COMMISSIE VOOR HYDROLOGISCH ONDERZOEK TNO

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ECONOMIC INSTRUMENTS FOR RATIONAL UTILIZATION OF WATER RESOURCES

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(Netherlands contributions, not-related to the PAWN-study, for the ECE-seminar 1980)

TNO

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ECONOMIC INSTRUMENTS FOR RATIONAL UTILIZATION OF WATER RESOURCES

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Authors

J. P. Ancot	Netherlands Economic Institute and Erasmus University, Rotterdam.
G. J. Baaijens	Research Institute for Nature Management, Leersum.
H. Bosma	Government Service for Land and Water Use, Utrecht.
E. C. W. A. Geuze	Joint Technological Service East-Brabant, Boxtel (N.B.).
J. G. de Graan	National Institute for Drinking Water Supply, Leidschendam; at present: Waterloopkundig Laboratorium, Delft.
A. de Kort	Ministry of Health and Environmental Hygiene, Leidschendam.
F. Langeweg	National Institute for Drinking Water Supply, Leidschendam.
L. J. Locht	Institute for Land and Water Management, Wageningen.
J. A. Los	Provincial Waterboard of Drenthe, Assen.
L. Lijklema	Twente University of Technology, Enschede; at present: Agricultural University, Wageningen.
J. G. de Molenaar	Research Institute for Nature Management, Leersum.
Th. J. van de Nes	Provincial Waterboard of Gelderland, Arnhem.

H. F. J. PETERS	Government Institute for Waste Water Treatment, Lelystad; at present: Rijkswaterstaat, Den Haag.
E. ROMIJN	Provincial Waterboard of Gelderland, Arnhem.
J. E. RIJNSDORP	Twente University of Technology, Enschede.
J. W. M. SCHAFFERS	Twente University of Technology, Enschede.
M. TAMMINGA	Provincial Waterboard of Drenthe, Assen.
T. TROUWBORST	Ministry of Health and Environmental Hygiene, Leidschendam.
B. G.M. VAN DE WETERING	Government Institute for Waste Water Treatment, Lelystad.
F. WILDSCHUT	Ministery of Health and Environmental Hygiene, Leidschendam.

GOVERNMENT INSTITUTE FOR
WASTE WATER TREATMENT,
LELYSTAD

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Preface

One of the methods, used by the United Nations 'Economic Commission for Europe' (ECE, Geneva) to gather and exchange information, is the organization of seminars. One of the ECE bodies, the 'Committee on Water Problems', held a seminar in Leipzig, GDR, in 1979, the subject of which was 'Rational Utilization of Water Resources'.

The year after, a seminar was held at Veldhoven, Netherlands, (13th-18th October 1980), that was meant to be a continuation in a more specific form, of the previously mentioned seminar. Its subject was 'Economic Instruments for the Rational Utilization of Water Resources'. The venue in the Netherlands was not by chance: this country had just completed a large and rather ambitious project, called 'Policy Analysis of Water Management in the Netherlands' (PAWN), that, to a high degree, fitted the subject matter.

There is an urgent need in the Netherlands, to make known as widely as possible, not only the results but also the philosophy and the methodology of PAWN. For this reason, CHO/TNO dedicated one of its Technical Meetings to this subject: the meeting took place on June 2nd, 1982.

Usually, the texts of the lectures given during these meetings are published in the TNO-series 'Verslagen en Mededelingen' some time afterwards. In this case, it was decided to publish no 29 a of this series prior to the meeting, and to print not the lectures, but the Netherlands PAWN-related contributions to the Veldhoven seminar. Those attending the meeting will thus have an opportunity to familiarize themselves with the subject. At the same time, the ECE desisting from publication, it seemed a good way to make these contributions more widely known.

The latter reason is also behind the simultaneous publication under the same title ('Policy Analysis of National Water Management in the Netherlands') of these contributions in the series 'Rijkswaterstaat Communications', under no. 31.

The remainder of the Netherlands' Veldhoven-contributions (i.e. not PAWN-related) were considered equally worth publishing; they appear in the CHO/TNO-series under no. 29 b. This volume is entitled 'Economic Instruments for the Rational Utilization of Water Resources'. These papers do not appear, though, in the Rijkswaterstaat Communications.

A multi-criterion analysis of the future water supply of East IJsselmonde using the Saaty-De Graan method

J. G. de Graan and F. Langeweg

1 A multi-criterion analysis of the future water supply of East IJsselmonde using the Saaty-De Graan method

SUMMARY

A short description of the recently completed interdisciplinary study on the future water supply of East IJsselmonde (Netherlands) is given. This area consists of five municipalities, having a total number of inhabitants of 130,000, and a total future drinking water demand of 10 to 11 million m^3 per year.
Basically four different sources of raw water are available in or near the IJsselmonde area, namely fresh groundwater, brackish groundwater, bank infiltration water and surface water. Also, the drinking water can be bought wholesale from neighbouring large cities. Using these sources, eleven alternatives for the future water supply may be defined.
Four different criteria have been identified which influence the final choice to be made, namely total cost, quality of the water supplied, reliability of the water supply, and various external effects.
The study was cast in the framework of a multi-criterion optimization study in which the decision makers weighed the four criteria, and the experts evaluated the eleven alternatives. Using a multi-criterion optimization approach, two alternatives were selected for further detailed study in order to make a final selection.

1.1 Introduction

In 1978 the National Institute for Water Supply was requested to study the future water supply of East IJsselmonde. This area, located to the south-east of Rotterdam, consists of the municipalities of Ridderkerk, Barendrecht, Heerjansdam, Hendrik-Ido-Ambacht and Zwijndrecht. Estimated total inhabitants in the year 2010 has been projected at approximately 130,000, and their total drinking water demand is expected to be 10 to 11 million m^3/year.

The aim of the study was to generate initially a large number of feasible alternatives, and to select a few of these alternatives to be studied in greater detail for a final selection. The demand was estimated using various forecasting techniques. In accordance with the general situation in the Netherlands, demand is assumed to be independent of either the cost or the quality of the water supplied.
Basically four different sources are available in this part of the Netherlands, namely fresh groundwater, brackish groundwater, bank infiltration water and surface water. Apart

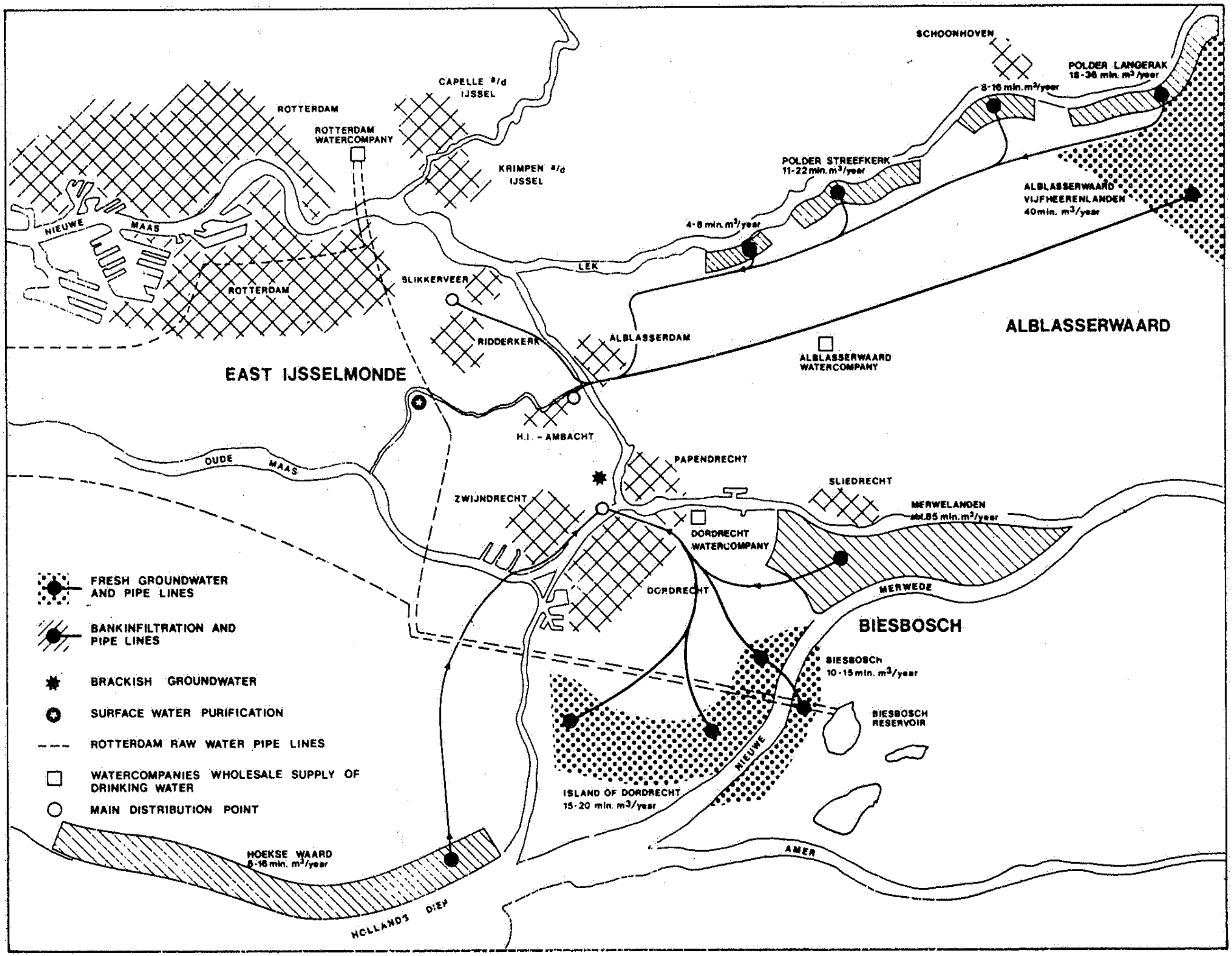

Figure 1 Alternatives for the future watersupply of East IJsselmonde

from having separate production facilities for East IJsselmonde, it is also possible to obtain drinking water wholesale from several large towns in the vicinity. This also has been considered. In total eleven alternatives were identified.

In order to obtain just a few alternatives sufficiently attractive to warrant an in-depth study, a simple multi-criterion optimization method was used. Four criteria were considered: total cost, quality of the water supplied, reliability of the supply system and various external effects. In the following some attention will be given to the alternatives, criteria and the multi-criterion optimization method used.

1.2 The alternatives

Basically four different sources of raw water are available in or near the East IJsselmonde area, while it is also possible to obtain drinking water wholesale from several large towns in the vicinity. In this section these alternatives will be described (see figure 1).

1.2.1 *Fresh groundwater*

Within the area involved, withdrawal of fresh groundwater is very limited due to its poor quality and the difficulty to protecting the extraction wells against pollution. Salination is the main problem as far as the quality of the groundwater is concerned. In the vicinity of East IJsselmonde fresh groundwater can be withdrawn on the Island of Dordrecht, the Biesbosch area and in the Alblasserwaard-Vijfheerenlanden. In those areas the available amount of fresh groundwater exceeds the demand for drinking water.

1.2.2 *Brackish groundwater*

Brackish groundwater can be abstracted near Zwijndrecht. Calculations show that within a period of 50 years after the beginning of this withdrawal, the chloride content of the abstracted water will reach a value of about 250 mg/l. This value will be about 500 mg/l in other parts of the area. The use of desalination should preferably be restricted to groundwater to be abstracted near Zwijndrecht. To reach a sodium standard for drinking water of 120 mg/l about 25 per cent of the abstracted groundwater has to be treated by hyperfiltration. The hyperfiltrated water will be mixed with untreated groundwater.

1.2.3 *Bank infiltration water*

Bank infiltration seems to be a very good method of producing drinking water, although this method is not very often used in the Netherlands. The aim of this method is to abstract infiltrating river water with different residence times in the subsoil. By mixing, a

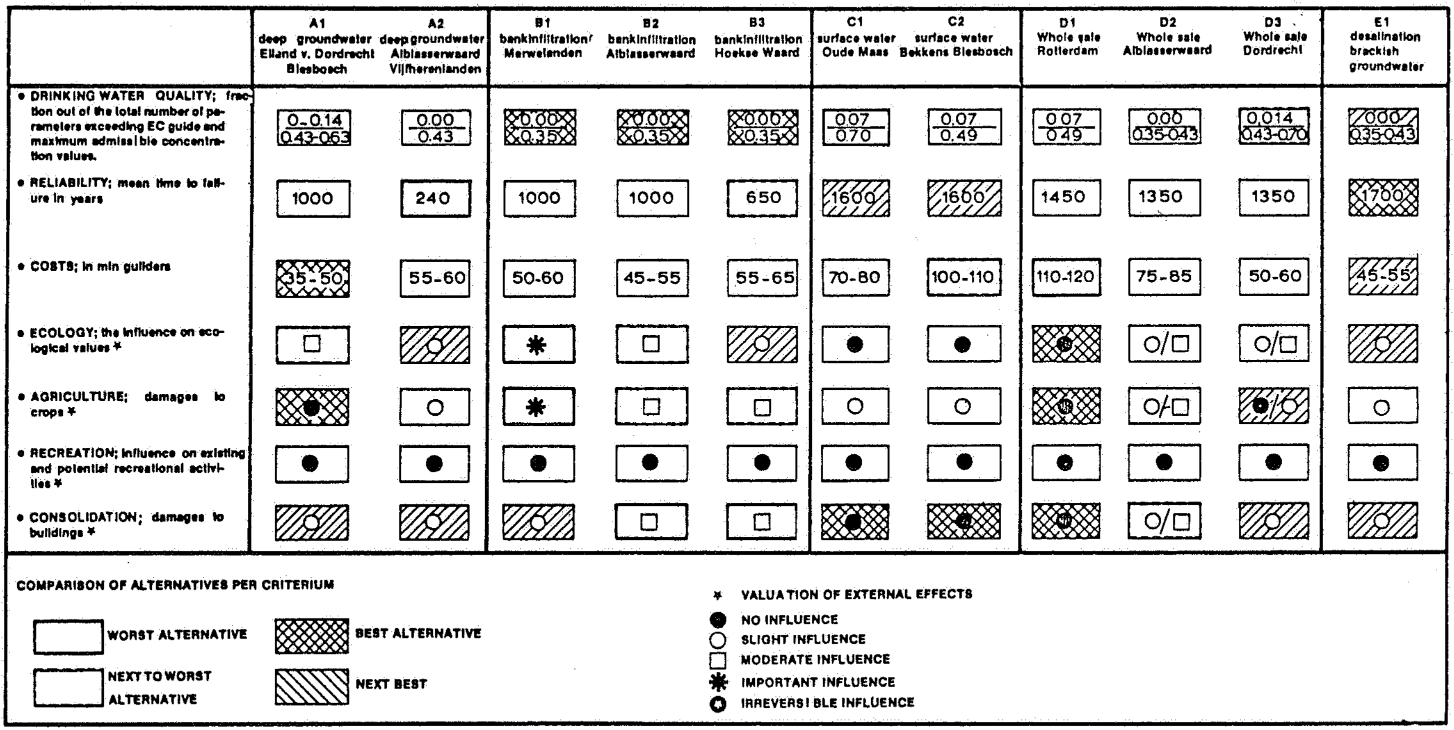

Figure 2 Score card

constant quality of the abstracted water can be obtained comparable to the average value of the original quality of the river water over the average residence time. In the vicinity of East IJsselmonde, bank infiltration can be used in the Alblasserwaard, the Merwelanden and the Hoeksche Waard to an extent exceeding the demand.

1.2.4 *Surface water*

In general, the river Oude Maas shows the best water quality compared with the other rivers surrounding East IJsselmonde. Water from this river can be abstracted to produce drinking water using an enclosed old river branch as a reservoir. The municipality of Rotterdam uses water of the river Amer, which is the lower part of the river Meuse, to produce drinking water. The main pipeline to transport this water to Rotterdam crosses East IJsselmonde so that a connection to this pipe can also be considered. In this case, the abstraction point at the river Oude Maas can be used as an emergency intake. If the Oude Maas is chosen as the main abstraction point, a connection to the Rotterdam pipe may have this function. The capacity of the Rotterdam system is sufficient to meet the raw water demand of East IJsselmonde.

1.2.5 *Wholesale supply of drinking water*

Nearby water companies can deliver drinking water on a wholesale basis. The companies concerned are Rotterdam, Dordrecht and Alblasserwaard of which only the Rotterdam company has sufficient capacity for immediate delivery. The other two companies will have to install additional capacity to meet the demands. For this purpose those companies will have to develop one of the alternatives mentioned.

1.3 The criteria

Four different types of criteria have been identified which will influence the final choice to be made (see figure 2). They are:

1.3.1 *Total cost*

The cost of the different alternatives includes the following components:

- the cost of the wholesale supply of drinking water by other water companies if applicable (in Dutch guilders per m^3);
- the investments related to construction of transport pipes to the area, purification plants, pumping stations, etc.

Variable costs are capitalized on an interest rate of 10 per cent using the annuity method. The following costs are not taken into account:

- the cost of operation of the system;
- the cost of the distribution of drinking water within the municipalities involved;
- the investments in a main transport system between the municipalities of East IJsselmonde, since such a system is needed in all the alternatives.

For reasons of simplicity the monetary value of the existing system in the area is ignored and the assumption is made that the whole system will be realized simultaneously at its full capacity.

1.3.2 *Quality of the water supplied*

The quality of the drinking water to be supplied is estimated using conventional purification techniques depending on the source of water to be applied. Seventeen parameters are used for comparison with E.C. standards for the quality of drinking water. A distinction is made between MAC-values (MAC = Maximum Admissible Concentration), and guide values. The fraction of the total number of parameters not meeting the standards is considered to be a measure of the drinking water quality.

1.3.3 *Reliability of the water supply*

The reliability of each alternative method of water supply is estimated as follows. Every possible water supply can be described by a network consisting of elementary error-prone components in series and parallel. These components can be physical (water mains, storage basins, etc.) or abstract (naval accidents or radioactive cooling water of nuclear reactors resulting in serious surface water pollution making it temporarily unfit for abstraction; salinity problems due to salt intrusion; temporary peak demands exceeding the capacity of the supply; etc.). It is assumed that failures of components can be described as time-invariant, independent Poisson processes, and that the duration of a failure, i.e. the repair time or the time needed to replace a defective component, has a negative-exponential distribution. The stochastic properties of the complete system are found from those of the components using the theory of discrete Markov processes. For the availability, the main time to failure (MTTF) and the mean time to repair (MTTR) of the complete system analytical (i.e. in closed form) expressions have been derived. The mean time to failure is considered to be a measure of the reliability of the system.

1.3.4 *Various external effects*

The external effects considered in this study are effects on ecology, recreation, agriculture and damage to edifices.

1.3.5 *Effects on ecology*

The main effects on ecology are to be expected in areas where the existing environment is considered to be unique in the Netherlands. This is for instance the case in the Biesbosch, the island of Dordrecht and the Merwelanden which consists of an ancient delta area. Lowering the groundwater table in those areas may affect the environment in a drastic way. Withdrawal of groundwater in *polder* areas such as the Alblasserwaard and the Hoeksche Waard will also influence environmental values to a certain extent. Surface water withdrawal influences these values generally only in a minor way.

1.3.6 *Effects on recreation*

No effects on existing or potential recreation activities are expected by the alternatives considered.

1.3.7 *Effects on agriculture*

Damage to agriculture can be expected if the water management of the *polder* areas is influenced by the withdrawal of groundwater. This is for instance the case in the Merwelanden, where the groundwater table will be lowered by 5 to 10 metres in case of bank infiltration. Other sensitive alternatives are bank infiltration in the Alblasserwaard and Hoeksche Waard and to a lesser extent the withdrawal of fresh groundwater in the Alblasserwaard. In general, compensatory measures can be taken to restore the water management of the *polder* areas.

1.3.8 *Damage to edifices*

Lowering the groundwater table may cause consolidation of the subsoil, depending on the nature and structure of the soil. This consolidation may cause damage to buildings and should therefore be reduced to an acceptable level. Consolidation is to be feared in case of bank infiltration in densely populated areas as for instance the Alblasserwaard and Hoeksche Waard.

1.4 Multi-criterion optimization

The purpose of multi-criterion optimization is to reduce the number of feasible alternatives, eleven, to a few attractive alternatives, which can be studied in more detail in order to make a final choice. In present-day society it is obvious that such a choice should not be made by experts only. The various criteria are so different that their weighing should not be done by experts, but by those (politically) responsible for the final decision: they are denoted in this discussion paper as the decision makers. On the other hand, the choice must also not be made by decision makers only. The various alternatives differ so much from a technical point of view that the ranking of the alternatives with respect to every separate criterion must be left to the experts.

Recently, Professor Thomas L. Saaty (1978) of the University of Pennsylvania (United States) has developed a simple multi-criterion optimization method which is particularly well-suited for these separate responsibilities and can be applied if some criterion values can be stated objectively (e.g. cost), while other criterion values can only be formulated in a rather subjective way (e.g. influence on ecological values). It results in a number (between zero and one) for each alternative, which is called its priority, or its attractiveness. The higher the priority, the more attractive the alternative. It is not always wise, however, to choose blindly for the alternative with the highest priority. It might happen that this alternative is a bad choice with respect to one or more low- or medium-ranked criteria.

Therefore, at the National Institute for Water Supply, Saaty's method has been extended to include a coefficient of concordance with each alternative. This coefficient is high if the weighed ranking of the alternative with respect to the various criteria has low variance; it is low if the opinions of the various experts differ greatly with respect to this alternative, or if the alternative scores as 'average' (not good, not bad) on all criteria. A high coefficient of concordance also indicates a low sensitivity with respect to changes in the weighing of the decision criteria.

In the NIWS-version of the method of Saaty, both the decision makers and the experts are either interviewed, or requested to complete certain questionnaires. The decision makers are interviewed in the following manner. First, the decision criteria themselves are formulated. Next, every possible combination of two criteria is presented, and the decision makers are requested to indicate quantitatively which of the two criteria will have the greatest influence on their decision. The answers of the decision makers are quantified using scale numbers 1 up to and including 9, as defined by Saaty. The scale number 1 means that the two decision criteria compared have the same influence on the decision, while a '9' means that the evidence favouring the first criterion over the second is of the highest possible order of affirmation. If the second criterion is favoured over the first, the scale number is reciprocated. The scale numbers are entered into the appropriate positions of the so-called pair-wise comparison matrix A, which satisfies the reciprocal property $a_{ij} = 1/a_{ji}$. The priority, or weight, of any criterion is then computed as the normalized geometrical mean of the corresponding row of the pair-wise comparison matrix. This procedure has both computational and statistical advantages over Saaty's eigen-vector approach. All computations can be performed on a hand calculator.

Separate from the interviews of the decision makers, the experts involved are questioned on their views on the relative attractiveness of the available or conceivable alternatives with respect to all criteria. They use the same scale numbers and, from their answers, the attractiveness of all alternatives to all criteria are likewise computed as normalized geometrical means of rows of pair-wise comparison matrices.

Because the decision makers and the experts have to supply more answers than are strictly required to compute the priorities, it is possible to check their answers for internal consistency by computing a multiple correlation coefficient for each pair-wise comparison matrix. If this coefficient exceeds 0.9 the answers are sufficiently consistent.

The overall priority of any alternative can be computed according to either the so-called conflict model or the harmony model. In the conflict model, the overall priority is defined as the arithmetical average of the attractiveness of the alternative to all criteria, weighed by their priorities as set by the decision makers. In the harmony model, the overall priority is defined as the normalized geometrical average of the attractivenss of the alternative to all criteria, exponentially weighed by their priorities as set by the decision makers. It should be noted that the original method of Saaty uses only the conflict model. An alternative which is clearly unattractive to any alternative with reasonable priority will never show up with the harmony model as the overall most attractive alternative. This aspect contrasts with the conflict model. Also the overall order of the alternatives obtained with the harmony model is less sensitive to changes in the priorities of the decision criteria than the one obtained with the conflict model.
Whether the conflict model or the harmony model should be used depends on the application. If it is considered feasible that a low rating on one criterion can be compensated by a high rating on another one, then the conflict model is appropriate. Linguistically, the conflict model corresponds with Zadeh's operation for 'or' on fuzzy sets (see Zadeh, 1973). If an alternative is only accepted as overall attractive if it is attractive with respect to all decision criteria, then the harmony model is appropriate. Linguistically, the harmony model corresponds with Zadeh's operation for 'and' on fuzzy sets.

In applications, in general, it appears to make little difference whether the harmony or the conflict model is used, especially if, with the conflict model next to the priority, the coefficient of concordance is used as a decision variable. In this application the conflict model was used.

It is always advisable to carry out a sensitivity analysis with respect to changes in the weighing of the decision criteria. This is especially true if the decision makers do not form a coherent group, as is often the case in public decision making. In this application, the sensitivity analysis was performed by using three sets of weights of the decision criteria. As far as the alternatives with a higher than average priority are concerned, the results of this analysis are:

- Highest weight on drinking water supply criteria
  - Desalination of brackish groundwater: priority .141, concordance . 82
- Average weight on all criteria
  - Desalination of brackish groundwater: priority .121, concordance . 60

– Wholesale supply by Rotterdam company: priority .117
concordance . 34

– Local purification of surface water: priority .112
concordance . 29

- Highest weight on criteria related to external effects
  – Wholesale supply by Rotterdam company: priority .144
  concordance . 63

  – Local purification of surface water: priority .129
  concordance . 51

  – Desalination of brackish groundwater: priority .101
  concordance . 28

1.5 Conclusions

In close co-operation with the lowest level of decision makers, namely the management of the water companies involved, two alternatives were selected for further detailed study. These alternatives are desalination of brackish groundwater and wholesale supply of drinking water by the Rotterdam company. The results of this study and the conclusions derived will be presented to the next level of decision makers, i.e. the councils of the municipalities involved and the provincial authorities. The national authorities are also informed in order to obtain their approval for the next phase of the selection and choice of a final solution.

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Design and economic evaluation of alternative schemes for combined use of groundwater and surface water in East Gelderland (The Netherlands) with the use of the multi-criteria method QUALIFLEX

J. P. Ancot and E. Romijn

2 Design and economic evaluation of alternative schemes for combined use of groundwater and surface water in East Gelderland (The Netherlands) with the use of the multi-criteria method QUALIFLEX

SUMMARY

Multi criteria analysis can be used to prepare the decision making process, with respect to water management in a region. The purpose of such analyses is to determine guidelines for choosing between alternative medium-term water management plans, on the basis of a set of selected decision criteria which should provide a fair representation of the various regional interests. The method can also be seen as a tool for iterative respecification of the plans until a set of internally consistent and well-differentiated alternatives and decision criteria are obtained. An illustrative example is the application of this technique to the region of East Gelderland in the Netherlands.

Six alternative schemes are specified: a reference plan; a nature-favouring plan; an agriculture-favouring plan; a groundwater-saving plan; a minimum, and a maximum plan; these plans are evaluated with the aid of six criteria: the three large groups of regional interests (agriculture, nature conservation and water-supply to households and industry) and three general criteria (costs, environmental hygiene and economy on groundwater usage).

For a large number of weight combinations of the criteria, the optimal rankings of the alternative schemes are obtained, in the general analysis of the decision space and also in detailed study of an arbitrarily selected sub-space corresponding to a particular ordinal priority ranking of the criteria.

The general conclusion is that, by the selected criteria, the reference plan is, on the average, the preferred alternative, followed by the agriculture-favouring plan. The results are fairly robust with respect to small variations in the weight combinations. A similar robustness is found when the primary evaluations of the alternative schemes, with respect to individual criteria, undergo marginal alterations. On the other hand, structural constraints such as the physical limit of the available groundwater resources appear to be extremely restrictive.

2.1 Introduction

From 1970 until 1978 studies with respect to economic aspects of water management have been carried out under the direction of the 'Committee for the Study of Water Resources Management in Gelderland' (CWG) along with many other studies in the field of water quantity and water quality (see also: *Modelle für die regionale* *wasserwirtschaftliche Planung I* (1977) and *II* (1979)). During preceding years (1957 to 1970) the 'Committee for the Study of the Water Demand for Agriculture in Gelderland' (reports: Tielerwaard, 1962; Leerinkbeek, 1970) calculated the physiological water demand of pasture and crops. This water demand consists of the difference between potential and actual evapotranspiration. Some results are given in table 1.

Table 1 Water demand for agriculture in regions of Gelderland (potential minus actual evapotranspiration)

Area	Return period (average number of years within which the demand is equalled or exceeded)	
	10-year	20-year
Tielerwaard (clay; mainly pasture)	1 April to 1 October 50 to 60 mm	1 April to 1 October 70 to 80 mm
Leerinkbeek (sandy soils; grass, cereals, etc.)	1 May to 1 September 150 mm	1 May to 1 September 210 mm

Nevertheless, the importance of an economic approach to complement the physiological one was recognized as agriculture had to compete with demands for drinking and industrial water. In the report 'Leerinkbeek', it was expected that by reducing the excess water, the net profit for the farmers would be Dfl 25 to Dfl 35 per hectare per year on the average but that by reducing both the water excess and the water shortage the profit would be Dfl 80 to Dfl 100 per hectare per year (1969 prices). [The costs of the improvement works are *not* included in these profits.] Nowadays, much higher profits are calculated as a result of intensification of cattle breeding and dairy farms.

During the CWG study period, a more integral socio-economic approach was needed to study the relation between water demands of: agriculture; households; industry; waste water control; conservation of nature reserves; recreation; etc. and the available water. One proposal was to apply the (neo) classical price theory and to determine the intersection point of the demand and the supply curves as the optimum, just as might be done with a market model under conditions of perfect competition. This optimum should be the base for long-term planning.
Apart from the difficulties inherent in this programme, a very important problem was the bridging of the gap between the analytical approach and the policy decision-making aspects. Politicians want to have the freedom of choosing between different weight combinations with respect to different aspects (e.g. water supply, nature conservation, costs) relevant to the decision process. In order to tackle these problems a new study programme was carried out for East Gelderland in co-

operation with the Netherlands Economic Institute (NEI 1979, Ancot 1982); this study comprised:

- a parametric analysis of the water demand of households (including such explanatory variables as water price, income, household size, urbanization, metering, hours of sunshine during summer, trend factor) resulting in a computer simulation program HUISIM;

- a parametric analysis of the water demand of different sectors of the industry (including the explanatory variables water price, levy on effluent, change in production, trend factor) both for process and cooling water and for drinkingwater and groundwater abstraction by the factory itself, resulting in the computer program AQUISM;

- a calculation of the physiological water demand for agriculture (programs METEO and UNSAT) under different climatic conditions and the water demand for the cattle and stable cleaning.

The relation between water demand and water supply was then explicitly formulated in a set of water management plans, $P_1 \ldots P_6$, for East Gelderland expressing a variety of hypothetical strategies. These plans constitute only an arbitrary selection among many other possible and feasible plans.
However, given the definition of these tentative plans and given a selection of decision criteria, the multicriteria method, QUALIFLEX, was used to derive the optimal ranking of the alternative plans for a very large variety of weighted combinations of these policy criteria. It is important to emphasize that this method of analysis not only aims at preparing the optimal final decision as such, but can also be used as an aid to obtain a clear insight in the decision process itself and in the relative structure of the specified plans.

2.2 Description of the alternative schemes and the decision criteria

Initially a relational scheme between the regional interests was constructed (see table 2). With the aid of table 2, six alternative plans $P_1 \ldots P_6$ were derived and water demand predictions for a 10 percent year in 1990 were calculated. (Ancot, 1982; NEI, 1979). The following assumptions were made:

2.2.1 *Improvement works*

- The total area of pasture in East Gelderland is about 80,000 hectares.

Table 2 Water management goals (diagonal) and interrelations for East Gelderland (simplified)

	Households	Industry, services	Agriculture, livestock	Forest, nature area	Hygiene (environment)	Costs
Households	*safe* supply (incl. protection of water sources)					
Industry, services	competition for the water sources	*optimal* as production factor				
Agriculture, livestock	agriculture *v* water quality protection --- groundwater abstraction *v* level control, sprinkling and drought damage vegetation		*optimal* production circumstances through level control and drainage			
Forest, nature area	groundwater abstraction *v* protection wetlands --- water harvesting *v* foresting (interception!)		level control *v* wetlands --- microclimate enhancement through foresting	protection and conservation of natural elements		
Hygiene (environment)	quality standards of sources --- waste water disposal *v* standards of water resources		quality standards sprinkling & watering --- outwash of pollutants	no influence on water quality	quality standards & prevention from pollution	
Costs	abstraction, treatment reservoirs, distribution (incl. transport)		level control, --- sprinkling (incl. transport)	(flexible) constraint to others	sewerage & treatment, --- disposal of sludge	minimum

Reduction of water excess is needed urgently for about 46,000 hectares (figure 1), the net profit of these works being estimated at Dfl 30 per hectare on the average (costs of improvement works included). Whenever, within the improvement area, nature reserves (wetlands) have to be protected by compensatory works, the net profit becomes negative (about (-) Dfl 100 per hectare);

- The predictions of the water demand are based on a 10 percent year drought.

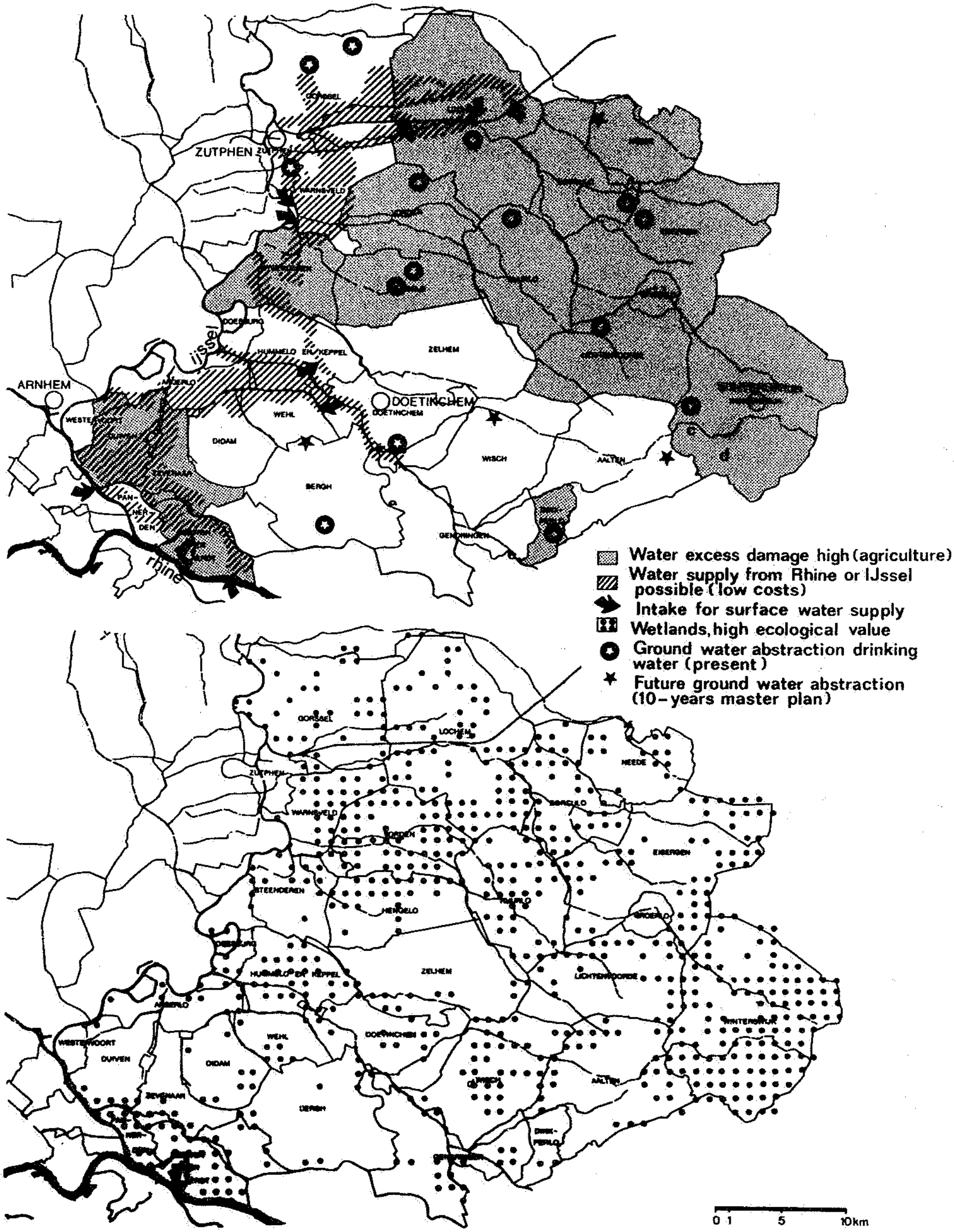


Figure 1 Geography of East Gelderland.

