata.

3.2.2 AQ-FEM

AQ-FEM is a computer code for groundwater flow consisting of several programs developed at the RIVM (Kovar et al., 1992). The nucleus of the code consists of the program EPGO, a finite element network generator, which solves the differential equations which govern groundwater flow in a layered system. The layered system consists of a number of aquifers separated by aquitards. The entire system rests on an impermeable layer, and is covered by a 'top' layer. The flow in the aquifers is assumed to be horizontal, while that in the aquitards is considered to be vertical. The 'top' of the system has a working surface water package and a prescribed top system flux relation (Lieste and Verlouw, 1993).

AQ-FEM includes a particle tracking program to determine the streamlines and travel times of a particle from point A to point B, the points being specified by the user. This will generate one of the datasets used in the prioritization scheme; the time lapsed before the leachate ostensibly reaches a sensitive area. In this case, another instrument should be used, for example a chemical equilibrium model as considered in Preliminary Study 1, to incorporate the chemical risk aspects of the landfill.

3.3 Fuzzy logic software

This software has not yet been written. Fuzzy logic is one mathematical method to classify vague data collections whose elements do not clearly belong to one set or another. Fuzzy multi-criteria analysis weighs each pair of elements to determine which conforms more to the given criterium.

First, a number of criteria are subjectively defined. In the case of a landfill, these could be the construction of the landfill, the environment in which it is located, the contents of the landfill, socio-economic factors such as cost of remediation, the landfill phase, the geohydrology of the site, etc. These criteria would either be subjectively ranked (for example, excellent, very good, good, bad, very bad), or, as in the case of the soil types in the preliminary studies, ranked as to sensitivity. For an exaggerated example, if the preliminary studies show that all the components in landfill leachate adsorb in 6 meters of clay, then the remediation priority for landfills sitting atop 6 meters of clay or greater automatically have a low priority.

For different criteria, expert opinions should be obtained to ascertain the ranking within the criterium. For example, the ranking of different land use classifications, or chemical constituents in leachate. This ranking can then be applied to the existing landfill datasets to make the prioritization. Due to the lack of a clear distinction between most of the groups within a criterium, these judgements should be given by an experienced observer of the criterium in question.

MATHEMATICAL EXAMPLE OF A FUZZY MULTI-CRITERIA ANALYSIS (Hoogeveen, R., private communication)

Assume that there are 8 landfills (numbered 1 - 8) that need remediation. The remediation urgency needs to be determined. This determination will be based upon 4 criteria.

Step 1: Arrange the objects in order per criterium:

Criterium A: $\{1,2\} > \{3,4,5\} > \{6,7\} > \{8\}$

Criterium B: $\{2,4,6\} > \{7,8\} > \{1,3,5\}$

Criterium C: {3,4,6} > {1,2,5} > {7,8}

Criterium D: {5,6,8} > {3,4} > {7} > {1,2}

Step 2: Determine the dominance value between each pair:

R	1	2	3	4	5	6	7	8
1	1	3/4	2/4	1/4	3/4	1/4	2/4	2/4
2	1	1	2/4	2/4	3/4	2/4	3/4	3/4
3	3/4	2/4	1	3/4	3/4	2/4	3/4	2/4
4	3/4	3/4	1	1	3/4	3/4	1	3/4
5	3/4	2/4	3/4	2/4	1	2/4	3/4	3/4
6	3/4	3/4	3/4	3/4	3/4	1	1	1
7	2/4	1/4	1/4	0	1/4	1/4	1	3/4
8	2/4	1/4	2/4	1/4	2/4	1/4	3/4	1

Note: R(1,2) = 3/4 means that for 3 of the 4 criteria is object 1 of the same or greater urgency as object 2.

Step 3: Determine the net dominance value n(i)

The definition of n(i) is Σj (R(i,j) - R (j,i))

	1	2	3	4	5	6	7	8
n	-6/4	8/4	1/4	11/4	0/4	11/4	-13/4	-8/4

Therefore;

{4,6} > 2 > 3 > 5 > 1 > 8 > 7

This system also weighs each pair of landfills against the other for all the criteria. The number of criteria will probably have to be adjusted depending upon the results; i.e., if one set results in a membership of 700 landfills, the number of criteria will have to be increased to make a finer definition.

