"OPERATIONAL RESEARCH AND ENVIRONMENT"

by

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OPERATIONAL RESEARCH AND ENVIRONMENT

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Operational Research (OR) is a discipline which primarily aims at improving the effectiveness and the efficiency of processes of decision-making. These processes take place in every segment of our society: industry, banking, agriculture, government, politics,... The distinctive feature about OR is that it commonly makes use of optimization models. From the very start of the eighties these models have been increasingly 'cloaked in user-friendly wrappings', the so-called Decision Support Systems.

In previous publications the authors have already pointed at the potential significance of OR for society [2, 3]. The following will illustrate, using a number of daily recurrent environmental issues, how OR can be used in describing and solving them.

Things are going bad for the environment. This general and maybe even blunt-sounding statement is pre-eminently valid for a country like ours which very much likes to characterize itself as "The Netherlands, Land of Distribution", but which at the same time is being tackled by society as well as politics to keep a close eye on the protection of the environment. The area of tension between profiting from the economic activity, reducing deficit on the national government's budget, expansion of the public sector and concern for a good social climate, for both our children and our grandchildren, is getting stronger every day. There is a tendency to give economic growth the highest priority. Therefore it is getting more and more important to increase the effectiveness of environmental measures.

Operational Research can play an important role in visualizing and solving environmental problems. This observation is at the same time an implicit appeal to increase the OR-contribution to the variety of environmental research carried out. Furthermore the subject of Operational Research should get more attention in the different environmental courses at the Dutch universities and students of OR should be encouraged to apply their experts' appraisal to environmental problems.

Environmental problems on a world scale

On Thursday 19 October 1989 the Economics Supplement of NRC Handelsblad (a high quality Dutch Newspaper) contained the following articles: 'Bonn finances environmental research out of privatization', 'Notorious environmental pollutionist out of Iran' and 'Building of manure factory delayed'. The frequent publication of environment-related contributions of this kind is bound to grow. In that very same week the magazine SAFE [8] contained the article 'Assistance from space is to help the environment'. In this article pictures taken by NASA-astronauts distressingly show that the ecological balance of our Earth is in danger; this due to human activity (overpopulation, environmental pollution, excessive use of energy). NASA votes an amount of more than a hundred million dollars to get the project 'Mission to Planet Earth' off the ground. By means of observations during satellite flights the dynamics of the Earth can be sufficiently fathomed. Consequently environmental disasters can be predicted and there will be time to find ways to avert them.

An IIASA-study (International Institute for Applied System Analysis) about the *acidification issue* in Europe [4, 11] specifically takes the RAINS-model (Regional Acidification INformation and Stimulus) as its guiding principle. With the help of RAINS people are capable, basing themselves on mathematical-physical relations, to pronounce upon the SO_2-and NO_x-deposition within Europe when the locations and size of the SO_2- and NO_x-sources are known (figure 1). The model translates the calculated deposition values into effects on the environment.

RAINS is wholly interactive: the user selects an energy scenario for his point of departure, he decides upon which emissions he would like to calculate, for which future years, which sets of measures will have to be implemented per country and per year and which output will have to be generated. The output of RAINS largely consists of maps of Europe showing for example deposition patterns and soil acidification.

Next Operational Research gets involved. For the question is how, with limited financial means, one can reach a previously agreed environmental objective, with the best results. But the question can also be put differently: Try, with the available budgets, to invest in emission reduction in such a way so as to realize a maximum effect on the environment. For sulphur (S) the environmental objective can then be translated into grams per m^2 per year. In order to do optimizations of the kind RAINS has at its disposal an optimization module.

RAINS can be used for several aims. First of all, it offers the possibility to show on a map of Europe what the SO_2-deposition pattern will look like in the year 2000, when no SO_2-emission reductions have taken place. The places with the maximum sulphur deposition are mainly located in Central and Eastern Europe. The highest peaks are the Donetz Basin in the southeast of the European part of the Soviet-Union, the area around Leipzig and Dresden in (former) GDR, and the Krakow/Katowice territory in the south of Poland. The peak load here is more than 10 grams S per m^2 per year. In Western Europe the high loaded areas are situated in Northern Italy, the Ruhr Gebiet in West Germany and in Central England. Here the values are lower than in Eastern Europe, but they are still considerably above 0.5...1 grams S per m^2 per year, which is considered the maximum value permitted for ecosystems in Europe. The same exercise can be done for the year 2000, taking into account agreements concerning emission reduction on a European level. Some 12 billion guilders have been set aside for this reduction, equally divided over Eastern and

Western Europe. Now, too, do we see a fairly high peak load of 7.5...10 grams S per m^2 per year.