Alternatives are formulated for 50 per cent (40,000 hectares), 25 per cent or 13 per cent (situation 1976) sprinkling of the pasture land. The net profit for replenishment by sprinkling with groundwater is estimated at Dfl 130 per hectare on the average, for sprinkling with surface water, Dfl 85 per hectare (assuming low costs of water supply which apply to only 10 per cent of the total pasture area) or (-) Dfl 20 per hectare (high costs of supply, requiring canals to be dug and pumping works). The surface water is taken from the rivers Rhine and IJssel (figure 1). It is interesting to compare the results with those of the Tielerwaard and Leerinkbeek reports (table 1). The water needs are less than the evapotranspiration excess because of the water content of the soil and the capillary action (table 3).

Table 3 Evapotranspiration surplus and physiological water demand for agriculture in East Gelderland.
A. Normal groundwater levels.
B. Lowering of groundwater table with 25 cm (between brackets: water demand in $10^6\,m^3$ for 40,000 hectares). Programs UNSAT and METEO.

	Weighted mean	Return period in years				
		100 y	10 y	5 y	2 y	0.9 y
Precipitation	324 mm	169 mm	237 mm	260 mm	328 mm	419 mm
Potential evapotransp.	448 mm	495 mm	470 mm	450 mm	440 mm	440 mm
Evaporation excess	124 mm	326 mm	233 mm	190 mm	112 mm	21 mm
A. Water demand	19 mm ($11.10^6\,m^3$)	132 mm ($79.10^6\,m^3$)	50 mm ($29.10^6\,m^3$)	26 mm ($15.10^6\,m^3$)	7 mm ($4.10^6\,m^3$)	0 mm –
B. Water demand with lowered watertable	27 mm ($16.10^6\,m^3$)	163 mm ($98.10^6\,m^3$)	76 mm ($46.10^6\,m^3$)	42 mm ($25.10^6\,m^3$)	11 mm ($6.10^6\,m^3$)	0 mm –

2.2.2 *Drinking water*

- The tariff for drinking water is Dfl 1 per m^3 according to the basic rate (small users) and Dfl 0.50 per m^3 according to bulk rate for water supply companies that abstract groundwater only.

- The available groundwater is estimated to be around $70.10^6\ m^3$ per year in a 10 per cent dry year.

- The locations of new pumping stations are taken from the 10-year master plans of the water companies or determined according to the criterion of minimal damage to agriculture (computer program GELGAM).

- The water supply by drinking water companies was in 1976 about 27.10^6 m^3, the groundwater abstraction by industry, about 13.10^6 m^3. The water supply companies delivered 13 per cent to the industry.

2.2.3 *Nature conservation*

- A map was prepared indicating for every km^2 where wetlands of high ecological value occur (often in only a small part of this area).

- Five municipalities have so many wetlands of ecological value that they were given a special status and called 'nature-municipalities' (altogether 13,000 hectares pasture). In some plans, no technical works are undertaken in these municipalities.

2.2.4 *Waste water treatment*

- The costs of removal of phosphates from the effluent of the 'nature-municipality' Winterswijk are estimated to be Dfl 100,000 per year (the effluent is about 4.10^6 m^3 per year).

The different plans $P_1 \ldots P_6$ are summarized in table 4.

P_1 *(reference plan):* a more or less equal distribution of the available water is aimed at. There is a shortage of sprinkling water of 19.10^6 m^3 in a 10 per cent dry year.

P_2 *(nature friendly plan):* the water demand is compressed by a tax of Dfl 0.25 per m^3 for groundwater abstraction by industry and by an increase of 20 per cent of the drinking-water tariff; sprinkling is restricted to 25 per cent of the pasture. Because of the protection of wetlands, the costs of improvement works are higher.

P_3 *(plan with emphasis on agriculture and nature conservation):* compensation works for nature protection lead to rises in the costs of improvements, farmers have priority over drinking water companies with respect to groundwater abstractions, and, as a consequence, the water supply companies have to abstract about $19.10^6 m^3$ per year surface water from the big rivers Rhine or IJssel.

P_4 *(groundwater economy plan):* groundwater is saved by a tax on groundwater abstraction (Dfl 0.25 per m^3) to be payed by industry and farmers and sprinkling is restricted to the areas of 1976 (13 per cent of pasture).

Table 4 Alternative schemes

Characteristic \ Plan	P_1 *Reference* (r)	P_2 *Nature friendly* (n)	P_3 *Agriculture favouring* (l)	P_4 *Groundwater economy* (g)	P_5 *Minimum plan* (a)	P_6 *Maximum plan* (z)
A. *Agriculture*						
A 1 Drainage	areas of fig. 1, see B	as P_1 see B	as P_1, Winterswijk is drained	as P_3	as P_1	as P_1, see B
A 2 Sprinkling	50% of pasture (10%-drought)	25% of pasture (10%-drought)	as P_1	13% of pasture (10%-drought)	as P_4	as P_1
A 3 Ground/ Surface water	groundwater and paying surface w., see C_4	as P_1	groundwater priority see C_4	as P_1	groundwater, see C_4	as P_1, also expensive surface water
B. *Nature conservation*	no works in 'nature-municipalities'*	as P_1, in other municip. drainage costs are risen to protect nature	as P_2 plus drainage of Winterswijk	as P_3	as P_1	drainage of all nature municip. plus risen costs
C. *Watersupply*						
C 1 Quantity	mean prediction	as P_1	as P_1	as P_1	minimum prediction	maximum prediction

Table 4 (continued)

C 2 Tariff	no change	tax on groundwater (industry); drinking water tariff + 20%	as P_1	tax on groundwater (industry and agriculture)	as P_1	as P_2
C 3 Situation pumping stations	10-year master plan,** see B	min. damage to agriculture see B	as P_2	as P_2	as P_1	as P_2
C 4 Ground/ Surface water	groundwater priority over agriculture	as P_1	groundwater and surface water	as P_1	as P_1	as P_1
D. *Environmental hygiene*						
D 1 Quality	plan of Water Board** (biol. treated)	as P_1 plus phosphate removal in Winterswijk	as P_1	as P_1	as P_1	as P_2
D 2 Situation water treatment plants	plan of Water Board**	as P_1	as P_1	as P_1	as P_1	as P_1 plus reuse of waste water

* Winterswijk, Vorden, Herwen-Aerdt, Pannerden, Hummelo-Keppel.
** Existing plans.

P_5 *(minimum plan)*: minimum predictions for water demand and minimum change with respect to the existing situation.

P_6 *(maximum plan)*: maximum predictions for water demand and maximum change (within the realm of feasibility) with respect to the existing situation. To compress the water demand, water prices are raised.

In tables 5 and 6 the water demand for the six different schemes are given.

Table 5 Water demand in 1990 *for a return period of 10 years*, in 10^6 m^3 per year (about $\frac{1}{4}$ of the water demand for cattle which amounts to $8.5.10^6$ m^3 falls under 'households'). Losses in pipes, etc. are not accounted for.

Sector \ Plan	P_1	P_2	P_3	P_4	P_5	P_6
Agriculture (sprinkling)	45.5*	22.8	45.5	11.8	11.8	45.5
Households	27.3	24.5	27.3	27.3	19.3	34.7
Cattle	pm	pm	pm	pm	pm	pm
Industry	23.4	8.1	23.4	9.3	19.4	9.7
Commercial, hospitals etc.**	2.1	2.1	2.1	2.1	2.1	2.1
Total	98.3*	57.5	98.3	50.5	52.6	92.0

* Not feasible.
** Constant because of lack of information.

Six policy criteria were chosen, namely, the conservation of nature, the interests of agriculture, the supply of drinking and industrial water, costs and benefits, aspects of environmental hygiene, and groundwater reserves. Environmental hygiene was considered somewhat less important in the study than the first four criteria in terms of policy decisions, because the waste water treatment aspects leave little scope for variation in the specified schemes. The same holds for the groundwater level, the relevant criterion being probably a direct result of the first four. So, a certain hierarchy may be distinguished among the criteria selected, a point that is explicitly retained in the application of the multicriteria method used.

2.3 The multi-criteria method QUALIFLEX

The QUALIFLEX multicriteria method used in this application has been developed

Table 6 Distribution of water demand according to groundwater and surface water (1990) in 10^6 m^3/year for a return period of 10 years

Plan	Sector	Groundwater $\leqslant$ 70.10^6 m^3	Surface water	Total
P_1 $79{,}5.10^6$ m^3	*a* agriculture (sprinkling)	17.3	9.5	26.8
	b own abstr. industry	20.4		20.4
	c water supply co.	32.3		32.3
P_2 $57{,}5.10^6$ m^3	*a* agriculture (sprinkling)	22.8		22.8
	b own abstr. industry	1.0		1.0
	c water supply co.	33.7		33.7
P_3 $98{,}3.10^6$ m^3	*a* agriculture (sprinkling)	36.0	9.5	45.5
	b own abstr. industry	20.4		20.4
	c water supply co.	13.6	18.7	32.3
P_4 $50{,}5.10^6$ m^3	*a* agriculture (sprinkling)	11.8		11.8
	b own abstr. industry	1.0		1.0
	c water supply co.	37.8		37.8
P_5 $52{,}6.10^6$ m^3	*a* agriculture (sprinkling)	11.8		11.8
	b own abstr. industry	16.9		16.9
	c water supply co.	23.9		23.9
P_6 $92{,}0.10^6$ m^3	*a* agriculture (sprinkling)	23.5	22.0	45.5
	b own abstr. industry	1.2		1.2
	c water supply co.	45.3		45.3

at the Netherlands Economic Institute to deal with very broad categories of problems including those for which only very meagre information is available (see Paelink, 1978). Once the alternative schemes and the policy criteria have been defined, each plan must be evaluated with respect to each criterion. In contrast to unicriterion methods, these evaluations can be expressed in 'natural' units of measurement so that they must not be reduced to a common dimension, such as money. Water consumption can be expressed in m^3 per year, noise nuisance in decibels, water quality aspects in equivalents, etc. Further, the QUALIFLEX method is such that these evaluations must not necessarily be made along a cardinal scale so that whenever accurate quantitative information is lacking, a simple ordinal ranking is sufficient. Once these evaluations have been made, the technique can then be used to determine the optimal ranking of the alternative schemes for any weight combination of the decision criteria.

This combination of criteria leads to the concept of decision space and decision sub-spaces. The decision space is defined by the set of all possible combinations of weights which can be associated with the policy criteria. This decision space is then divided into sub-spaces corresponding to all possible weight combinations respecting a particular priority ranking of the criteria. For example, with three criteria, the decision space consists of all the points corresponding to all the possible values of the triplet (w_1, w_2, w_3) such that $w_1+w_2+w_3 = 1$ and w_1, w_2 and w_3 are non-negative values. A particular sub-space can then be defined as the set of all points where, e.g., $w_1 \geqslant w_2 \geqslant w_3$, (see figure 2), meaning that within that sub-space, criterion number one is always more important than criterion number two, and that criterion number two is always more important than criterion number three. With three criteria, one obtains six such sub-spaces. This division of the decision space into sub-spaces is useful for the organization of the study of the optimal solutions to the decision problem corresponding to all possible priority rankings of the policy criteria. Indeed, especially when the number of criteria increases, it may become extremely laborious to investigate in detail all possible choice situations. Although it is not the role of the researcher to determine the specific weights which should be associated with the criteria (and not even their priority ranking), one may like to make a more detailed examination of certain parts of the decision space, because they may appear to be particularly sensitive to marginal variations in the relative values of the weights or because they correspond to typical 'political' profiles. This partitioning of the decision space into sub-spaces, leads to two

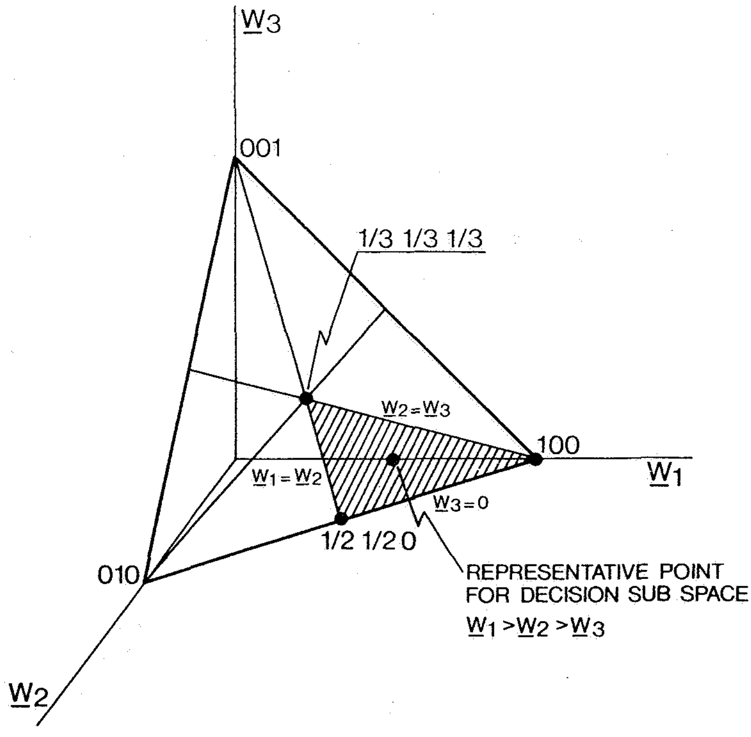


Figure 2 Decision space w_1, w_2, w_3.

types of multicriteria analyses: a general study of the whole space or of a very large part of that space to obtain a general picture of the variability and the occurrence frequencies of the optimal decision possibilities as a function of the possible priority rankings of the criteria and a much more detailed study of the local structure of any selected sub-space.

Given de formulation of the alternative plans and the definition of the criteria, the evaluations of the six alternative plans have to be made in relation to the six criteria. As far as nature and environmental hygiene are concerned, these evaluations were of an ordinal nature; with the other criteria there was in principle sufficient information available to establish cardinal or quantitative measures. Regarding the criteria agriculture and costs/benefits, these measures could, in the first instance, be expressed in net yields in guilders per year; water supply and groundwater reserves could be measured in cubic metres per year. The evaluations thus found were further normalized by translating the quantitative information into percentages; those with respect to the criteria agriculture and costs/benefits were transformed in a simple way to ensure non-negative values for all quantities. When only ordinal information with respect to a specific criterion is available for $P_1 \ldots P_6$, the most representative point of the sub-space for this criterion is used; e.g. the centre of gravity. This results in a set of (cardinal) weights for the different plans with respect to this criterion (figure 2, for example $w_1 > w_2 > w_3$ gives $w_1 = 0.58$; $w_2 = 0.24$; $w_3 = 0.18$). The normalized values are presented in table 7; the elements of this table constitute the matrix of core values that was used as the point of departure for the application of the multicriteria method.

Table 7 Matrix of core values (in percentages)

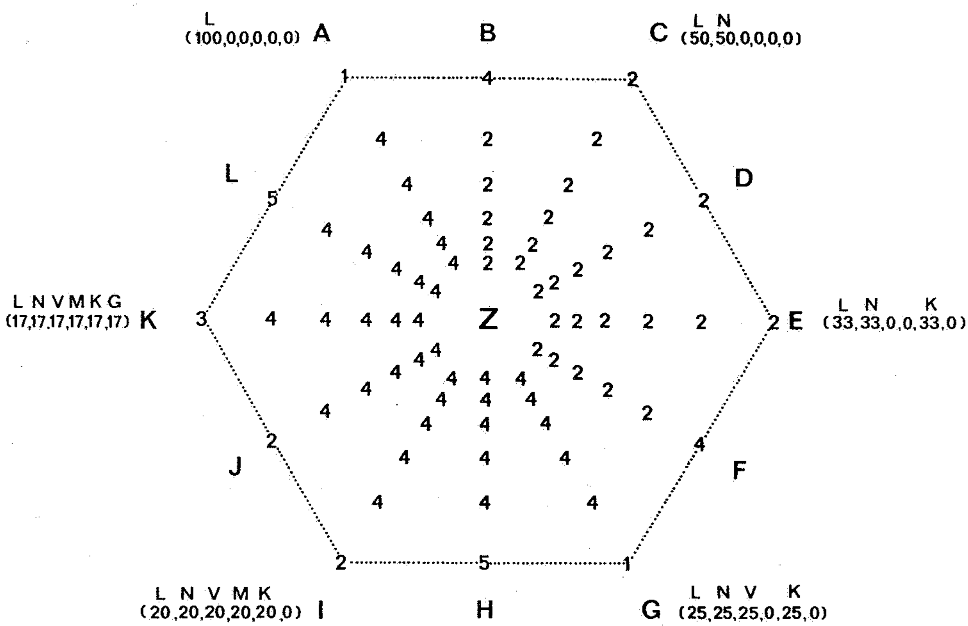
Criteria \ Plans		Reference plan r	Nature-favouring plan n	Agriculture favouring plan l	Saving on ground-water g	Minimum plan a	Maximum plan z
Agriculture	L	29	16	22	0	18	15
Nature	N	15	37	12	12	15	9
Water supply	V	19	13	19	15	17	17
Environment	M	11	28	11	11	11	28
Costs & Benefits	K	28	15	26	3	28	0
Groundwater	G	0	28	0	41	31	0

2.4 A detailed study of the decision space for a given ranking of the criteria ($L \geqslant N \geqslant K \geqslant V \geqslant M \geqslant G$)

To get an insight into the nature and frequency of the optimum ranking of the alternative plans at various points of the policy space, a number of systematically generated points was examined for a situation in which the weights of the criteria are ranked as follows by decreasing priority: agriculture, nature, costs, water supply, environmental hygiene, and groundwater reserves. This sub-space was chosen so as to limit the number of optimum permutations and to keep the analysis fairly simple.

Figure 3 represents the results of scanning the sub-space studied. A direct graphic

QUALIFLEX



Number	Optimal ranking	Number	Optimal ranking
1	r l a n z g	4	r n l a z g
2	n r l a z g	5	r l n a z g
3	n r a l z g		

Legend:

Alternative schemes:

r : Reference plan
n : Nature favouring plan
l : Agriculture favouring plan
g : Groundwater economy plan
a : Minimum plan
z : Maximum plan

Criteria:

N : Nature
L : Agriculture
V : Water supply
K : Costs
M : Environment
G : Groundwater preservation

Figure 3 The optimum permutations in a decision subspace. Ranking of the weights L-N-K-V-M-G.

reproduction of these results is not possible, because six criteria imply a five-dimensional sub-space. The graph is a hexagon of which the vertices represent the extreme combinations of the weights, given the ranking chosen. In A the first criterion, agriculture, gets all the weight; the others playing no part there; in the next vertex, C, the first two criteria, agriculture and nature, get equal weight, the others being left out of consideration; in that way more criteria are gradually introduced until, in K, all criteria play their part, all having the same weight. The other points to be investigated are then generated as follows. In five-dimensional space, schematically represented in figure 3 by a hexagon, every pair of successive vertices are linked by straight lines, producing the segments AC, CE, EG, etc., in the graph; of each such segment the middle is determined, which produces points B, D, F, etc. Still in five-dimensional space, these points are again connected pairwise by straight-line segments, and the middles of the segments found, and so on, and so forth. The procedure has several advantages: it permits simply and systematically to generate points within a five-dimensional sub-space; it leads to a well-ordered and clear graphical representation, and it allows the generated points to converge to the centre of gravity of the five-dimensional figure.

For each point examined, figure 3 indicates the optimum permutation of the alternative plans by the integers from one to five; the corresponding permutations are defined in the accompanying table. In point A, e.g., where agriculture is given weight 1 and where the other criteria are left out, the optimum ranking of the plans is ranking number 1, with the reference plan in the lead, followed by the agriculture-favouring plan, the minimum plan, the nature-favouring plan, the maximum plan, and with the groundwater-saving plan bringing up the rear. In point C, where the criteria agriculture and nature both get weight $\frac{1}{2}$, the nature-favouring plan takes precedence (as a result of bringing in the criterion nature), while the agriculture-favouring and the minimum plan drop back in respect of the optimum ranking of point A. In the next vertex, point E, where the third criterion, that of costs, is introduced with a weight equal to $\frac{1}{3}$, the optimal ranking remains unchanged compared with the situation in point C. In the fourth vertex, point G, the optimal permutation is the same as in point A: introduction of the fourth criterion, water supply, with a weight equal to $\frac{1}{4}$, has neutralized the impact of the previous two criteria.

The most important conclusion arising from the study of figure 3 is the division in about equal parts of the largest part of the sub-space into two areas where permutations number two and four respectively, are found to be optimal; the only difference between these two permutations is the relative ranking of the first two plans. When nature and costs are rated to be relatively important criteria, the nature-favouring plan is the winner and in the other cases the reference plan is the preferred alternative.

Although figure 3 already indicates clearly how the policy sub-space can be studied, with respect to the calculated optimum rankings of the plans and their dispersion in decision space, it is even more important to have an evaluation of the relative position of the alternatives within the permutation that has been found optimal for a certain point. The question may be asked, for example, whether the first two plans in point A within permutation 1 are clearly separated or, on the contrary, hardly distinguishable from each other; this question is answered in figure 4 for some selected points. It emerges from this graph that at point A, where the criterion agriculture is the only one that counts, the reference plan occupies a first place, closely followed by the agriculture-favouring plan, the groundwater-saving plan is clearly last; the other three plans form a cluster in the middle of the interval. It is interesting to find out what happens when, starting from point A, one moves along the segment AC to C and next from C to E, nature being introduced as a new criterion, as yet with a low weight, at point B. The new permutation that comes into being as a result, number 2, is easy to interpret with the help of figure 4: in comparison with the situation at point A, plan n advances, showing an inclination to take the first position, whereas the positions of the other plans remain practically unchanged. The moves become much more pronounced when, as at point C, the weight of a new criterion increases relatively: plan n takes the first place and pushes plan r clearly to second place; the plans l, a and z fall back significantly and l and a are hardly distinguishable. At the next two points, points D and E, this configuration remains practically unaltered. At these points, the plans r, l and a become again somewhat more attractive and plan z gets steadily worse. The improved performance of r, l and a relative to n, and the deterioration in the position of z, are the consequence of the cost implications for households and industry of the price policies implied by plans n and z.
The points with the greatest stability in respect to the optimum ranking of the alternative plans are those that in figure 3 are nearest to the centre of the hexagon, or in, five-dimensional space, near to the centre of gravity. It is evident from figure 4 that in the centre of gravity, Z, plans r and n practically share the first place, followed by plans l and a, while plans z and g clearly take up the last but one and the last place, respectively. Presumably this ranking and the relative distances between the objects within it are most representative of the ranking of weights studied here. The study of figure 4 inspires two further remarks. One regards the 'strictness' with which the groundwater-saving plan is consistently treated; even if all criteria are given equal weight (in point K), this plan very clearly brings up the rear in the optimum ranking. It follows that this plan does not defend any one of the large interests, and is rather costly into the bargain. The second remark concerns the optimum permutation at point K, which is to be considered the most neutral point in policy space, because it is there that all criteria take the same weight. At this point, the nature-loving one is preferred to the hardly distinguishable reference and minimum plans; these are followed by plan l; next comes plan z; and finally plan g.

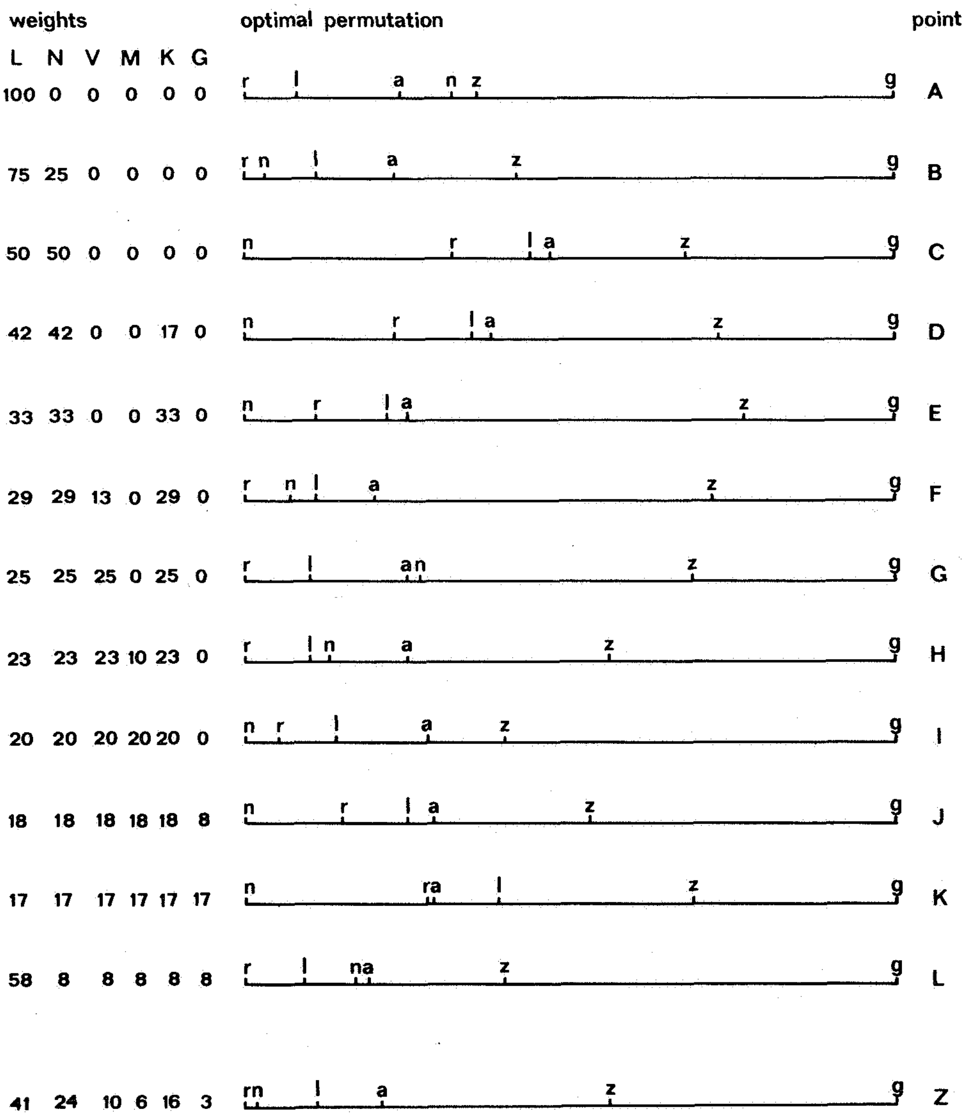


Figure 4 Relative position of the plans within a number of selected optimal permutations.

2.5 General study of the decision space

In the previous section, a detailed study was made of one part of the decision space, corresponding to a given priority ordering of the criteria. With six criteria there are 6! = 720 similar sub-spaces all of which could in principle be examined in the same detailed way. It is clear, however, that this is practically unfeasible and largely irrelevant because a large number of sub-spaces will correspond to unrealistic priority rankings.
In this section it is shown how the detailed study of a small number of cases can be completed by a general study of a very large part of the decision space. All 24 possible priority rankings of the criteria obtained when groundwater and environment are always given respectively the lowest and the second lowest priorities, are studied globally. The reasons why the criteria groundwater and environment are held on the two lower rankings are the lack of variability of the plans with respect to waste water treatment and the nature of the groundwater criteria which could be seen as a consequence of other criteria such as nature, agriculture, water supply and even costs.
For each of the 24 selected sub-spaces, 50 points or weight-combinations were examined; these points were largely chosen in the more eccentric parts of the sub-spaces (or in the vicinity of the perimeter of the hexagon in figure 3), in order to allow for maximal variability in the corresponding permutations of the plans at those points.

The results of this general study can be summarized in the form of a frequency distribution. Given that there are six plans the maximum number of different permutations is 6! × 720. Analysis of the frequency distribution has shown that, although 1200 points were examined, only 15 different permutations were found, and that for individual sub-spaces that number is even lower: between 5 in the case $L \geqslant N \geqslant V \geqslant K \geqslant M \geqslant G$, $L \geqslant N \geqslant K \geqslant V \geqslant M \geqslant G$ and $L \geqslant K \geqslant N \geqslant V \geqslant M \geqslant G$, and 12 in the case $K \geqslant N \geqslant V \geqslant L \geqslant M \geqslant G$. Since the generation of points was concentrated in the more eccentric parts of the sub-spaces (where, as can be seen from figure 3, the variability of the optimal permutations is much higher than in the region around the centre of gravity) one can already conclude that the results are fairly stable with respect to changes in the priority of the criteria. This conclusion is confirmed when one studies the distribution in detail. It appears from this study that only four permutations cover 73 per cent of the examined points: rlanzg in 24 per cent of the points, rlnazg in 18 per cent of the points, rnlazg in 16 per cent of the points (this ranks 4 in figure 3) and nrlazg in 15 per cent of the points. At a further 19 per cent of the points two additional permutations hold: nralzg and rlazng. The main information contained in the frequency distribution is presented, in an aggregate way, in table 8. This table presents a cross-classification in percentages of the plans and the frequency of occurrence of their rankings (r comes in 72 of 100 cases in the first place).

From table 8 an average picture emerges. The best plan is undoubtedly the reference plan; the second place, on an average, is taken by the agriculture-favouring plan, the last-but-one and last places are taken, respectively, by the maximum and groundwater-saving plans. The nature-loving plan shows a wide spread among the first four rankings; it is handicapped in several instances by the high drinkingwater prices it implies. Without this handicap its average ranking could become clearer; a 'pure' nature-loving plan could presumably take second place. It may be observed in this connection that, e.g., a levy on the abstraction of groundwater by industry as supposed in the nature-loving plan, will have only a slight impact on the nature areas.

Table 8 Percentage distribution of the rankings among alternative plans

Ranking \ Plan	r	n	l	g	a	z
1	72	28	–	–	–	–
2	28	17	54	–	1	–
3	–	18	33	–	49	–
4	–	25	13	–	50	12
5	–	10	–	8	–	82
6	–	2	–	92	–	6
Average Ranking	1.28	2.78	2.59	5.92	3.49	4.94
Variance	0.20	2.07	0.50	0.01	0.47	0.18

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An econometric spatial demand model for water with an application to the demand for water in East Gelderland

J. P. Ancot

3 An econometric spatial demand model for water with an application to the demand for water in East Gelderland

SUMMARY

This paper presents a number of demand models for water which are part of a broader study designed to provide a tool for water resource management in Gelderland. The purpose of these models is to lead to medium-term forecasts of the water requirements of a region and to the evaluation of alternative policies in the area of water resource management. The models are macro-economic and spatial in character: they aim at the determination of strategic economic parameters, such as price and income elasticities, and at the characterization of local differences. The level of spatial disaggregation is the municipality and this choice results from a compromise between data availability and the desirability of linking these models with existing hydrological models. Three major sectors are distinguished: the demand for water by households, industrial demand for water, and water requirements in the agricultural sector. The results of the empirical estimation of the models for the case of East Gelderland suffer from imperfections as a consequence of the deficiency and incompleteness of the available data. In view of this, the paper concludes with some guidelines for future research.

3.1 Introduction

Within the framework of the water resources management project, the Netherlands Economic Institute was commissioned towards the end of 1977 by the Committee for the Study of Water Management in Gelderland, to develop a quantitative approach to integrate the economic aspects of the water resources management problem. This paper presents the results of an econometric demand model for water; its purpose was to prepare forecasts of the regional water requirements in 1990, as well as provide simulation exercises to evaluate the impacts of various changes in parameters representing policy instruments, such as prices, levies, taxes and subsidies. The supply of water is mainly determined by institutional and physical factors. This is, therefore, one of the important links between the economic model and the physical models developed elsewhere. One aspect of the supply, however, does have an economic connotation: effluent discharge, mainly as a result of industrial activity. To the extent that this effluent discharge is treated in waste water treatment installations, the resulting water can be recycled into the system. The effluent discharge depends on the level of industrial activity, on the state of technical production processes, on the system of levies imposed, etc. As a consequence of its economic character, this very special part of the water supply has indeed been integrated in the economic model.

The demand models which are the specific subject of this paper have a much deeper economic character. Three main sectors are distinguished: the demand for water by households, industrial demand for water, and agricultural demand for water. In the latter case, one finds a second important link with the physical model, as is briefly explained in section 3.4. The purpose of the demand models is two-fold. Firstly, they are designed to estimate certain major economic parameters, from cross-section and time-series data, such as direct and cross price elasticities, income elasticities, etc., which should allow the decision maker to evaluate the impact on the demand for water of different categories of changes in the structure and levels of these variables. Secondly, they should also lead to projections about water requirements during the planning period. Only the first of these aspects is discussed in this paper. Concerning the second one, we will simply add here that simulation and forecasting models have been built to make projections under various alternative assumptions for the target year and in such a way that they lead to the construction of interval predictions rather than simply point predictions.

One important problem which arose from the outset, was the choice of the level of spatial aggregation (or disaggregation) which should be adopted. On the one hand, it was desirable to subdivide the region into as many subregions or polygons as possible, in order to allow an accurate linking of the economic model with the physical one. [The physical models operate on a grid in which the unit element measures one square kilometre.] On the other hand, however, this subdivision is constrained by the availability of the data which are necessary to estimate the econometric relationships. We have decided that the best compromise would be a subdivision into municipalities. Indeed, at that level, time-series for many of the relevant variables were available, such as income, population, water consumption, etc., which would certainly not be available at a finer level of disaggregation. Even so, the assembly of the data base led to very considerable problems. For some variables, only time-series data at the regional level were available (or worse, at the provincial or at the national level); for others, at best, one or two cross-sections were available (across municipalities). In other words, one constantly had to tackle missing data problems (see also Gilbert, 1977), and many gaps in the data material had to be filled by means of interpolation, extrapolation, averaging, etc. In the case of industrial demand models, for example, models were defined and estimated, for eight distinct industries, at the regional level. Only after the estimation round was completed, could the resulting estimated equations be combined for each municipality, according to the particular industrial configuration of the municipality, in a weighted average fashion.

