Developing the CLEAN Model: a Tool to Evaluate Policy Options for Reduction of Mineral surplus, Ammonia Emissions to Air and Nitrogen and Phosphate Emissions to soil

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Abstract

Agriculture in the Netherlands produces high emissions of minerals to soil and ammonia to air, which cause environmental problems. The CLEAN model is a tool to evaluate policy options to reduce these problems. An overview of the model is presented and the difficulties in calculating manure surpluses and manure destinations are highlighted. To fulfil its purpose the model needs to be rather detailed, use large amounts of data, be fast, and produce reliable results. The model concepts and information technology that were chosen to meet these requirements are discussed. Special attention is paid to the position of the model in a larger information system and the use of a relational database. The development of this environmental information system will be evaluated and based on this experience, some remarks will be made on model integration.

1   Introduction

This paper presents the development the CLEAN model, a tool to evaluate effects of environmental and agricultural policies on emissions to soil and air. The acronym CLEAN stands for **CROPS, LIVESTOCK AND EMISSIONS FROM AGRICULTURE IN THE NETHERLANDS.** Starting from an outline of the manure problems in Dutch agriculture in chapter 2, chapter 3 will present the requirements that a policy evaluation model in this field must meet. After a short description of the model itself in chapter 4, the paper will go more into detail on the choices that were made on the model-concept and information technology aspects (chapter 5). After a description of the development process (6), we will discuss the results of these choices (7) and draw some conclusions (8).

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2 Environmental problems in Agriculture

Agricultural systems (livestock farming, arable production and horticulture) in The Netherlands are, in general, very intensive, reaching high production levels on small acreage. This is only possible with high inputs of concentrate animal feed and chemical fertiliser. Although economically successful, this intensive farming evokes a number of interrelated environmental problems:

- Surplus of manure which is expensive to transport,

- High emissions of Ammonia to the air, contributing to acidification,

- High emissions of minerals (mainly nitrogen and phosphate) to the soil, threatening the quality of soil, groundwater, drinking water and surface water.

The Dutch Government has enacted a series of environmental laws and regulations to control the agricultural emissions. A system of *restraints* on the application of phosphate from animal manure to crops, which were sharpened every few years, had considerable impact on nutrient emissions. Together with the obligation to use low-emission manure application techniques, this has resulted in a decrease of the pressure on the environment. However, the problems persist and keep demanding attention, from policy makers, farmers and environmental scientists, including those at RIVM. In 1998, a new policy was issued, based on mineral bookkeeping on farms, and a shift from input restraints to restraints on mineral losses per hectare. For more details on the manure problems and possible solutions see (Dietz/Hoogervorst 1991).

3 Requirements to Models for Agricultural Emissions

To determine agricultural emissions, the use of models is a necessity. It is almost impossible to measure emissions directly, with satisfactory detail, at the source (every stable/farm). Therefor, models have always been used to calculate the emissions to air and soil. While emissions can't be measured, other key factors can be determined instead, like numbers of animals, acreage's of crops and pastures and emission factors (of grazing, stables, manure storage and manure spreading)
We can distinguish between two types of models for two purposes:

a) Monitoring and

b) Policy Evaluation.

These different purposes have their own requirements. Simply said, the tool for Monitoring should have a high level of detail and should be validated with empirical data as much as reasonably possible. Response-time is less important than certainty and regional detail. The Policy Evaluation tool should be suitable for evaluating extrapolations, policies, estimations, and what-if questions. Interactivity and quick response are important, uncertainty and lower detail are acceptable to a certain degree.

In the following chapters, we will make clear that this distinction is only partly valid.

One could expect that there was a need for more than one model. Several models have indeed been build to gain understanding of the manure surplus and ammonia problems (e.g. Knol et al. 1987) but these had a high level of aggregation and were meant for qualitative studies. Until recently, there was only one model with sufficient detail available for both monitoring and policy evaluation purposes: the Manure and Ammonia Model (MAM, Oudendag/Luesink 1998), which is operational at the LEI/DLO institute in the Netherlands. This detailed model uses livestock- and acreage-data from individual farms, which are gathered by the Ministry of Agriculture and are secret because of privacy regulations. Other institutes, like RIVM do not have direct access to these data or the model. Though RIVM has used the opportunity to let LEI/DLO carry out calculations based on their assumptions, it felt the need to have an instrument at its own direct disposal. For this new agricultural emission model, there were the following requirements:

1. A moderate *level of detail,* based on *freely available data*, and still results that match those of the more detailed MAM model as close as possible.