In order to truly optimize, the said amount of 12 billion guilders per year has been taken as a starting point. This amount has to be spent in such a way so as to minimize the peak load. Analysis with the help of RAINS demonstrates that with that sum a peak load of 4.....5 grams S per m^2 per year will be possible. However, in order to reach that minimum, the money will have to be allocated in a different way, namely 8.2 billion guilders in Eastern Europe and 3.8 billion guilders in Western Europe. In other words: assuming the previous allocation of the resources for the purpose of the reduction of SO_2-emission (divided on a fifty-fifty basis), a shift of 2.2 billion guilders from Western to Eastern Europe will lead to halving the peak load!

The optimization module in RAINS can also be applied in a different manner. Suppose the peak load has to be reduced to 3.0 grams S per m^2 per year. How much money will then be needed every year (in 2000), assuming an optimal allocation of money? It appears that this would require 5.4 billion guilders in Western Europe and 9.0 billion guilders in Eastern Europe. It is interesting to see that in total this will cost 'only' 2.4 billion guilders more than in the case in which a total of 12 billion guilders has been set aside (and which shows a peak load of 7.5 ...10 grams S per m^2 per year!). So it is true that while one can reserve a large amount of money, staking it optimally can also be a problem. Here OR can help.

Conclusively it can be stated that decision support systems, such as RAINS, can be used in order to

- evaluate various scenarios, thereby visualizing effects such as 'peak load ' of the SO_2-deposition geographically;
- make evident the effects of investments in SO_2-emission reduction;
- optimize investment allocations, thereby aiming at minimizing the peak load;
- display other deposition patterns (such as nitrogen).

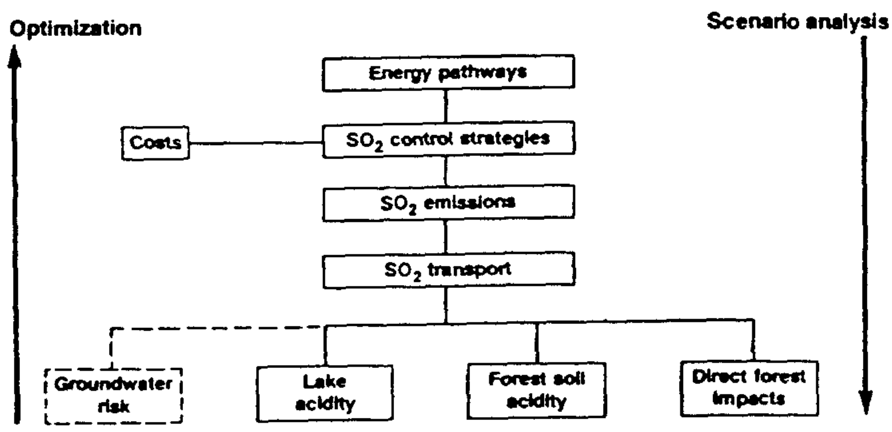

Fig. 1 Diagram of the RAINS-model (Source: Alcamo., J., et al., Acidification in Europe: A Situation Model for Evaluating Control Strategies; in: Ambio, Vol. 16 (1987), pg. 232ff.)