3.2 The demand for water by households (see NEI, 1979)

Preference has been given to a macroeconomic approach and to a model centred upon the most important economic parameters, such as price and income elasticities, rather than to a model which would be microeconomic in character and which would divide the demand for water by individual households into a certain number of specific components (e.g., water consumption of washing machines, dishwashers, toilets, baths and showers, etc.). The reasons for this choice are the data availability at the chosen aggregation level and, more important, the fact that the model, aiming at preparing policy decisions for water management purposes, should allow the decision maker to evaluate the impact of changes in the policy instruments, such as the price system on the demand for water by households.

Apart from the specific influence of prices and income on the demand for water, the following other explanatory variables have been introduced into the model: the growing wealth of the population (implying better housing conditions, with more extensive sanitary and other water-consuming facilities), the household size, the change in the mentality of the population, the effect of installing meters, the degree of urbanization and the climate. The dependent variable is the water consumption per head and the income variable is also expressed in per capita terms. The effect of installing meters is introduced as a dummy variable, equal to one in the years and municipalities where water consumption is metered, and equal to zero otherwise. Three alternative variables were considered to represent climate: temperature, average rainfall, and number of hours sunshine, in each case averaged over the summer months. The price structure of the water boards consists of a variable rate per m^3 and a fixed rate; for the price variable, an average price per m^3 was used, including an imputation of the fixed rate. Price and income variables were deflated by means of the national index of retail prices. The variable characterizing the degree of urbanization will be discussed below.

As was explained in the previous section, the chosen aggregation level is the municipality. Time-series were in principle available or could be constructed for all years of the sample period 1965–1976 at the regional level. For a limited number of years, cross-sectional information per municipality was also available: water consumption in 1976–1977 and in 1970, and income in 1964 and in 1969. Given that these two variables had to be coupled in order to evaluate the income elasticities, only the 1970 consumption cross-section and the 1969 income cross-section could be used together with the aggregated time-series (this implies a lag of one year for the income effect to work itself out) [For all other variables, where applicable, cross-section information was also available for the year 1970; obviously, in certain cases such as price, climate, etc., there was no cross-sectional variation.] To take maximum advantage of the available information, and, in

Table 1 The models for the demand for water of the households

Model 1:

$$\frac{q_{rt}}{\text{pop}_{rt}} = a_0 + a_1 u_{1r} + a_2 u_{3r} + a_3 \frac{p_t}{P_t} + a_4 \frac{Y_{rt}}{\text{pop}_{rt}} \frac{1}{P_t} + a_5 u_{1r} \frac{Y_{rt}}{\text{pop}_{rt}} \frac{1}{P_t} + a_6 u_{3r} \frac{Y_{rt}}{\text{pop}_{rt}} \frac{1}{P_t} + a_7 d_{rt} + a_8 k_t + a_9 t + a_{10} g_{rt}$$

Model 2:

$$\ln \frac{q_{rt}}{\text{pop}_{rt}} = a_0 + a_1 u_{1r} + a_2 u_{3r} + a_3 \frac{p_t}{P_t} + a_4 \frac{Y_{rt}}{\text{pop}_{rt}} \frac{1}{P_t} + a_5 u_{1r} \frac{Y_{rt}}{\text{pop}_{rt}} \frac{1}{P_t} + a_6 u_{3r} \frac{Y_{rt}}{\text{pop}_{rt}} \frac{1}{P_t} + a_7 d_{rt} + a_8 k_t + a_9 t + a_{10} g_{rt}$$

Model 3:

$$\frac{q_{rt}}{\text{pop}_{rt}} = a_0 + a_1 u_{1r} + a_2 u_{3r} + a_3 \frac{p_t}{P_t} + a_4 \left(\frac{Y_{rt}}{\text{pop}_{rt}} \frac{1}{P_t}\right)^{-1} + a_5 u_{1r} \left(\frac{Y_{rt}}{\text{pop}_{rt}} \frac{1}{P_t}\right)^{-1} + a_6 u_{3r} \left(\frac{Y_{rt}}{\text{pop}_{rt}} \frac{1}{P_t}\right)^{-1} + a_7 d_{rt} + a_8 k_t + a_9 t + a_{10} g_{rt}.$$

Model 4:

$$\ln \frac{q_{rt}}{\text{pop}_{rt}} = a_0 + a_1 u_{1r} + a_2 u_{3r} + a_3 \frac{p_t}{P_t} + a_4 \left(\frac{Y_{rt}}{\text{pop}_{rt}} \frac{1}{P_t}\right)^{-1} + a_5 u_{1r} \left(\frac{Y_{rt}}{\text{pop}_{rt}} \frac{1}{P_t}\right)^{-1} + a_6 u_{3r} \left(\frac{Y_{rt}}{\text{pop}_{rt}} \frac{1}{P_t}\right)^{-1} + a_7 d_{rt} + a_8 k_t + a_9 t + a_{10} g_{rt}$$

Model 5:

$$\frac{q_{rt}}{\text{pop}_{rt}} = a_0 + a_1 \frac{p_t}{P_t} + a_2 \left(\frac{Y_{rt}}{\text{pop}_{rt}} \frac{1}{P_t}\right)^{-1} + a_3 d_{rt} + a_4 \ln(k_t) + a_5 t + a_6 \ln(g_{rt}) + a_7 v_{rt}$$

Model 6:

$$\ln \frac{q_{rt}}{\text{pop}_{rt}} = a_0 + a_1 \frac{p_t}{P_t} + a_2 \left(\frac{Y_{rt}}{\text{pop}_{rt}} \frac{1}{P_t}\right)^{-1} + a_3 d_{rt} + a_4 \ln(k_t) + a_5 t + a_6 \ln(g_{rt}) + a_7 v_{rt}$$

Meaning of the symbols:

q	yearly consumption of water by the households;
pop	populattion on 30th June;
u_1	dummy variable equal to one for uban areas and to zero otherwise;
u_3	dummy variable equal to one for rural areas and to zero otherwise;
P	unit price of water, paid by households;
p	deflator;
y	yearly gross nominal income;
d	dummy variable equal to one where and when meters are installed, and to zero otherwise;
k	average number of hours of sunshine during the period May to September;
t	time-trend;
g	household size;
v	percentage users in the core area of the corresponding municipality.

particular, to measure the effect of the degree of urbanization, the cross-sectional data were pooled with the time-series data, in models derived from the so-called parameter-component model developed at the Netherlands Economic Institute (see Ancot et al., 1978). In this type of model, the parameters are divided into several elements corresponding to the different dimensions of the data set. This enabled a distinction to be made among three effects with respect to the degree of urbanization: a neutral effect, an effect resulting from a high level of urbanization and one resulting from a low level of urbanization.

Many different specifications of the demand equation were tested, both linear and non-linear. From these estimated models, six models were selected on the basis of economic and statistical criteria combined. The formal specification of these models is given in table 1. The best results were obtained with linear and log-linear specifications and with models which combine linear, log-linear and reciprocal terms. All three climatological variables were tested and the statistically most significant result was consistently obtained with the average number of hours sunshine during the period May to September. The main results of these models are presented in tables 2 and 3.

Models 3 and 4 perform statistically better than models 1 and 2 (see headings in the tables); the corresponding R^2 and t-values are higher in the former than in the latter. Especially the coefficients of the income variables show an improvement. All estimated coefficients have the expected signs. A possible exception is the coefficient of the variable representing the household sizes, but this positive effect could be interpreted as resulting from a sort of 'diseconomy of scale'. The most significant variables are the relative price variable, the metering dummy, the household size and the climate. The income effect is statistically less significant and the same can be said for the urbanization effects. The time trend, which was introduced into the models as a proxy for the wealth of the population (this variable is difficult to quantify), has an estimated coefficient which, though positive, is the least significant of all.
Models 5 and 6 attempt at improving on the weaker aspects of the previous ones. The estimation of the income effect was not totally satisfactory in the four initial models: the difference between highly urbanized areas and rural ones did not appear to be significant and the relative orders of magnitude of the corresponding elasticities did not seem to agree with the expected ranking. Furthermore, it is probably more realistic to consider the household size and the climate elasticities as constant parameters rather than as functions of the corresponding variables, as implied by the specifications of models 1 to 4. Given these considerations, the following changes were made in the specification of models 5 and 6. The income variable is given an autonomous existence, independently of the degree of urbanization (i.e., only the total income effect is measured); the latter variable is

Table 2 Results of a few specifications of the demand for water of the households
Part I – Estimated coefficients

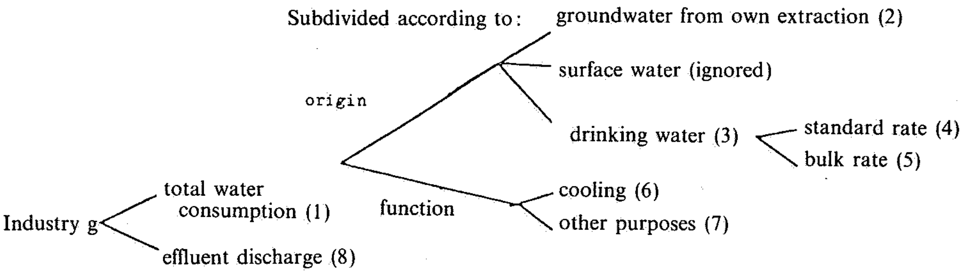
Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Constant	linear 0.0438 (0.0106)	linear −2.8623 (0.4110)	linear 0.0481 (0.0096)	linear −2.7171 (0.3729)	linear 0.0138 (0.0167)	linear −3.5561 (0.6504)
Urban constant dummy	linear −0.0048 (0.0043)	linear −0.1596 (0.1653)	linear 0.0051 (0.0044)	linear 0.1842 (0.1709)	–	–
Rural constant dummy	linear −0.0013 (0.0031)	linear −0.0456 (0.1222)	linear 0.0009 (0.0033)	linear 0.0332 (0.1281)	–	–
Price	linear −0.0591 (0.0174)	linear −2.1812 (0.6781)	linear −0.0571 (0.0172)	linear −2.1105 (0.6648)	linear −0.0572 (0.0162)	linear −2.1276 (0.6335)
Income	linear 0.0606 (0.0455)	linear 2.1049 (1.7670)	inverse −0.000158 (0.000103)	inverse −0.00576 (0.00398)	inverse −0.000195 (0.000096)	inverse −0.00713 (0.00375)
Urban income dummy	linear 0.1123 (0.0975)	linear 3.7594 (3.7890)	inverse −0.000217 (0.000190)	inverse −0.00780 (0.00736)	–	–
Rural income dummy	linear 0.0267 (0.0703)	linear 0.9098 (2.7327)	inverse −0.000050 (0.000144)	inverse −0.00180 (0.00559)	–	–
Metering	linear −0.0027 (0.0011)	linear −0.1579 (0.0416)	linear −0.0023 (0.0011)	linear −0.1456 (0.0415)	linear −0.0023 (0.0010)	linear −0.1455 (0.0394)
Average hours sunshine during summer months	linear 0.000037 (0.000016)	linear 0.00078 (0.00064)	linear 0.000040 (0.000016)	linear 0.000907 (0.000637)	logarithmic 0.0076 (0.0028)	logarithmic 0.1802 (0.1082)
Trenddummy	linear 0.000418 (0.000507)	linear 0.00674 (0.01971)	linear 0.000400 (0.000497)	linear 0.00545 (0.01923)	linear 0.00046 (0.00046)	linear 0.00682 (0.01789)
Household size	linear 0.0011 (0.0007)	linear 0.0386 (0.0273)	linear 0.0012 (0.0007)	linear 0.0467 (0.0276)	logarithmic 0.0046 (0.0026)	logarithmic 0.1712 (0.1026)
Percentage users in core	–	–	–	–	linear 0.0016 (0.0018)	linear 0.0558 (0.0719)
Water consumption per head (to be explained)	linear	logarithmic	linear	logarithmic	linear	logarithmic

Table 3 Results of a few specifications of the demand for water of the households
Part II – Other statistical and econometric parameters

Parameter	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
R^2	0.9723	0.9474	0.9732	0.9494	0.9734	0.9489
Average elasticities						
(i) price	−0.6543	−0.8790	−0.6322	−0.8503	−0.6333	−0.8577
(ii) incomes						
(a) urban	0.2149	0.2654	0.2314	0.3046		
(b) middle class	0.0753	0.0952	0.0975	0.1294	0.1200	0.1602
(c) rural	0.1086	0.1364	0.1284	0.1698		
(iii) climate (K3)	0.2011	0.1531	0.2162	0.1775	0.2088	0.1802
(iv) household size	0.1217	0.1555	0.1405	0.1880	0.1264	0.1712
(v) degree of urbanization	–	–	–	–	0.0377	0.0645
Saturation level						
(a) urban	–	–	0.0448	0.0490		
(b) middle class	–	–	0.0399	0.0411	0.0408	0.0308
(c) rural	–	–	0.0411	0.0428		

introduced as a continuous variable, measured by the percentage number of users in the core area of each municipality. The household size and the climate are entered in logarithmic form, so that the corresponding elasticities become constant.

The estimated average price elasticities vary between −0.63 and −0.88. Although this seems to be rather high (in absolute values), it must be stressed that prices are expressed in relative terms with respect to a general price index. The average income elasticities are highest in municipalities with a high degree of urbanization (between 0.21 and 0.30) and lowest in municipalities with an average degree of urbanization (between 0.08 and 0.13). These relative orders of magnitude are a little surprising even if it is remembered that the interpretation is complicated by the fact that it was not possible to distinguish completely specific household consumption from some commercial and agricultural consumption. For this reason, the income effect and the urbanization effect were treated independently in models 5 and 6. In these models, the general income effect becomes significant and the income elasticity varies between 0.12 and 0.16. On the other hand, the degree of urbanization still remains insignificant, with a very low elasticity, between 0.04 and 0.06. The estimated elasticities for the climate variable vary from 0.15 to 0.22 and for the household size, from 0.12 to 0.19. Models 3 and 6 lead to the calculation of saturation levels for water consumption; these vary from 84 litres to 134 litres per person per day. [These saturation levels are, in fact, functions of the explanatory variables, with the exception of the income variable; the estimates given correspond to average values of these variables during the period.]



$$\frac{p_E Q_E + p_L Q_L}{pQ} = a_0 + a_1 p_{AF} + a_2 \Delta_{\text{prod}} + a_3/t \tag{1}$$

$$\frac{p_E Q_E}{pQ} = b_0 + b_1 p_E + b_2 p_L \tag{2}$$

$$\frac{p_L Q_L}{pQ} = c_0 + c_1 p_E + c_2 p_L \tag{3}$$

$$\frac{p_{LK} Q_{LK}}{pQ} = c_0^1 + c_1^1 p_{LK} + c_2^1 p_{LG} + c_3^1 \frac{p_L Q_L}{pQ} + c_4^1/t \tag{4}$$

$$\frac{p_{LG} Q_{LG}}{pQ} = c_0^2 + c_1^2 p_{LK} + c_2^2 p_{LG} + c_3^2 \frac{p_L Q_L}{pQ} + c_4^2/t \tag{5}$$

$$Q_K = d_0^1 + d_1^1 \Delta_{\text{prod}} + d_2^1/t + d_3^1 (Q_K + Q_A) \tag{6}$$

$$Q_A = d_0^2 + d_1^2 \Delta_{\text{prod}} + d_2^2/t + d_3^2 (Q_K + Q_A) \tag{7}$$

$$\frac{Q_{AF}}{pQ} = f_0 + f_1 p_{AF} \tag{8}$$

Meaning of the symbols

Q_E	total yearly consumption in volume of 'own' groundwater of the sector, in the region;
Q_L	total yearly consumption in volume of drinking water of the sector, in the region;
p_E	unit cost of extraction for 'own' groundwater;
p_L	average price of drinking water;
Q	yearly volume of production of the sector, in the region;
p	average price of the product of the sector;
p_{AF}	unit levy on effluent discharge;
Δ_{prod}	yearly changes in production in the sector;
t	time trend;
Q_{LK}	total yearly consumption in volume of drinking water in the sector according the basic rate;
Q_{LG}	total yearly consumption in volume of drinking water in the sector according to the bulk-rate;
p_{LK}	price of drinking water according to the standard rate;
p_{LG}	price of drinking water according to the bulk-rate;
Q_K	total yearly consumption, in volume, of water used in the sector, for cooling purposes;
Q_A	total yearly consumption, in volume, of water used in the sector, for purposes other than cooling;
Q_{AF}	total yearly effluent discharge, of the sector, in accounting units.

Figure 1 Structure of the typical submodel for the industrial demand for water

3.3 The industrial demand for water

The final specification of the model for the industrial demand for water results from a compromise between the theoretical specification of this model and the available sample information for the region under study. The latter aspect has indeed been felt as a very important limitation in making operational a conceptual framework because of the inaccuracies of the data and their irregularities resulting, *inter alia*, from the subregional aggregation level at which one is operating; sometimes total lack of quantitative information on some variables had to be faced. These data problems are not discussed here and the reader is referred to the original document for a full treatment of these aspects (see NEI, 1979); only some elements will be briefly mentioned below.

In its final specification, the industrial demand model consisted of eight submodels, one for each of eight broad sectors into which the industrial activity has been partitioned. [These sectors are: food, drink and tobacco; textiles; leather and rubber; paper; chemicals and allied industries; building materials; metal; other manufacturing.]

Each submodel, schematically presented in figure 1, contains, in principle, eight equations: a sectoral total demand equation for water (1); this total demand is then subdivided according to the origin of the water, into demand for 'own' groundwater, (this is groundwater extracted by the firm for its own use) (2) and demand for drinking water, (that is, water extracted and distributed by the water boards) (3); the latter demand is further subdivided according to the two different rates applied by the water boards: the standard rate (4) and the bulk rate (5). On the other hand, total sectoral water consumption is also subdivided according to the function which the water fulfils in the production process, into cooling water and water consumption for other purposes (mainly, of course, as process water); these are the technological relations (6) and (7). A last equation (8) is a supply function of industrial effluent discharge. Given that the consumption of surface water is negligible in East Gelderland, this aspect of the problem has been ignored in the final specification. [In 1976, only two firms were using surface water: a textile firm in Eibergen (consuming 550,000 m^3/year from the Berkel); and a dairy in Lochem (consuming 850,000 m^3/year from the Twente canal).] In other words, the model is confined to the description of the industrial demand for groundwater.

- *Total sectoral water consumption* (equation (1))

The explanatory variables in this equation are the technological evolution (represented by a time trend), the short-term production changes and the levies on effluent discharge, which essentially operate as a dummy variable here. [These levies were introduced, for the first time, in 1973.] The dependent variable is the total sectoral, yearly water consumption, in value per guilder gross value added at factor costs. All values are expressed in constant 1970 prices. The introduction of a proper dummy variable to represent the technological progress was considered, but, although some fragmentary information could be obtained for individual firms, given the macroeconomic character of the model, this proved to be insufficient for any serious implementation. [Such as a variable which would equal 1 for modern production processes, 3 for old ones and 2 for intermediate ones.] The time trend, in this equation as well as in the following ones, was introduced in the form 1/t, in order to avoid that – when the model would be used for medium-term forecasting – the forecasts would become too sensitive to this time element: a linear form would have implied that the water consumption, at least in principle, could increase linearly or decrease indefinitely (and thus could go to zero).

- *Consumption of 'own' groundwater* (equation (2))

This equation explains the 'own' groundwater consumption, in value and relatively to gross value added at factor costs (in 1970 prices) as a function of the cost of extraction of groundwater and the price of drinking water. The purpose of this equation is the estimation of the direct and cross-price elasticities of demand for 'own' groundwater.

- *Total drinking water consumption* (equation (3))

In this equation the total drinking water consumption per guilder value added is related to the same variables as in the previous equation; the interpretation of this equation is therefore, symmetrical to that of the previous one.

- *Drinking water consumption according to the basic rate* (equation (4))

This category of consumption is written, in this equation, as a structurally stable fraction of the total drinking water consumption (3), and, additionally as a function of direct and cross-price effects (according to the two rates of the water boards), and of the trend variable, 1/t. In other words, one assumes that there exists a fairly stable partition of total drinking water consumption into two classes as a result of the two-tier tariff system, which can however undergo marginal changes owing to changes in relative prices and in the general production situation. This rigidity partly results from the fact that, in order to benefit from the cheaper bulk tariff, individual firms must negotiate with the water authorities on the basis of specific capacities to be supplied.

- *Drinking water consumption according to the bulk rate* (equation (5))

This equation is exactly symmetrical to the previous one.

- *Water consumption for cooling purposes* (equation (6))

Water consumption for cooling (in absolute quantities) is explained, on the one hand, as a fraction of the total water consumption, and, on the other hand, as a function of yearly changes in the volume of production and of the 'proxy' variable 1/t, which represents technological changes and other factors related to the time trend.

- *Water consumption for other purposes* (equation (7))

This equation is, once again, the analogue of equation (6).

- *Effluent discharge* (equation (8))

The dependent variable is the number of accounting units per guilder of gross value added at factor costs and the only explanatory variable is the discharge levy. This equation was introduced in the submodels in an attempt to make maximum usage of the available information. Not too much is to be expected from this equation, however, because of structural changes in the discharge levy system during the sample period and because of the lack in degrees of freedom in the estimation.

Each of the eight submodels has been estimated by three-stage least-squares with additivity restrictions (Zellner and Theil, 1962), using data covering the period 1967 to 1976. The estimation results of equations (1), (2), (3), (4) and (6) are given in tables 4 to 8. Because of the additivity restrictions, the results for equations (5) and (7) have not been reproduced as they can easily be derived from the given tables and the associated restrictions. The results for equation (8) are not reproduced here because, given the poor data material and the isolation of this equation in the submodels, satisfactory and reliable results could not be achieved. Inasmuch as results were obtained for that equation, they point to high direct price elasticities (in absolute values) with the expected negative sign: the discharge levy could have a strong beneficial influence on the pollution of surface water.

Before these results are discussed two general remarks of a statistical nature must be made. The first one concerns the interpretation of the coefficient of determination R^2. The range of variation of the values obtained for this coefficient is exceptionally large: some values are very low (about 0.3) and others are

Table 4 Total industrial water consumption *

Industry	Total consumption	Levy on effluent discharge	Production changes	Trend	Constant	R^2
Food, drink and tobacco	–	−0.000469	$-3.941 \cdot 10^{-7}$	0.207	0.775	0.632
	–	(0.001171)	$(34.458 \cdot 10^{-7})$	(0.084)	(0.034)	
	–	0.006	–	–	–	
	0.723	8.594	7,872	0.2	1	
Textile	–	0.00213	$-1.311 \cdot 10^{-5}$	0.208	0.334	−0.996
	–	(0.00092)	$(0.316 \cdot 10^{-5})$	(0.063)	(0.064)	
	–	0.035	–	–	–	
	0.522	8.594	458	0.2	1	
Leather and rubber	–	−0.00303	$-1.189 \cdot 10^{-5}$	0.303	0.279	0.403
	–	(0.00356)	$(1.286 \cdot 10^{-5})$	(0.303)	(0.090)	
	–	−0.085	–	–	–	
	0.305	8.594	1,094	0.2	1	
Paper	–	−0.000101	$3.120 \cdot 10^{-6}$	0.0112	0.407	0.358
	–	(0.000602)	$(8.416 \cdot 10^{-6})$	(0.0499)	(0.027)	
	–	−0.002	–	–	–	
	0.399	8.594	1,522	0.2	1	
Chemicals	–	0.00305	$-5.298 \cdot 10^{-6}$	0.599	0.164	0.804
	–	(0.00183)	$(2.026 \cdot 10^{-6})$	(0.152)	(0.048)	
	–	0.090	–	–	–	
	0.291	8.594	5,151	0.2	1	
Building materials	–	0.00428	$2.129 \cdot 10^{-6}$	−0.181	0.291	−0.859
	–	(0.00151)	$(6.213 \cdot 10^{-6})$	(0.123)	(0.038)	
	–	0.127	–	–	–	
	0.289	8.594	117	0.2	1	
Metal	–	0.00326	$-7.313 \cdot 10^{-7}$	−0.189	0.312	−0.943
	–	(0.00075)	$(3.800 \cdot 10^{-7})$	(0.062)	(0.020)	
	–	0.098	–	–	–	
	0.287	8.594	17,269	0.2	1	
Other manufacturing industries	–	0.00318	$-7.441 \cdot 10^{-7}$	−0.0947	0.101	0.953
	–	(0.00075)	$(6.307 \cdot 10^{-7})$	(0.0631)	(0.0204)	
	–	0.0260	–	–	–	
	0.105	8.594	5,464	0.2	1	

* In the first two lines of each box appear the estimated values of the coefficient and its standard error (in brackets) of the corresponding term; the third figure is the estimated average (price) elasticity; the fourth figure is the average value of the corresponding variable (average over the sample period).

particularly high (0.9 and more). If, however, one compares the values predicted by this estimated model with the observed ones, there appears to be little grounds for such discrepancies. This apparent contradiction is probably a consequence of the integration of the additivity restrictions in the estimation procedure. The same problem has been encountered in other studies where similar models were used; (see e.q. Ancot et al., 1977). A second remark concerns the estimated standard errors. These values are, on the whole, lower than they would be if there was no *a priori* information available in the form of additivity constraints. Consequently, the estimation with restrictions is, on the whole, statistically more significant than without restrictions; in other words, the incorporated *a priori* information (here, in the form of linear restrictions between the parameters to be estimated) helps in solving the estimation problem resulting from deficient data material.

- *The total water consumption* (table 4)

With the exception of the constant term, the statistically most significant variable in this equation, is the discharge levy; this variable is significant in all cases, with a positive coefficient (when the estimate is significant) and a very low (positive) price elasticity. This unexpected result (at least, as far as the sign of the elasticity is concerned) is even more remarkable given that one is concerned here with a dummy variable which should represent the impact of the introduction in 1973 of the discharge levy on the industrial water consumption. From figures 2 to 9, comparing predicted and actual series for total water consumption, drinking water consumption and 'own' groundwater consumption, the introduction of the levy does not appear to have had any immediate effect on total water consumption. Although a relative decline in the water consumption as a result of the introduction of the levy can be expected, it is not a necessary consequence of this. Indeed, the first objective of this regulation is to limit the pollution of the surface water and this is explicitly dealt with by equation (8). On the other hand, one could argue that, as a result of technical and other rigidities, the effect, if any, would only work itself through to total consumption with a delay of one or more years. Such a lag effect could be introduced in the model and this may be a subject for further research.

The second most significant variable is the trend variable. For the food, drink and tobacco industry, the textile industry, and the chemical industry, the technological changes and other changes related to the trend lead to lower water consumption whereas for the metal industry, the reverse effect seems to hold; in the other cases, the coefficients are not significantly different from zero. [A positive sign points to a negative relation between the dependent variable and the time, because the latter has been introduced as 1/t in the submodels; see RID, 1976a].

This result for the food, drink, and tobacco industry is consistent with the findings

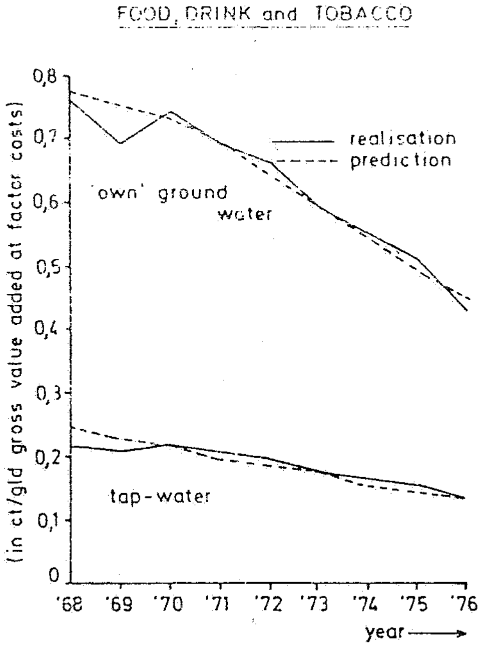


Figure 2

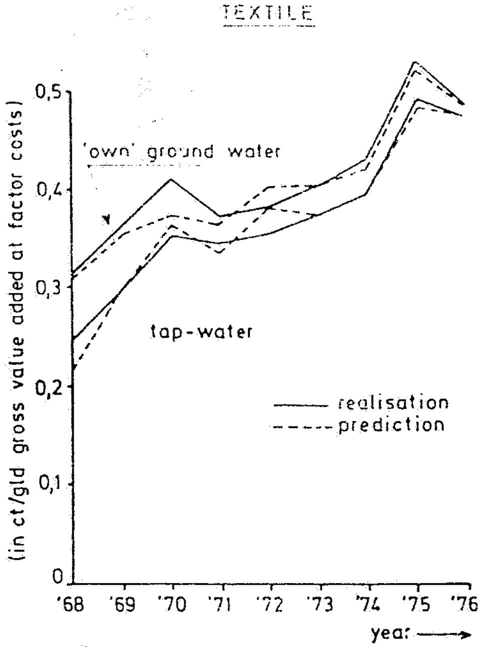


Figure 3

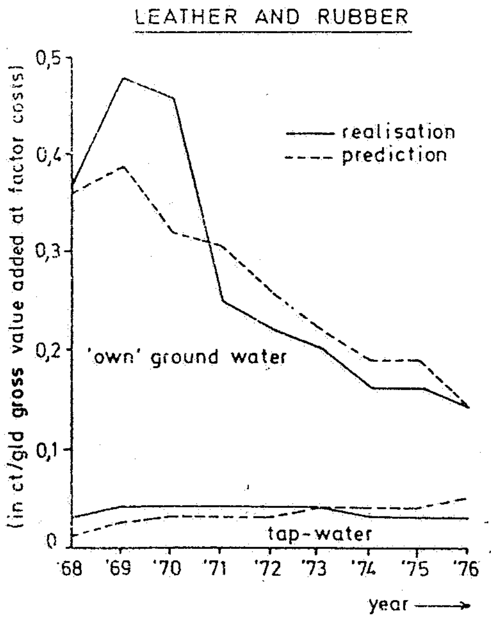


Figure 4

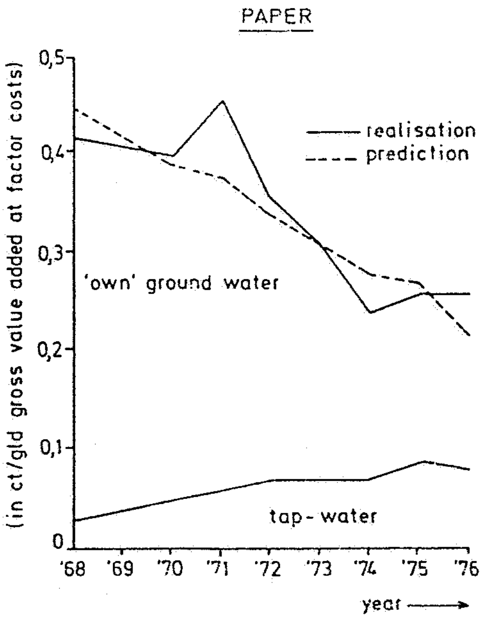


Figure 5

Figure 2–Figure 9 Measured and calculated values of the water consumption per industry for the years 1968–1976

CHEMICALS

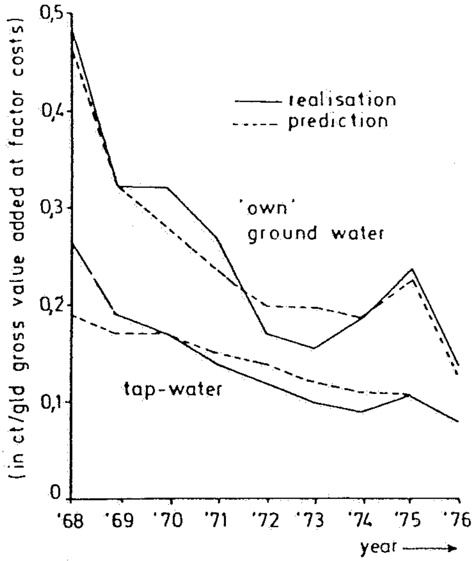


Figure 6

BUILDING MATERIALS

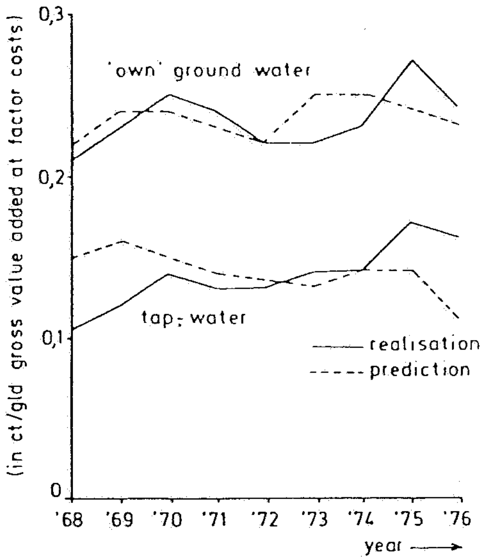


Figure 7

METAL

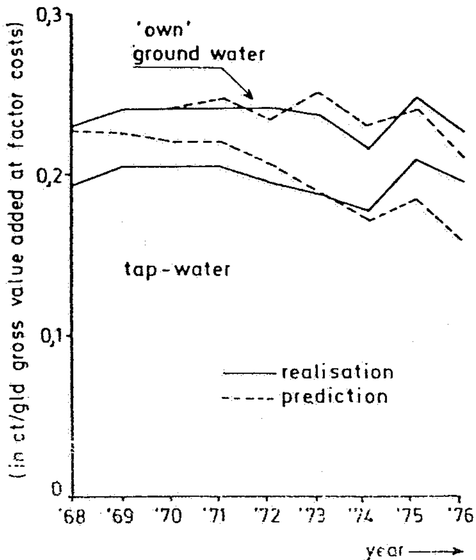


Figure 6

OTHER MANUFACTURING INDUSTRIES

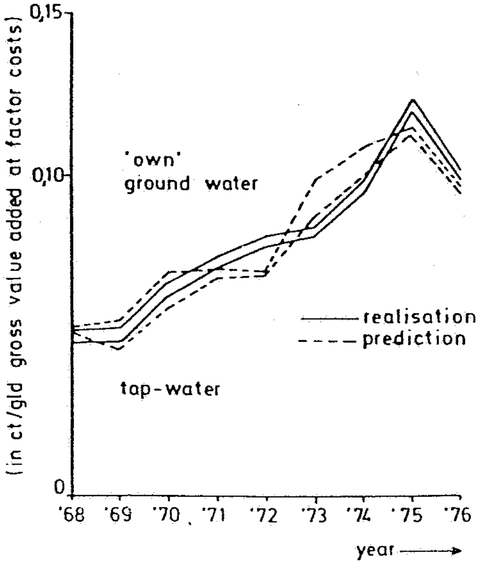


Figure 9

of the Rijksinstituut voor Drinkwatervoorziening (RID) for the branch of meat and meat products, at the national level (see RID, 1976a, pp. 26 to 28). In the case of the metal industry, it is possible that complications arise in the estimation process as a result of high correlation between the trend variable and the discharge levy. The simple correlation coefficient between the two variables is equal to 0.91. Indeed, especially for this industry one might expect a negative sign for the coefficient of the discharge levy variable. The positive sign of the coefficient of the trend variable for the paper industry also agrees with the RID-study on the water consumption in the (national) paper industry (see RID, 1976b, pp. 21 to 23). Finally, for the textile industry, the chemical industry, and the metal industry the changes in production volume do have a significant (negative) influence on total water consumption.