2. *Appropriate to incorporate in a model chain*. As agricultural emissions are only one stage in the environmental cause-effect-chain, the new model had to be incorporated in a model chain, describing the whole acidification and eutrophication problem.

3. *Quick response time*. Results of a new policy analysis should be available within 24 hours, so the emission model itself should run in a few minutes.

4. *Data should be stored in a structured way.* As the model would need much data, it was important that updating and editing would be easy.

5. *The model should be part of an integrated emission information system.* Agricultural emission data had to be integrated with that of other target groups like traffic and industry.

Chapter 5 will describe and what solutions we found to meet these requirements. However, let us first take a closer look at CLEAN itself.

4   Overview of the CLEAN model

Fig. 1 shows the main elements of the model.

The first stage is to calculate the amounts of **manure produced** by the livestock. We distinguish 42 categories of animals in 31 regions, each of which has it's own excretion figures for manure volume, nitrogen, phosphate, potassium and organic matter. The distribution of these animals among stable types has to be taken into consideration for two reasons. It determines:

a) the type of manure that is produced (This is *fluid or solid*, depending on the sta-
    ble type and amount of water used) and

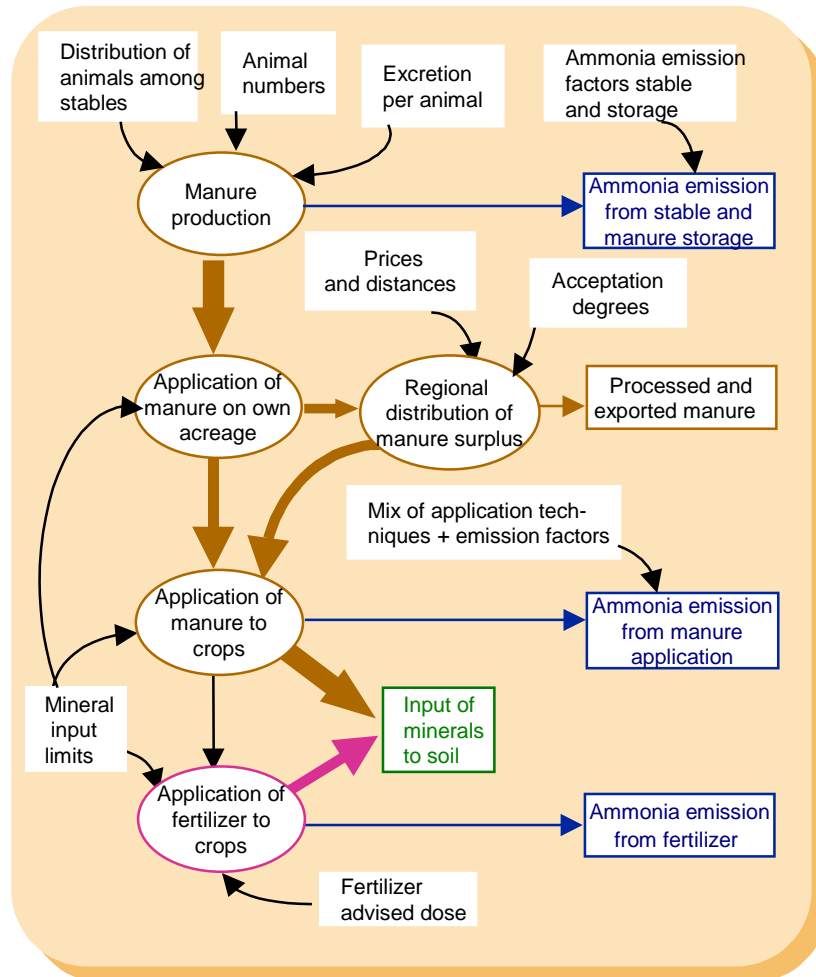b) the ammonia emission (Nitrogen volatization depends on the stable type).