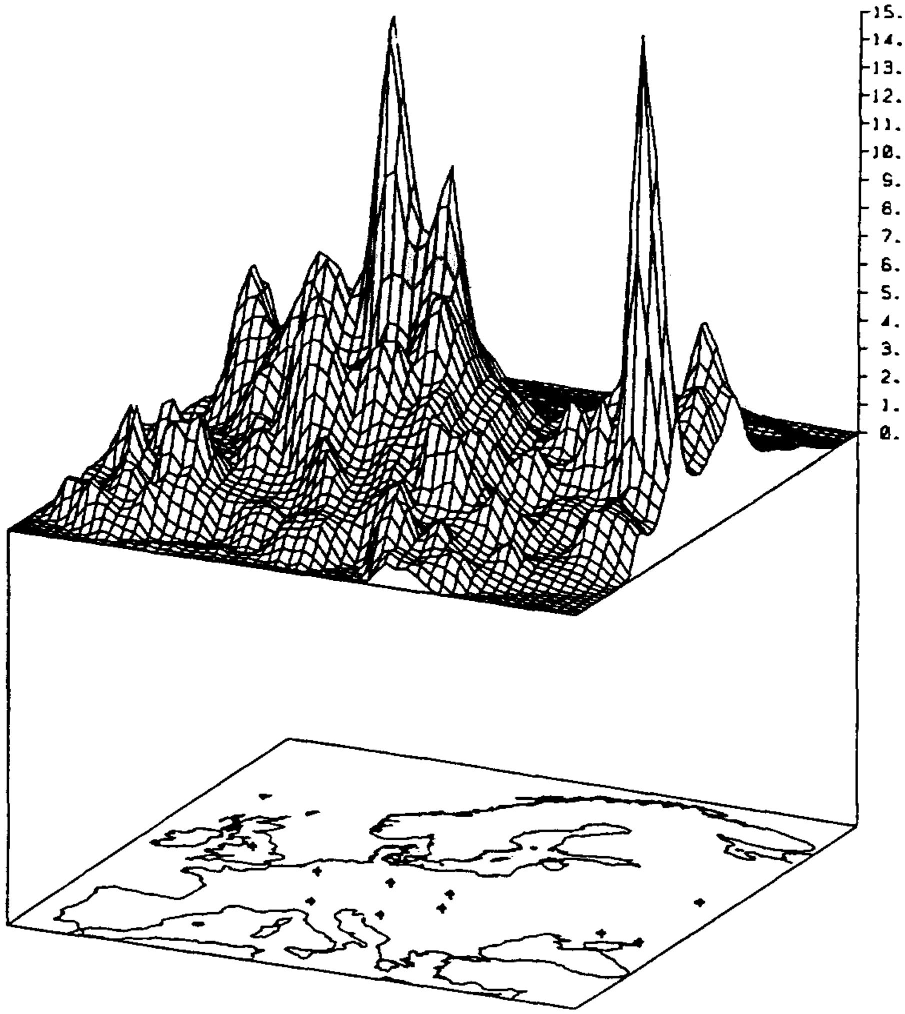

Fig. 1a Total deposition of sulphur (in g/m² per year) in Europe (1980). The crosses indicate the ten highest deposition points (Source: [4]).

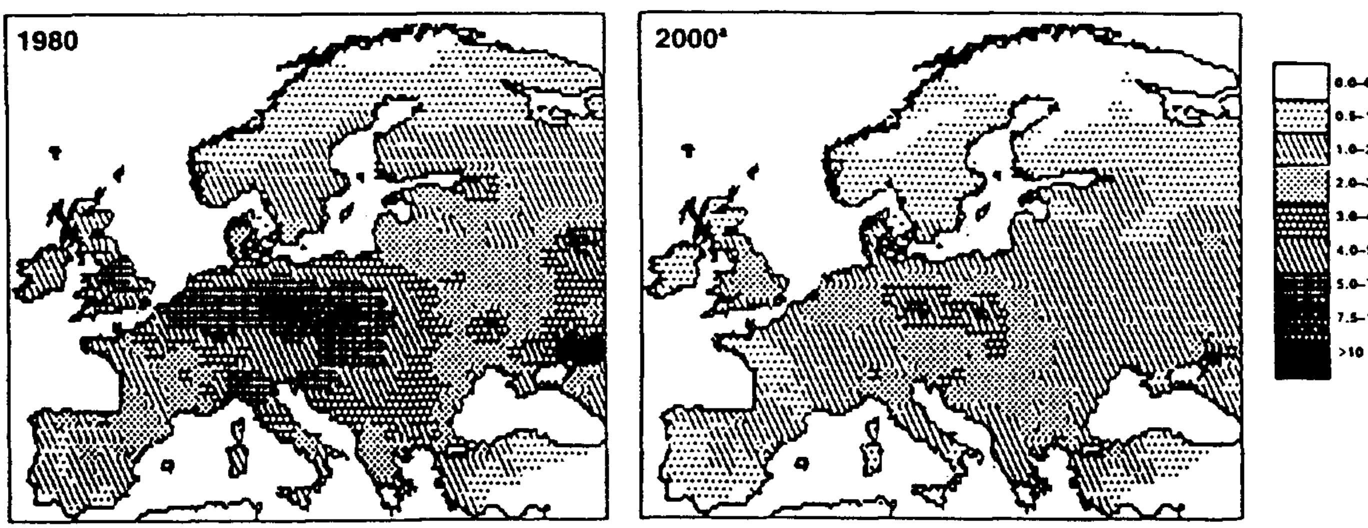

Fig. 2 The sulphur deposition in Europe (Source: see fig. 1).