- *'Own' groundwater consumption*

These results are not very satisfactory from the statistical point of view. The values of the coefficient of determination are, in general, low and the estimated coefficients are not significant (with the exception of the constant). The direct price elasticities have the expected negative sign (except in the case of other manufacturing industries), whereas the cross price elasticities, in four cases, have the most likely positive sign. However, a negative sign is not to be excluded on theoretical grounds: this would mean that drinking water and 'own' groundwater would be complementary; this could, for example, result from the fact that in the production process, the two types of water would respond to different requirements (for example, from the point of view of water quality), so that the two would not be interchangeable, or from limited supplies of 'own' groundwater so that, even if the price of drinking water increased, substitution would be impossible above this capacity level. Furthermore, the importance of the choice between tapwater and 'own' groundwater depends on the water input necessary to produce one unit of the product; the price of water will be of little or no importance in firms which consume small quantities of water per unit of their product.

- *Consumption of drinking water*

The general picture, here, is rather similar to that of the previous case. The constant seems to dominate the fit and the explanatory variables only have a limited influence. The sign of the direct price elasticity is not clear, and that of the cross price elasticity is consistently positive. The combination of these results with the previous ones seems to indicate that extraction costs are more important than the price of drinking water. Although this appears to contradict the opinion of experts in the field, it is consistent with the fact that more firms are partly or totally abandoning 'own' extraction, as appears clearly from the data series. The less important production changes have a negative coefficient when the latter is significant. In other words, the above-average production increases tend to have a saving influence on drinking water consumption.

- *Drinking water consumption according to the standard rate*

As expected, the most significant variable is the total drinking water consumption. The consumption of drinking water according to the standard rate relative to total drinking water consumption lies, for all sectors, except food, drink and tobacco and leather and rubber, above the 90 percent mark. In the chemical and metal industries, these fractions increase during the period, as might be expected: expansion of existing firms as a result of groupings, etc. substitution of drinking water for 'own' extraction, closing down of small businesses. Although, on the whole, the price elasticities show the correct signs, they are not often significant and, in general, they are low in absolute values. Changes in relative prices lead to little or no substitution between drinking water at the standard rate and drinking water at the bulk rate. The interpretation of the estimated equation for drinking water consumption priced according to the bulk rate is completely symmetrical, *mutatis mutandi*, as a result of the additivity constraints.

- *Consumption of water for cooling*

In the case of the equations allocating total water consumption between cooling water and water for other purposes, it appears, as in the previous case, that the most significant effect is this partitioning. The trend effect is usually positive, except for the building-material industry, which means that the technological demands for cooling water are increasing. Although that can be true of some processes, it is, in general, a doubtful result: according to the RID-study (1976a) concerning the water consumption in the meat and meat products branch of the food, drink, and tobacco industry, the future technological evolution in the Netherlands would be such that the percentage water consumption for cooling with respect to total water consumption would decrease from 59 percent in the period 1971 to 1973, to 37 percent in 1990. One could expect that, in general, modern cooling installations would take more and more advantage of recirculation cooling and, whenever possible, such as in the paper industry, cooling water would be re-used as process water. This unexpected result is most probably a consequence of the unrealiability of the underlying data.

In summary, it can be concluded that, generally speaking, the different price effects are statistically not very significant, even if the absolute values of the elasticities are high (in the region of 0.3 to 0.4, on average, for the direct price elasticities). The costs of 'own' extraction of groundwater seem to be more important than the average price of drinking water to explain the gradual substitution of drinking water for 'own' groundwater. The introduction of a levy on effluent discharges seems to have had a favourable influence on the pollution of surface water, but has had no significant impact on the total industrial water consumption (at least, in the short run). If it is accepted that the trend variable can be interpreted as a proxy variable for the technological evolution, it has been found that the latter has had a saving influence on total water consumption in the food, drink, and tobacco industry, in the textile industry and in the chemical industry, whereas the opposite holds for the metal industry. This is consistent with the observation that the most water-dependent industries (per unit product) are the first ones to take measures to economize on the corresponding input. The short-term production fluctuations only have a small, generally saving, influence on total water consumption and on the consumption of drinking water. Concerning the relationships existing between the consumption of 'own' groundwater and that of drinking water, it can be said that firms tend more and more to switch from the first to the latter. Concerning the partitioning of drinking water consumption according to the two-tier price system, it has been seen that this relation remains very stable during the sample period with a small tendency to increased consumption of the more favourably priced water; this is probably more a consequence of the changing structure of the industry in East Gelderland than of the changes in relative prices. The model has little to say about the partitioning of water consumption into water for cooling and water for other purposes, most probably because of the unsatisfactory character of the available data. Figures 2 to 9 give a graphical representation of the estimated total water consumption, 'own' groundwater consumption and drinking water consumption per industry, compared with the corresponding observed series. It appears from these figures, that, although the value of the determination coefficient was sometimes rather low, the fits are fairly satisfactory; not only is the trend well predicted by the model, but the deviations from the trend and/or the turning points are, in many cases, correctly identified.

3.4 The demand for water in the agricultural sector

The agricultural aspects will very briefly be mentioned here, mainly to complete the picture. Given the nature of the problems, the treatment of the agricultural demand for water is heavily based on strainghtforward agricultural data and on the results of the physical hydrological model of De Laat. In other words, the economic content of the approach is, in this case, very much lower than in the previous ones. Also, compared with the study of the other sectors, as discussed in the previous paragraphs, the economic relevance appears to be of secondary importance in the case of the agricultural sector next to the purely physical data and constraints.

The computations for the demand for water in the agricultural sector are exclusively concerned with predictions of water needs in 1990. Predictions for water consumption in the stock-breeding sector, per municipality and per type of stock, are obtained as the product between predicted number of animals and the water requirements per animal. This includes water from own extraction as well as drinking water and water for consumption by the animals, as well as water for cleaning and other purposes.

Projections concerning the water requirements of crops have been confined to grass. The reason is that, from the agricultural point of view, it only makes sense to artificially sprinkle grass and potatoes (apart from horticulture, which is ignored here; this sector is not important in East Gelderland) and potatoes constitute a very marginal crop in the study region. The starting point is the calculation of the average moisture deficit for grassland per municipality for different alternative climatological situations, given data on the potential evaporation, the results of the physical model of De Laat concerning relative evaporation per soil profile and the soil configuration of the municipalities. This was done for two groundwater levels at the beginning of the season (the definition of the season used here is from 15 April to 15 September, that is, 150 days): no groundwater reduction and 25 cm groundwater reduction, which could be the consequence of a dry winter. These calculated moisture deficits were then used to compute relative yields and absolute yields (in ton Dfl/ha), yield depression (in ton/ha and in guilders/ha), averaged for the different municipalities and for the various climatological alternatives. These calculations were made using an empirical linear relationship between relative evaporation and relative yield, for a battery of alternative assumptions concerning the value of the parameter in that equation, the potential yield (in ton Dfl/ha) and the average price of Dfl. Finally, and this was the main purpose of the exercise, a computation was made per municipality and per climatological hypothetical situation of the quantities of water which – given the previous results and predictions concerning the acreage of grassland in 1990 – would be necessary to artificially sprinkle 50 percent of the grassland in that year. In order to complete the picture, a very brief analysis has also been made, per municipality, of the needs for water discharge in order to improve the agricultural situation in certain areas.

3.5 Conclusions

The demand models which have been discussed in the previous sections still suffer from a considerable number of imperfections. To obtain more accurate and more reliable estimates and forecasts, the approach could be improved in several directions and it is the purpose of these concluding remarks to point to a certain number of these. They should provide guidelines for further research in this area.

The quantification and the estimation of the equations of the various submodels has constantly been complicated by the deficiency and by the unreliability of the data. It is, however, important to differentiate the quantitative model further, not only to obtain a closer coupling of the economic model with the existing physical one, but also to lead to reliable statistical forecasts of the future regional water requirements in the medium term and to permit an accurate study of the effects of alternative decisions concerning water management. Some equations must be estimated from historical data and the reliability of the resulting estimates depends heavily on the length and on the accuracy of these series. For these reasons an effort should be made by the relevant institutions to collect and to update detailed data. To take but one example, it ought to be possible to subdivide drinking water consumption according to the following criteria:

- *the type of consumer:* household, commercial and public institution (e.g. shops, hospitals, schools, etc.), industrial firm (which should further be classified according to a system of homogeneous industries), agriculture, other uses (such as own consumption of the water boards, leaks in the transportation system);

- *the reason for water consumption:* e.g. pure household consumption *v* consumption for washing cars and gardening; cooling water *v* process water in industry; artificial irrigation *v* consumption by cattle in agriculture;

- *the tariff structure:* standard rate *v* bulk rate;

- *the spatial subdivision of the region:* e.g. consumption per municipality or per agricultural and hydrological homogeneous areas.

Some aspects which have not been examined or only scarcely in the present study merit further consideration. Examples of these are the quality of the water, the problems in relation with surface water and the use of water for recreation purposes. Such elements should be integrated into the models and the corresponding data collection should be organized.

Other problems which have been tentatively treated in the present study, should be developed further. For example, in the industrial submodels, the problem arises that in a region as small as East Gelderland, several industries are represented by only a very small number of firms. The consequence of this is that when a business is closing down or when a business has expands, this has a considerable effect on the corresponding data, which, at a higher level of spatial aggregation would be smoothed out as a result of the large numbers. Where this type of difficulty arises, supplementary information should be incorporated from studies at broader based levels (national or international). Another (complementary) way of solving this problem is to consider the combination of the present type of macroeconomic analysis, with microeconomic models based on budgetary and other survey-type data. Such a combination should lead to cross fertilization between micro-economic and micro-economic approaches and to beneficial feedback effects, arising from the multi-dimensionality of the corresponding data base on the accurate determination of the values of the important parameters.

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Applicability of multi-criteria decision models with multiple decision makers in water resources systems

Th. J. van de Nes

4 Applicability of multi-criteria decision models with multiple decision makers in water resources systems

Summary

Planners and decision makers are increasingly confronted with the evaluation of social revenues and losses of public investments. Therefore the water resource planning profession is currently engrossed in a period of reformulation of its project evaluation procedures and development of corresponding mathematical techniques. The current transformation is from traditional benefit-cost analyses and its associated uni-objective planning model to multi-objective analyses. The general feature of these methods is that the project impacts are not necessarily transformed into monetary units. In this paper two multi-criteria decision models are explained and compared with each other. These are the method of Saaty (United States) and the method of Paelinck (Netherlands).

Both methods can be used for the integration and evaluation of the results, given by complex simulation models of the water-resources system in Gelderland. An extension of the method of Saaty and an application on the location problem of a pumping station for the domestic water supply will be presented. Attention is given to the situation with multiple decision makers.

4.1 Introduction

Planners and decision-makers are increasingly confronted with the evaluation of social revenues and losses of public investments. The rise in interactions between the public and private sector as well as the presence of many intangible effects of public investments imply that an unambiguous evaluation of public projects on the basis of their social utility is, in general, very difficult. The main reason for this difficulty is the fact that the various aspects of a public project are very hard to transform in the same dimension; particularly into the monetary dimension.

Therefore, the water-resource planning profession is currently engrossed in a period of reformulation of its project evaluation procedures and development of corresponding mathematical techniques. The ongoing transformation is from traditional benefit-cost analysis and its associated uni-objective planning models to multi-objective analysis, which has promoted two field of decision models:

A the mathematical programming models with more than a single objective function;

B the multi-criteria decision models.

With these two type of decision models many attempts have been undertaken to develop new evaluation methods which are based more adequately on the multi-dimensionality of a decision problem (including the intangibles). The general feature of these methods, which are based on weighing systems for the decision criteria, is that the project impacts are not necessarily transformed into monetary units. Instead, a weighing scheme is developed which reflects the relative importance of each of the decision criteria.
The models of group A, which have been developed since 1950, consider the objective functions as continuous functions of the decision variables, while the decision variables are also continuous. A review and evaluation of multi-objective programming techniques has been given by Cohon and Marks (1975), and Nijkamp and Rietveld (1976). For the application in complex water resources systems it is very often necessary to simplify the description of the system or to split up the system in simple subsystems in a hierarchical structure. The disadvantage of all these techniques is that the social aspects of planning, the decision and the decision-making process have been neglected.

The models of group B, in which development has been started since 1970, consider the objective functions as discrete functions of the decision variables, while the decision variables are also discrete. In this case there are a number of distinct alternatives, while further the methods are closer to the decision-making process.

In practice, a combination of both types of decision models is possible and necessary. Another possibility is the combination of complex simulation models (hydrological supply models and econometric spatial demand models) for the water resources management system and the multi-criteria decision models. In this case the consequences of a number of alternative plans or measures, will be calculated by the simulation models. The evaluation of the consequences can be done by the multi-criteria decision model. This approach has been followed in Gelderland.

In this paper only two recent, multi-criteria decision models will be presented, which has been or will be applied in Gelderland:

- the method of Saaty (United States) (see Saaty, 1977 and 1978);
- the method of Paelinck (Netherlands) see Paelinck, 1975 and 1977; Mastenbroek and Paelink, 1976).

Both methods are very similar, but there are some technical differences.

An extension of the method of Saaty and an application on the location problem of a pumping station for the domestic water supply will be presented. Attention is given to the situation with multiple decision-makers.

4.2 Method of Saaty

One starts from a decision problem, where a number of alternative projects or objects (denoted by $o_1 \ldots, o_n$) are compared in relation to a number of aspects or criteria (denoted by $c_1 \ldots, c_m$). For a given weight distribution of the criteria one is looking for the best project, a so-called multi-criteria decision.

First one looks on every criterion separately and compares the projects in relation to this criterion one-by-one. For the calculation of the weights of the projects for every criterion one constructs a matrix of pair-wise comparisons. Suppose that the absolute weights for n projects are $w_1 \ldots, w_n$, then matrix A has the elements $a_{ij} = w_i / w_j$. Matrix A may be written as follows:

c^i	o_1	o_2	....	o_n
o_1	$\frac{w_1}{w_1}$	$\frac{w_1}{w_2}$	....	$\frac{w_1}{w_n}$
o_2	$\frac{w_2}{w_1}$	$\frac{w_2}{w_2}$	....	$\frac{w_2}{w_2}$
$\vdots$	$\vdots$			
o_n	$\frac{w_n}{w_1}$	$\frac{w_n}{w_2}$	....	$\frac{w_n}{w_2}$

A is a so called reciproque matrix, that means

$$\forall_{ij}: \quad a_{ij} = \frac{1}{a_{ji}}$$

$$a_{ii} = 1.$$

If $\mathbf{w} = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix}$ the absolute weightvector, which will be normalized, that means $w_1 + w_2 + \ldots + w_n = 1$.

If one multiplies the matrix A with the vector $\mathbf{w}$, one gets the vector $n\mathbf{w}$:

$$\begin{bmatrix} 1 & \frac{w_1}{w_2} \dots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & 1 & \frac{w_1}{w_n} \\ \vdots & & \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & 1 \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} w_1 + \frac{w_1}{w_2} \cdot w_2 + \dots + \frac{w_1}{w_n} \cdot w_n \\ \frac{w_2}{w_1} \cdot w_1 + 1 \ + \dots + \frac{w_2}{w_n} \cdot w_n \\ \vdots \\ \frac{w_n}{w_1} \cdot w_1 + \frac{w_n}{w_2} \cdot w_2 + \dots + w_n \end{bmatrix} \begin{bmatrix} w_1 + w_1 + \dots + w_1 \\ w_2 + w_2 + \dots + w_2 \\ \vdots \\ w_n + w_n + \dots + w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix}$$

or $A\mathbf{w} = n\mathbf{w}$.

This is a well-known linear algebra problem, where n is called the eigen value and $\mathbf{w}$ the eigen vector of the matrix A. If A has been known, n and $\mathbf{w}$ can be calculated.
Matrix A satisfies the cardinal consistency-property $a_{ij} \cdot a_{jk} = a_{ik}$, and we call A therefore consistent.

It can be proved easily that if A is consistent there is only one eigen value $\lambda = n$, while all other eigen values are zero, and the corresponding eigen vector $\mathbf{w}$ is the weight vector we are looking for and this one is unique. In practice however we have to make estimates of the relative weights $a_{ij} = w_i/w_j$, if the information is rather soft. In this case subjective judgment and feelings of people are not always consistent, specially if a large number of projects has to be compared. Therefore the matrix A will not be consistent and the eigen value λ will be deviated from n. Moreover the other eigen values are not zero. It can be proved that we have to look for the largest eigen value and the corresponding eigen vector.

As a measure for the consistency of the matrix A the following relation can be derived:

$$\mu = \frac{\lambda - n}{n-1}.$$

It is clear if $\mu = 0$ the matrix A is consistent, further how larger μ how larger the inconsistency of A. In the latter case this calls for revising judgments in the matrix.

4.2.1 *Scale*

For the estimation of the values w_i/w_j in matrix A, Saaty uses a scale from 1 to 9. By experience he has shown that this one gives the best results. At a scale with more numbers (for example 1 to 25) the matrix becomes rapidly less consistent, whereas with a smaller scale, (for example 1 to 5) the differences in judgment give more difficulties. Saaty explains that the numbers 1 to 9 represent judgment entries as follows:

1: equally important;
3: weakly more important;
5: strongly more important;
7: demonstratedly more important;
9: absolutely more important.

The values 2, 4, 6 and 8 are a compromise in judgment of importance between 1 and 3, 3 and 5, 5 and 7, 7 and 9 respectively. Given a_{ij} one enters the reciprocal value $a_{ij} = 1/a_{ji}$. Thus also $a_{ii} = 1$ always. For this reason only the relative weights below the diagonal of the matrix have to be estimated.

4.2.2 *Hierarchy*

In this way one can find for every criterion an absolute weight vector of the projects. This results for m criterion in m (normalized) absolute weight vectors, which can be summarized in one matrix C as follows:

$$C = \begin{bmatrix} w_{11} & w_{12} \cdots\cdots & w_{1m} \\ w_{21} & w_{22} & w_{2m} \\ \vdots & \vdots & \vdots \\ w_{n1} & w_{n2} & w_{nm} \end{bmatrix}$$

with w_{ij} = absolute weight of project o_i in relation to criterion c_j.

If the information on projects in relation to some criterion is cardinal (for example monetary values), then the absolute weights of the projects can be directly calculated without using the relative weights of the matrix A.
Now one wants to know for a given weight distribution of the criteria, which are the best projects. Therefore, it is necessary first that the absolute weights (also normalized) of the criteria will be fixed. In the same way as for matrix A, now a

matrix B has to be estimated, which gives the relative weights of the criteria. This work has to be done by the decision maker with the help of the system analyst, who has to give the necessary information on which the matrix A has to be based.

$$B = \begin{array}{c|cccc} & c_1 & c_2 & \cdots\cdots & c_m \\ \hline c_1 & \frac{v_1}{v_1} & \frac{v_1}{v_2} & \cdots\cdots & \frac{v_1}{v_m} \\ c_2 & \frac{v_2}{v_1} & \frac{v_2}{v_2} & & \frac{v_2}{v_m} \\ \vdots & \vdots & & & \\ c_m & \frac{v_m}{v_1} & \frac{v_m}{v_2} & \cdots\cdots & \frac{v_m}{v_m} \end{array}$$

In this case one must always make an estimate of the value v_i/v_j.

From the matrix B, one can derive the normalized eigen vector $v = \begin{bmatrix} v_1 \\ v_2 \\ \vdots \\ v_m \end{bmatrix}$, which presents the absolute weights of the criteria.

The absolute weights of the projects for a given weight distribution v of the criteria, can be calculated by multiplying the matrix C with the vector v.

$$C \times v = \begin{bmatrix} w_{11} w_{12} \ldots w_{1m} \\ w_{21} w_{22} \quad w_{2m} \\ \vdots \qquad \vdots \\ w_{n1} w_{n2} \cdots w_{nm} \end{bmatrix} \times \begin{bmatrix} v_1 \\ v_2 \\ \vdots \\ v_m \end{bmatrix} = \begin{bmatrix} w_{11} \cdot v_1 + w_{12} \cdot v_2 + \ldots + w_{1m} \cdot v_m \\ w_{21} \cdot v_1 + w_{22} \cdot v_2 + \ldots + w_{2m} \cdot v_m \\ \vdots \qquad \vdots \qquad \vdots \\ w_{n1} \cdot v_1 + w_{n2} \cdot v_2 + \ldots + w_{nm} \cdot v_m \end{bmatrix} = \begin{bmatrix} g_1 \\ g_2 \\ \vdots \\ g \end{bmatrix} = g$$

From the vector g, which is also normalized, one can see which project has the largest weight, also one can see which projects have the same weight, or which projects are very bad.

For different weight distributions of the criteria, there are different 'best' projects. However these 'best' projects are always pareto-optimal or non-inferior. A solution is pareto-optimal if an improvement in relation to one criterion only can be reached by a deterioration in relation to another criterion.

4.2.3 *Remarks*

In the above explanation of the method of Saaty a hierarchy of only three layers has been used for simplicity: the general objective, the sub-objectives (criteria) and projects. It is also possible to take more layers in the hierarchy by splitting up criteria into sub-criteria. In this case, the weighing of the sub-criteria must be done on a higher level. It is also possible to introduce an extra layer in the hierarchy to represent the weight of various decision makers, as the decision makers together determine the weights of the criteria.

4.3 The method of Paelinck

The principle of the method differs from the method of Saaty. In this method also first one looks to the projects in relation to the different criteria separately. The differences between the projects in relation to a criterion must be expressed in an ordinal scale. Suppose a number of projects $o_1, o_2 \ldots o_n$ and the criteria $c_1, c_2 \ldots c_m$. The problem can be stated in the matrix X

$X =$

		$o_1 \quad o_2 \ldots\ldots o_n$
w_1	c_1	
w_2	c_2	x_{ij}
$\vdots$	$\vdots$	
w_m	c_m	

$\boldsymbol{o}$ = row vector of the projects

$\boldsymbol{c}$ = column vector of the criteria

w = column vector of the absolute weights of the criteria

x_{ij} = element that will be expressed in some ordinal scale (project i in relation to criterion j).

Paelinck uses three further hypotheses:

H_1: every project can be judged in relation to several criteria;

H_2: the intensities of the criteria can be measured on some ordinal scale;

H_3: for the judgment of the importance of every criterion in the final decision one uses ranked (ordinal) weights.

Example: suppose one has the next matrix X, in which the weights of the criteria are ordinally expressed.

X	**w**	**c**	o_1	o_2	o_3
	++	c_1	++	+	+++
	+	c_2	+	++	+
	0	c_3	+++	++	+

With a problem of n projects there are $n!$ possibilities for ranking the projects. In this case there are $3! = 6$ rankings:

$$R_1\colon o_1 > o_2 > o_3$$
$$R_2\colon o_1 > o_3 > o_2$$
$$R_3\colon o_2 > o_1 > o_3$$
$$R_4\colon o_2 > o_3 > o_1$$
$$R_5\colon o_3 > o_1 > o_2$$
$$R_6\colon o_3 > o_2 > o_1.$$

In these expressions $o_i > o_j$ means that o_i is better than o_j in relation to the considered criterion. One may now test all possible rankings with the aid of matrix X to find out the best ranking. Therefore, one gives every ranking a judgment, which can be done as follows.

First one considers one ranking and gives the value $+1$ if the partial ranking is in agreement with the data in matrix X, otherwise one gives the value -1. The judgment of the total ranking is the sum of the values of the partial rankings. If one considers the ranking R_1 in relation to criterion c_1, then:

$o_1 > o_2$	is in agreement with the data	value $+1$
$o_1 > o_3$	disagrees with the data	value -1
$o_2 > o_3$	disagrees with the data	value -1
		—— +
	judgment for ranking R_1:	-1

This one can do for all rankings and all criteria, which yields the following results (matrix Y):

Y	c_1	c_2	c_3
R_1	-1	0	$+3$
R_2	$+1$	-2	$+1$
R_3	-3	2	$+1$
R_4	-1	2	-1
R_5	$+3$	-2	-1
R_6	$+1$	0	-3

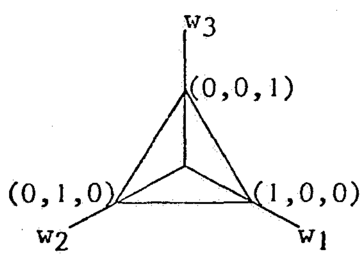
For the further solution of the problem one now states:

(1) $w_1+w_2+w_3 = 1$ (normalized weight vector)

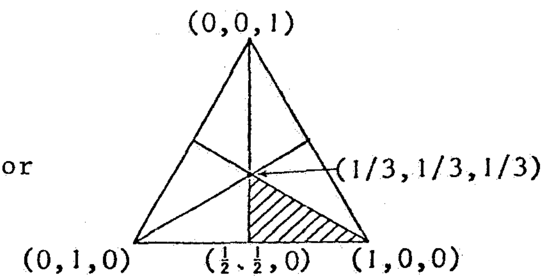
(2) $w_1 \geqslant w_2$ (criterion c_1 is equal or more important than c_2)

(3) $w_2 \geqslant w_3$.

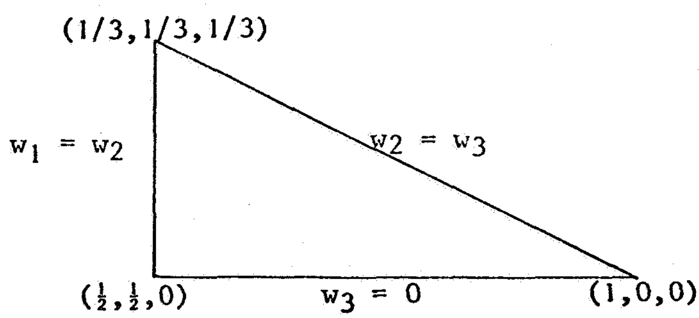
These hypotheses are in agreement with the ordinal ranking of the w_i's (+ +, +, 0). Now if one starts from the general weight or decision triangle for the 3 criteria:



or



then with the hypotheses (1), (2) and (3) it is only necessary to consider the small shaded triangle

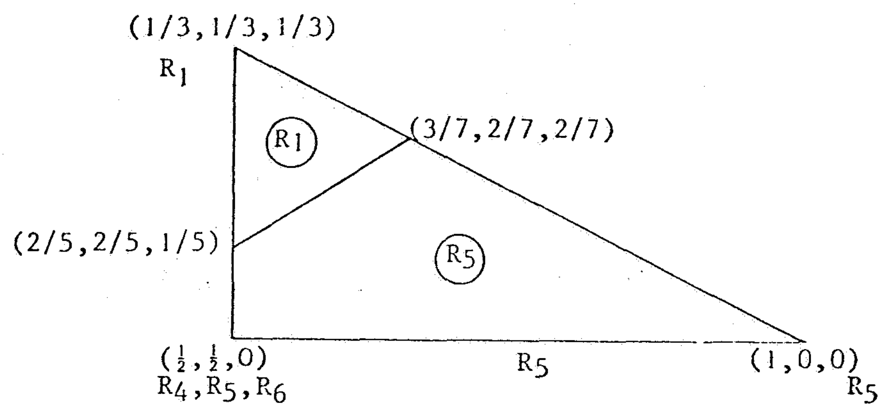


One can finally determine the best ranking for different weight vectors of the criteria by multiplying the matrix Y with the weight vector of the criteria. For example for the weight vector $(\frac{1}{3}\cdot\frac{1}{3}\cdot\frac{1}{3})$:

$$Y \times \begin{bmatrix} \frac{1}{3} \\ \frac{1}{3} \\ \frac{1}{3} \end{bmatrix} = \begin{bmatrix} -1\cdot\frac{1}{3}+0\cdot\frac{1}{3}+3\cdot\frac{1}{3} \\ 1\cdot\frac{1}{3}-2\cdot\frac{1}{3}+1\cdot\frac{1}{3} \\ -3\cdot\frac{1}{3}+2\cdot\frac{1}{3}+1\cdot\frac{1}{3} \\ -1\cdot\frac{1}{3}+2\cdot\frac{1}{3}-1\cdot\frac{1}{3} \\ 3\cdot\frac{1}{3}-2\cdot\frac{1}{3}-1\cdot\frac{1}{3} \\ 1\cdot\frac{1}{3}+0\cdot\frac{1}{3}-3\cdot\frac{1}{3} \end{bmatrix} = \begin{bmatrix} \frac{2}{3} \\ 0 \\ 0 \\ 0 \\ 0 \\ -\frac{2}{3} \end{bmatrix}$$

In this ranking $R_1(o_1 > o_2 > o_3)$ is the best.

In the same way one can complete the decision triangle:



In this triangle one can see, which rankings are the best for different weight vectors of the criteria. It also shows the sensitivity of the criteria for the different rankings of the projects.

4.3.1 *Ties*

A difficulty arises with the judgment of the ranking, if projects have the same ordinal scale in relation to a certain criterion. This is called 'ties'. In this case the ranking cannot have a maximum value, because with a partial equality of projects no +1 or −1 can be scored, except 0. This happens in the example for criterion 2, where the maximum score of 3 cannot be reached (matrix Y). In this case a correction will be applied by multiplying the scores for criterion c_j with a factor $n(n-1)/2 \cdot \max j$, where n is the number of projects and $\max j$ the maximum score for criterion c_j. In the given example, this factor is $\frac{3}{2}$. There are some doubts about this type of correction.

4.3.2 *Remarks*

The explanation of the method of Paelinck has been given in the most simple form. If there is more information than only a ranking of projects, it is also possible to introduce this information in the method (non-linearities). In this case the results become more explicit. Also if there is uncertainty about the ranking of the projects in relation to a criterion, Paelinck's method gives then as results the probabilities; which of the different projects are the best. In the case with many projects (n) the total number of possible rankings ($n!$) increases very fast.

4.4 Evaluation of both methods

In a study of Van de Nes and Van Lohuizen (1978) both methods are applied on the same problems. A comparison of both methods in their basic form has been carried out and attention was given to the results, the efficiency of the method and the applicability in water resources planning.

In the following, a summary of the conclusions will be given:

- an advantage of the method of Paelinck is, that if the information only exists of a ranking of projects, it still works;
- an advantage of the method of Saaty is that the results are not only a ranking, but also the absolute weights of the projects;
- the method of Saaty is more efficient than the method of Paelinck. Because in the latter case with many projects the number of possible rankings increases very rapidly;
- if the same information has been used, the accuracy of the results are nearly the same, except in the cases where ties occur. Then the method of Paelinck becomes less accurate;
- in the case of many projects, in the method of Saaty the preparation of the matrix of relative weights of the projects in relation to the criteria can easily be done. This is not so easy with ranking the projects in the method of Paelinck;
- the method of Saaty can be applied in a hierarchical structure of a decision making process, where multiple decision makers can interact with the model.

4.5 The method of Saaty and the optimization of the water-supply system

A general description of the water resources management system has been given already by Van de Nes (1977) and Romijn (1979). Three management sub-systems may be distinguished:

- water supply (groundwater and surface water extractions, price policy and permits);
- water management (level management and water distribution by means of dyke-building, brook improvements, weirs, etc.);
- water purification (purification plants, discharge permits for effluents and price policy).

In this paper discussion will be restricted to the water supply system. In Gelderland up to now groundwater is the most important resource, because it is of good quality and relatively cheap. However, the increasing withdrawal of groundwater causes damage to agricultural and natural vegetation; furthermore it decreases the discharge of rivers, causing water-quality problems. From this it may be seen that many interests are involved with the management of groundwater resources.

In the water supply system there are three aspects of water supply projects:

(1) the location problem;

(2) the capacity on every locations;

(3) the regional distribution of the locations;

(4) the time-planning of the projects.

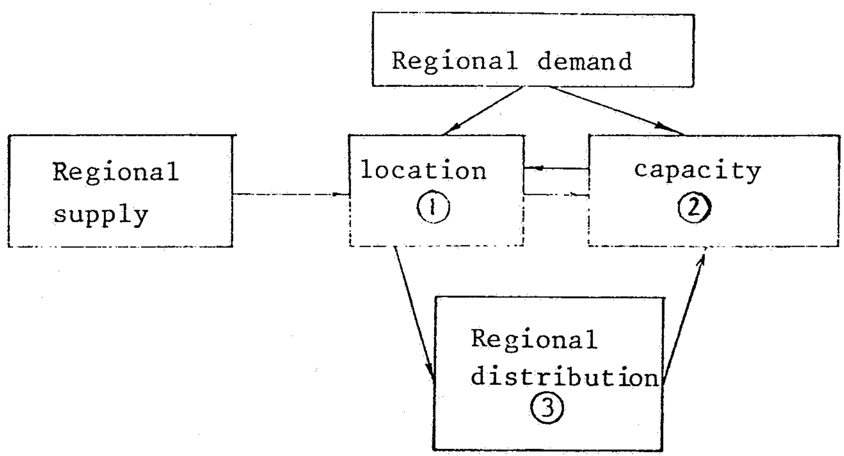


Figure 1 Aspects of regional water supply and demand.

In figure 1 three aspects of the regional water supply are given schematically in relation to the regional demand. The combination of both water supply and water demand determines the time-planning of the projects.

Between the decision problem of the location (1) and that of the capacity (2) there is a close link. Namely if the capacity per location is very restricted, more locations are necessary to meet a given demand for water. This means that less appropriate locations must be used. The decision problem (3) which arises is that of the distribution of the damage to agriculture and nature over a larger area and the effect on the technical costs of water withdrawal and distribution. The four types of decision problems can be solved with the aid of the multi-criteria decision models in an iterative way.

4.5.1 *The location problem*

For the application of the method of Saaty one may take only the location problem of a pumping station for domestic water supply. For an area of eight kilometres square, 17 alternative projects are given.

The criteria which will be used are:

CRITERION 1

Physical availability of groundwater, expressed by geohydrological information

The information which has been used is the thickness (D) of the waterbearing layer and its permeability (K). Multiplication of both gives the transmissability (KD). The larger the transmissability of the water-bearing layer, the more favourable the location.