The above example considers all four criteria to have equal weight. Should this prove not to be the case, a weighing function can be built in the fuzzy analysis to give criteria different weights in relation to each other. For example, it may be decided that construction criteria may function as a means to differentiate different landfills, but it is not nearly as important as travel times. Therefore, a judgement would be made as to the relative importance of the two criteria (5:1, or 10:1 for example) and an appropriate weighting function would be included. This technique is outlined in the literature sources quoted in Appendix B.

3.4 DSS

A Decision Support System, or DSS, is a computer code designed to aid the user in making decisions concerning problems that are not well defined, or that have too many criteria to efficiently organize. These systems are commonly used in environmental decision making, where many influencing factors must be integrated, and precise data are not available.

A classical DSS is given in Figure 3. This consists of a modelbase, a database, and a dialogue module, all of which are interactive with each other. The user interactively communicates with the dialogue module. The fuzzy multi-criteria analysis outlined above will be incorporated into the dialogue module. The modelbase will consist of the calculations performed with the LGM. As the hydrological conditions change; for example, new groundwater abstraction areas are put into operation, or particular polder areas are no longer maintained, the change in the groundwater flow will have to be recalculated to provide a new dataset. The database consists of the multiple datasets generated by the models described above.

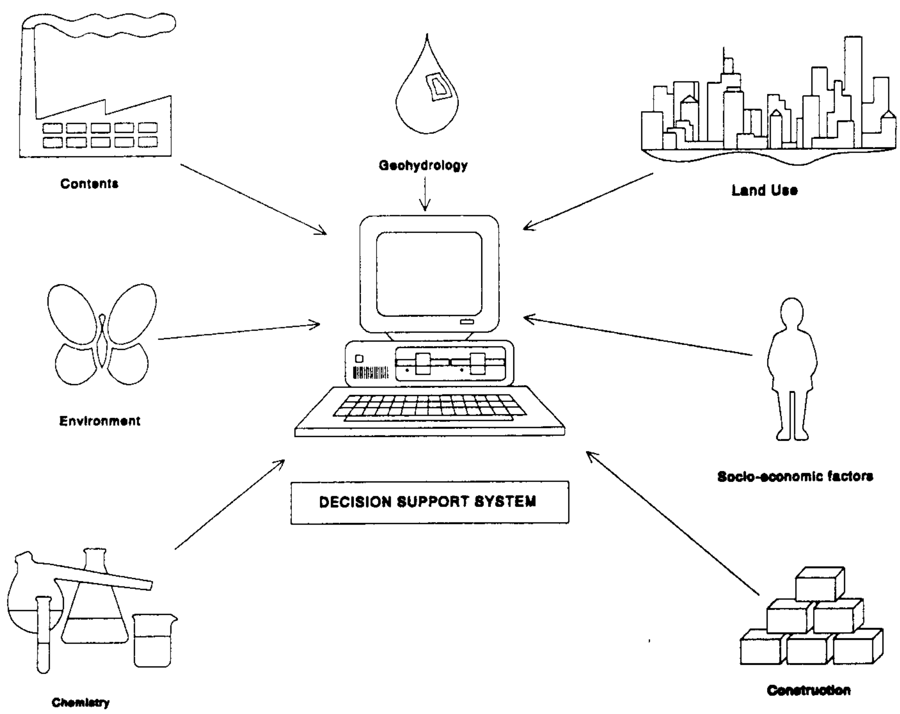

Figure 3: Interaction scheme of a classical Decision Support System

4. WORK PLAN

4.1 Preliminary Study 1: METROPOL and CHARON Calculations

The purpose of this preliminary study is to determine the sensitivity of the 'potential' dispersion to geological parameters. METROPOL will be used to generate a three-dimensional flow field for use in CHARON. CHARON will be used to determine the effect of a change in sediment/soil type on the composition of landfill leachate during two different landfill phases, the aerobic acidic and the anaerobic methanogenesis phases. Since the composition differs in the two phases (Beker, 1992), a different behaviour would be expected as the leachate percolates through the soil. For example, during the acidic phase, heavy metals would be liberated which may re-precipitate in the soil. Some may adsorb to clay particles. It is presently not known if this would have a significant effect as regards the composition of the leachate as a whole.