At the moment the RIVM (the Dutch National Institute for Public Health and Environmental Protection) are developing a simulation model which is to give a clearer understanding of the mechanisms behind *the greenhouse effect*

[10]. This model, by now known as IMAGE (Integrated Model for the Assessment of the Greenhouse Effect), aims at giving an integrated view of the greenhouse effect, as well as providing an insight into the basic mechanisms of this problem. It is based on a large quantity of data, obtained from literature and by calling in several experts. Experimental research is also playing a role in this. All the information is being integrated and brought to the same level of aggregation. At the centre here is interweaving knowledge from various sciences.

The core of IMAGE consists of: emission modules, concentration modules, a radiation absorption module and a sea level rising module. These modules are linked in such a way that the outcome of the one module will serve as input for the other. In the greenhouse effect it is especially the gasses CO_2, CH_4, N_2O, CFC-11 and CFC-12 that play a role (figure 3).

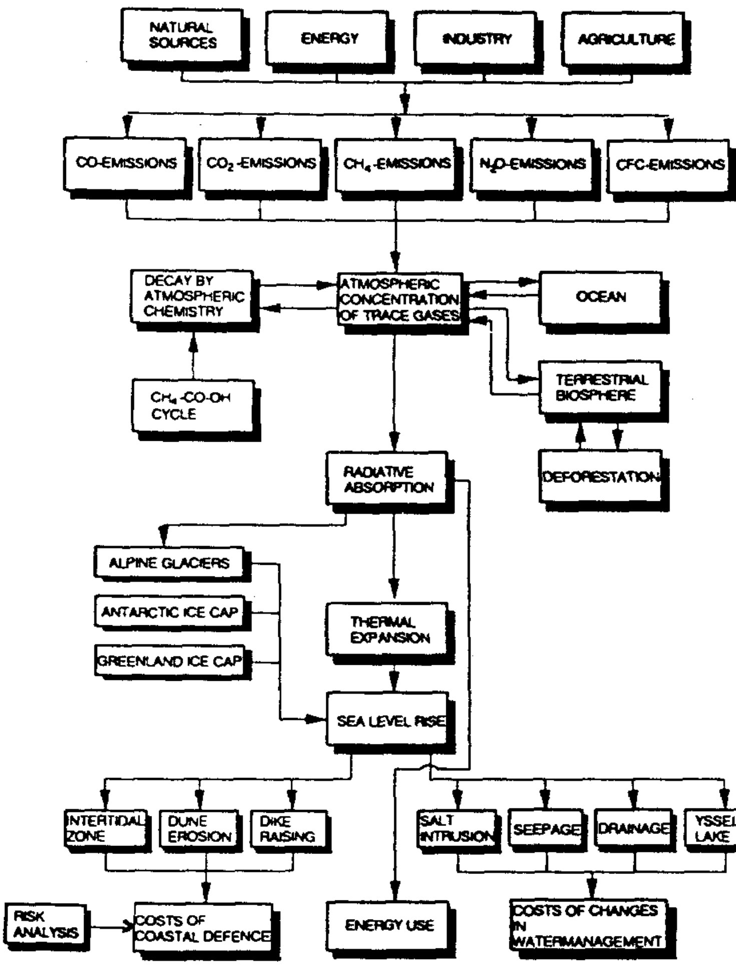

Fig. 3 The IMAGE-model (Source: R.J. Swart, RIVM)

In the emission modules the historical emissions of the period 1900-1985 have been put into the computer; for the period 1985-2000 four emission scenarios have been selected: a *continued trend*, a *bended trend*, a *changing trend* and finally a *forced-reduction trend*. The different scenarios are based on a study of both the anthropogenic sources of trace gas emission (such as energy usage, agriculture and industry), and of those of the growth of the world population and the natural sources.