CRITERION 2

Damage to agriculture in a weighed average year

The withdrawal of groundwater causes a lowering of the groundwater table. The capillary rise of groundwater to the roots of the crops therefore will decrease, causing damage to the crops. A simulation model for the flow through the unsaturated zone and evapotranspiration (submodels of GELGAM: De Laat and Awater, 1979) has given, for different climatological conditions and for different values

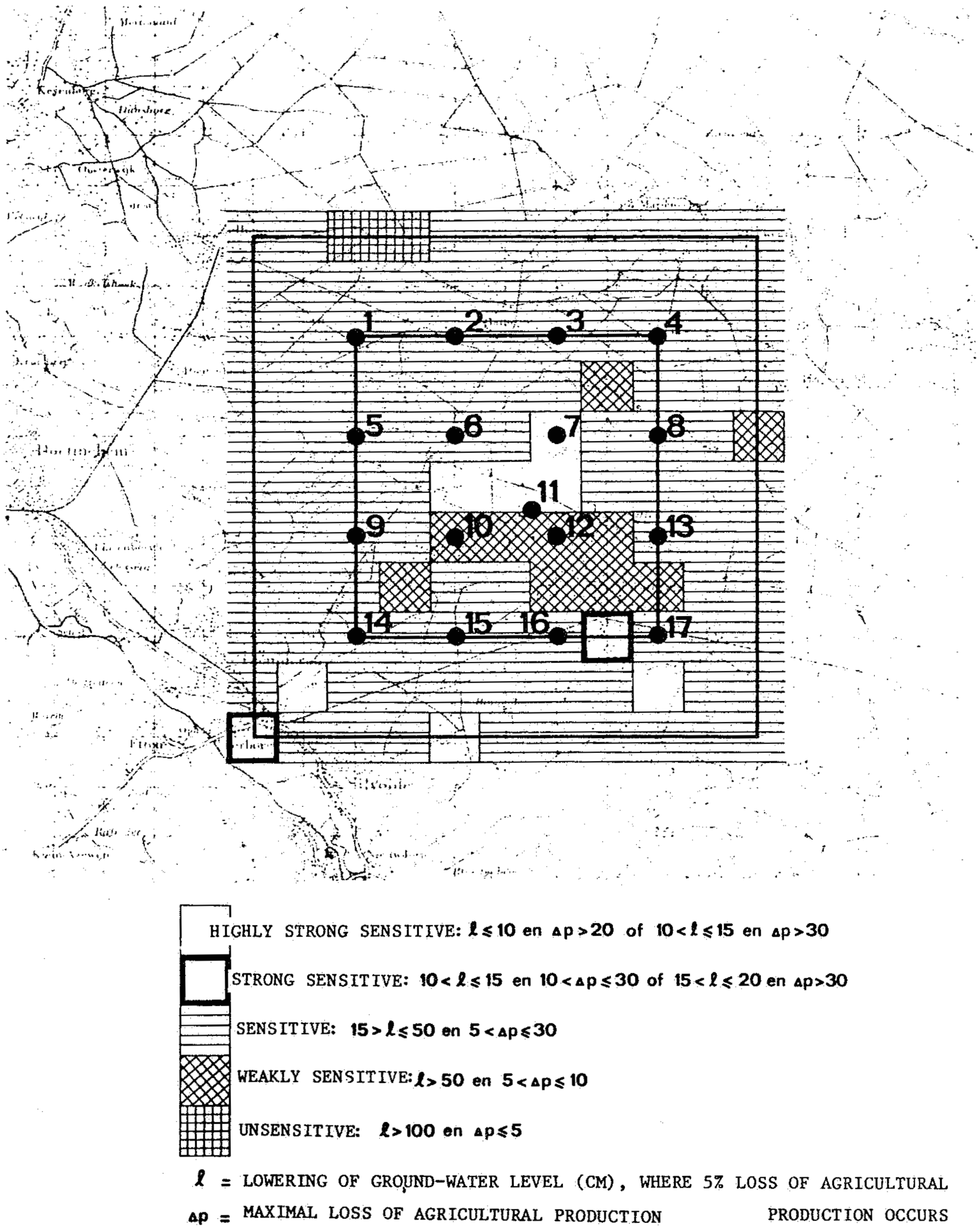


Figure 2 Agricultural damage in a weighed average year

of the lowering of the groundwater table, the losses in agricultural productions (in percentage) for every km^2. Soil-physical information was therefore necessary. As an example, the results of the calculations are summarized in figure 2 which illustrates five classes of soils, representing the sensitivity of agricultural crops to lowering the groundwater table. It is clear that the class which is nearly insensitive is the most favourable location of the project. In table 1 the relative weights of the projects are given, also the calculated absolute weights of the projects.

CRITERION 3

Damage to agriculture in a one per cent dry year

In a very dry year, like a one per cent dry year, the sensitivity of crops to a lowering of the groundwater table increases strongly.

CRITERION 4

The costs of water transportation

These costs depend on the location of the pumping station in relation to an existing main transport channel. The transport costs to this main channel are ± 0.5 cent/km/m^3 water. The closer the pumping station to the main channel, the lower the costs of transportation.

CRITERION 5

Damage to natural vegetation (ecology)

The determination of water needs of natural areas makes it necessary first to describe nature itself more precisely. A biological evaluation and a relation with the water resources management enables the minimalization of damage to nature by management measures. A very rough vegetation survey of all woods and heath in East Gelderland and a hydro-biological survey of all brooks have already been implemented. In a first effort to evaluate nature, a decimal ordinal (order) scale of values was used, which is based especially on the rarity of vegetation type. The relation with water resources management was sought primarily via the groundwater level. The lower the botanic value or the loss in botanic value after lowering the groundwater level, the more favourable would be the location for the project.

4.5.2 *Remarks*

For the estimation of the relative weights of the projects in relation to the criteria,

Table 1 Relative weights of the projects for criterium 2 (see figure 1)

c_2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	eigen vector:
1	1																	0.1089
2	$\frac{1}{2}$	1																0.0753
3	$\frac{1}{3}$	$\frac{1}{3}$	1															0.0472
4	$\frac{1}{2}$	1	3	1														0.0802
5	$\frac{1}{5}$	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{1}{3}$	1													0.0414
6	$\frac{1}{6}$	$\frac{1}{5}$	$\frac{1}{4}$	$\frac{1}{5}$	$\frac{1}{4}$	1												0.0142
7	$\frac{1}{8}$	$\frac{1}{6}$	$\frac{1}{5}$	$\frac{1}{6}$	$\frac{1}{5}$	$\frac{1}{4}$	1											0.0086
8	$\frac{1}{4}$	$\frac{1}{3}$	2	$\frac{1}{3}$	$\frac{1}{2}$	4	6	1										0.0445
9	2	2	3	2	5	7	9	4	1									0.1269
10	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{3}$	4	5	$\frac{1}{2}$	$\frac{1}{4}$	1								0.0349
11	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{3}$	1	4	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{2}$	1							0.0200
12	$\frac{1}{3}$	$\frac{1}{2}$	1	$\frac{1}{2}$	2	4	6	2	$\frac{1}{4}$	2	3	1						0.0489
13	3	3	3	3	4	6	8	4	2	3	4	3	1					0.1567
14	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{3}$	1	4	6	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{2}$	3	$\frac{1}{2}$	$\frac{1}{5}$	1				0.0370
15	1	3	3	2	4	6	8	4	1	4	4	3	$\frac{1}{3}$	3	1			0.1126
16	$\frac{1}{5}$	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{2}$	4	5	$\frac{1}{3}$	$\frac{1}{6}$	$\frac{1}{3}$	2	2	$\frac{1}{5}$	$\frac{1}{3}$	$\frac{1}{4}$	1		0.0288
17	$\frac{1}{6}$	$\frac{1}{5}$	$\frac{1}{4}$	$\frac{1}{5}$	$\frac{1}{5}$	1	4	$\frac{1}{5}$	$\frac{1}{6}$	$\frac{1}{4}$	1	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{5}$	$\frac{1}{6}$	$\frac{1}{4}$	1	0.0138

eigen value = 18.6668
consistency measure μ = 0.1041

it was assumed that the pumping station has an influence-sphere of a circle with a diameter of 4 km. For the criteria, concerning agriculture, the land-use pattern (urban area and nature) was considered. The preparation of the matrices of the relative weights, based on the maps, for five criteria takes about five hours.
De Graan (1978) has developed an extension to the method of Saaty, so that it is not necessary to estimate all relative weights. He reduces the preparation time with a factor 4. This is at the cost of decreasing accuracy of the absolute weights.
The calculation of the absolute weights of the 17 projects for five criteria requires totally about 10 seconds on a HP computer (9830 A). It is very hopeful that the

method is rather effective for differences in judgment of the projects in relation to the various criteria.

4.5.3 *Absolute weights of the 17 projects in relation to the five criteria*

In table 2 are summarized the absolute weights of the projects for the five criteria. A ranking of the projects for the various criteria has been given. No. 1 is the best with the highest weight. It shows that for every criterion one has different rankings of the projects. From this information, it is possible to derive the pareto-optimal projects (non-inferior projects) by comparing the projects for two criteria together. It can be proved by complete analyses that the projects 3, 6, 7, 10, 12 and 17 are inferior. So, from the 17 projects, only 11 projects have to be considered. In table 2, above the horizontal lines all projects are pareto-optimal. The final decision depends on the weighing of the criteria.

4.5.4 *Integral weighing of the projects by multiple decision-makers*

Therefore, it is necessary to weigh the criteria. In general this must be done by the decision maker and needs policy-relevant information. This information must be given by the system analyst or technician. In this example even the basic information on the different maps is very essential.
In general the weighing of the criteria can be based on two general, distinct policy objectives:

(a) economic efficiency;

(b) environmental quality.

The estimate of the relative weights of the criteria is very subjective. The accent of different decision makers on the general objectives (a) and (b) may be different. If one were to suppose a decision situation with seven decision-makers, who each have the following general objectives:
(1) Maximize a;
(2) Maximize b;
(3) a and b have the same weight (compromise);
(4) a has more weight than b (compromise);
(5) b has more weight than a (compromise);
(6) special case, agriculture is very important;
(7) special case, maximize a, but geohydrology is not important.

In table 3, the absolute weights of the criteria for the seven decision-makers

Table 2 Weights of the projects for the 5 criteria separately

Criterium 1: geohydrology			Criterium 2: average agricultural damage			Criterium 3: agricultural damage 1% dry year			Criterium 4: transportationcosts			Criterium 5: ecology		
ranking	project-nr.	weight	ranking	project-nr.	ranking	project-nr.	weight		ranking	project-nr.	weight	ranking	project-nr.	weight
1	9	0.1426	1	13	0.1567	1	1	0.2582	1	15	0.1977	1	2	0.2134
2	14	0.1405	2	9	0.1269	2	5	0.1175	2	13	0.1320	2	16	0.1447
3	5	0.1287	3	15	0.1126	3	11	0.1035	3	16	0.1320	3	8	0.0967
4	1	0.0984	4	1	0.1089	4	14	0.0912	4	17	0.1130	4	10	0.0921
5	10	0.0815	5	4	0.0802	5	4	0.0857	5	8	0.0909	5	4	0.0902
6	15	0.0786	6	2	0.0753	6	2	0.0654	6	14	0.0733	6	3	0.0664
7	6	0.0746	7	12	0.0489	7	8	0.0619	7	12	0.0575	7	5	0.0618
8	7	0.0501	8	3	0.0472	8	6	0.0434	8	10	0.0389	8	9	0.0471
9	11	0.0490	9	8	0.0445	9	7	0.0332	9	11	0.0389	9	12	0.0367
10	4	0.0312	10	5	0.0414	10	13	0.0282	10	7	0.0279	10	7	0.0303
11	12	0.0302	11	14	0.0370	11	15	0.0242	11	4	0.0256	11	11	0.0297
12	8	0.0294	12	10	0.0349	12	12	0.0222	12	9	0.0213	12	17	0.0210
13	2	0.0209	13	16	0.0288	13	3	0.0180	13	3	0.0152	13	14	0.0166
14	3	0.0132	14	11	0.0200	14	17	0.0138	14	6	0.0123	14	15	0.0160
15	16	0.0120	15	6	0.0142	15	10	0.0132	15	5	0.0095	15	13	0.0156
16	13	0.0118	16	17	0.0138	16	9	0.0115	16	2	0.0082	16	6	0.0119
17	17	0.0070	17	7	0.0086	17	16	0.0088	17	1	0.0060	17	1	0.0096

Table 3 Integral weights of the projects for the 7 decision-makers separately

Ranking	person (1) a) economic efficiency maximal		person (2) b) environmental quality maximal		person (3) a and b equal weight		person (4) a more weight than b		person (5) b more weight than a		person (6) agriculture maximal		person (7) a maximal, geohydrology unimportant	
	project	weight	project	weight	project	weight	project	weight	project	weight	project	weight	project	weight
1	15	0.1362	2	0.1524	15	0.0958	15	0.1252	2	0.1336	1	0.1545	15	0.1225
2	13	0.0901	16	0.0985	9	0.0798	13	0.0860	16	0.0901	13	0.0903	13	0.1104
3	14	0.0887	4	0.0822	2	0.0784	14	0.0856	4	0.0770	15	0.0819	16	0.0838
4	16	0.0752	8	0.0780	13	0.0765	9	0.0772	8	0.0739	5	0.0739	9	0.0737
5	9	0.0731	10	0.0704	16	0.0736	16	0.0706	9	0.0703	4	0.0739	2	0.0700
6	8	0.0644	5	0.0660	1	0.0711	1	0.0681	10	0.0667	14	0.0681	8	0.0693
7	1	0.0612	9	0.0655	14	0.0682	8	0.0627	5	0.0661	9	0.0674	4	0.0587
8	17	0.0596	1	0.0603	8	0.0648	5	0.0614	1	0.0657	2	0.0645	1	0.0580
9	5	0.0573	3	0.0529	5	0.0642	10	0.0527	15	0.0576	11	0.0576	14	0.0556
10	10	0.0515	13	0.0489	4	0.0592	17	0.0520	13	0.0565	8	0.0572	17	0.0503
11	12	0.0456	15	0.0456	10	0.0580	12	0.0442	3	0.0483	12	0.0377	10	0.0488
12	11	0.0425	12	0.0380	12	0.0419	4	0.0442	14	0.0453	16	0.0344	12	0.0480
13	4	0.0393	14	0.0377	11	0.0392	11	0.0424	12	0.0388	10	0.0307	5	0.0415
14	6	0.0334	11	0.0365	17	0.0365	2	0.0390	11	0.0373	3	0.0305	3	0.0357
15	7	0.0325	7	0.0273	3	0.0344	6	0.0337	7	0.0275	6	0.0291	11	0.0326
16	2	0.0291	17	0.0204	7	0.0292	7	0.0319	17	0.0232	17	0.0246	7	0.0228
17	3	0.0203	6	0.0195	6	0.0292	3	0.0232	6	0.0221	7	0.0235	6	0.0183

weights of the criteria

	person (1)	person (2)	person (3)	person (4)	person (5)	person (6)	person (7)
1	0.3088	0.0639	0.2284	0.3059	0.1048	0.0553	0.0730
2	0.1343	0.2067	0.2428	0.1694	0.2301	0.4036	0.3739
3	0.0505	0.0989	0.0721	0.0644	0.0974	0.4036	0.0244
4	0.4816	0.0268	0.2284	0.4024	0.0659	0.1110	0.3610
5	0.0248	0.6037	0.2284	0.0580	0.5019	0.0265	0.1677

crit. 1 = geohydrology
2 = agricultural damage average year
3 = agricultural damage 1 % dry year
4 = transportationcosts
5 = ecology

are given, also the integral weights of the projects. These integral weights of the projects can be calculated by multiplying the matrix of the absolute weights of the projects for the five criteria separately (table 2) with the weight vector of the criteria for the seven decision-makers. In the table the projects are ranked, where nr. 1 is the best project with the highest weight. Above the horizontal lines all projects are pareto-optimal.
In general one may distinguish two different decision-making situations:

- one decision-maker;
- multiple decision-makers.

4.5.5 *One decision-maker*

This situation is the simplest one. After estimation of the absolute weights of the criteria, one gets an optimal ranking of the projects, one project is the best. It is in this case very useful to do a sensitivity analysis with the weight vector of the criteria. This can result in information as presented by table 3. It shows how robust the 'best' project is for a change in weight distribution of the criteria. For the decision-maker, this information may be very helpful if he is not very sure about his weighing of the criteria.
For this purpose, De Graan (1978) introduced the concordancy coefficient, which is a measure for the agreement between absolute weights of the projects in relation to the criteria. The concordancy coefficient for project i is defined as follows:

$$c_i = \sqrt{\frac{\left(w_i - \frac{1}{n}\right)^2}{\sum_{k=1}^{m} p_k \left(w_{ik} - \frac{1}{n}\right)^2}}, \qquad (1)$$

where n is the number of projects, w_i integral weight of the project, p_k absolute weight of criteria k and w_{ik} is the absolute weight of project i in relation to criteria k. If there is complete agreement ($w_i = w_{ik}$) then $c_i = 1$ and if the integral weight of the project is equal to the 'averaged' project ($w_i = 1/n$) then $c_i = 0$. For the over-all concordancy coefficient of all n projects, the following equation is valid:

$$c = \sqrt{\frac{\sum_{i=1}^{n}\left(w_i - \frac{1}{n}\right)^2}{\sum_{i=1}^{n}\sum_{k=1}^{m} p_k \left(w_{ik} - \frac{1}{n}\right)^2}}. \qquad (2)$$

We can also say that c_i is a measure for the variation of w_{ik} around w_i. In conclusion one may state that if a project has a high integral weight and a high concordancy coefficient, the project is robust. However, if the concordancy coefficient is low, then the project is rather sensitive to a change in the weight vector of the criteria.

4.5.6 *Multiple decision-makers*

This situation is simple only if after all discussion, for example, through bargaining to the same weight distribution of the criteria is reached. This situation has then been reduced to the situation of one decision-maker. However, for the most part this will not occur, because many interest groups are involved in such decisions. One may imagine the establishment of a provincial water management plan, in which has been indicated the locations for groundwater withdrawal. In this case, of seven decision-makers, where the results are summarized in table 3, there are four procedures possible to decide about the 'best' project.

Procedure 1: all decision-makers have equal weight; the weights of the criteria of the decision-makers will be averaged. In the example, it follows for the average weight vector of the criteria:

Weight of the criteria:

c_1	c_2	c_3	c_4	c_5
0.17	0.15	0.11	0.24	0.23

From calculation it follows that project nr. 15 is the best.

Procedure 2: The decision-makers have different weights. The weight ratio between the decision-makers will be established by a higher level, for example the minister or the provincial Government. The weights of the criteria will then be weighted averages. This results also in one optimal ranking, where one project is the best.

Procedure 3: The decision-makers have equal weight and try, by bargaining, to find an acceptable project. In this case the estimation of the final weights of the criteria is not explicit, but is implicit in the decision-making process. In this case, a concordancy coefficient of project i can be similarly defined as equation (1) and may be very helpful. After De Graan (1978) now it is a measure for the agreement between the decision-makers as follows:

$$c_i = \sqrt{\frac{\left(w_i - \frac{1}{n}\right)^2}{\sum_{j=1}^{m} p_j \left(w_{ij} - \frac{1}{n}\right)^2}}, \tag{3}$$

where w_i is the over-all integral weight of the project by all decision-makers; n is the number of projects; p_j is the weight of the decision-maker j and w_{ij} is the integral weight of the project for decision-maker j.
If there is complete agreement between the decision-makers, so $w_i = w_{ij}$ then $c_i = 1$, if w_i is equal to the 'average' project ($1/n$) then $c_i = 0$. We can also say that c_i in this case is a measure for the variation of w_{ij} around w_i.

Similar to equation (2) one can also formulate the over-all concordancy coefficient for all projects.

In table 4 are given the results of the integral weights and the concordancy coefficient of the projects, where it has been assumed that the weights of the decision-makers are equal (so 1/7).

Table 4 Ranking, integral weights and concordancy coefficient of the projects for the 7 decisionmakers (with equal weight)

Ranking	Projectnr.	Weight of the project	Concordancy coëfficiënt
1	15	0.0949	0.74
2	2	0.0810	0.46
3	13	0.0798	0.73
4	1	0.0770	0.49
5	16	0.0752	0.65
6	9	0.0724	0.94
7	8	0.0672	0.79
8	14	0.642	0.29
9	4	0.0621	0.21
10	5	0.0615	0.27
11	10	0.0541	0.36
12	12	0.0420	0.98
13	11	0.0412	0.92
14	17	0.0380	0.81
15	3	0.0350	0.91
16	7	0.0278	0.99
17	6	0.0265	0.98

overall concordancy: 0.73

Table 4 shows one group of projects with high integral weights, where project nr. 15 has the highest integral weight and concordancy coefficient, so it is the best in this group. In the second group (with lower integral weights) project nr. 9 has a very high concordancy coefficient. This means that there is a rather complete agreement about the ranking of this project. The third and the fourth group are bad projects. Especially concerning the fourth group, everyone agrees that these are bad projects (high concordancy). The third group has very low concordance coefficients, so this project gives a lot of trouble. From this table it can be concluded that only project nr. 15 and project nr. 9 are favourable projects. The final choice depends on a trade-off between the 'best' project with a possible conflict (conflict model) or a 'compromise' project in harmony (harmony model). However this problem has to be solved by the decision-makers; there is no role for the system analyst or technician in this case.

Procedure 4: The decision-makers have different weights. The weight ratio between the decision-makers will be established by a higher level. In the same manner as for procedure 3, one can use the concordancy coefficient, but now with different weights for the decision-makers. In this case, it is clear from the beginning which decision-maker must make the largest concessions.

4.6 Conclusions

1. The application of the method of Saaty on a real water problem proves that it is possible to split decision-making and planning, without losing the feedback between both. This is also true for the method of Paelinck.

2. The decision-makers, after consultation with systems analysts and technicians, have to establish the criteria (in some dimension) and the weight distribution of the criteria (implicit or explicit).

3. The planning-activities of different technicians and the weighing of alternative projects in relation to the various criteria follows from point 2.

4. Working with dimensionless weights for the projects in relation to the various criteria has the advantage that the comparability for the decision-makers is rather simple. It is not necessary to express the criteria in the same dimension.

5. For the weighing of the criteria by the decision-maker, it is necessary that the systems analysts or technicians give information about the criteria in a quantitative way (the measured dimensions).

6. More research has to be done on structuring in a hierarchical way the weighting criteria and the project aspects (location, capacity, time-planning, etc.) for the water-supply (sub)system, the water-management (sub)system (water-level control) and the water-purification (sub)system. In this way, integral water-management and planning will be promoted, while further the direction of research activities can be determined.

7. It is necessary that the decision-makers become familiar with the rather simple multi-criteria decision models. Therefore, it is useful to start with some experimental project. In this way the responsibilities of the planner and the decision-maker becomes more clear and can therefore better be formulated.

8. It seems that the method of Saaty and also the further-developed method of Paelinck may be very useful in the management and planning of water-resources systems.

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Application of multi-objective decision making methods in regional water management

J. W. M. Schaffers, L. Lijklema and J. E. Rijnsdorp

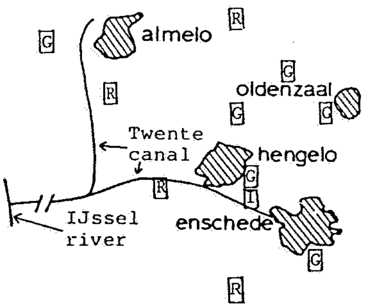
5 Application of multi-objective decision making methods in regional water management

Summary

This paper discusses the application of design methods and selection procedures for the water resources in the Twente area (Netherlands). On the basis of a systems description (hydrological situation, supply and demand, objectives, constraints, policy-making process) plans can be generated through supply and demand models, in which methods are integrated for multi-objective decision-making. Application possibilities are discussed of generating and selection methods in non-technical groups.

5.1 Introduction

Many water resource systems show a high degree of complexity: there are different types of water sources, users, processes, objectives and geographical alternatives. As an example, the case of the region Twente (Netherlands) will be analysed. The existing water resources system is shown in figure 1.



EXPECTED NEEDS IN 2000: (in $10^6 m^3/yr$)	
Industries	22.3
Public needs	22.8
Miscellaneous	12.7
	58.5

cities
R potential reservoir locations
G groundwater pumping stations
I artificial infiltration

Figure 1 Water resources and demands in the Twente region

In view of expected future demands, it is useful to generate several different alternative water supply possibilities. Options include, *inter alia*, extension of existing resources (groundwater pumping stations, artificial infiltration), creation of new resources (storage reservoirs) and re-allocation of water from sources to users. Table 1 depicts the nature of sources and users.

Table 1 Water resources, production and distribution, demands

Sources	Production and distribution	Demands
Canal	Pumping stations *	Industries
Brooks	Infiltration *	Agriculture
Groundwater *	Mains *	Public needs
Import water *	Reservoirs **	

* To be extended.
** New.

Water management encompasses evaluation of alternative water resource systems with respect to (often conflicting) objectives. These objectives are related to interests pursued by interest groups, authorities, committees, political parties and individuals. This brings about the need for clear decision-making procedures, planning methods and techniques to generate acceptable results.

Traditionally, optimization and selection methods, models, ergonomic aspects (presentation of information) and public decision-making are considered as more or less isolated topics. Hwang (1979) gives an overview of multi-objective optimization methods, with a taxonomy based on the type of information processing. With respect to the information about preferences, four situations can be discerned:

- No information needed.
- All information needed *a priori.*
- Interactive development of information.
- Information needed in the final phase of the optimization process.

Differentiations with respect to the type of information are: qualitative or quantitative, implicit or explicit preferences. The choice of method is unfluenced by: problem characteristics, man-machine interface, and type of output required of multi-objective decision-making methods. Other overviews can be found also (see Cohen e.g., 1975; Haimes, 1975; Nijkamp, 1975).
Haimes (1977) discusses the integration of one optimization method (the SWT-method) in a public decision structure. Interest groups (committees, public planners with individual tasks) were involved in various aspects of the decison process. However, the method has not been compared with other methods.
Rouse and Sheridan (1974) present one of the few studies devoted to technology for group decision-making. Different decision-making methods (utility theory, Delphi, Cross-Impact) were analysed in situations with real groups. These authors propose a differentiation in computer implementation to achieve flexible use.
Warfield (1976) presents a method (Interpretive Structural Modeling) in which the modeling process is structured for use in groups. Graph theory is applied in a

man-machine dialogue to perform network representations of relations between sets of elements. These representations can be depicted as graphs or schemes to be discussed in the group. A further possibility shown by Burns et al. (1979) is the

Actors	Instruments	Actions	Results
general public; policy-making committee; interest groups	information available; interviewing; literature; brainstorm; presentation of information	problem definition	set of elements and relations between elements; inventarization data needs; data collection
planning institute; policy making committee	simulation; model structuring methods	modeling	model structure, parameters, model equations, simulation models
policy-making committee	available criteria/ models; interviewing; brainstorm; presentation of information	formulation of trade-off criteria	criteria for: .evaluation of individual plans; .evalutaion of sets of plans; .group decision making rules
policy-making committee; planning institute	relation schemes; models; optimization methods; presentation of information	generating alternatives	plan-effects matrix
policy-making committee; interest groups	tables; schemes	presentation of results	tables; schemes; displays
planning institute; policy-making committee	selection methods; relation schemes	assessing hierarchical orders	schemes; tables
policy-making committees	methods .with computer technology .without technology: voting, discusion	group decision making	end result

Figure 2 Actions, actors and instruments

interactive building of dynamic models. The ISM-method also can be used in problem definition, evaluation of alternatives, generation of goal structures, possibly without software, in combination with Delphi-like approaches. A drawback of this approach is the fixed group decision structure (see Watson, 1978).

Evidently, there is a need for an integrated approach of planning, modeling and decision making. In this study we concentrate on methodological aspects, integration of basic system and optimization models, and the feasibility of their implementation in decision-making processes.

5.2 Methodological aspects

The logical structure of the over-all process is depicted in figure 2, together with the structure and result of individual steps in this process. This process is

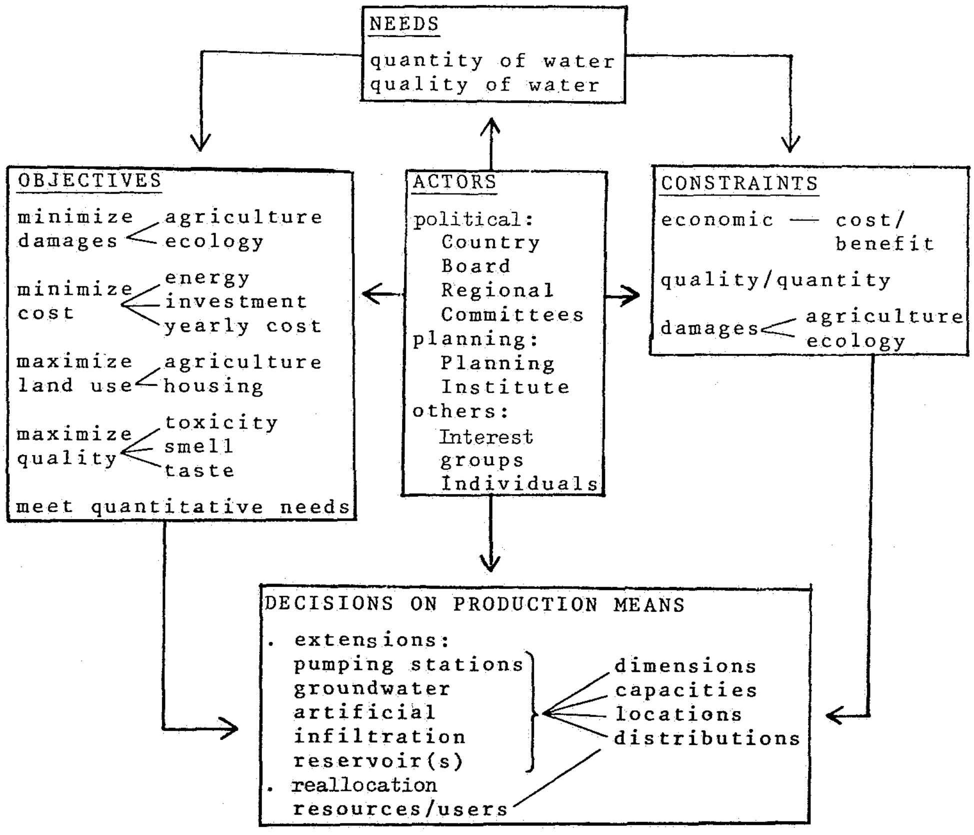


Figure 3 Basic elements and problem defintion

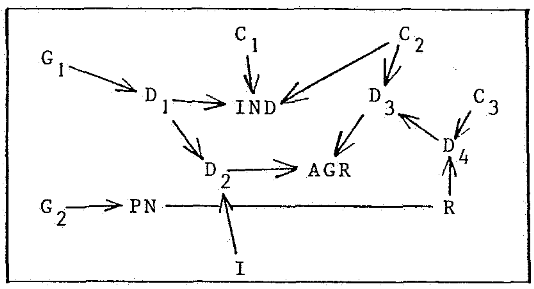
characterized by actions, in which actors use instruments. Results of each current action are used in the action following. As a further illustration, the problem definition phase of figure 2 is shown in figure 3 in some detail. In this step, the structure of the problem (physical/hydrological system, decision system) is defined by assessing relevant elements and their mutual relations.

5.3 Basic models

5.3.1 *General*

In this section, a general approach to modeling is described which will be specified later in more detail. Elements in a water resources structure are: water sources, users, and junctions in the production/distribution system, as depicted in the example in figures 4a, 4b and 4c.

In figure 4b, flows between elements are represented in a matrix structure. In figure 4c, possible connexions from sources to users are represented in a reachability matrix.



$G_{1,2}$: groundwater
$C_{1,2,3}$: canal water withdrawals
R : reservoir
I : imports
IND : industries
PN : public needs
AGR : agriculture
$D_{1,2,3,4}$: distribution junctions in pipe line network

Figure 4a Water resources system.

	↗	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Σ
G_1	1								1							1
G_2	2												1			1
C_1	3									1						1
C_2	4									1					1	2
C_3	5													1		1
R	6												1	1		2
I	7											1				1
D_1	8									1		1				2
IND	9															
AGR	10															
D_2	11										1					1
PN	12															
D_4	13														1	1
D_3	14										1					1
	Σ								1	3	2	2	2	2	2	14

Figure 4b Matrix representation of connection between elements

→	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Σ
1								1	1	1	1				4
2												1			1
3									1						1
4									1	1				1	3
5										1			1	1	3
6										1		1	1	1	4
7										1	1				2
8										1	1				2
9															
10															
11										1					1
12															
13										1				1	2
14										1					1
Σ								1	3	9	3	2	2	4	24

Figure 4c Reachability matrix

Models relating water quality, damages, cost and distribution (allocation) to decision variables can be integrated in a system description, which also includes demand and supply structure, objective structure, and the structure of public decision-making. A multi-objective optimization method is used as a co-ordinator (see Haimes, 1977). The principle is shown in figure 5.

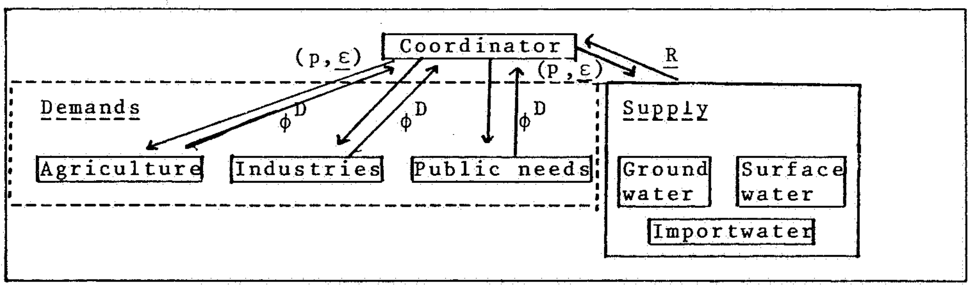


Figure 5 Coordination of supply and demand

In this multi-objective structure, both prices p and constraints on effects ε (e.g. on water quality) serve as information for the demand categories to assess demands ϕ^D. In the supply section, effects $\boldsymbol{R}$ of these demands are calculated in a cost optimization programme. The co-ordinator optimizes over-all objectives (cost, damages, quality) by choosing p and ε. In reality, policy-making committees will serve as co-ordinator, interest groups formulate demands. The planning institute intermediates between these two groups, calculating the necessary information (see figures 2 and 3).

As a first choice the Surrogate Worth Tradeoff Method (see Haimes, 1977) is taken for the co-ordination. In this method, political trade-offs can be made explicit. Other multi-objective optimization methods, with different participative (inter-active) characteristics from the user's point of view, will be implemented later.

5.3.2 *Submodels*

A. *Demand*

In modeling user's demand, the following possibilities exist:

- empirical relationships between demands to water management effects (price, quality);
- demands formulated as a deterministic time-dependent function, to be adjusted during the project time.

The latter can be achieved by users in three ways:

- Only quantities required are defined as a function of time.
- A quantitative demand with a priority scheme for the different water sources is formulated; these sources correspond to a water quality vector.
- A quantitative demand is formulated for water from specific sources, corresponding to specific qualities.

As will be shown, these three possibilities will give different optimization problem formats for the supply model.

B. *Supply*

Four types of water sources can be distinguished: withdrawals from canals; withdrawals from reservoirs; groundwater; and imports. Sources can be distributed spatially.

Effect variables of the system are:

(a) *Costs*, resulting from investments in pumping stations, transport pipes, reservoirs and operational costs from maintenance, personnel, energy; and import costs over the project time are discounted to their present values. The general cost-relation is represented by:

$$C = f^k(x_d, \Phi),$$

in which $\boldsymbol{x}_d$ represents a vector of design variables (e.g. reservoir dimensions, production capacities); Φ represents a matrix of interjunctional flows (see figure 4).