4.1.1 Calculations

First, the groundwater flow field will be generated in METROPOL. This groundwater flow field will be entered into CHARON for the transport calculations. Next, leachates for both phases should be chemically defined (see 7.2) and simulations run incorporating slow reactants, equilibrium reactions and transport. The differences should make up a dataset for geological strata.

These calculations could also be done as a column experiment, using the particle tracking paths generated by the LGM (see section 3.2). For example, if a particle must travel through 1 meter holocene, horizontally through 3 meters sand and then vertically through 1 meter clay, a "column" could be simulated of 1 meter holocene over 3 meters sand which is over 1 meter of clay. This would solve the problem of the METROPOL/CHARON coupling described in Section 7.2.

4.1.2 Output

The output of this preliminary study would either be the ranking of the risks for different types of geologic strata that occur in the Netherlands, or the ranking of the risks for different sediment types:

1. clay;
2. silt;
3. sand;

depending upon what is used as the input in CHARON.

These are just suggestions; a geologist should be consulted for the sediment classifications before the modelling is begun.

4.2 LGM Calculations

The LGM (RIVM National Groundwater Model), which is a combination of a Geographic Information System (ARC-INFO) and a groundwater flow model (AQ-FEM) will be used for the calculation of travel times and streamlines, as well as the generation of several of the necessary datasets.

4.2.1 Calculations

The first subproject is to enter the x,y coordinates of the landfills into the LGM. Once the coordinates are mapped, they should be sorted into several different groupings. These will include the classification of the land use of the surrounding area in which the landfills are located (groundwater abstraction area, nature reserve, urban area), the geological strata underlying the landfill, and the hydrological conditions (seepage area, infiltration area) and the soil type in the upper layer. These data should be stored in different datasets for use in the DSS.

Streamlines and transit times should be calculated for each of these landfills. These data will make up another of the dataset on the landfills; one which classifies them as to their time-potential for polluting.

4.2.2 Output

The expected output from the LGM-calculations and ranking is as follows:

Dataset with the landfills classified by travel time to a sensitive area (surface water or to a groundwater pumping area):

1. 0-25 years
2. 25-50 years
3. 50-75 years
4. 75-100 years
5. 100-250 years
6. 250-500 years
7. 500-1000 years
8. >1000 years

Note: you can model to 100,000 years or more, but it has little physical meaning, since the leachate composition will have vastly changed by this time, and so will the land use and many of the other characteristics. One thousand years is probably also a bit exaggerated.

4.3 LAE Database Manipulations

Most of the relevant information concerning the history and construction of the landfills in the Netherlands is contained in the LAE (Laboratory for Waste Materials and Emissions) database. This would need to be sorted as to the physical characteristics of the sites.

4.3.1 Landfill physical characteristics

The landfill files from LAE need to be reclassified for this schema into groups based on the physical characteristics of the landfill itself; whether or not it has a top liner, bottom liner, both or none; what sort of waste has been deposited, domestic, industrial or both, whether or not it is an operating landfill or a closed landfill and if closed, how many years it has been closed, etc.

At this time, very few of the landfills in the Netherlands have an approved cap, liner, leachate collection system or groundwater recirculation system, so perhaps this is not a relevant criterium at this point. In the future, as more landfills are being developed in accordance with the new guidelines, this criterium could be included in the decision making process.

It has also been noted that many of these criteria, including the chemistry of the different phases, the contents of the landfill and the construction methods are all based upon a certain age of the landfill. For example, in the 1940's, most landfill sites were deserted sand/gravel/other mining sites, without upper or lower protective layering, and the contents had very few plastics, more lead and solvents, and different market wastes. Therefore, rather than making these three criteria (content, construction, chemistry) it can be left as one (age). This sort of grouping is probably just as effective, since the data concerning the other three more specialized criteria are almost impossible to find.