The first scenario (the continued trend) assumes a continuation of the current economic growth with no environmental restrictions. The bended trend scenario presupposes that measures have been taken against environmental problems, like acidification. These measures are also of important consequence to the greenhouse effect. The third scenario (the changing trend) contains assumptions regarding a strict observance of international agreements. Finally the forced-reduction trend scenario presupposes a maximum effort (on a worldscale) aimed at a livable development.

IMAGE shows that the Montreal Protocol (an agreement concerning the restriction of CFK-gasses [12]) is important in order to stabilize the relative contribution of CFKs to the greenhouse effect.

From the system of international agreements (such as the Montreal Protocol) standards for the emission of CFKs are laid down. Models like IMAGE can determine the effects of this standardization in advance and for a longer period and can therefore play an important part in determining (international) standards. Operational Research will, to an important extent, be able to help in finding effective measures to approach the appointed standards as close as possible and such with the lowest financial effort. A model for optimizations of the kind will be added to IMAGE in the near future. However, by and large it has to be stated that filling in the optimization criterion may be difficult, since qualifying the cost related to longterm environmental effects is sometimes hardly possible.

2. Three Dutch cases

Let's, in the light of three examples of Dutch applications, have a closer look at the role of OR.

The manure issue

Due to legal measures against topdressing, people will, in future much more than now, have to deal with transport, storage and manure processing on a large scale. Since the cost involved in this are bound to increase it is important to select the means of transport, the depots and the processing installations in such a way that the cost will be kept at a minimum. In order to gain some more insight into this logistic issue people are, as part of a cooperative project between the IMAG (Institute for Mechanization Labour and Construction) and the Wageningen University of Agriculture (Faculty of Mathematics), working on a decision support system. This system is based on a mathematical model which determines an optimal logistic structure in a real situation - production of manure and possibilities for disposal, transport, storage, etc. By changing the starting-points and subsequently determining once again the optimum structure, the effect of the different starting-points becomes clearer.

Because of the growth of intensive stock-breeding it has become harder and harder to find an acceptable destination for the amount of manure that is being produced. This has led to topdressing the estates, followed by groundwater pollution. The introduction of legal measures has made this problem clearer every day and it is bound to present even more difficulties in practice.

The core of the problem is the surplus of minerals (phosphate, nitrate and potassium) and heavy metals (copper, cadmium and zinc) in the animal manure. The balance between the supply and drainage of minerals in agriculture has been disrupted by the use of feeders from outside the farm. It is especially the import of feed produce for the intensive stock-breeding , which plays a major part here. Due to the surplus of minerals it will no longer be possible to dispose of the amount of animal manure within the agricultural sphere, that is, not in a sensible way. An overdose of animal manure will affect the soil fertility and lead to a deteriorating quality of the crops.

Furthermore overdosing affects the quality of the groundwater and it contributes to the eutrophication of the surface water in areas poor in nourishment. Ammonica emission from manure is one of the causes of acid rain.

The possible ways of disposing of animal manure are restricted because of the *phosphate standards*. In practice often more manure will be produced than is legally permitted. This amount of manure has to be taken off the market - fully or partially. This is what we call processing. In doing so, other manure products can be originated. For example, after the purfication of calf manure, one is left with calf manure silt which is being disposed of in agriculture. Processing pig manure on an industrial scale, as Promest in Helmond and MeMon in Deventer are planning to do, yields an 'organic granular manure substance', which can be compared to artificial fertilizer and which should be brought on the market at a similar price.

While discussing *disposal* and *processing*, aspects like (ways of) transport, storage and manufacturing are important. In order to enlarge the disposal prospects of animal manure, a number of treatments are possible, such as separation, stumming, sedimentation and drying. The destination for manure that has been treated is disposal. Most of the treatment techniques are also applied in processing.

The use of ways of transport, storage facilities, processing installations etc. is necessary in order to give the amount of animal manure a destination - disposal or processing. There are a lot of logistic possiblities in filling this in. It is not clear a priori which ones are to be preferred.

In order to get an insight into this logistic issue, the IMAG and the Wageningen University of Agriculture (Faculty of Mathematics, section Operations Research) have, since 1987, been working on a computer system which could be of help. This decision support system will, in specific cases, determine an optimal logistic structure, including transport and storage needs. A structure like this is dependent on the given *possibilities*. By gradually altering these and by again calculating the optimal structure, the effects of the adaptations will become visible. The system regards the issue on a regional level; there are two areas that are worked on: a surplus area and a shortage area. An example of a possible combination between a surplus and a shortage area is the combination North Brabant and Zealand.