(b) *Water quality*. For each water resource, there exists a water quality vector which consists of quality indices such as concentrations of relevant substances (chloride, algae, etc.). These indices are related to decision variables (design variables $\boldsymbol{x}_d$) in quality models. For the hydrological system, models have been developed with respect to chloride and algal concentrations. Quality indices can be aggregated to more general quality parameters such as odour, toxicity, taste, or to an over-all parameter, using fuzzy weights (see Gum et al., 1976). Weights can be assessed systematically by using the Saaty-method based on pairwise comparison (Saaty, 1978).

- *The aggregated quality model* is of the form:

$$\boldsymbol{Q} = \boldsymbol{F}^Q(\boldsymbol{f}^Q(\boldsymbol{x}_d), \boldsymbol{w}^Q)$$

where $\boldsymbol{Q}$: vector of aggregated qualities Q_i for all water resources i;

$\boldsymbol{f}^Q$: vector of specific quality indices, related to $\boldsymbol{x}_d$;

$\boldsymbol{w}^Q$: set of weights W_i^Q, relating quality parameter i to aggregated parameters ($\sum_i W_i^Q = 1$).

- *The non-aggregated quality model* can be represented by:

$$Q_{ji} = f^{Qi}(\boldsymbol{x}_d)$$

in which Q_{ji} : specific quality index j in water resource i.

In each junction k of the water resource system, including users junctions, the water quality (aggregated or specific) $\boldsymbol{Q}^k$ after mixing can be calculated using mass and flow balances. In a test model, the aggregated representation is used.

(c) *Damages*. Analogous to water quality, agricultural and ecological damages due to groundwater withdrawal can be specified in aggregated or specific format:

– $\boldsymbol{S} = \boldsymbol{F}^s(\boldsymbol{f}^s(\boldsymbol{x}_d), \boldsymbol{w}^s)$ (aggregated representation)

in which $\boldsymbol{S}$: vector of aggregated damages S_i for groundwater resources i;

$\boldsymbol{f}^s$: vector of specific damage indices, related to $\boldsymbol{x}_d$;

$\boldsymbol{w}^s$: set of weights relating damage index i to aggregated parameters.

$S_{ji} = f^{si}(\boldsymbol{x}_d)$ (specific representation) in which S_{ji}: specific damage index j in groundwater resource i.

In a test model, the aggregated representation is used.

5.3.3 *Optimizing the supply model*

The objective of the supply model is cost minimization for a given demand structure, subject to constraints formulated by the co-ordinator. The three demand structures, mentioned previously lead to three alternative problem formulations:

(a) *Quantitative demand*

$$\underset{x_d, \Phi}{\text{MIN}}\ f^k(x_d, \Phi) \quad \text{s.t. } f^Q(x_d, \Phi) \geqq \varepsilon^Q$$

$$f^s(x_d, \Phi) \leqq \varepsilon^s$$

elements i connected to user j: $\sum_j \phi_{ij} = \phi_j^D$ (demand user j).

elements i, junctions j: $\sum_j \phi_{ij} = \sum_j \phi_{ij}$

As a result, x_d (including supplies $\phi_i^s = \sum_j \phi_{ij}$ from source i) and $\Phi\{\phi_{ij}\}$ can be calculated, with trade-offs (multipliers) of binding constraints.

(b) *Quantitative demand with priority scheme*

In this case, the problem is more complicated due to the priority schemes of the demand sectors, which may cause conflicts of interest. Also, a given network

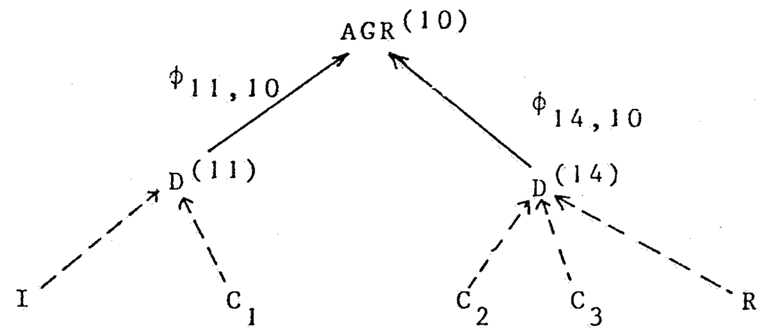


Figure 6 Connection between agriculture (AGR) and sources

distribution system may include mixing of water resources in pipeline junctions with more than one inflow. The reachability matrix (figure 4c) determines the accesible resources for each user. As an *ad hoc* solution of this problem, each user j assesses a priority scheme $\{\lambda_{ij}\}$ for the desired inflows ϕ_{ij}, based on information about the distribution system. Figure 6 gives an example, derived from figure 4a.

($\rightarrow$: direct flows to Agriculture; $--\rightarrow$: sources connected to elements 11, 14).

Then, the following problem can be formulated:

$$\underset{\phi,\, x_d}{\text{MAX}} \sum_j \hat{g}_j \hbar \sum_i \lambda_i^j \phi_{ij}) \quad \{i\}: \text{set of elements connected with } j$$

$$\begin{aligned} \text{s.t.:} \quad & f^k(x_d, \Phi) \leqq \varepsilon^k \\ & f^Q(x_d, \Phi) \geqq \varepsilon^Q \\ & f^s(x_d, \Phi) \leqq \varepsilon^s \end{aligned}$$

$$\text{elements } i, \text{ junctions } j: \quad \sum_j \phi_{ij} = \sum_j \phi_{ij}.$$

Variation of the vector $\hat{g}\{\hat{g}_j\}$ $(\sum_j \hat{g}_j = 1)$ produces results for different weights $\hat{g}_j$ on users j.

(c) *Quantitative demand specified for sources*

In this case the problem formulation reads:

$$\underset{x_d,\, \Phi}{\text{MIN}} \; f^k(x_d, \Phi)$$

$$\begin{aligned} \text{s.t.:} \quad & f^Q(x_d, \Phi) \geqq \varepsilon^Q \\ & f^s(x_d, \Phi) \leqq \varepsilon^s \end{aligned}$$

5.3.4 *Co-ordination of supply and demand*

In a multi-objective formulation, calculated effects and Lagrange multipliers (trade-offs) from the first level serve as a means to adjust prices and constraints by the co-ordinator (policy making committee). The over-all Lagrangian reads:

$$L = \underset{\text{cost}}{C} + \underset{\text{damages}}{\lambda^s(f^s - \varepsilon^s)} - \underset{\text{quality}}{\lambda^Q \cdot (f^Q - \varepsilon^Q)}$$

subject to realization of the chosen demand structure.

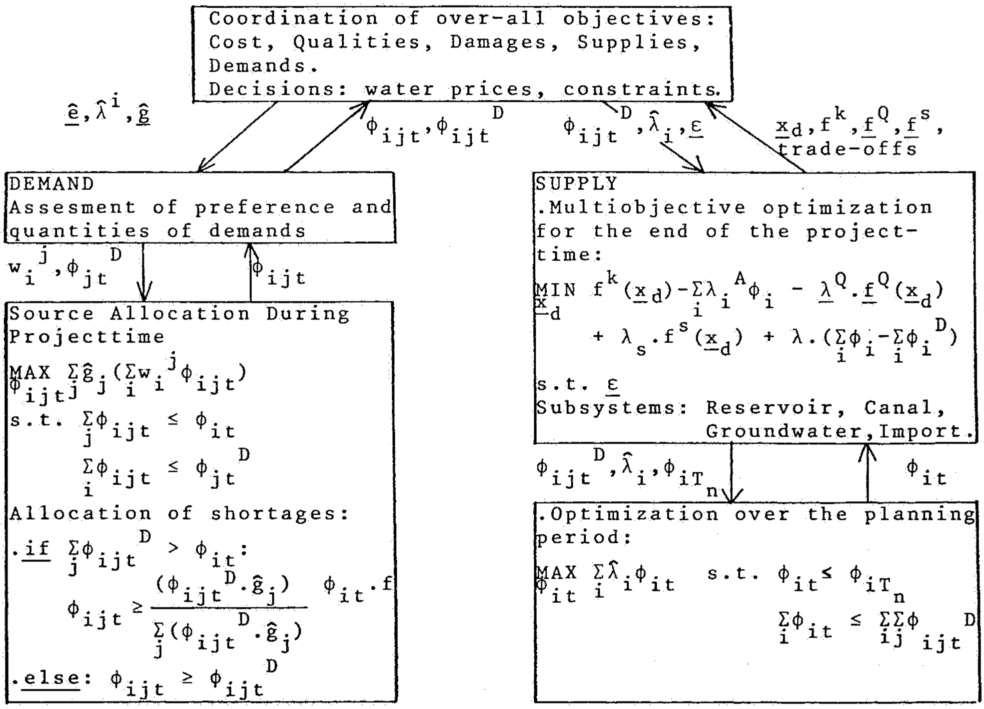


Figure 7 Coordination of supply and demand

5.3.5 *Results of a test model*

In a test model, a water resources structure was investigated consisting of two groundwater sources, three canal withdrawal points, one reservoir and one import. All of these were connected directly with three demand groups: agriculture, industry and public needs.

The optimization problem was divided in two sub-problems:

- design of source capacities;
- allocation of supplies from sources to users.

The problems are formulated as shown in figure 7.

In the *demand model*, the demand sectors j assess their demands ϕ_{jt}^D over the project time, and the preference structure w_i^j for sources i, given information about prices $\hat{\lambda}_i$ and expected quality effects $\hat{e}$ from the co-ordination level. As a result, source demands ϕ_{it} and specific demands ϕ_{ijt}^D are computed. Also, supplies ϕ_{it}

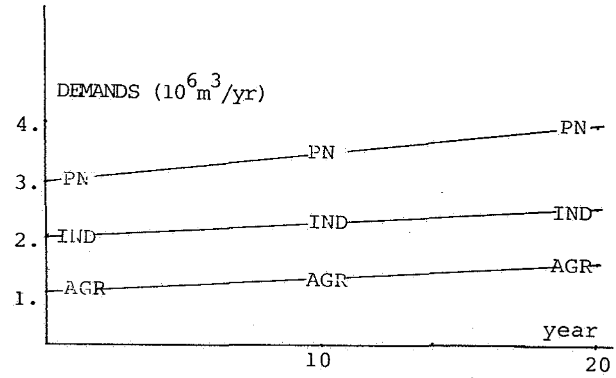


Figure 8 Total demand of users (PN, IND. AGR) during the projecttime

of sources i during the project time, calculated with the supply model, are allocated to users j. In this allocation, contradictory preferences are solved by the co-ordinator in choosing weights $\{\hat{g}_j\}$ on the demand sectors; a minimum supply is guaranteed from each source to each sector by choosing a reduction factor f in order to distribute shortages. In the *supply model*, a multi-objective optimization problem is solved for the end of the project time (T_n), given 'prices' $\hat{\lambda}_i$, constraints ε on effects and system supplies ϕ_i. A decomposition approach is used to analyse the sub-systems separately. Computed supplies ϕ_{iT_n} (production capacities) serve, with demands ϕ^D_{ijt}, as constraints in a simple LP-formulation for the optimization over the planning period, giving supplies ϕ_{it}. In the *co-ordination* level, prices $\hat{\lambda}_i$ are assessed, to co-ordinate effects (costs, qualities, damages, supplies) and demands. In fact, more formulations with respect to allocation of tasks to demand level and co-ordinating level are possible. Also, additional constraints in the allocation level may replace or complete the assignment of $\{\hat{g}_j\}$.

Some illustrative results are presented in the figures 8 to 11. The demands are

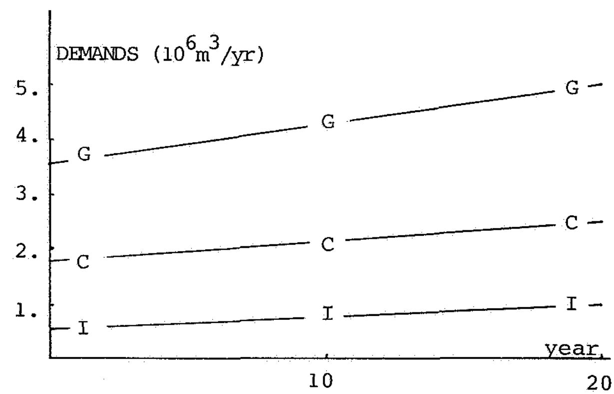


Figure 9 Source demands Groundwater (G), Canal water (C), Import (I)

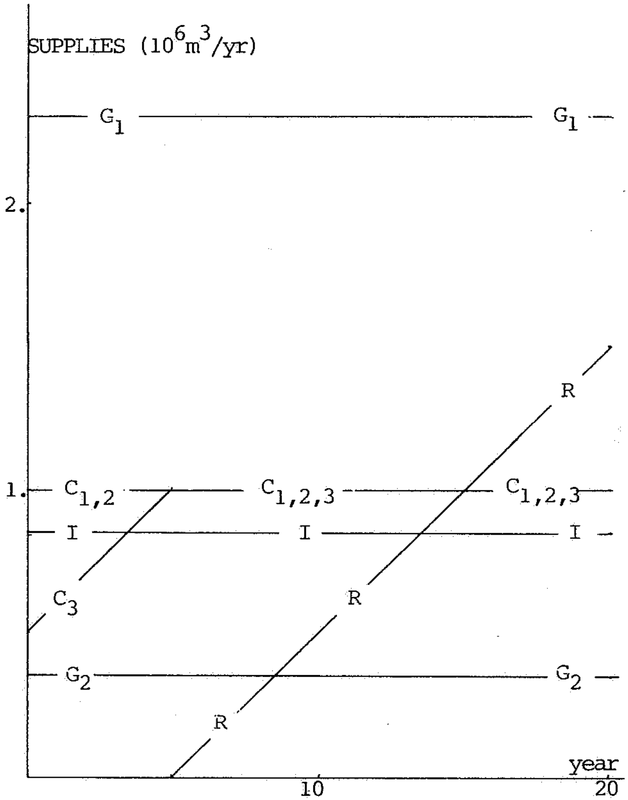


Figure 10 Source supplies during the projecttime

depicted in figure 8 and figure 9. Effects of some generated plans are depicted in table 2; plan effects for qualities and damages are expressed in 'fuzzy' terminology (see also Kempf et al., 1979) defined in table 3. Results of the optimization,

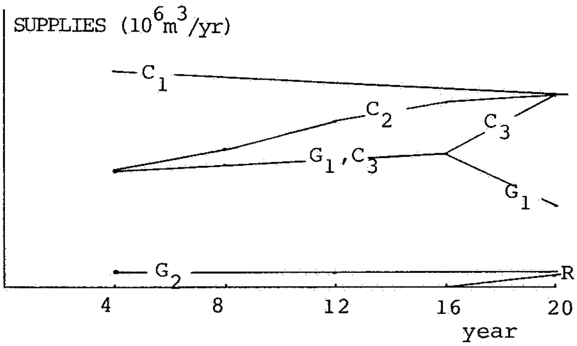


Figure 11 Allocation of supplies to industry during the projecttime.

Table 2 Effects of plans

EFFECTS	CANAL					RESERVOIR	
Plan	Cost 10^6 Dfl	Quantities C_1	C_2	C_3	Supply $10^6 m^3/yr$	Quality R	Supply $10^6 m^3/yr$
1	38.0	0.25	0.27	0.28	3.0	0.43	1.5
2	60.0	0.40	0.42	0.43	1.5	0.47	2.0
3	65.5	0.26	0.28	0.29	2.1	0.46	2.5

EFFECTS	GROUNDWATER					
Plan	Quality G_1	G_2	Supply $10^6 m^3/yr$	Damages	Quality I	Supply $10^6 m^3/yr$
1	0.90	0.80	2.65	0.69	0.85	0.85
2	0.90	0.80	1.84	0.53	0.85	2.66
3	0.90	0.80	3.14	0.81	0.85	0.24

during the project time, of source supplies, are shown in figure 10. As an example, the allocation is shown of sources to all users, at the end of the project time, in table 4 and of sources to industry, during the project time, in figure 11.

Table 3 Conversion table

1.0–0.8 very high	0.8–0.6 high	0.6–0.4 moderate	0.4–0.2 low	0.2–0.0 very low

5.4 Application of computer models in non-technical groups

5.4.1 *General*

Use of computer models for generating and selection of alternatives in planning situations is usually restricted to planners (technical groups). A small set of alternatives is produced for decisions in committees. This section deals with the possibilities and conditions for the use of design and selection models, and special characteristics of these models, in non-technical groups. Two related problems are important:

- structure of group interactions, given methods and models;
- choice of adequate methods; this problem will be restricted to the choice of selection methods.

Table 4 Allocation of sources to users (Plan 1, Time = 20, supplies in $10^6 m^3/yr$)

Users \ Sources	G_1	G_2	C_1	C_2	C_3	R	I	TOT
AGR	0.19	0.03	0.3	0.3	0.3	0.38	0.0	1.5
PN	1.8	0.27	0.0	0.0	0.0	1.08	0.85	4.0
IND	0.31	0.05	0.7	0.7	0.7	0.04	0.0	2.5
TOTALS	2.3	0.35	1.0	1.0	1.0	1.5	0.85	8.0

5.4.2 *Group interactions*

An experimental game was constructed to study decision behaviour and group interactions of seven individuals, acting as decision-makers in the selection of plans for a storage reservoir. Plans were constructed by a 'planner', who was also a group member. Individual decision makers could interact with a mathematical model in order to test their preferences for realization with the model, and to generate efficient alternative plans according to these preferences. Four objectives (cost, water quality, agricultural losses, land use) were included in the model. Trade-offs between effects could be computed as additional information.
Seven interest groups were identified: consumers organizations; natural conservation organizations; agriculture; industry; public authorities; planners; and water authorities. Individual decision-makers acted as representatives of these interest groups.

The game was organized in three sessions. In the first session, which consisted of a number of separate meetings, the individual representatives could interact with the mathematical model, with the assistance of an analyst. In the second session, the planner constructed alternative and trade-offs for each location under study, using information about preferences of representatives. In the third session, a game was used (duration: two hours) to provide a structure for the group's decision-making process. First, plans generated by the planner were presented to the representatives. A computer could be used to calculate additional plans and effects according to desires of group members. Also, an analysis of individual group results could be made.

5.4.3 *Analysis*

In fact, during the third session little use was made of the computer terminal. Some additional plans were formulated and calculated. In practice, with more complex problems, emphasis should lie on clearness of the used model and mathematical techniques.

A fundamental problem exists in the basic construction of the game: most representatives behaved strongly as interest groups, whereas in reality, both interests and specific knowledge of each representative should influence the discussion.

5.4.4 *Selection methods*

For use in groups, these methods can be combined with techniques for synthesizing a group opinion, and/or with techniques for showing divergent opinions. See table 5.

Table 5 Use of methods in groups

Type of groups / Expected result	Technical groups (Planners; experts)	Non-technical groups (Interest groups, public committees)
One final group result	– Methods based on decision theory (utility). (See Rouse et al., 1974) – Delphi (dialogue structure)	Simple algorithms, based on clear understanding by the group; emphasis on presentation methods voting (possibly at the end)
Divergent opinions; debate	– Delphi, with/without computer technology (dialogue structuring) – Displays	Emphasis on information presentation (schemes, graphs, etc.)

For use in non-technical groups, selection methods might be preferred in which the group can observe continuously the preliminary selected plans. At the beginning, the set of plans shows no hierarchical order; successively hierarchical orders are producted, resulting in a final differentiation; such a procedure is in accordance with the observation (see Haimes, 1977) of conventional decision-making as goal-oriented instead of value oriented. In technical groups, which more easily accept mathematical logic, value-oriented approaches can be feasible. Table 6 shows some existing selection methods analysed according to these principles.

5.4.5 *Lexicographic approach*

The lexicographic approach is in accordance with principles discussed previously. In this method, plans are eliminated stepwise by comparing their effectiveness with respect to one objective. In the first step, the most important objective acts as the selector and sorts out the best alternatives with respect to this objective. The maximum number of alternatives N_1^{MAX} remaining after this first selection can

Table 6 Selection methods and their characteristics

Method	Characteristics
1. Concordance Method (see Nykamp, 1977)	Effects and weights result in indices; according to decision rules, a final hierarchy is selected. *Value oriented.*
2. Method Saaty (see Saaty, 1978)	Pairwise comparison of effects and importance of objectives; one resulting index per plan gives the final hierarchy *Value oriented.*
3. Satisfaction Analysis based on fuzzy sets (see Kempf et al., 1979)	A fuzzy satisfaction index is connected with each project effect; sensitivity analysis produces a discrimination of plans. *Goal oriented/value oriented.*
4. Lexicographic approach	Plans are subsequently eliminated by using constraints on effects as criteria. *Goal oriented.*

be chosen by the decision maker(s). At the second level the discrimination between alternatives is based upon their effectiveness with respect to the second objective, resulting in N_2^{MAX} remaining alternatives. An additional constraint is a tolerance with respect to the most important objective nr. 1 which can be generalized for each selection level r as:

$$f_{r-1} < f_{r-1}^{MIN} + \alpha_{r-1} \cdot (f_{r-1}^{MAX} - f_{r-1}^{MIN}),$$

in which f_{r-1}^{MIN} is the best (lowest) value, f_{r-1}^{MAX} the worst value among the alternatives left at the $r-1$ level for the active objective. α_{r-1} can be chosen beforehand; if an insufficient number of alternatives remains either α_{r-1} or N_r^{MAX} can be adapted.

A decision-cycle in which this method has been applied to a set of plans, generated for the design of a storage reservoir at two locations, is depicted in figure 12. Plans are shown in table 7. Effects were cost, average chloride concentration up

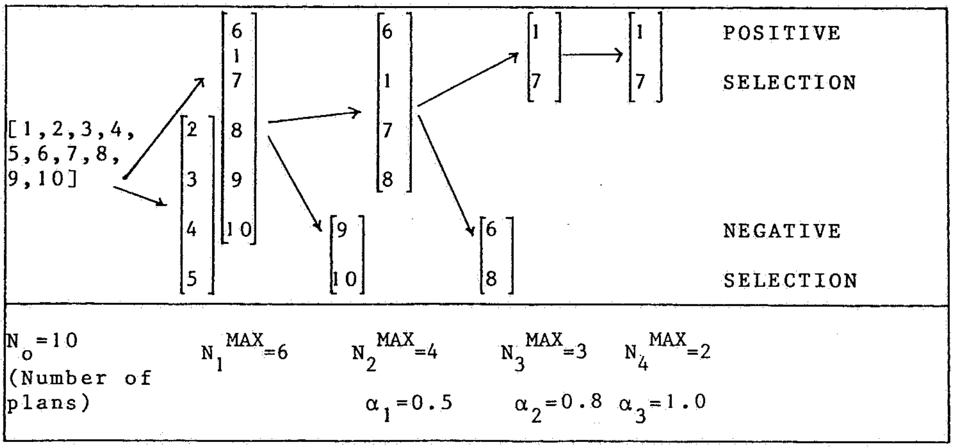


Figure 12 Decision cycle.
In each of the steps, a differentiation between positive selected plans and negative selected plans is available.

Table 7 Results of plan generation for location I(1–5) and II(6–10)

PLAN NUMBER	Cost (10^6 Dfl)	Chloride (y_1^c) (g/m^3)	Algae (y_2^A) (kg chl. -*A*/*yr*)	Land use (10^4 m^2)
1	32.2	0.0	350	20.3
2	32.5	0.0	400	21.4
3	33.3	0.0	500	23.5
4	34.1	0.0	600	25.3
5	35.7	0.0	800	28.5
6	32.0	0.33	340	19.9
7	34.8	0.20	360	23.2
8	36.0	0.14	370	25.0
9	37.0	0.10	380	26.3
10	39.3	0.0	398	29.5

to a given norm; algal mass, land use. In this cycle, N_r^{MAX} is related to N_{r-1}^{MAX} by using weights on objectives W_r, obtained by using the Saaty-method [10] based on pairwise comparison of objectives (see table 8) and a regulator factor k:

$$N_r^{MAX} = \text{INT}\{(1-w_r)^k \cdot N_{r-1}^{MAX}\},$$

where INT means the integer operation.

In each step r, a hierarchy for resulting plans can be produced using concordance analysis with quantitative weights resulting from application of the Saaty-method to compute the concordance indices for the plans. (See table 8.)

Table 8 Weight structure

Objective	Weight
Algae	0.40
Cost	0.25
Chloride	0.20
Land use	0.15

Generally, application of various selection methods produces different results, caused by structural characteristics. The interpretation of the logical steps and indices in concordance methods may be difficult for use in non-technical groups; in fact in any method abstract procedures or indices will produce confusion. These methods require acceptance of results on a ratio scale instead of on an ordinal scale. Hence, in the groups involved in water resources decision-making, a lexicographic method seems more appropriate.

5.5 Information presentation in the decision-making process

Information presentation is an important element in the interaction process between models and decision-makers during the whole decision procedure (see figure 2). In table 9, as a hypothesis, a division is made of several types of displays over decision phases and decision groups involved.

As a first step, alternative visual presentations for plan effects have been designed and will be tested, with specific attention to the orientation of decision-makers towards different modes of presentation.

5.6 Final remarks

The general problem of using qualitative and quantitative methods for generation and selection of plans in public administration was discussed. Methodical aspects have been considered such as structure of the decision-making process and choice and structuring of information presentation. Models for regional water management have been developed. Possibilities for use of models in non-technical groups have been investigated, with emphasis on the use of selection methods.

Table 9 Types of displays and information required (----→ : course of action)

Phase / Involved	Planning institute	Decision committees	Users
I Geographical System Description	• Map (figure 1) • Scheme (figure 4a) • Connexion Matrix (figure 4b) • Reachability Matrix (figure 4c)	• Map • Scheme	• Map
II Definition of System Variables	• Lists, etc.	• Scheme of relations between variables • List of effects to be assessed	• List of effects
III Generation of Plans	• Table and/or graphs with detailed, quantitative effects as a function of time • *ibid*, for trade-offs		
IV Preselection of Plans		• Simplified tables and/or graphs with quantitative and/or qualitative main *effects* • Table of qualitative trade-offs • Ordered representations according to decision rules (e.g. figure 12)	
V Comparison of plan effects and users' objectives			• Table of plan effects and users' objectives • Ordered representations according to decision rules (e.g. figure 12)
VI Final Selection of Plans		• See phase IV	

5.7 List of symbols

p	prices
$\boldsymbol{\varepsilon}$	vector of constraints
ϕ^D	demands
$\boldsymbol{R}$	vector of effects
$\boldsymbol{x}_d$	vector of design variables
C, f^k	cost function
$\Phi(\phi_{ij})$	matrix of interjunctional flows ϕ_{ij}
$\boldsymbol{Q}$	vector of aggregated qualities Q_i for sources i
$\boldsymbol{f}^Q$	vector of specific quality indices
$\boldsymbol{w}^Q$	set of quality weights
Q_{ji}	specific quality index j in water source i
$\boldsymbol{S}$	vector of aggregated damages S_i for (groundwater) sources i
$\boldsymbol{f}^S$	vector of specific damage indices
$\boldsymbol{w}^S$	set of damage weights
S_{ji}	specific damage index j in (groundwater) resource i
ϕ_j^D	demand of user j
ϕ_i^S	supply from source i
$\{\boldsymbol{i}\}$	set of elements, directly connected with a user
$\{\lambda_i^j\}$	priority set of user j for sources i
$\boldsymbol{\lambda}^s$	vector of trade-offs for damage indices
$\boldsymbol{\lambda}^Q$	vector of trade-offs for quality indices
$\hat{\boldsymbol{e}}$	vector of expected quality effects
$\hat{\boldsymbol{g}}$	vector of weights $\{\hat{g}_j\}$ on users j
w_i	preference of user j for source i
$\hat{\boldsymbol{\lambda}}_i$	price for source i
ϕ_{jt}^D	total demand of user j at time t
ϕ_{ijt}	demand of user j for source i at time t
f_{r-1}	value of an objective f on the $r-1$ level in a hierarchy.

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Some aspects of the information required prior to the introduction of economic instruments for the management of water resources

M. Tamminga and J. A. Los

6 Some aspects of the information required prior to the introduction of economic instruments for the management of water resources

SUMMARY

In the province of Drenthe (268,500 ha) an inquiry has been made into the extent of water shortages occurring, and some possibilities have been mentioned for coping with the increasing demand for water.
The water supply serves various economic sectors, such as: agriculture (sprinkling and sub-irrigation); horticulture (in the open field and under glass); livestock, drinking and industrial water supply (almost completely from groundwater); shipping (lock losses, evaporation losses, etc.); flushing (necessary to drain off effluents from sewage treatment plants); national parks; raising the water level in spring (to form a groundwater level which is optimal for farming); water loss caused by sprinkling (infiltration and evaporation); infiltration out of water courses.

In order to calculate the soil moisture content, the area has been divided in three soil types, distinguished by different heights. The cultivated fields have been divided in six hydrological soil types.
In order to calculate the necessary quantities of water, the water shortages have been determined in various grades of dryness during long series of years (1911 to 1977). From these series, four years have been chosen which are characteristic for frequency of occurrence. For these dry-class-years, the evaporation surplus has been determined.
The supply has been calculated for a maximum, a minimum and an intermediate area. The required quantities for each area combined with the four dry-class-years resulted in twelve plans.
After comparison of costs and benefits and also of further material and immaterial advantages and disadvantages, only the three most favourable plans were left.

6.1 Introduction

As a result of many developments the demand for water is increasing slowly. This appeared especially during the very dry summer of 1976. In order to get a view of the extent of water shortages occurring and the possibilities to supply these shortages, in the province of Drenthe a study group was created to examine following subjects:

- purposes for which water supplies are necessary;
- quantities which are needed for many years, on an average;
- the creation of the plans in which the whole province, or some parts, can be supplied and in which these areas can be supplied with water depending on different degrees of dryness;
- comparison of costs and benefits of the plans and of further material and intangible advantages and disadvantages.

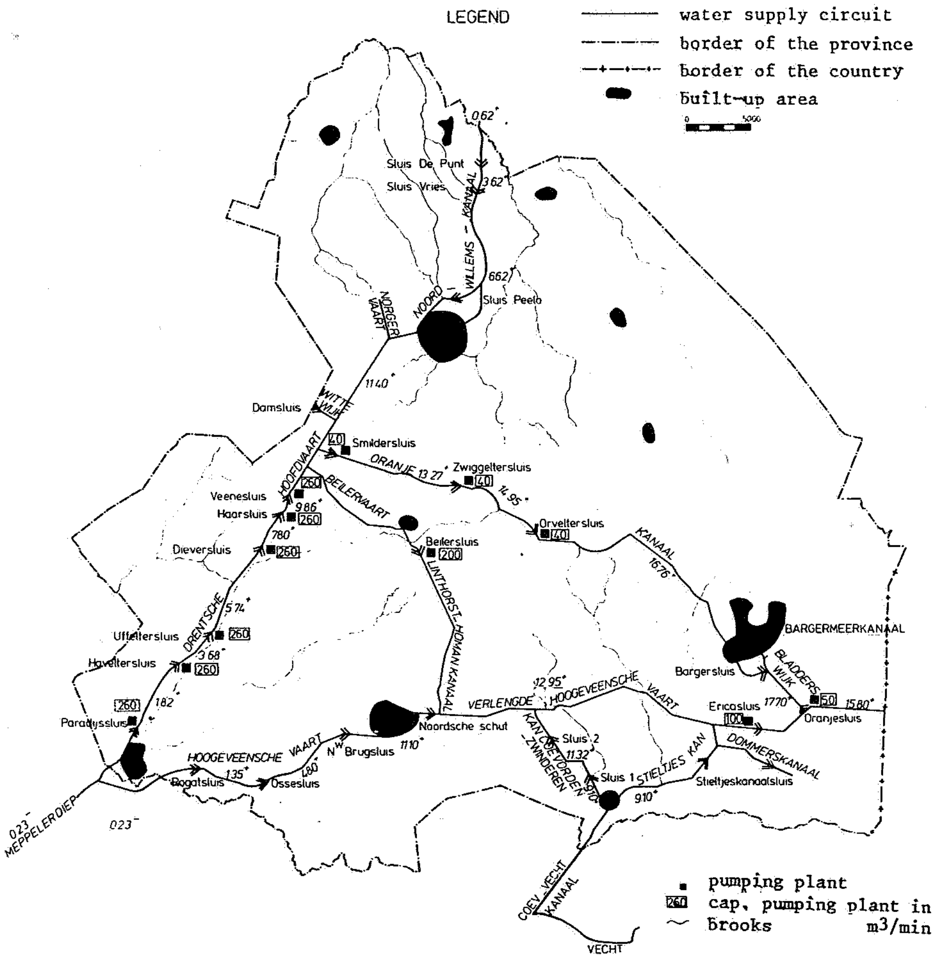

Figure 1 Infrastructure of the water management

The province of Drenthe comprises an area of 268,500 ha. The central part, with an altitude roughly 15 to 25 m above sea level, inclines to the borders with heights ranging between 0 to 5 m above sea level. The territory of the province does not border on the sea and is not cut by a river. Within the province, the fields mostly drain into existing brooks. In addition, the canal system plays an important part. Over the centuries this system was dug to open up extensive peat complexes which were in the province. The water control works added in recent decades made it necessary to enlarge considerably the discharge capacity of some canals. Natural water supply is not possible because the province has no river. During the growing season there is a shortage of water; the fields depend completely on precipitation; although, limited water replenishment is possible by pumping water out of the Meppelerdiep, which has an open connexion with the IJsselmeer. For this purpose pumping plants, with capacities varying from 40 to 260 m^3 per minute, were built near some sluices. These pumping plants are essential to keep up the water levels in canals. If the supply is sufficient, fields bordering on the canals can be supplied with limited water. A survey of the water management situation may be seen in figure 1.

6.2 Land use

Land use in Drenthe is as follows (expressed as per hectare):

Cultivated fields:					
– pasture				112,267	
– agriculture:	– cereals	25,797			
	– root crops	61,465			
	– other crops	3,039		90,301	
– horticulture:	– open fields		681		
	– glasshouses		88	769	203,337
Open water:					
lakes, pools, ditches, canals, brooks, etc., wider than 6 m					3,664
Recreational areas:					
parks, public gardens, sports grounds					967
National parks					43,468
Others					17,016
					268,452

6.3 Soil moisture

For estimating the soil moisture supply, the theory of Rijtema has been used (a method to calculate the agricultural damage caused by groundwater withdrawal, Institute for Land and Water Management Research, reprint no. 587, 1971). The soil moisture content has been distinguished by moisture from the root zone and moisture from underground. The root zone is that part of the soil profile which supports 80 to 90 per cent of the root mass. To apply this method the area has been divided in three soil types:

- lowlands: continuous capillary supply to the root zone possible during the whole growing season;

- middle-highlands: continuous capillary supply to the root zone possible only during the beginning of the growing season, because in summer the groundwater sinks too deep to be reached by the roots;

- highlands: capillary supply to the root zone not possible during the growing season.

For cultivated fields, a classification in hydrological soil types has been made; the province has been divided into soil types which have nearly the same properties for soil moisture content and capillary supply:

- low moor peat (8,600 ha): soil with more than 0.40 metres of peat remaining;

- cut-over high moor peat and high moor peat (55,200 ha): high moor peat lands which have partly or not become peaty and cut-over high moor peat;

- poorly drained sandy soils and sandy soils with overlying glacial till within 1.25 m below soil surface (60,000 ha);

- brook valleys (45,500 ha);

- moderately-drained sandy soils without overlying glacial till (17,200 ha);

- excessively-drained sandy soils (16,700 ha).