4.3.2 Output

The important physical characteristics should be characterized into datasets as follows:

- Dataset for landfill construction (possibly useful in the future):
    1. Neither cap nor liner
    2. Intact liner
        a. Geotextile
        b. Plastic

        c. Soil (for example, clay)

    3. Intact cap

        a. Soil (clay) with topsoil

        b. Plastic or geotextile with topsoil

    4. Both intact cap and liner

    5. Groundwater recirculation system

    6. Leachate collection system

- Dataset for contents of landfill (possibly useful in the future):

    1. domestic

    2. municipal

        a. sewage

        b. market waste

        c. other

    3. industrial (Nieuwkoop, 1993)

        a. textile

        b. leather

        c. graphics

        d. chemical

        e. metal

        f. energy

        g. transportation

        h. miscellaneous (sugar, felt, ceramic, lamps)

- Dataset for age of landfill:

    1. <5 years

    2. 5-10 years

    3. 10-20 years

    4. 20-30 years

    5. 30-40 years

    6. 40-50 years

    7. 50-75 years

8. >75 years

- Dataset with the landfills divided into classes based on the land use of the surrounding area:

1. groundwater abstraction areas
2. nature areas
3. recreational facilities
4. urban areas
5. agricultural areas
6. wetlands
7. historical sites
8. other (sensitive)
9. other (insensitive)

- Dataset with the landfills sorted into classes based on the underlying geologic strata:

1. clay
2. sandy clay
3. loamy clay
4. peat
5. sandy peat
6. sand

5. INTEGRATION OF DATASETS INTO A DECISION SUPPORT SYSTEM

The integration of the aforementioned datasets into a full Decision Support System will require the use of innovative statistical analysis techniques. One of the preferred techniques in environmental problem solving, where the categories of data are often vague, and there are so many complicating factors, is the use of the fuzzy multi-criteria analysis.

Ideally, this decision support system should be developed so that it is also a useful planning tool for decision makers who need to find a new landfill location, and not only to prioritize landfill remediation. Since the GIS database in the LGM is for the whole of the Netherlands, it should not be that difficult to adapt this system to site planning. Other uses may be to prioritize the remediation of industrial terrains, sludge depots, and other point sources of contamination.

6. RELATED WORK IN OTHER INSTITUTIONS

At present, both IWACO and Staring Centrum are busy with other aspects of Risk Assessment for landfills. Staring Centrum is conducting research as to both the consequences and the probabilities of construction failures in landfill design using their model SWATRE (Soil Water Actual Transpiration Rate Extended). The Staring Centrum model begins with infiltration into the landfill, and models percolation through the landfill body into the groundwater. They have simulated several generalized plume-forming scenarios for different geohydrological conditions (Boels, 1993).

IWACO's project is more involved with remediation costs. Their model, FONS (Financiele Omvang Nazorg Stortplaatsen) uses the same database from LAE mentioned above. This project also includes the development of a risk-assessment model, based on data from the national as well as provincial levels. As of February 1993, this project was still in the planning stage (Ruardi, 1993).

7. PROBLEMS AS YET UNSOLVED

As with most concepts, there are always a few technical details that are not yet incorporated in the procedure of the methodology.

7.1 Coupling Problems -- METROPOL/CHARON

At present, there is no coupling between CHARON and METROPOL, due to the different mathematical formulations. The Darcy velocities given in the nodal points in METROPOL cannot be averaged and used, as they are in CHARON, without violating the mass balance principle upon which CHARON is based.

7.2 Leachate Composition

There is no standard leachate that can be simply used in the Preliminary Study 1. A leachate composed of averaged values of all the measured quantities in Dutch landfill leachate (Beker, 1992) was found to be chemically impossible, and would in any case not be representative of older landfills. Leachate can only be collected from new landfills with installed leachate collection systems. It may be possible to compare the chemical constituents of groundwater samples from monitoring wells with those of the local groundwater samples to obtain an idea of what may be coming from the landfill, but this is not a very accurate method. However, in the absence of other data, it is a possibility.

It is suggested that a chemical analysis be obtained from actual leachate samples from both phases, and used in the simulations.

7.3 DSS

Although this may not be a problem within the scope of this concept report, care should be taken to include more than just technical data in this final step of the DSS such as:

- socioeconomic factors: budget constraints, optimization of economic factors;
- social factors: odours emanating from a site, children playing on the site;
- environmental factors: hazards for ecosystems, increase of rodent and/or insect populations.