Figure 1
Overview of the CLEAN Model

The second stage is to determine **manure surpluses**. These occur as a farm pro-
duces more manure than can be utilised on its own land. The amount of manure that
may be **applied on the own acreage** of crops and pasture depends on the *mineral
input limits* imposed by environmental legislation, first for phosphate only and since

1998 for nitrogen as well. For a manure surplus from a farm, there are three possible **destinations.** The surplus may be:

A) *transported, within* the own region or to other regions, to farms with lower animal densities per acre. Here it is legal to apply manure, but acceptance of foreign manure is limited to a certain *acceptation degree*, hence not all room for manure will be utilised.

B) *exported or processed*

C) *applied illegally* to crops that tolerate high mineral inputs, like fodder maize

Such high inputs did indeed occur in the past, before the mineral input restrictions were imposed (It was legal then!). Now this options functions as the last resort when manure cannot be disposed of in any other way.

The mix of these destinations is calculated with an optimisation routine, based on room for manure, acceptation degrees, transport distances, transport and processing prices and fines.

Once the total supply of manure per region is calculated, the model determines the **application of manure to crop**s (and soiltypes) and the mineral input and ammonia emission are calculated. Environmental legislation now restricts the superficial spreading of manure, and prescribes low-emission techniques like injection. Several application techniques are permitted, each with their own emission reductions. The model allows the user to specify a mix of techniques per crop and soiltype.

The final step is to calculate the amount of **chemical fertiliser** used. Key factors here are advised doses per crop, the recovery of nutrients in manure (which determines availability of minerals for plants), and correction factors, which account for the intensity of the farming system. Nitrogen-fertiliser also causes ammonia emissions, which depend on emission factors.

5 Choices on the Development of CLEAN

During the development process, a number of decisions had to be made on how to meet the requirements that were specified in section 3. There were choices to be made regarding the *information technology* to use, the *model concept* and *the development process.* Here we will describe some of those choices, with the ideas and considerations that guided us.

5.1 Choices on the Model Concept

Basically, the CLEAN model applies rather simple calculus to large amounts of data. However, there are a few interesting problems to discuss.

Manure surplus is a key-factor in the system, but this is difficult to calculate. It originates at farm level, when there are too many animals on too small an acreage. To calculate this, one needs to know the relation between animal numbers and acreage at farm level. These data are determined every year with the Agricultural Census, but become available to RIVM only in aggregated form (municipality level). If one uses these aggregated data only, the surplus is *underestimated*, as local manure surpluses will be compensated by shortages in other parts of the municipality.

To work around this data problem an *own-acreage factor* is used, which indicates the fraction of the acreage of crops and pastures which is directly available to the livestock farmers to apply manure. This fraction differs per crop and region. For pastures these figures range from 50 to 80 percent, for fodder maize from 70 to 100% , but for wheat from 0 to 20 %. These factors were estimated indirectly from results of the MAM model. This is complicated, as the amount of manure that farms can apply on their own land decreases over time, as input restrictions become more severe.

Another interesting concept in the model is the use of an **optimisation routine** to determine destinations of manure surplus. The model minimises national environmental costs for transport, processing, and export. However, does such an optimisation occur in the real world? It is fair to believe that each individual farmer will try (though not always succeed!) to minimise his costs, but this does not necessarily result in a national optimum. Fortunately, manure transports were not only guided by an "invisible hand". A National Manure Bank has been established to co-ordinate manure transports, and this institute has actually used results of the MAM model. They also registered manure transports, which could be used to verify simulation results. Quite some tuning on the acceptation degree factors is necessary to fit simulation to empirical data, in both MAM and CLEAN.

5.2 Choices on the Model Architecture

To be useful, a model needs a (*graphical) user-interface* (GUI), *data,* and a *calculation module*. For CLEAN these three components are fully separated. The combination of the three we denote as AGRIM (The AGRIcultural Module, fig 2.).

CLEAN itself is only a calculation module. It reads data from one input stream and writes to one or more output streams. It provides an option to produce additional reports and logging info.