As has been claimed the destination of manure can either be disposal or processing. In determining the optimal ways of disposal and processing three steps can be distinguished: (1) the disposal on one's own farm, (2) the disposal on other farms in the same region, (3) the disposal in a different region as well as the processing. Most of the manure can probably be diposed of on people's own farm. This disposal is calculated by considering the production of manure and the disposal possibilities for each farm. It is estimated in the best possible way how the possibilities are being utilized. Since every farmer is autonomous there are no further optimizations involved in this step. Instead it is tried to give a reproduction of the real situation as well as possible.

After the disposal on the people's own farms has been determined, it is assessed for each municipality which amount of manure can be disposed of on other farms within the same region. This step, too, is based on an estimation of the actual use of manure. If there is still a matter of surplus after these steps have been taken, the question arises whether this can be disposed of in an area which has a shortage of manure. If this is not the case, the only possibility that remains is processing.

The flows of manure that occur in that case will be optimized. The outcome will depend on the possibilities. For each kind of manure it has to be indicated which destinations are available and in what way they can be realized in terms of storage, transport etc. It goes without saying that it will also have to be indicated which cost are involved.

The structure of the flows of manure strongly depends on the possibilities. In case of direct transport from surplus farms in a surplus area to shortage farms in a shortage area, the flows will have a simple structure. But the structure will be more complicated in case of a central storage in either a surplus or a shortage area and in case transport involves transfer (due to the use of different means of transport). The structure of the flows of manure are then modified in a *network*, with flows of manure going through branches to different nodes in the network. A branch stands for the transport of manure products, a node is either a point of departure and/or a destination for a branch and can visualize a place of storage or a possible means of processing.

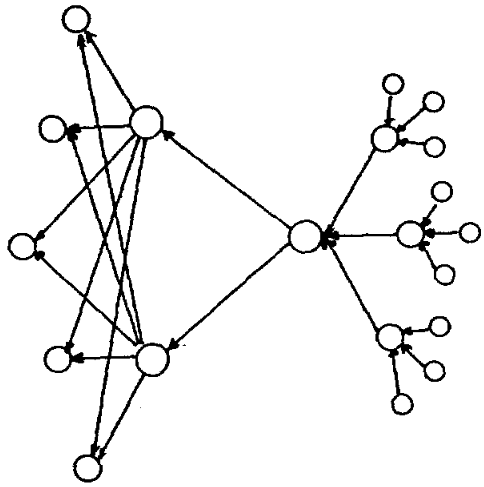

Fig. 4 Network for storage, transport and processing of manure

The flows in the network are optimized within the existing possibilities, in which case use is made of *Linear Programming* (LP). The following conditions are taken into account in solving this LP-problem:

- all surplusses have to get a destination (disposal or processing);
- the flows going to a processing installation (or place of storage) are not to surpass its capacity;
- the inflow at a place of storage (or place of transfer) is equal to the outflow;
- if processing involves the production of manure products, the size of this production will be related to the size of the flow to the processing installation;
- the total disposal is not to surpass the available storage space for manure;
- the disposal of a certain kind of manure is limited, in the same way as the disposal to other farms in the same area.

All conditions are linear. If the locations of for example storage facilities are not predetermined, this option can be included in the optimization, just like scale effects regarding storage and processing.

At the moment the decision support system for the manure issue BOSMEST (Beslissing Ondersteunend Systeem voor MESTproblemen) is finished. Part of it is used at the National Manure Bank. The optimal logistic structure can be determined in any real situation. Furthermore BOSMEST can be used in determining the correct standards and the cost of the logistic structure going with it. Therefore also politicians can use it order to come to useful standards.

Soil Clearance Projects

The clearance of the Dutch soil is a socially sensitive subject which, from the beginning of the eighties, has involved a lot of money and other means. In dealing with the clearance of the Dutch soil the provinces play a central part by means of the Interim Law for Soil Clearance. The province is in charge of: stock-taking cases of soil pollution, establishing priorities for research and clearance, supervising and/or carrying out research and clearance together with dealing with their financial completion.