6.4 Dry-class-years

For its natural water supply Drenthe is completely depending on precipitation

(N). Annual precipitation is more than sufficient to cope with evaporation. However, during the growing season an evaporation surplus occurs. The Royal Dutch Meteorological Institute (K.N.M.I.) calculated the evaporation of open water (E_0) for a number of observation stations according to the method of Penman. In the moisture calculations, the potential evapotranspiration (E_{pot}) has been used as a decisive factor. This occurs when the crop is optimally supplied with water. The connexion between the potential evapotranspiration and the evaporation of open water is as follows:

$$E_{pot} = f \cdot E_0,$$

in which f represents the reduction or crop factor;
f depends on crop factors (stage of development, length, grade of overlap) and climatological circumstances. In Drenthe the coefficient f is determined as 0.8 on an average. In this way the evaporation surplus of the crop can be fixed as $0.8E_0 - N$.

The length of the period, in which water supply is necessary, is based on the duration of the growing season; in Drenthe this is the period from 1 April to 1 October. In the calculation of the necessary replenishment, the following has been taken into account:

- the total need during one growing season;

- the peak need (the maximum necessary quantity per period), for which one month has been taken.

The evaporation surpluses have been calculated for the period 1911 up to and including 1976, for open water as well as for crops. In order to get a perspective on the water shortage in various grades of dryness and also on the moisture shortage during long series of years on an average, four years have been chosen which are characteristic for frequency of occurrence in these series. These four years, marked as dry-class-years, are:

- the year 1976, as an example of an extremely dry year, which for Drenthe can be considered as a 5 per cent dry year; this means that in that year the evaporation surplus during the growing season is reached or crossed in five of every hundred years;

- a 10 per cent dry year;

- a 20 per cent dry year;

- a 50 per cent dry year.

For these years, the evaporation surpluses are cumulatively plotted against the time (see figure 2).

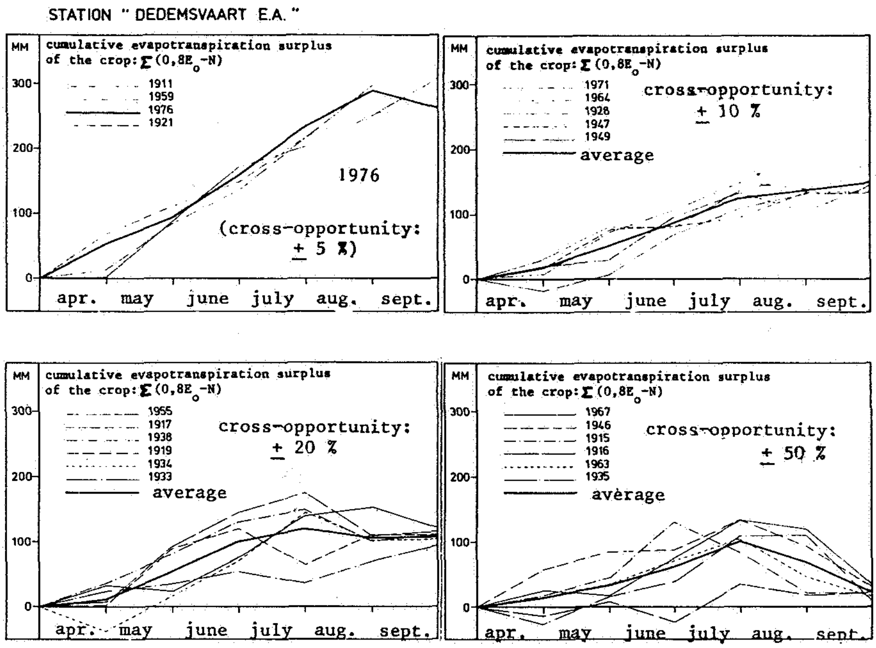

Figure 2 Evaporation surpluses cumulatively plotted against time

6.5 Water requirements

Supplementary water requirements serve various purposes. However, the water is partly consumed, so it is no longer available for reuse. Another part is used only and can afterwards be taken up again, although the water is sometimes of an inferior quality. In Drenthe the following important purposes may be distinguished.

6.5.1 *Agriculture*

The moisture shortage in agriculture is based on the evapotranspiration surplus less the water quantity available in the soil (the soil surplus). The moisture shortages are determined per month and during the whole growing season for the different hydrological soil types (pasture and agriculture are separated). The total supplementary water requirement for agriculture is as follows:

dry-class-year	1976	10 % dry	20 % dry	50 % dry
quantities 10^6 m^3	333	96	42	8

In Drenthe the supplementary water for crops is made available mostly either by infiltration or by sprinkling. Sub-irrigation occurs by means of water-level control in the water courses. This might be promoted with the help of pipes. This method is used primarily on the lowlands. From investigations it has appeared that, in this way, about 1.5 mm water daily can be supplied to the crop. In dry years this is not sufficient and so supply by sprinkling is necessary. Sprinkling is also used on highlands and middle-highlands, as these are not suitable for sub-irrigation because of the irregular relief, the large distances between water courses and the infiltration losses.

6.5.2 *Horticulture*

For horticulture in the open soil the water requirement has been put on a level to that for pasture. The percentage of sprinkling, however, is considerably higher. Horticulture in glasshouses demands markedly larger water quantities. This is to compensate for the evapotranspiration and to stop the accumulation of salt by flushing the soil. The following mean amounts have been taken for evapotranspiration:

6 mm/day in May, June and July

5 mm/day in April, August and September.

For flushing it has been taken into account that 10 per cent of the total area gets a weekly water donation of 250 mm (2,500 m^3/ha).

The total requirement is:

Moisture requirement		*Total 180 ha*
May, June, July	– 6 mm/day	970,000 m^3
April, August, September	– 5 mm/day	810,000 m^3
Total		1,780,000 m^3

6.5.3 *Water for livestock*

In Drenthe there are about two cows on each hectare of pasture. These each consume 50 litres a day. Livestock also needs another quantity of water made available again, directly of indirectly. The use has been calculated per hydrological soil type. The total water requirement amounts to about 2,032,200 m^3 per growing season.

6.5.4 *Drinking and industrial water supply*

This water is almost completely withdrawn from groundwater. These withdrawals lower the groundwater level so that less water is available for crops. A large part of the abstracted water returns as surface water again through the discharge points. It is assumed that these two quantities almost balance.

6.5.5 *Shipping*

Water losses out of the canals have to be replenished in order to maintain the canal level wanted. These losses are lock losses, evaporation losses, infiltration losses and leak losses. The lock losses determined by the sluice contents and the number of vessels locked through amount to totally 5,350,000 m^3 during the summer season. The evaporation losses vary strongly according to the dry-class-year. All infiltrations and flushings, caused by height differences between canal level and groundwater level, may be considered as a circulation stream within the province and as such has no influence on the water quantity which has to be supplied from outside the province. Leak losses occur near construction works like sluices, culverts, irrigation inlets, etc. By visual observations these are estimated to be 0.2 m^3/s. The total losses which are connected with the water level control amount to 8,460,000 m^3 per growing season. The largest water loss occurs in summer.

6.5.6 *Flushing*

A number of sewage treatment plants are discharging effluents into the canals in Drenthe. Especially when the weather is warm and dry, regular flushing of the canals is necessary. However, the water quantity which has to be supplied for this purpose may be disregarded as a loss, because the water is afterwards completely useful again for other purposes. Starting from only one dilution of the effluent, the necessary quantity of flushing water amounts daily to 75,000 m^3.

6.5.7 *National parks*

The low-lying, naturally-wet national parks attract most attention in connexion with the water supply. The moisture-loving flora and fauna are generally very sensitive to long changes in the water management. The higher situated areas will not make such tough demands, because in natural environment in those areas has always been dependent on the moisture in the vadose zone. For this reason, only the low areas have been taken up in the calculation of water requirements. The norm for pasture has been used as a supply norm. In the management of nature the supply of surface water to national parks mostly meets with qualitative objections. For this reason, in Drenthe one tries to avoid withdrawal of water from national parks, for instance by chosing hydrologically justified reserve borders. The calculated quantities amount to:

dry-class-year	1976	10 % dry	20 % dry	50 % dry
quantities in 10^6 m^3	1.102	0.465	0.294	0.074

6.5.8 *Raising the water level in spring*

The principal reason for water level control in the water courses is to form a groundwater level which is optimal for farming. In order to prevent the groundwater level from falling too fast in spring, the levels of the ditches are raised by bringing the weirs to a higher level. Generally speaking, one tries to obtain from the natural outlet the necessary water quantity for raising the levels. If this is impossible, replenishment out of the canals must occur. To effect this in the lower and also partly in the middle highlands covering an area of 116,000 ha, the water level in an area of open water totalling 2,320 ha has to be raised 0.65 meters, on the average. From these facts, the necessary quantity may be calculated: $15 \times 10^6 m^3$. In Drenthe this quantity can be obtained from the natural outlet. For the rest of the middle highlands and the highlands it is impossible to raise the level in this natural way, because the necessary water is missing. For the calculation of the water quantity which has to be supplied, it has been assumed that the feeders have a mean mutual distance of 600 m. This distance is based on the present sprinkling equipment, which can serve a strip of about 300 m. Starting from a water stock which has to be brought to a depth of 1 m in the water courses, about $3m^3$ per m^1 water course is required (bottom width 1m; slopes 1:2). The necessary water quantity then amounts to 50 m^3/ha. The total necessary quantities amount to:

dry-class-year	1976	10 % dry	20 % dry	50 % dry
quantities in 10^6 m^3	4.37	3.53	2.64	0.84

6.5.9 *Water loss caused by sprinkling*

These losses consist of infiltration losses and evaporation losses. The infiltration losses are caused by irregular distribution of the sprinkling water over the plots and/or by a too-large quantity of sprinkling water. The literature fixes these losses at about 15 per cent of the quantity supplied. The loss which is caused by direct evaporation of sprinkling water is fixed at about 3 per cent. The total losses caused by sprinkling amount to:

dry-class-year	1976	10 % dry	20 % dry	50 % dry
quantities in 10^6 m^3	28.0	7.6	3.2	0.6

6.5.10 *Infiltration out of feeders*

In Drenthe few figures are known about these losses. On the basis of some data, a loss of 0.12 $m^3/24$ hours/m^2 surface water has been retained. These quantities are calculated at:

dry-class-year	1976	10 % dry	20 % dry	50 % dry
quantities in 10^6 m^3	75.6	31.9	27.0	5.6

6.5.11 *Evaporation losses of open water*

These losses are fixed by the area of open water and by the climatological conditions. In Drenthe the area of open water with a breadth larger than 6 meters amounts to 3,650 ha and with a smaller breadth 2,600 ha, forming altogether 6,250 ha. Total evaporation losses amount to:

dry-class-year	1976	10 % dry	20 % dry	50 % dry
quantities in 10^6 m^3	25.8	17.2	14.3	10.3

6.5.12 *Remaining requirements*

Besides the requirements mentioned, some of a smaller extent have been calculated:

- control of diseases and control of weeds: 0.13×10^6 m^3;

- recreation: no separate requirement quantity;

- steam injection project of N.A.M. for the benefit of oil extraction: 5,000 m^3/day;

- water supply to some small areas in neighbouring provinces.

Summing up the requirements mentioned gives the following total (during the growing season):

dry-class-year	1976	10 % dry	20 % dry	50 % dry
quantities in 10^6 m^3	486	172	104	39

The division of this requirement during the summer months is represented in figure 3.

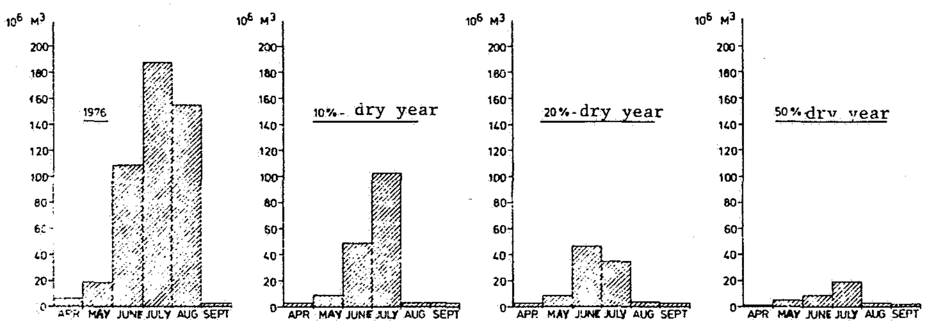

Figure 3 Total complementary water requirement

6.6 Required supply

In the present situation it is technically possible to supply the areas bordering on the canal reaches (93,000 ha) with water to a limited extent. This happens by way of inlets. This is called the minimum plan (min). The situation has been investigated further by which the complete area of arable land (203,200 ha) is supplied with water. This is called the maximum plan (max). Also an intermediate plan (int) has been developed in which a water-supply possibility can be created for an area of 137,800 ha at relatively low supplementary expenses. With the four dry-class-years the combination results in the 12 possibilities mentioned in the list below:

dry-class-year	minimum plans 93,200 ha	intermediary plans 137,800 ha	maximum plans 203,200 ha
1976	min '76	int '76	max '76
10 % dry year	min-10	int-10	max-10
20 % dry year	min-20	int-20	max-20
50 % dry year	min-50	int-50	max-50

Generally speaking, in Drenthe it is possible to withdraw a part of the water required in the growing season from the quantity which has been preserved in spring. Preservation can especially be effected by raising the weirs soon after winter, by which means higher levels are obtained in surface water and groundwater. Calculations prove, that in all dry-class-years sufficient water is available in April. In the 10 per cent and 20 per cent dry years this is also the case in the first half of May and for the 50 per cent dry years throughout the month of May. In 1976 this also happened in September. During the remainder of the growing season, water has to be supplied from outside the province. This quantity can be withdrawn from the IJsselmeer. Because of height differences this water has to be pumped up. Of course the quantities will vary strongly. In order to calculate the expenses incurred with pumping, the water quantities which have to be pumped up during the growing season, on an average, are calculated over several years (see table 1):

Table 1 Quantities of water which have to be pumped up from the Meppelerdiep during the growing season over several years on an average in 10^6 m^3

plan	minimum	intermediair	maximum
'76	35.4	50.4	81.8
−10	32.1	46.2	75.5
−20	23.4	32.9	56.0
−50	17.4	22.8	35.8

If realizing a plan, which does not give an optimal water supply, rationing of the water has to be applied in years which are drier than computed.

6.7 Expenses for supplementary arrangements

The expenses for the arrangements to be made, refer to the principal feeding system (primary feeding system), to the feeders to the supply areas (secondary feeding system) and to the distribution courses in the supply areas (tertiary feeding system). Because supplying plans, which should make canal widenings necessary, are left out of consideration, the amounts to be invested in the primary system refer only to the building and exploitation of pumping plants. Therefore, the existing system (see figure 1) is enlarged with a pumping system on the Hoogeveensche Vaart with complementary capacities of the pumping plants on the Verlengde Hoogeveensche Vaart and the Oranjekanaal. For the supply through the secondary supply system, almost the whole province can use the existing water discharge system. Often the upstream sections of the feeders have to be widened, because these have been dug at minimum discharge capacities over those sections, while the quantities to be taken there are mostly maximal. The tertiary system is largely sufficient at present in the low areas, and relatively few adjustments are necessary. In the middle high and high areas the tertiary system is only present in rudimentary form or totally absent. To allow the conveyance of water to the areas concerned, a completely new tertiary network of water courses will have to be constructed. The total expenses are given in table 2 and the yearly expenses in table 3.

Table 2 Investment expenses in 10^6. Dfl (total) supply system

plan	primary	secondary (s)	tertiary (t)	s+t	total
1	2	3	4	5	6
min'76	62.5	14.0	62.5	76.5	139.0
min-10	33.2	4.7	37.5	42.2	75.4
min-20	12.0	2.8	31.8	34.6	46.6
min-50	5.7	0.9	26.1	27.0	32.7
int-10	47.6	11.0	80.5	91.5	139.1
int-20	23.3	6.9	69.4	76.3	99.6
int-50	8.3	5.5	60.4	65.9	74.2
max-20	37.8	159.3	69.4	228.7	266.5
max-50	12.9	137.6	60.4	198.0	210.9

6.8 Benefit in farming

The theory of Rijtema and Endrödi (1970) has been taken as a starting point for the gross increasing yield in farming, related to the complementary water supply.

Table 3 Annual expenses in 10^6 Dfl

Plan	Primary supply system			Sec. and tert. supply system			Complete plan		
	overheads	var.	tot.	overheads	var.	tot.	overheads	var	tot.
1	2	3	4	5	6	7	8	9	10
min'76	5.3	0.5	5.8	6.8	0.4	7.2	12.1	0.9	12.9
min-10	2.8	0.4	3.2	3.7	0.4	4.1	6.6	0.8	7.3
min-20	1.0	0.3	1.3	3.1	0.4	3.4	4.1	0.6	4.7
min-50	0.5	0.2	0.7	2.4	0.4	2.8	2.9	0.6	3.5
int-10	4.1	0.6	4.6	8.1	0.6	8.7	12.2	1.1	13.3
int-20	2.0	0.4	2.4	6.8	0.6	7.3	8.8	0.9	9.7
int-50	0.7	0.3	1.0	5.9	0.6	6.4	6.6	0.8	7.4
max-20	3.2	0.7	3.9	20.3	1.0	21.4	23.5	1.7	25.3
max-50	1.1	0.4	1.5	17.6	0.9	18.5	18.7	1.4	20.1

In this a connexion has been proven between evapotranspiration and complete dry-material production. The following norms of increasing yields have been calculated:

- cereals (grain): 18.5 kg/ha per mm complementary water supply;
- cereals (straw): 17 kg/ha per mm;
- potatoes (tuber): 190 kg/ha per mm;
- grass/hay: 48.5 kg/ha per mm.

Taking mean prices during the last years this results in the following mean increasing yields per ha per mm complementary moisture supply:

Table 4 Mean increasing yields per ha per mm complementary moisture supply

Crop	Increasing yields kg	Price per kg (Dfl)	Increasing yields in money, excluding VAT
cereals/grain	18.5	0.45	Dfl 7.05
straw	17.0	0.085	Dfl 1.23
total			Dfl 8.28
potatoes	190	0.11	Dfl 17.71
hay	48.5	0.245	Dfl 10.07

Because of the fact that the calculated complementary water supply has been distinguished per type of soil use, the increasing yields have also been expressed in those types. For pasture, the mean increasing yields are determined on Dfl 10/ha/year/mm complementary water supply and for agriculture on Dlf 15.

In the calculation of the gross increasing yields, when executing each of the nine plans, one started from a yearly average of the complementary moisture supply over long series of years. In this, a distinction has been made in supply by means of sub-irrigation and by means of sprinkling. The sprinkling percentage is of great influence upon the benefit calculation in farming. The water quantity, which has to be supplied in each plan, was calculated per soil type, per soil use, over many years. Furthermore, the increasing yields from the above calculations were determined for the total amount, as well as for pasture and agriculture separately. In the calculation of the gross increasing yields, no account was taken of the money the farmer had to spend on farming in order to realize a higher production. These expenses refer especially to sprinkling. The money for sprinkling consists of overheads, resulting from the investment and of variable expenses like power and labour. It appears that the costs for sprinkling are relatively high in Drenthe. Especially in the areas where the mean yearly water shortage is comparatively small, the overheads mount sharply when supplying the water optimally. This results in an unfavourable influence of the net increasing yields. Moreover, in the present situation the sprinkling percentage also falls short of the average in the Netherlands. Probably this is also caused by the fact that in Drenthe the precipitation is higher ($\pm$ 25 mm) and the evapotranspiration is lower ($\pm$ 25 mm) than the average in the Netherlands. Further, the sandy soils preserve more moisture than elsewhere in the country. The mostly shallow loam layer, which can be found in many places, has also a favourable effect. On the basis of calculations, it is expected that in future the sprinkling percentage over the complete area of cultivated fields will not become higher than 20 to 30 per cent.

Table 5 Complementary water supply and gross increasing yields

	Pasture		Agriculture		Total
Plan	compl. water supply $10^6\,m^3$	gross increasing yields 10^6 Dfl	compl. water supply $10^6\,m^3$	gross increasing yields 10^6 Dfl	gross increasing yields 10^6 Dfl
min'76	16.4	16.4	4.5	6.8	23.2
min-10	13.2	13.2	3.4	5.1	18.3
min-20	8.7	8.7	1.8	2.7	11.4
min-50	3.8	3.8	0.7	1.1	4.9
int'76	23.5	23.5	7.1	10.6	34.1
int-10	18.9	18.9	5.4	8.1	27.0
int-20	12.3	12.3	2.9	4.4	16.7
int-50	5.3	5.3	1.2	1.8	7.1
max'76	32.4	32.4	14.2	21.3	53.7
max-10	25.7	25.7	11.3	16.9	42.6
max-20	16.7	16.7	6.6	9.8	26.5
max-50	7.1	7.1	2.8	4.2	11.3

Table 6 Net plan-effect of complementary water supply

Plan	Net farming benefits minus water supply costs in 10^6 Dfl/year			Total benefits of the remaining pressure groups with a valuation of Dfl 0.10/m^3 compl. water supply in 10^6 Dfl/year	Net plan-effect: Benefits – Costs in 10^6 Dfl/year		
	optimum sprinkling	20-30% sprinkling	5-10% sprinkling		optimum sprinkling column (1+4)	20-30% sprinkling column (2+4)	5-10% sprinkling column (3+4)
	1	2	3	4	5	6	7
min'76	−21.8	− 4.8	+ 4.9	+1.44	−20.4	− 3.4	+ 6.3
min-10	− 6.8	− 6.8	+ 5.2	+1.49	− 5.3	− 5.3	+ 6.7
min-20	−10.5	−10.5	+ 2.2	+1.34	− 9.2	− 9.2	+ 3.5
min-50	− 6.9	− 6.9	− 3.0	+1.32	− 5.6	− 5.6	− 1.7
int-10	−15.2	− 3.1	+ 4.8	+2.05	−13.1	− 1.0	+ 6.9
int-20	−21.0	− 8.2	+ 0.8	+1.76	−19.2	− 6.4	+ 2.6
int-50	−16.6	−16.6	− 4.0	+1.65	−14.9	−14.9	− 2.3
max-20	−48.0	−15.7	−10.9	+2.75	−45.2	−12.9	− 8.1
max-50	−44.5	−21.5	−14.7	+2.29	−42.2	−19.2	−12.4

6.9 Costs and benefits

In the determination of the cost/benefit considerations, a comparison has been made between the situation with and the situation without a water supply project. In the latter situation, the zero-situation, it is assumed, that the existing supply system has not been used at all. The expenses for the supply by means of the water supply system have been put on the side of the costs; so this is the increase of costs with respect to the zero-situation. The benefits also include the increase of the gross yields less the increase of the production costs caused by the use of water. In various situations it is impossible to indicate directly the benefits of complementary water supply. These, for instance, consist of savings of production costs, or savings that can be obtained with respect to the most favourable alternative water supply possibility in the zero-situation.

The plan in which the difference between the total benefits and the total costs of the water supply system, the net plan-effect, is maximal, is the most attractive. In order to get a better view in this matter, the costs and the benefits have been expressed in the same unit. For this purpose the mean value of the complementary water supply on behalf of the pressure groups, which can scarcely, or cannot, be expressed in money units, has been estimated on f. 0.10/m^3. The net plan-effect of this is mentioned in table 6. The application of different sprinkling percentages in farming has also been considered.
It appears that the net plan effect is favourable if the sprinkling percentage is low. This is especially caused by the fact that sprinkling by means of expensive automatic reels is, in national economic terms, not profitable on better soils which need only a small complementary moisture supply over more years on an average. If sprinkling is limited to soils which are sensitive to drought, a number of plans turn out to be positive. Calculations of sensitivity prove that the order in the net plan effect does not change if the value of the complementary water supply is changed for the benefit of the various pressure groups. Attaching importance to the different values of the various pressure groups may influence the choice. The importance of the values will be determined on the grounds of political considerations, which will influence the order of plans.

6.10 Optional order of plans

The calculations and the speculations lead to a classification of the plans in three groups:

- promising plans : int-10; min-10; min '76
- moderate plans : min-20; int-20
- bad plans : min-50; int-50; max-20; max-50

The most important data of the three promising plans are mentioned in table 7.

Table 7 Some data of the three promising plans

Plans	Pumping capacity in m^3/min. (when 5-10% sprinkling)			Total quantity to be pumped up in 10^6 m^3 (yearly, long-term on an average)	Expenses for water supply, long-term on an average in 10^6 Dfl yearly			Benefits of complementary water supply in 10^6 Dfl yearly			Benefits minus expenses in 10^6 Dfl yearly (10−7)
	existing	new to build	total (1+2)		prim. supply system	sec. and tert. supply system	total (5+6)	farming	remaining pressure-groups value Dfl 0,10/m^3	total (8+9)	
	1	2	3	4	5	6	7	8	9	10	11
min'76	260	900	1 160	32.3	3.8	4.6	8.4	13.3	1.4	14.7	6.3
min-10	260	620	880	30.8	2.8	4.0	6.8	12.0	1.5	13.5	6.7
int-10	260	960	1 220	42.0	3.8	8.4	12.2	17.0	2.1	19.1	6.9

Possibilities for more efficient use of drinking water and industrial water supplies in The Netherlands

F. Wildschut

7 Possibilities for more efficient use of drinking water and industrial water supplies in The Netherlands

SUMMARY

In the paper the following categories of use of water are distinguished: domestic use; industrial use; commercial, public, agricultural and recreational use; etc.
The total annual water use in the Netherlands (excluding cooling water obtained from surface water sources and water used for irrigating crops) is approximately 1,580 million m^3. About two-thirds of this is supplied by water supply companies. There is considerable variation in the structure, as well as in the level of rates charged by the 100 or so water-supply companies. Such differences are the result of disparities in the nature and the level of costs incurred in the exploitation of drinking-water resources; they depend to a large extent on local circumstances and historical factors.
Ways of influencing water consumption by means of rating are: raising the charges; a further shifting of the costs from the fixed rate to the charge per cubic metre; the introduction of a progressive charge and the differentiation of rates according to the pattern of usage.
There are a number of practical drawbacks associated with the implementation of these measures and their effect on domestic use would probably be very small.

In addition to measures relating to the level and structure of rates charged, the following factors may also influence water consumption:
- linking the amount of the statutory water-purification levy to actual water consumption.
- promoting the installation of individual water meters in buildings hitherto unmetered, and fitting meters in new buildings.
- providing information.

The impression exists, that there is a great deal of scope for saving water, especially with regard to industrial use, where in recent years consumption per unit has already been reduced. This can be encouraged by making funds available for selective research projects.

7.1 Categories of use

A distinction can be made between the following categories of water use:

• Domestic use; this is water used in and around homes intended for permanent occupancy.

• Industrial use; that is, use of water by enterprises listed under the Industry and Mining category according to SBI (Standard Business Classification) 1974 of the Central Bureau of Statistics (CBS).

• Commercial, public, agricultural and recreational use, (COAR) use; that is, water used by enterprises classified by SBI in the following groups:
- agriculture and fisheries;
- building construction, installation and repair companies;
- trading companies, hotels and restaurants;
- transport, storage and communication companies;
- banks and insurance companies, professional services;
- other services, social services, hospitals.

• Other use; this is calculated by subtracting the total quantity used by the various categories from the total supplied, and includes the following:
- rinsing water used in purification plants and water used by water-supply companies to flush their network of supply lines;
- unmetered water used by fire brigades, fountains, etc.;
- leakages at the water-supply company, the mains and branch pipes;
- discrepancies in quantities measured.

7.2 Water use

The following table shows the quantities of water used in the abovementioned sectors (supplied by the water-supply companies and from the resources of the users themselves).

Year	1967	1972	1976
Sector	Annual Use (10^6 m^3)		
Households	417	452	521 **
Industry (excluding cooling water from surface water)	785	793	648
COAR * (excluding ground and surface water used for spraying crops, etc.)	145	264	320
Other	68	69	90
Total	1415	1578	1579

* As far as is known.
** Calculated.

7.3 The role of water-supply companies in water use

According to statistics provided by the Vereniging van Exploitanten van Waterleidingbedrijven in Nederland (VEWIN) Association of Water Suppliers in the Netherlands), the quantities of water supplied in the years referred to in the table were as follows:

Year	Volume supplied (10^6 m^3)	Drinking water supplied (10^6 m^3)
1967	762.9	741.7
1972	957.5	909.9
1976	1,084.5	1.033.7

The abovementioned statistics also show that domestic use accounts for approximately 55 per cent of the total amount of water supplied, non-domestic use approximately 38 per cent and use in water-supply plants and leakages about 7 per cent. For reasons associated with the methods of supplying data these percentages are not completely accurate.
The corresponding figures for the year 1952, in which 339.9 million cubic metres were supplied (of which 338.9 cubic metres were drinking water), show that since then water use has increased considerably.

7.4 The cost of supplying water

The cost of supplying water may be divided into production costs, distribution costs and selling costs. Once these costs have been established accurately, the problem of determining rates can be related to the question of how costs are allocated among user-categories.
One component of the costs is more or less directly related to the existence of a take-off point, e.g. the cost of reading the meter, accounting, invoicing and debt collecting services and the cost of the water meter and service pipes; such expenses are largely independent of the quantity of water supplied. These costs, and a proportion of the general costs allocated to this service component, are usually charged at a flat rate.

If the rate of water use was constant, production costs could easily be charged on the basis of the amount used; however it hardly ever shows such regularity.
The fact that water use is not constant is a factor resulting in increased costs. As a consequence:

- the capacity of various types of equipment in the production sector has to be increased;

- water reservoirs have to be constructed for processed water;
- the capacity of the supply network has to be larger than if the use of water was regular in time;
- energy costs are higher.

7.5 Factors influencing rating

The variations in the consumption pattern of the various users complicates the allocation of costs to them.
On the other hand, there is a need to keep rating procedure simple, so that rates are unambiguous and understandable to the general public and also easy to deal with administratively. The number of rate categories should not be too large; this leads very often to a discrepancy between what is theoretically desirable and practically possible.
For example, tariffs generally do not take into account the location of the consumer within the water-supply company's distribution area. For practical reasons therefore, there is no distinction according to residential density, distance from the water main or distance from the pumping station.

It is further to be noticed that a number of social criteria, in combination with other factors, play a role in determining the various rates.
The main criteria used in determining domestic rates are:

- the diameter of the pipes;
- the number of taps or outlets;
- the ground area of the dwelling;
- the floor area of the dwelling;
- a flat rate plus a charge per cubic metre used, or used in excess of a certain quantity;
- the rentable value of the property for tax purposes;
- the number of persons occupying the dwelling.

The manifold combinations of the abovementioned criteria employed by the water-supply companies, and the different emphases they place on each of them, makes it extremely difficult to make comparisons. Not only are the levels of the rates different, but also the rating structure on which they are based. On 1 January 1978 there were 103 water-supply companies active in the Netherlands.
One may well wonder whether the application of the various criteria – for some of which there are historical reasons – is sufficiently justified in view of the current social situation. At present, there is a clear tendency to introduce uniformity in the rate bases. The VEWIN has appointed a special committee to study this matter and its recommendations may be expected in the near future.

As regards the present rates, it may be said that generally speaking the water-supply company's fixed income (mostly the flat rate charges) is insufficient to cover its overheads. In order to cover their total costs, the companies are therefore compelled to charge more for the quantity of water used than would be justified on the grounds of the simple allocation of costs.
In addition, most rates are subject to a certain degression, in other words the higher the consumption, the lower the price per cubic metre since, provided total use remains within the existing capacity of the water supply plant, it is only the running costs that go up.
With regard to the smaller users, distinction between the following groups of rating systems can be made:

- Unmetered: a fixed rate per period of time, regardless of the quantity used. This may be based on the number of rooms in the house, the ground area, the number of taps, the aperture of the water meter, etc.

- Metered:

- a flat rate, i.e. a fixed rate per period of time plus a charge for the cubic metres used;
- a guaranteed flat rate, i.e. a fixed rate per period of time that includes the certain quantity of water that may be used at no extra charge. Any quantity used above that is charged per cubic metre;
- the so-called 'unitory' rate, whereby there is no fixed rate and the user only pays for what he has used.

The fixing of the rates is the responsibility of the water-supply companies, although the approval of the Minister for Economic Affairs is required for any change.

The cost-price of water is affected by the following factors which may differ considerably:

- the location of the source;
- the nature of the source;
- the need for reservoirs;
- the method of treatment used;
- the length of pipe lines and mains needed in relation of the number of user outlets.

A reorganization is expected to reduce the numbers of water-supply companies and thus the number of different rate levels, but this is not expected to reduce the spread between the rate levels themselves. In addition to the factors mentioned above, the differences in cost price are also the result of differences in depreciation rates and methods of calculating depreciation, and whether or not the aim is to cover costs annually. Depreciation may be calculated on the basis of the historical cost price or on the basis of the replacement value. With few exceptions the water-supply companies calculate depreciation on the basis of the historical cost price.

In private enterprise, an important factor in favour of calculating depreciation on the basis of the replacement value is, that when investments have to be made for replacing equipment, they are not dependent on external sources of finance and the continuity of the company is not endangered on that score. The special position of the water-supply companies with their monopolies removes in fact all external financing problems. Moreover, one might wonder, whether it was morally acceptable for a public utility to create capital with the aid of borrowed money of which only the nominal value and interest have to be repaid, when its investments are completely free from risk.

In view of this, it is understandable, that practically all water-supply companies take as their point of departure the historical cost price. Furthermore, it should be borne in mind, that depreciation on the basis of the replacement value is extremely complicated and if companies were to switch to that method, it would lead to considerable increases in the rates charged.

Of an entirely different nature is the problem of covering the costs annually or over a much longer period. Expansion of the capacity of companies using groundwater as a source will, generally speaking, not take place in large increments, and investments for expansion will accordingly be relatively modest. In that case, covering the total costs from year to year would present no problem.

Expanding the capacity in minor steps is far more difficult for companies that are dependent on surface water, and the costs of the expansion would constitute a far larger proportion of the total increased costs than in the previous case. Furthermore, during the initial period there would be unused capacity which only gradually would decrease as water-use increases. If the annual system were used, the rate would initially have to be raised drastically and dropped gradually as the degree of utilization of the capacity created by the new investment improved. In order to prevent such an irregular pattern of charges, the water-supply companies use a so-called 'unit' system, whereby the expected total costs spread over a number of years are divided by the total estimated supply of water for the same period. The result is the average cost per cubic metre on which the tariff may be based.

However, the application of this method must be accompanied by a special system of financing, because during the initial period, the income derived from water rates will be insufficient to cover repayments and interest due. The company is therefore compelled to obtain funds from other sources, and this, depending on a number of factors, may well cause the total amount borrowed to rise to twice the value of the actual investment.