The *model* contains **definitely no data**. Even the **dimensions** of data (like the number of animal categories, number of crops, soiltypes, regions, manure application techniques etc.) are all set at runtime. This *"instant model definition"* makes CLEAN very flexible. It may run for a single year or 30 sequential years, calculate with only one or 10 minerals in the manure, work with 10 or 30 manure types, etc. Of course, there is a documented set of internal consistency rules, which must be

obeyed and are checked. In fact, the runtime of half the model is spent with range- and consistency-checks of the input data.

The *data* are stored in a relational database (Open INGRES, running under HP_UX on a HP-K200 system with 3 processors and 750 MB internal memory). From the database, a *clean-inputfile* can be generated by an export routine (agrim_ex, written in C with embedded SQL, fig 2). Even on a powerful system as mentioned, this process takes 20 to 30 minutes to complete. The inputfile for one year takes up about one megabyte of data.

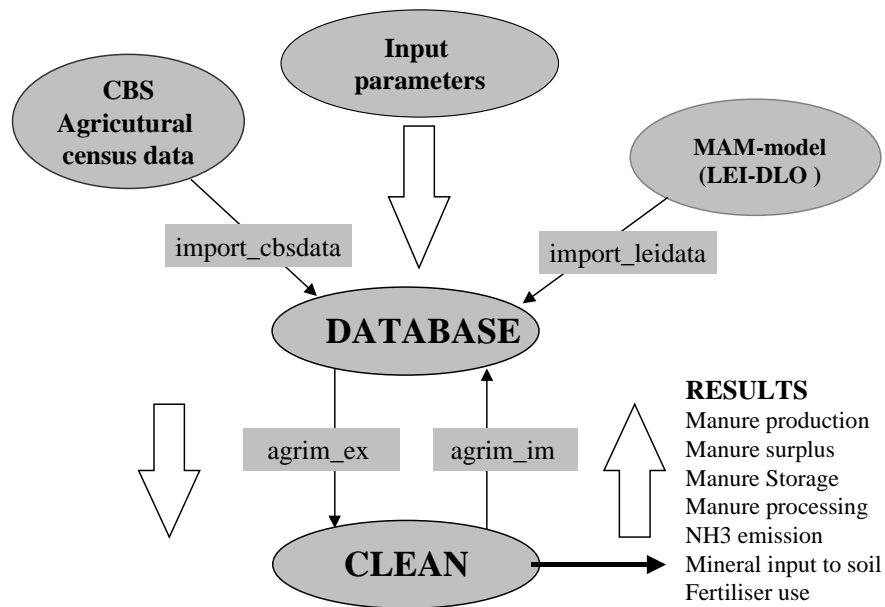# AGRIcultural Module (AGRIM)

Figure 2
CLEAN as part of the AGRIM information system

As mentioned before, RIVM also uses the MAM model for calculations. The resulting data can also be imported into the database and may be used for analysis, or preparing input for the CLEAN model. (fig. 2)

The information system, in which CLEAN is incorporated, allows *multi-user operation:* several persons can simultaneously edit the data for one modelrun. Date and ownership of each individual update action are registered in the database. The database provides automatic backup and roll- back facilities, which prevent loss of data.

Neither CLEAN, nor the AGRIM information system, provide provisions for presentation of the output. This is intentionally; as so many analyses can be carried out on the results, like time series analysis, regional comparisons with maps, etc. Results of CLEAN can be imported simply into a spreadsheet where the user may process them further to his/ her own need. A simple post-processing program reports a summary of the results and allows one-to-one comparison with the results of MAM.

5.3   Choices on Programming Tools.

CLEAN was programmed in Borland C++, with Rogue Wave Math Tools to ease matrix calculations. The ratio for C++ is that it's a modern programming environment, flexible, scalable and portable. Development started on a UNIX platform (HP-UX), but has now moved to the WIN-NT/Win98 environment. Rogue Wave tools made it rather easy to create program code from the equations in the design report for CLEAN, as specified in mathematical format by (Mooren/Hoogervorst 1993).

Ideally, we would have chosen a dedicated simulation and modelling environment, that supports building and running *multi-user* models and maintaining data in a relational database. It is striking however that -as far as we know- such software was not available (and still is not). Therefor, a general purpose-development environment was chosen to create a GUI and store the data that was promising in the early 90's: INGRES WINDOWS-4GL, now called CA Open-Road. Now we suffer from the *dialectics of progress:* far more sophisticated general purpose software is available nowadays on the WINTEL platform.