The amounts of money that the provinces can spend on soil clearance (some few to several tens of millions of guilders each year) are far too small to achieve a near conclusion of the soil clearance operation. The soil clearance programme, drawn up yearly by the province, indicates which cases of soil pollution are qualified for research or clearance the coming year. It also indicates the urgency of the projects; the ways in which the degree of urgency has been determined, in view of the Interim Law for Soil Clearance, varies for each province.

The urgency determining systems differ in the extent of detail, in the criteria that are taken into account and in the extent in which the system is of a quantitative or a qualitative kind. The soil clearance policy pursued by the province has as its aim to select the projects and clearance variants to be carried out in such a way that the budget available for soil clearance will be exploited in the best possible way.

For each case of soil pollution several possibilities are known to arrive at handling the project and these are translated into the clearance variants. The variants consist of applying a soil clearance technique or a combination of soil clearance techniques. In describing these techniques one can distinguish between techniques without preceding clearance and techniques that are applied after clearance has taken place. One can also distinguish between purifying and non-purifying techniques.

People have as yet gained a lot of experience with the techniques that imply clearance and transport to a cleansing installation. The techniques to be applied without clearance have less often been tried; they are still even partly in the development phase. Because of the lower cost and the often less radical activities involved in the latter group of soil clearance techniques, these are bound to be more often applied in future. However, the problem here is that the degree of soil clarification that will finally be reached can often be insufficiently or with difficulty be checked (this because of inhomogeneous clarification).

The *environmental effect* of carrying out a project according to a specific clearance variant is determined by comparing two variables: (a) the risk of the pollution for the national health, and (b) the same risk after clearance has taken place. As a matter of course the use of the soil and the kind of clearance techniques to be applied are important factors.

The risk of the pollution is determined on the basis of criteria which are related to the nature and the concentration of the pollutants, to the extent of the pollution, to the possible ways of distribution and to the risks of exposure. It is the nature of the location in particular which is normative for the use of the soil. In selecting the clearance techniques, implementation, effectiveness and reliability play the key roles. These three aspects are determined by way of a scoring system; it is the user himself who assesses the score of the criteria that have been included by way of a assigning weight to the different criteria.

The aim of soil clearance can be described as selecting combinations of 'project/clearance variant' in such a way so as to maximize the sum of the environmental effects (total environment-effect), without overrunning the budget.

This objective has been translated into a linear programming model (LP) with integer variables. The possibility exists to include as an additional objective, that a specific number of projects, minimal or maximal, will be carried out. Addition of objectives of this kind to the first objective has been translated into the so-called goal programming model. Determining the environmental effects and cost per variable and maximizing the total environment-effect together constitute the allocation model. The model has been applied to eight projects and corresponding clearance variants in the province of Overijssel. The LP-model can be transcribed into mathematical terms. The problem is solved with the help of the computer packages LINDO and SCICONIC.

Conclusively it can be stated that:

- the allocation model can be a useful aid in pursuing a soil clearance policy on a provincial level. On a national level the system could be used in determining the projects to be carried out nationally, and with that in determining the distribution of the budgets among the provinces. The advantage of it is that on this level the progress of the soil clearance will be less influenced by non-predictable factors than on a provincial level;
- the system as a whole can be computerized so that the effects of the different policy views and the appointed limiting conditions can be calculated in an efficient and simple way.

Optimization models in the water treatment technology

In the last twenty years people in Holland have worked really hard to reduce the effects of waste water draining on the quality of the receiving surface water. The result was the installation of hundreds of sewage treatment plants in our country (the so-called RWZIs). It is not very likely that people have, in many cases, been able to make the optimal choice of purification techniques and designs of these RWZIs. For the optimal choice depends on the specific limiting conditions that characterize each situation. These are enforced among others by:

- the amount and the quality of the waste water to be purified;
- the accessibility of (new) technologies;
- the requirements for the quality of the effluent;
- the location of the RWZI;
- the advantages and disadvantages of the technologies that are being applied.

As an example we have the model which was used in a certain province in the seventies for the planning of new sewage treatment plants. The provincial department of Public Works had, together with an engineering firm, done a study in which research was done into the cheapest way of purification, from a provincial point of view. The cheapest alternative appeared to be purification by means of a so-called oxidation ditch, so it was decided to dig a number of oxidation ditches all over the province. However, after the plan had been carried out it appeared a few years ago that extension of an oxidation ditch for the removal of phosphate by way of a tertiary water purification stage would cause problems.