8. CONCLUSIONS AND RECOMMENDATIONS

Although the task of developing a risks assessment methodology is rather complicated, involving the use of several types of computer codes and simulation studies, the end result should be quite a useful tool for sanitary engineers and planners. Even the preliminary studies, such as the effect of soil types on landfill leachate composition and transport should yield useful results for further studies in many disciplines.

It is recommended, however, that this project be a team effort instead of an individual effort, due to the complexity of the problem and the extensive knowledge required not only of mathematical modelling techniques and groundwater movement, but also of chemical principles and interactions, software development, programming and statistics. This project should be split into several components, perhaps one being groundwater flow, calculation of streamlines and transit times, another being the complex chemistry of landfill leachate over time through differing geological strata present in the Netherlands, the third being the development of software to carry out the fuzzy multi-criteria analysis, and the fourth being the programming of all the links between the different models and software packages.

A supplementary study that would be of use would be to model the effects of density on transport with METROPOL 3. It has been noted that landfill leachate often forms not a singular plume, but more a series of "fingers" during leaching (Taat et al., 1986).

Another supplementary study to 'validate' the METROPOL and CHARON formulations would be to use the same groundwater flow field in both models, and run simulations of an adsorbing contaminant and compare the results.

None of these calculations take the unsaturated zone into account, but assume that the leachate leaves the landfill and enters the groundwater immediately. A third supplementary study would consider the effect of the unsaturated zone.

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APPENDIX A:
CHEMICAL COMPOSITION OF 'STANDARD LEACHATE' - ANAEROBIC ACIDIC PHASE (percolation rate = 300 mm/year)

Compo- nent	dimension	average value in leachate*	distr. coefficient	average value grw. in NL**	A value (target value)	B value
CZV	mg/l	22000			100	-
pH		6.1	n/a		6.5-6.9	6.5-6.9
Cl	mg/l	743		x	25	150
NH4-N	mg/l	237		x	0.4	1.0
NO3	mg/l	218		x	5.6	11.3
Kjehl- dahl-N	mg/l	438		x		
SO4	mg/l	500		x	25	250
As	ug/l	51			-	30
Cd	ug/l	4			0.5	2.5
Cr	ug/l	67			-	50
Cu	ug/l	30		259.8	-	50
Hg	ug/l	1		19.0ng	-	0.5
Ni	ug/l	92			-	50
Pb	ug/l	394			-	50
Zn	ug/l	5			-	200
Ba	ug/l	556		230.6	50	100
Fe	mg/l	780				
Ca	mg/l	1200		x	100	-
Mg	mg/l	470		x	30	50
Na	mg/l	2988		x	20	150
K	mg/l	1813		x	10	12
PAK	ug/l	2			-	10
EOCl	ug/l	29			1	15
Oil	mg/l	1386			50	200
Ar. op- losm.	ug/l	1042			-	30

APPENDIX A (continued):
CHEMICAL COMPOSITION OF 'STANDARD LEACHATE' - METHANOGENIC PHASE (percolation rate = 300 mm/year)

Compou-nent	dimension	average value in leachate*	distrib. coefficient	Average value grw. in the NL**	A-value	B value
CZV	mg/l °	3000			100	-
pH		8.0	n/a		6.5-6.9	6.5-6.9
Cl	mg/l	743		x	25	150
NH4-N	mg/l	237		x	0.4	1.0
NO3	mg/l	218		x	5.6	11.3
Kjehl-dahl-N	mg/l	438		x		
SO4	mg/l	80		x	25	250
As	ug/l	51			-	30
Cd	ug/l	4			0.5	2.5
Cr	ug/l	67			-	50
Cu	ug/l	30		259.8	-	50
Hg	ug/l	1		19.0ng	-	0.5
Ni	ug/l	92			-	50
Pb	ug/l	394			-	50
Zn	ug/l	0.6			-	200
Ba	ug/l	556		230.6	50	100
Fe	mg/l	15				
Ca	mg/l	60		x	100	-
Mg	mg/l	180		x	30	50
Na	mg/l	2988		x	20	150
K	mg/l	1813		x	10	12
PAK	ug/l	2			-	10
EOCl	ug/l	29			1	15
Oil	mg/l	1386			50	200
Ar. op-losm.	ug/l	1042			-	30

APPENDIX B:
LITERATURE SOURCES FOR SPECIFIC TOPICS

FUZZY SETS

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