6   The Development Process

The development of CLEAN has taken a long time. The need for an agricultural emission model at RIVM resulted in a design in 1993 (Mooren & Hoogervorst). A scientific programmer developed a basic, stand-alone version of the model in C++ in 1993. It was build according to the "*single user, single purpose"* concept. There was no user interface, and data came from a spreadsheet.

In 1994 it was decided to incorporate the model in RIM+, the Environmental Information and Planning system of the Laboratory of Waste Materials and Emissions (Laan/Bruinsma 1993). The RIM+-database was not only to store agricultural data, but emissions, wastestreams and environmental costs of the other polluter groups (like traffic, consumers) as well.

There was an explicit need for an integrated emission model. Not only had the need for integration grown,[2] external and internal standards for the quality of tools

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[2] The publication of "Concern for tomorrow" (Langeweg 1988), had caused a major impact on environmental policy in the Netherlands. It contributed to growth of RIVM and enforced the

had become important too. Calculations had to be reproducible. Data used for calculations would have to be stamped "approved" by a specialist before other specialists were allowed to use it. All final calculations had to be based only on approved data. The information system would not only be *"multipurpose",* as people were to work in parallel with each other, it would be *"multi-user"* as well.

The GUI and the database-related functions for CLEAN were created using an *evolutionary development approach*: a prototype is constructed and evaluated with the end users. Then this prototype is gradually improved and adapted within an "evolutionary process", until approved. It is very useful in situations where neither the end user, nor the system development team knows exactly the functionality to build beforehand. Serious testing still has to be carried out afterwards. The development of this integrated information system is described in more detail in (Knol 1994).

7   Discussion

In chapter 3, we have formulated a number of requirements for CLEAN. Here we will discuss to what extend we succeeded in meeting these.

The first challenge was to create a model on a *moderate aggregation level*, based on *free available data* that still matches the *results of a more detailed model*.

CLEAN version 1, working for 31 regions is now operational. While MAM calculates per farm, CLEAN allows the user to specify other factors in more detail, like 42 animal categories, excretion figures per region, mineral input restrictions per crop, soiltype and region.

Quite some tests have been done to compare the output of CLEAN and MAM. Fig 4 illustrates this.

Comparing emissions to soil from both models, shows that the results for phosphate are very much alike, but for nitrogen there are differences. There are two reasons for this. First, in CLEAN and MAM the calculation of excretion is different. CLEAN distinguishes 42 animal categories, where each category has its own excretion figures. In MAM those 42 categories are first aggregated to 9 and then multiplied with weighed excretion factors, which are calculated for the national aggregation level. Therefor, the national nitrogen and phosphate excretions of CLEAN and MAM are the same, but there will be different N/P ratios per region.

Second, the manure transport routines of CLEAN and MAM are different, so the mix of manure that is transported to each region differs. The input restrictions for phosphate determine the maximum amount of manure that can be applied; the amounts of nitrogen are depended. As all manure types differ in composition, it is understandable that differences will occur. It remains uncertain which manure mix has been administered in reality; both models only provide estimation.

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need of integrated models. Since 1995, RIVM produces an integrated Environmental Balance report on a yearly basis.
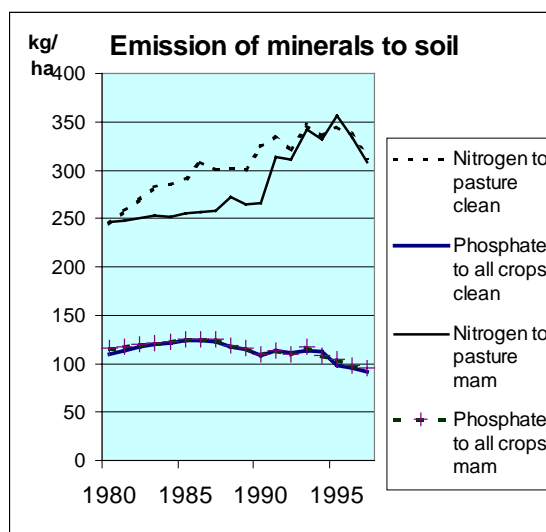
Emission of minerals to soil