The only method which is suitable for the removal of phosphate out of the effluent of an oxidation ditch is simultaneous de-phosphatization by way of precipitation through a chemical reaction. The amount of sludge this will generate is considerable, while at the same time the processing possibilities of this sludge are small because of the very high percentages of heavy metals.

In view of the efforts the government takes to accomplish in the coming years a reduction of the phosphate percentage in the effluent to be drained and in view of the problems described here, it seems justified to conclude that in this case people have not chosen the *optimal* way of purification. In retrospect they should have selected a method of purification which had taken into account the specific disadvantages of an oxidation ditch: hardly any possibilities for extension, neither in capacity nor in application of tertiary purification.

It is likely that in the future there will hardly be any new sewage treatment plants installed in the Netherlands. However, the existing RWZIs will have to be expanded or renovated, for example because of age, too low a capacity or negative secondary environmental effects (eutrophication due to phosphate draining, a high production of sludge, stench, etc.). At the moment most sewage treatment plants are not accomodated yet to remove the phosphate out of the surface water. In the years to come a tertiary purification stage will therefore have to be installed in many cases. For the time being the following variants are suitable for the removal of phosphate: chemical precipitation, a granular reactor, a granular reactor combined with biological de-phosphatization and magnetic separation. The Dutch administrators of the water quality will have to decide upon the way in which they will comply with more rigid standards, before these rigid phosphate standards come into force in 1992.

The financial consequences of the strict measures taken by the national government can best be illustrated with an example: the Top Dike Board Rijnland itself will have to cough up 70 millions of guilders for it. The other administrators will have to pay similar amounts.

Like the other administrators of the water quality, Rijnland will have to answer the following questions in the next two years:

- which method for de-phosphatization, available at the moment, is optimal;
- which locations are optimal for the tertiary purification stages;
- is it a matter of a few bigger or many smaller de-phosphatization installations?

The qualification 'optimal' which is used in the first two questions is dependent on weighing up among others the following criteria:

- cost (investment cost and yearly cost);
- primary environmental effects (results of the various methods for the removal of phosphate);
- secondary environmental effects (stench inconvenience for the people living in the neighbourhood, production of sludge) and the potential measures the government may consequently take (for example as part of the Nuisance Act);
- space occupation;
- stability and reliability;
- possibilities of extension (flexibility related to future policy);
- knowledge which, because of the different techniques, is required from the contractor, but particularly from the operator.

In determining the optimal method of de-phosphatization and the optimal location(s), the simulating models and the optimization models can be used. With these models people have tried to describe a real situation and with some models they have even succeeded in obtaining a better insight into that reality.

In the last few years information technologists have worked really hard on the development of the so-called expert or knowledge systems. The major advantage of a system like this compared to a human expert is the greater amount of knowledge it can contain. Another thing is that the computer cannot overlook or forget any knowledge, as long as the knowledge has been put in in the correct way. Furthermore it contains the possibility of an integrated use (on several places) of quantifiable (data) and non-quantifiable knowledge.
Improving and extending existing sewage treatment plants is an extremely complicated matter with great financial consequences. In view of its complexity and because of the large amount of knowledge it requires, an expert system is the obvious instrument to make a few things possible.
People within the Wageningen Agricultural University are at the moment initiating the development of expert systems on behalf of the water treatment technology.

Conclusively it can be stated that Operations Research can play an important role in the development of water purification systems. Optimization models show the way to the best location of treatment installations and to the technology to be used. Furthermore OR-models when integrated in expert systems are playing a role which is becoming more and more important.

3. Finally

The foregoing has shown, with the help of examples, how and where OR can be applied in environmental science. It goes without saying that this is an arbitrary choice. We cannot pretend to be exhaustive.

We conclude by enumerating some related areas, where OR has been or can be applied, namely:

- drafting environmental security systems;
- drafting reservoir systems and their control;
- water quality control;
- location policy for waste removal installations;
- determining environmental risks;
- location policy for polluting industrial installations;
- optimization of emission from industrial installations.

These examples come from [7] and [9]. Both publications contain a wealth of further examples that we cannot go into any further here.

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- ir. E.C. Doekemeijer who supplied us with the information concerning the simulation and optimization models for the purpose of the design of water treatment installations [1].

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<u>1991</u>

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