Figure 4

Comparison between model results of emissions to soil from CLEAN and MAM

The workaround solution for the calculation of manure surplus, as described in chapter 5.1, appears to provide satisfactory results, but the drawback is that it depends on MAM-output. We expect that the importance of the own-acreage factors will decrease when CLEAN will operate on municipality level. This will be the target for CLEAN version 2.0

The second requirement for CLEAN was to be appropriate to *be incorporated in a model chain*. The modular structure of CLEAN, the scalability, together with the transparent and simple structure of input- and output files, made it easy to implant into other information systems.

CLEAN now functions as emission module in STONE, (Alkemade et al. 1998) a model chain to calculate emissions to soil, groundwater and surface water, which is now being tested. In these tests, scenarios that had been developed by other agricultural environmental specialists and calculated with other models were redone with CLEAN This produced informative new insights and revealed flaws of the model. For instance, one policy option implied that *no manure transports* would occur. This option was unexpected for the CLEAN developers, as the transportation routine is one of the features of the model, which has taken much effort. However, the restriction could rather easily be imposed, by setting the acceptation degrees to zero and the own acreage factors to 1.

Requirement 3 was: *The response–time for CLEAN should allow results to be available within 24 hours*. This is certainly possible, the run-time of CLEAN is only a few minutes. The *rate-limiting step* however, is preparing the input file. It takes

quite some time to create such a file from scratch (several days), but once this is available, it is rather easy to translate the policy options to new input parameters. The aim to have results quicker than when working with MAM has certainly been reached, as this model has the same input-problems and has a runtime of many hours to produce results for one year.

Requirement 4: Data *should be stored in a structured way*. The decision to store all data in a logically structured relational database has it's pro's and cons. Pro is the ease with which large amounts of parameters can be updated. For instance, increasing all 378 stable-emission factors with 10 % takes only a one-line SQL statement. The drawback is that an end user must have knowledge of both the data-model and SQL to do this. Another drawback is that after an update in the database, a new input file must be created which takes 20 minutes. This seduces the user to sometimes edit the input file by hand, which creates version problems.

Requirement 5*: The model would be part of an integrated information system.* RIM+, the integrated environmental information and planning system has not been in operation very long. It has appeared to be too complex to

a) reach the aimed level of integration (e.g. between costs and emission reduction effects of measures)

b) maintain and keep up to date such an extended database

c) keep the calculation modules up to date with the growing demands of the environmental specialists.

This is not a problem of RIVM in particular. Comparable problems have been reported by (Yigitbasi et al. 1998). The LAE department has set now out a new course with a more moderate goal. Target groups are responsible for there own tools, which may or may not use a central database. The results will be collected in the so-called *Trend Tap,* a new but simple database with emission and waste data. Scenario trends will be maintained in a separate *scenario-base*. The CLEAN model will keep using a database for its input data, but this will be for agricultural data.

8   Conclusions

The CLEAN model fulfils its primary goal: it can successfully be used for quick policy evaluation. It is scalable and flexible to use. However, it is quite a lot of work to prepare and check the input data for it. Once a basic input file is available, *what–if questions* can be answered within short time.

The database that stores the input data is a necessity: it helps to maintain data integrity, and supports data manipulation by its logical structure. The drawback is that it takes some time to create a CLEAN-input file.

CLEAN version 1.0 calculates emissions for 31 regions. It depends on external data for calculation of the manure surplus. We are in the process of building a version

that will perform calculations at municipality level. (Available: early 2000).

The development of CLEAN has taught us a number of interesting lessons.

First, it has proven to be wise to separate data, GUI and calculation. The model may run as part of the RIM+ environment, but also stand-alone, or in another environment or model chain.

Second, we have learned to be more moderate in our ambition to create an integrated environmental information system. A *single user*, *single purpose* model may be developed within a rather short time. A complex *multi-user, multi-purpose* environmental information system that is to be used intensively needs much more effort, time, insurance of data- integrity, data, a consistent user –interface, co-operation, professional software developers, and good management.

The CLEAN model is available on CD-ROM for non-profit use and evaluation.

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