7.6 Ways of influencing water consumption

In addition to affecting the determination of charges from the cost price point of view, both the rate structure and the level of charges may be used to achieve other aims. In the past, the social element used to be of considerable importance. Nowadays, the question whether water use can be influenced by the rates set is receiving more emphases. There are a number of ways of achieving this:

7.6.1 *Raising the charges*

Although no research data is available for the Netherlands, it is surmised (based on research done abroad), that for a number of reasons, there is very little elasticity in the demand for drinking water, especially for domestic use. It is to be expected that only a rather drastic price increase would reduce consumption to some extent, at least in the domestic sector. It should be borne in mind that this would probably be at expense of the poorest groups of the population and would not be justifiable in view of the health risk it would entail. In other sectors, notably industry, the sensitivity to price increases is larger.

7.6.2 *A further diversion of the costs from the fixed rate to the charge per cubic metre*

This shift (which, as seen earlier, is already taking place to a certain extent) is toward lowering the fixed rate and raising the charge per cubic metre. This could perhaps bring about a slight reduction in consumption. One objection to this is that the price structure departs still further from the cost-price structure within the company, and that this limits the ability to recover the running costs, if the actual supply falls short of expectations.

7.6.3 *The introduction of a progressive charge*

By this, we mean a rate structure in which the price per cubic metre increases with the quantity used. Here too, there is the objection that such a price structure results in an increased deviation from the cost-price structure. Furthermore, there are a number of serious practical problems associated with the determination of the factors that regulate consumption and with the establishment of the relevant standards. This results either in an extremely complicated and expensive accounting system, or in a system which is not equitable to all users. Also, the progression would have to be very steep for it to have any appreciable influence on consumption.

7.6.4 *Differentiation of tariffs according to pattern consumption*

Variations in climate and temperature give rise to an irregular pattern of water use, especially in the case of domestic use. During a number of months (mainly June, July and August) there is a pronounced seasonal peak, to which the capacity of the water-supply company has to be geared and which causes the facilities to be used partly during the rest of the year. Smoothing down this peak, results in a considerable reduction in capacity required to satisfy demand, thereby permitting a reduction in the cost per cubic metre. Attempts can be made to reduce the increased consumption by introducing a higher rate during the busiest months and a lower rate during the other months of the year. But here too, the price increase would have to be considerable for it to have the desired effect. The question immediately arises, whether the curtailment in water use, to which the lower income groups of the population would be forced, is acceptable from the point of view of public health. An additional objection is that, although this system would save the water-supply company money, it would also involve additional costs, as it would necessitate the water meter being read at least twice a year, in principle simultaneously for all users, whereas at present the meters are read once a year at varying times throughout the year.
The effect the abovementioned measures would have is, at present, difficult to determine, because the relationship between price and use-patterns is inadequately understood. In view of the minor part the cost of drinking water plays in the family budget, the effect of such measures in this sector would probably be very small. In any case, there are a number of practical drawbacks to their implementation.

In addition to measures relating to price-level structure, the following may also influence water consumption:

• Linking the amount of the water-purification levy imposed under the Pollution of Surface Waters Act to water use: For private households the purification levy is a fixed one, and is the same for all dwellings (except for those occupied by single persons, who may request that they be assessed on the basis of one population equivalent (p.e.)). This system, which does not take into account the quantity of waste-water discharged and the degree of pollution, is felt to be unjust. Although it is not feasible to achieve an exact basis for assessment (the extent of pollution cannot be determined for each individual dwelling), it would eliminate some of the inequity, if the levy were linked with the amount of water used. Even though the price of water would remain the same, nevertheless, the link would lead to the result that should a reduced consumption of water occur, financially this would have a double-edged effect. The combined effect could, depending on the region, have some influence on water consumption. A drawback of this system is that it can be used only for metered dwellings.

- Promoting the installation of water meters in buildings hitherto unmetered and fitting meters in new buildings: At present about three-quarters of all houses in the Netherlands have water meters. There is also a small percentage of blocks of flats with one collective meter; the remainder is unmetered. The percentage of metered dwellings is increasing very gradually. The flat rate charge for unmetered use, which is independent of actual consumption, is not considered to stimulate the rational and efficient use of water. In view of this, and the fact that for reasons of equity everyone should pay only for what he or she uses, the installation of water meters should be promoted. One cannot expect however to reach a full 100 per cent coverage; for instance in Amsterdam, there are existing buildings where this would not be feasible either technically or financially.

- Providing information: As capacity expansion involves the use of considerable extra land (*inter alia* for reservoirs), especially for water-supply companies which are dependent on surface water, the attention of the public should be drawn at an early stage to the consequences of steadily increasing water consumption. With regard to industrial use, research should be done into production methods which save water; its results should be made widely-known. With regard to domestic use, information is needed about the quantities of water required by various types of domestic appliances. The aim should be to encourage the sensible use of water and a sense of responsibility in the individual in this regard.

The effect of these three measures is difficult to assess. It is surmised, that with regard to the provision of information there is a great deal of scope, especially for research into water-saving methods of industrial production.

Economic instruments to promote a rational use of water policy and experience in The Netherlands

T. Trouwborst and A. de Kort

8 Economic instruments to promote a rational use of water policy and experience in The Netherlands

SUMMARY

The following three economic instruments are available to promote the rational use of water: levies on discharges, levies on products that cause pollution of water, and levies on abstraction of water.
In the Netherlands, levies are imposed for a specific purpose; the revenue has to be used to finance measures to combat pollution. The basic principle is that the polluter pays. The aim is for the social costs of the production to be reflected in the costs of the products. In many cases the levies are high enough to discourage pollution and to stimulate abatement of pollution at source.
Emission standards and environmental requirements, where necessary adapted to local conditions, constitute a major instrument in efforts to combat the pollution of surface waters. Internationally accepted environmental policies and emission standards are economically important.
The promotion of clean technologies and measures to combat pollution at source are crucial in economic terms. To this end, it is important that companies should take account of environmental requirements at an early stage of process-development and anticipate them.

8.1 Introduction

In many countries the shortage of water largely derives from the fact that the water available is not of a suitable quality. Many surface waters have been polluted so heavily that they no longer serve their natural functions, and a great deal of effort is required to render the water suitable for human consumption or other purposes. It is often the case that expensive artificial means have to be resorted to on an extensive scale in order to provide water of adequate quality to meet local shortages. To illustrate the point, one need only mention the large buffer basins that had to be constructed in the Netherlands to ensure the supply of drinking water from surface water sources, while infiltration techniques had to be used in the dunes to help cope with major deviations in the quality of the raw water so as to ensure a continuous supply of good quality water. Even so, expensive purification processes are still required to remove any remaining impurities. In spite of all the measures taken, the question remains whether the methods applied do in fact filter out the impurities sufficiently to produce water which is not a danger to public health. Given the objective of a rational use of water, we must therefore set out to:

- reduce the impurities in effluents and combat pollution at source;
- reduce unnecessary consumption of water.

8.2 Economic instruments

The following instruments can be used to promote the rational use of water:

- discharge levies; levies on products which indirectly rise to water pollution;
- levies and licenses covering the abstraction of water; price regulation of water (for domestic or other purposes);
- the introduction of licences for discharges and the setting of uniform emission standards;
- grants to encourage pollution-abatement measures; and
- the promotion of research and development into new techniques of combatting pollution and into clean technologies.

8.3 Levies

The Netherlands' Minister of Health and Environmental Protection recently submitted a Policy Document to Parliament in which he outlined the basic premises of Dutch policy on environmental levies. The underlying idea is the 'polluter pays' principle which, in the form in which it has been worked out for the European Economic Community (EEC) means that parties in principle must bear all the expenses connected with:

(a) steps to prevent pollution of the environment by agents resulting from activities in which they have been engaged;
(b) measures taken within to prevent substances reaching the environment in an undesirable state, form or composition;
(c) a levy on the discharge of agents which arise and are discharged despite the anti-pollution measures referred to under (a) and (b); such levies may be used for joint (Government) measures to protect the environment. The application of the polluter pays principle means that the costs of certain Government measures, including purification by the community, is charged to the polluters by means of levies.

The application of the principle may have as a consequence that the price at which

the product or service is offered is a more accurate reflection of the total social costs of the product; this fosters the application of economically rational decision-making.
The levies are charged so as to be in a position to take measures to combat pollution and are therefore imposed for a specific purpose. Consequently, they do not reflect directly the damage caused by the particular discharge, though of course efforts should be made to establish as close a link as possible between the levy (both the basis for it and the actual rate) and the nature and volume of the substances discharged.

In the Netherlands levies are imposed on the discharge of oxygen-binding substances. The basis for the levy is the population-equivalent (p.e.). The actual rate differs according to the regional water authority and varies between Dfl 15 and Dfl 45 per p.e. (1978 figures). The levy on discharges into fresh open-water managed by the national Government (major rivers) was Dfl 20 per p.e. and for discharge into state-managed saline open-water (coastal waters) Dfl 14 per p.e. In many cases the magnitude of the levy on oxygen-binding substances is such as to induce companies to take extensive steps to reduce the emission of water-borne pollutants or to switch to purifying the effluent on their own account. In such cases the levies act as a deterrent.
A number of regional water authorities in the Netherlands have also introduced levies for other than oxygen-binding substances, such as heavy metals. There is a trend towards making a levy on heavy metals nationally applicable.
Measures recently proposed by the Dutch Government to reduce the imposition on the aquatic environment caused by phosphates, included a proposal to introduce a levy on their discharge. It was also suggested that a product levy be introduced on detergents containing phosphates, the target being to foster the introduction of phosphate-free detergents in the near future. The revenue from the levies was to be used to finance the requisite measures.
In many cases levies alone will not control the pollution of surface water, one reason being that the levy cannot fully reflect the harmfulness of the discharge. Additional instruments such as licensing then become necessary.

8.4 Levies on the abstraction of water; price regulation of water

At present no national levy is charged in the Netherlands for the abstraction of water from surface water or groundwater sources. Legislation is being prepared to regulate such withdrawals (the planned Water Management Act and the Groundwater Act). Only the abstraction of groundwater by drinking-water supply companies is currently regulated by law, while abstraction of groundwater by industry is regulated by provincial by-laws. Presently discussions are being held concerning the pros and cons of the introduction of levies for the abstraction of groundwater by industry so as to promote its more rational use. The price of water supplied by the drinking-water industry for domestic use was approximately Dfl 1.50 m^3 for treated surface water and approximately Dfl 0.75 per m^3 for treated groundwater. In general the current price of drinking-water is not the major inducement for reducing water consumption.

8.5 Licences and uniform conditions

Measures which impose constraints will generally have economic repercussions and it is therefore important that they find international acceptance. In this context it is worth mentioning that the European Economic Community has laid down or is preparing water quality standards and emission policies and is further working on harmonizing environmental policy. Its recent directive designed to protect groundwater against pollution by the discharge of certain dangerous substances was a significant step to counteract water pollution. The directive concerned prohibits in principle the discharge of dangerous substances (i.e. those on the 'black list') into groundwater throughout the entire region of the European Economic Community.

As indicated in the last paragraph of section 8.3, there should be a licensing system for discharges as well. Under the terms of the Pollution of Surface Waters Act (*Wet Verontreiniging Oppervlaktewater* – WVO) it is prohibited in the Netherlands to discharge substances without a licence. Factors taken into account in the issuance of licences include the nature of the substances to be discharged and local conditions. The basic principle is that pollution by substances which constitute a particular hazard to the environment by reason of their properties ('black list' substances) must be eliminated using the best technical means available. Pollution by substances appearing on the so-called 'grey list' must be reduced, and rehabilitation programmes must be drawn up taking due account of the best practical means of doing so. The principles set forth above have also been laid down in the EEC directive concerning pollution caused by certain dangerous substances discharged into the aquatic environment (directive 76/464/EEC Official Journal No L. 129 of 18 May 1976, p. 23). It appears that economic considerations and other factors will in the future lead to the imposition by law of more uniform constraints on the emission of water-borne pollutants. Such limitations will take the form of a minimum requirement which can be made more stringent according to the situation. The (Dutch) Committee on the Implementation of the Pollution of Surface Waters Act is in the process of drafting proposals for uniform regulations for the discharge of polluting substances for the various branches of industry, for example for (a) paint, lacquer/enamel and printing ink factories, (b) garages and allied businesses and (c) pesticide manufacture. The Union of Waterboards has compiled a list of recommendations on the requirements to be satisfied for the discharge of a number of heavy metals.

8.6 Grants as a means of encouraging anti-pollution measures

Conditions governing the allocation of grants towards the cost of combatting pollution were laid down in a recommentation of the Council of the Communities on 3 March 1975. The document indicated the Council's wish that the revenue from the levies should also be used to assist in financing installations to protect the environment, which polluters are obliged to install. Such measures should be incorporated into a medium-term financing programme of the national Governments. In exceptional cases government-financing of individual measures would be permitted, for example if the immediate application of stringent standards would cause serious economic disruption. Grants are allocated in the Netherlands for technical pollution-abatement for instance for the construction of treatment plants.

Measures against substances that constitute a hazard to the environment and which usually cannot be rendered harmless by biological treatment plants will often have to be taken at source, i.e. by modifications to the production process. It is difficult, however, to draft regulations concerning the issuance of grants for such cases.

8.7 The promotion of research and development into new techniques for combatting pollution and into clean technologies

Promoting the development of new technologies and equipment is to some extent a responsibility of the national Government. It belongs to the task of the Government to institute and apply a range of instruments which ensure that development in the desired direction does in fact take place. In particular the Government must intervene in areas where development cannot be expected to take place without its initiative, either by acting as co-ordinator or as provider of grants.

The Minister of Health and Environmental Protection has instituted formal co-operative links between the national Government and industry for the purpose of promoting the development of clean technologies, *inter alia* by subsidized research projects. Although the funds earmarked for this purpose are relatively modest, considerably importance is attached to this form of co-operation; a number of major projects have been supported, including the development of anaerobic treatment of waste water, projects in the leather, textile and electroplating industries, and the removal and recovery of chromium from the effluent of tanneries. In some cases the value of the material recovered was such as to make the technology so developed self-supporting. Application in practice of the findings of the research projects can be stimulated by giving wide publicity to the results of the new technologies.

Recently the Government of the Netherlands submitted to Parliament a Policy Document on Innovation which indicated in general terms the economic importance of taking full account of environmental factors when new processes and products are being developed. The document argued the case that technological developments should anticipate future environmental requirements. By taking due account of environmental factors at an early stage in the development of processes, it becomes easier to incorporate additional features into the process, facilities which certainly in the long run will produce better results, *inter alia* because they also take the energy and raw materials situation into account. A further important aspect with regard to the pollution of the environment is that in product and process development ample attention should be paid to such factors as the durability of the product and the scope for recycling waste. In general it can be stated that, given the environment policy, a vigorous effort by industry directed towards the development of clean technology may produce in the long run economic advantages for industry.

8.8 Industrial research

Some understanding of the economic repercussions of technical measures for pollution abatement is desirable, so that steps can be taken in good time to prevent possible economic disruption. Analysis of individual industries can provide this knowledge; such investigations could cover:

- a determination of the magnitude of the problems;
- a survey of possible counter-measures;
- an assessment of the effectiveness of these counter-measures;
- an estimate of the added investment and operating costs that the measures entail;
- a forecast of the consequences of specific techniques for investment, costs, turnover, employment, value added, etc. Conclusions should then be drawn from the analyses on the need for measures to deal with possible economic repercussions.

Charging policy in the protection of surface water against pollution in the catchments of the rivers Dommel and Aa

E. C. W. A. Geuze and B. G. M. van de Wetering

9 Charging policy in the protection of surface water against pollution in the catchments of the rivers Dommel and Aa

SUMMARY

In most provinces in the Netherlands, the task of water quality control was assigned to water boards, which traditionally perform the task of quantitative regional water control. As the conjunction of interest, payment and right of participation is characteristic for this functional type of government agency, the financial base for an active water quality management was laid by establishing a levying system, in which the pollutors are charged. As a unit of pollution, the population equivalent (p.e.) was introduced.
Waste materials subject to a charge are oxygen-consuming substances and certain toxic materials. For oxygen-consuming substances, the population equivalent has been fixed at 135 gr COD and 10 gr N-Kj *per capita* per day.
For domestic consumers, the pollution load has been set at a fixed number of p.e. per household. For industrial pollutors, the levy is based on the quantity of waste material, and of discharges to a treatment plant, including the volume of waste water. The fixing of the levy for a small pollutor (less than 1000 p.e.) is usually an administrative matter; the pollution caused by large pollutors, however, is determined by measurement. The proceeds of the levy are used to defer the costs of water pollution abatement measures.

9.1 Introduction

9.1.1 *Hydrological context*

The international reknown which the Netherlands has attained in the field of the development of water resources is largely due to the management of the western lowlands, a part of the country generally situated below tidal level and consisting of 'polders': tracts of land surrounded by dikes and drained by a system of closely-spaced drainage ditches, pumping stations and elevated canals, so-called 'boezems'. Little attention is, however, generally paid to the fact that approximately half of the territory of the Netherlands, roughly speaking the southern and eastern parts of the country, is elevated above sea level and therefore drains by gravity.

One of the provinces located in this part of the Netherlands is North Brabant. Among its most important rivers and streams are the Dommel and the Aa, which

join to form the Dieze just before debouching into the Meuse. The area drained by the Dieze (approximately 2,300 km^2 in the Netherlands) exceeds the catchment areas of the other local rivers. The area of the two catchments is approximately 188,000 ha for the Dommel and 87,000 ha for the Aa. About 40,000 ha of the Dommel basin is on the Belgian side of the border, the balance belongs to the Dutch province of North Brabant; 4,000 ha of the basin of the Aa is in the Dutch province of Limburg. Several important canals for inland shipping traverse both catchments.
In the Netherlands, there is usually a considerable abundance of rainfall in winter and in spring, whilst in summer precipitation is generally deficient. Consequently, in the summer the basins of the rivers Dommel and Aa often suffer from a shortage of rain. In a dry summer, the groundwater table often drops up to 1.5 m. below the winter level and many small streams dry up. In order to maintain groundwater elevation during dry periods at levels required for agriculture, an extensive system of dams and weirs has been built.

9.1.2 *Socio-economic framework*

The Dutch part of the catchments of the Dommel and the Aa are densely populated and now have a population of around one million, of which 43 per cent is concentrated in the towns of Eindhoven, Helmond, Tilburg and Bois-le-Duc; the balance of the population inhabits small towns and villages or lives in the countryside.
Whereas up to recent times, mixed farming was predominant, intensive cattle farming has for some time now shown considerable expansion; this development is continuing. The average size of a farm in this area is from 10 to 20 ha (24-50 acres).
Industry has evolved only since the early twentieth century. One of the factors which stimulated this development was the rapid growth of the local population. Manufacturing industry is mostly concentrated in and around the cities. Agrarian industries are distributed more evenly over the area. From a water management point of view, the significance of industry primarily derives from the discharge of (treated) effluent into the waterways and the withdrawal of groundwater used for cooling and processing purposes.

9.1.3 *Water quality and politico-administrative structures*

In the post-war period, water pollution in the catchments of the Dommel and the Aa assumed disturbing dimensions. Two main causes could be distinguished: the rapid growth of industry and population, and the expansion of drinking water networks, which in turn led to the construction of central sewage systems. The quality of water downstream from the sewage outlets often was very poor, and at many locations in the catchments, the effluent of towns and villages constituted a heavy burden for the streams, which generally were of small size. Problems arose especially in summer, when waste water made up a major proportion of the discharge of many streams.

At an early stage the provincial government of North Brabant province recognized the seriousness of the situation in respect of water pollution in these regions. Following the recommendations of two investigating committees, it decided upon a regional approach to the problem, in conjunction with the existing organization for quantitative regional water control (the water board). On 1 January 1950 the responsibility for active water quality control in the Dommel basin was assigned by the provincial authorities to the Dommel Water Board. In 1957, the Aa Water Board was similarly charged with the control of surface water quality in its territory.

Water boards are functional 'institutions', or government agencies created for a specific purpose and restricted to a specific area. This restriction in their function constitutes their main difference to the other representative public bodies such as provincial and municipal councils, which exercise a general authority and function in their respective territories. Constitutionally, the provincial governments exercise much power pertaining to these water boards, including their initiation, evolution, abolition and supervision. Water boards are characterised by the conjunction of interest, payment and right of participation. This implies that everyone who is affected by the actions of a water board contributes towards the costs of its activities according to the size of his interest, and is also represented on the councils of that board.
To provide for a financial base for the implementation of water purification measures, a system of charges was established by the Dommel and Aa Water Boards. Although the conjunction of the magnitude of the interest at stake with the degree of liability has been a characteristic feature of the operations of water boards for a long time past, the introduction of the Pollutor Pays Principle (P.P.P.) clearly constituted an important feature of the new approach in the field of surface water pollution abatement. Subsequently it was to be established as a general principle and it was to form a basis of the Pollution of Surface Waters Act. (W.V.O.)

Before the W.V.O. was passed (1970), the provincial governments were responsible for the quality control of regional surface waters. By means of provincial regulations, the actual implementation was actually often delegated to water boards. In general, however, there was little active quality management (treatment of polluted water); control was usually limited to regulating, restricting and preventing pollution (passive quality control).

Nationwide active quality control only became practicable under the W.V.O., which constituted a turning point into the fight against water pollution in The Netherlands. This act clearly regulated the evolution of authority pertaining to active and passive water quality control and introduced a system of licences, levies and contributions which made for an effective approach to the abatement of surface water pollution. Under this act, quality control of national waters remained under the authority of the national government, which exercises passive control only. Passive quality control of non-national waters was placed under the authority of the provincial governments which may, in turn, delegate it (to water boards for instance). The functions and authority of the provincial governments in matters concerning regional active and passive quality control have been detailed in the act. Most of the provincial governments have delegated active and passive quality control to water boards (which were already in charge of quantity control) or to special boards created for this purpose, called Waste-water Treatment Authorities. In 1972, by virtue of the W.V.O., water quality control in the province of North Brabant was delegated to five water boards, among which were the Dommel and Aa Water Boards.

The water quality management policy as evolved by the two water boards found formal expression in the publication in 1974 of their Pollution Abatement Plans 1975 to 1980. These plans included a complete inventory of the sources of pollution and of the state of affairs concerning water pollution as of December 1973. On the basis of an analysis of the quality of surface waters, a series of provisional objectives for the improvement of water quality were set. In addition to the rehabilitation of the oxygen regimen of surface waters, the exclusion of toxic pollutans was stated as a central goal. To achieve this, a stringent system of licensing was to be introduced. After this formulation of policy, a detailed working programme for its implementation was added. The plan also included several long-term budgetary estimates, including prognoses of the magnitude of levies to be imposed.

9.2 Charging policy

In general it can be said, that after 1970 it was not accepted anymore that municipalities, industrial plants, etc., just dumped their waste water wherever they considered feasible. All involved accepted that a price had to be paid for the maintenance of a reasonable level of environmental quality. Whatever starting point chosen for the water quality to be established, in the study of the economic effects of the rehabilitation of the quality of surface water, the accent lies on costs. The benefits mostly lend themselves poorly for economic analysis.
It has been determined that on completion of the national programme for the

abatement of surface water pollution by oxygen-consuming substances, the production volume (excluding the environment sector), will be approximately 3.5 per cent lower than would have been the case without this programme. If the consequences for future economic growth resulting from the more stringent conditions for the discharge of polluting substances are also taken into consideration, an eventual reduction of the production volume of 4.5 per cent results (Central Statistics Office (CBS) and Central Planning Office (CPB) studies 1972). The CPB has concluded that the abatement programme for biologically degradable substances will pose no great problems for employment or the balance of payments. For this reason, there are no macro-economic constraints in respects of the conditions to be laid down for biologically degradable substances. If, however, other sectors of the environmental policy are also included in the analysis, the retarding effect on economic growth will be appreciably larger than the reduction referred to above.

As regards the effect of the rehabilitation of surface water quality on the budgets of the central and local government authorities (such as the two water boards considered), it may be worth noting that frequently the expenditures concerned will be met from funds not deriving from the general account. This is a result of the fact that the financial basis of the treatment-policy is provided by 'the pollutor pays principle'. The annual costs of the rehabilitation will be recovered from the pollutors by means of pollution charges. The financing of the requisite investments will create an appreciable demand on the national capital market. Whether use will be made of the potentially available financial capacity for the abatement of water pollution depends on the willingness to pay the interest, in view of the priorities assigned to environmental measures. In this context, it may also be noted that during the period 1965 to 1975 the national government imposed controls on investments by regional authorities. This resulted in certain restrictions on attracting capital.
As has been mentioned earlier, in the first instance the emphasis is placed on combating pollution by oxygen consuming materials and the exclusion of toxic substances. During this phase, economic investigations could be restricted to analyses for cost-effectiveness. In view of the limited financial resources available, it appears essential that for the further rehabilitation of water quality, a more penetrating economic optimalization should be performed, taking into account the experience already gained.

9.2.1 *Emission charges; principles and practice*

The levy is based on the quantity of waste material and for discharges into a treatment installation of one of the two water boards concerned, and also on the quantity of water, except when residential premises are involved. The most important features of the assessment are:

- the determination of the pollution load,
- the conversion factor, and
- the volume correction.

The pollution load has been defined in the W.V.O. as the quantity and/or the nature of the waste material, expressed in terms of pollution units, introduced into surface water or into a treatment facility. For oxygen-consuming substances the unit of pollution is 'the population equivalent' (p.e.): the average load produced by one person in one day. For substances of a poisonous nature, the unit of pollution is the quantity of waste material that effects the self-purifying capacity of surface water to the same extent as one population equivalent. For such substances, the population unit is expressed in kg/day of the pollutants concerned. For oxygen-consuming substances, the population equivalent has been fixed at 135 gr COD and 10 gr N per capita per day. For substances of a poisonous nature, the population equivalent has been set at 1 kg of the material concerned per annum.

Before the entry into force of the W.V.O., the Dommel and Aa Water Boards used their own system of charges developed earlier. The pollution-charge for residents was then based on the value of houses and buildings for tax purposes, but the charges for industry were levied in much the same way as now, except that they were based on BOD, instead of on COD and N. Since 1975, however, the system as prescribed by the W.V.O. is followed.
For the inhabitants of the province of North Brabant, the pollution load has been fixed at 3.5 pollution units per household. For residents living alone, the pollution load may be set at 1 p.e. upon request. For non-residential premises, the pollution load is determined by measurement, or alternatively by the multiplication of a waste water coefficient by an index, which is characteristic for the activities performed. The index mentioned may be the number of people employed in an enterprise, the number of guests staying overnight, the units of manufactured product, the volume of water consumed, etc., or a combination of such indices, if the activities indulged in warrant it.

When the pollution load of an industry exceeds 1,000 p.e., the pollution load is derived from measurements and sampling. On such pollutors, the obligation is imposed to monitor the pollution continuously or periodically. From the data provided by monitoring, the pollution load W in pollution units is calculated by the following formulae:

(a) for oxygen consuming substances in waste water:

$$W = \frac{Q}{180}(\text{COD} + 4.57\,\text{N})$$

(b) for toxic substances:

$$W = A$$

(c) for biologically treated waste water:

$$W = \frac{Q}{180}(2.5\,BOD_5 + 4.57\,N)$$

where:

Q = the volume of waste water discharged in m^3/day
COD = the chemical oxygen demand in mg/l
N = the sum of ammonium nitrogen and organic nitrogen in mg/l
A = the weight of toxic substances discharged in kg/annum
BOD_5 = the biochemical oxygen demand in mg/l

Formula (a) applies to all types of waste water with the exception of the effluent mentioned under (c). Formula (c) applies to biologically treated waste water, provided it meets the conditions stated in the permit. When applicable, the result of formula (b) should be added to that of (a). A formula for waste water containing relatively large quantities of solids in suspension was recently abandoned, as it was seldom used. The pollution load of non-residential premises, as determined in the manner detailed above, can be adapted to special circumstances by the application of a certain correction. Such corrections can be applied when, for instance, the pollution load varies considerably in time, or if the discharge takes places irregularly.

If the pollution load of the untreated effluent of an industry is less than 1,000 p.e., it is not determined by measurement, but established instead by multiplying an index by a waste water coefficient. For instance, a waste-water coefficient of 10 p.e. per employee has been set for perfume and cosmetic factories, while for yeast and methylated spirits plants, a coefficient of 8.4 p.e. per 1,000 kg molasse per annum has been fixed. For the industrial pollutors the pollution load, expressed in pollution units, is therefore calculated according to the formula:

$$W = \sum_{i=1}^{n} K_i \cdot a_i$$

in which n = the number of activities for which a separate waste water coefficient is to be applied
K_i = the index pertaining to a given activity
a_i = the waste water coefficient applicable for that activity.

With reference to the levy on water quantities, the correction is applied when a given pollution load is discharged into a sewage treatment facility with either larger or smaller quantities of water than is deemed normal. In this respect it is assumed that a pollution load of 1 p.e. is discharged in 100 litres of water in one day. The volume correction is expressed in pollution units. Based on 365 days in a year, the population equivalent or the pollution unit for volume has been fixed at 292 m^3 per annum (800 1/p.e./day. The volume correction is calculated with the following formula:

$$V_c = \frac{Q - Q_s}{292}$$

in which V_c = the volume correction

Q = the total quantity of water discharged per year, where necessary after adjustment; see the explanation for the conversion factor (m^3/annum)

Q_s = the standard volume-equal to $365 \times 0.1 = 36.5$ times the pollution load W (m^3/annum)

A conversion factor is applied when the discharge of waste water is spread regularly over a 24-hour period, as this presents advantages for processing in the treatment plant. According to the bylaws of the two boards, a conversion factor of 0.8 is to be applied to the total quantity of waste water discharged per year, if 45 per cent or more of its volume is discharged during the night (from 7 p.m. until 7 a.m.). Where a conversion is applicable, the formula for the volume correction is as follows:

$$V_c = \frac{0.8\,Q - Q_s}{292}.$$

The volume correction may have a positive, as well as a negative value. It is applied only when a discharge surpasses 3650 m^3/annum.

The total pollution load is determined by the sum of all pollution units. From the pollution load established in this manner, the amount of the pollution charges payable may be calculated. To this end, the pollution load is multiplied by the unit rate (Dfl per p.e.) fixed by the water board concerned.

Levies are in principle intended to defer the costs of pollution abatement performed by public authorities. The magnitude of the charge – which is determined annually by the water board – derived from annual estimates of the pollution load and of the expenditure on abatement activities. An example of such calculation is given in table 1.

The charges are adjusted annually in order to cover the rising costs resulting

Table 1 Example: Computation of pollution charges (1973 prices)

Dommel Water Board

1973 Estimate of the charge per unit of pollution for the year 1977

	Investments Dfl 10^6	Annual expenses Dfl 10^6
Trunk sewers	86.1	8.6
Treatment stations	155.5	22.5
Collecting expenses	–	1.0
General expenses	–	1.0
	241.6	33.1

Charge for a total load of 1.435×10^6 pollution units – Dfl 23.– per p.e.

Aa Water Board

1973 Estimate of the charge per unit of pollution for the year 1978

	Investments Dfl 10^6	Annual expenses Dfl 10^6
Trunk sewers	23.6	2.6
Treatment stations	66.4	10.8
Collecting expenses	–	0.7
General expenses	–	0.7
	90.0	14.8

Charge for a total load of 6.3×10^5 pollution units – Dfl 23.40 per p.e.

from continued investments in treatment facilities and from inflation. Table 2 presents a summary of the development in time of the magnitude of the charge per unit of pollution. From the example referred to above, it is obvious that the amount of the levy is closely related to the pollution load, and to the extent in which pollution abatement facilities are being, or will be, constructed. The procedure used ensures that the cost for the rehabilitation of the quality of open water is apportioned pro rata to those who cause the pollution.

Within the area controlled by the two water boards, there is no discrimination in respect of the charges per pollution unit between residential and industrial pollutors. However, the magnitude of the charge imposed by different water boards varies. Such differences derive from the principle 'the pollutor pays', and are not aimed at slowing down or promoting industrial development. The relatively high

Table 2 Pollution charges
Rates in the periode 1957–1980 for the Dommel and Aa Water Boards

	Year	Dommel	Aa
		Dfl/p.e.	
Before W.V.O.	1957	0.57	
	1960	0.65	0.22
	1965	2.25	0.78
	1966	2.75	0.94
	1967	2.75	1.17
	1968	3.20	1.17
	1969	3.70	1.75
	1970	4.50	2.35
After W.V.O.	1971	5.20	3.00
	1972	7.00	3.50
	1973	9.00	5.80
	1974	11.00	8.60
	1975	13.00	10.68
	1976	18.00	17.04
	1977	23.04	22.32
	1978	25.92	25.92
	1979	28.08	25.92
	1980	30.48	31.44

charges of certain water boards are mainly caused by the recent construction of treatment facilities (rising cost of building), and by the fact that in some water (quality) boards fairly small treatment plants predominate.
Through legislation a system of pollution charges has been introduced in order to recover the cost of measures aimed at combating and preventing surface water pollution. An underlying assumption was that these levies would be an incentive to reduce water pollution, particularly in the case of oxygen-consuming substances. Levies cannot by themselves effect a rehabilitation of surface water quality, but in combination with a licensing system aimed at preventing the entry of deleterious substances they do create a good starting point for the initiation of an integral policy for the control of surface water pollution.

From an expenditure point of view, the fixing of the levy for the smaller pollutor (less than 1,000 p.e. and in some exceptions less than 100 p.e.) is usually purely an administrative matter. The pollution caused by large pollutors is determined by means of data derived from measurement by the enterprise. When based on measurements, the imposition of a levy is invariably preceded by a discussion of the results of the measurements with the enterprise concerned. After the levy is imposed, a period of grace is allowed in which to effect payment. If the account is not settled in time a demand notice is sent. If still no response is received, the claim may be handed over to a bailiff. As a rule, however, a last reminder will be sent in which a final data of payment is given. If this period is exceeded, a court order is obtained and a bailiff is instructed to obtain payment. If a ratepayer finds the levy demanded excessive, he or she can lodge an objection against the charge imposed to the executive of the water board by means of a memorandum of appeal. After evaluating the information contained in this notice, the board will arrive at a decision. If this is again not acceptable, further appeal is possible to the fiscal court of justice.

9.2.2 *Social and economic costs and benefits*

As regards the economic impact of pollution-abatement measures, it is very difficult to provide hard facts on figures to quantify the effects concerned. Undoubtedly, the rising level of charges has put an extra burden on pollutors, especially on industry, since part of it was in very weak position already. In the regions controlled by the Dommel and Aa waters boards, this is for instance the case with the textile and leather industry. The concurrence of an economic recession subsequent to the 1973 energy crisis, and the escalation in pollution charges can in no way be considered helpful for the maintenance of competitive industrial activities. Another effect has been that some industries, which until recently did not find it economic to reduce the volume or concentration of their waste water discharge, find it worthwhile to adapt their production processes after being confronted with the steeply-rising charges of pollution-abatement measures.
Faced with the heavy cost of pollution-abatement, some industries reacted by looking into ways and means to reduce it. This resulted in many cases in a workable solution, often arrived at in co-operation with, and some patience from, the authorities. Industry was given time to adapt and find solutions, often by terminating or changing production techniques. Another side-effect of the campaign for the rehabilitation of the water environment concerns the employment situation. Because of the high priority given to the abatement process, considerable growth in the volume of work for the engineering and contracting industry took place.

The expansion of biological purification capacity is now nearly finished. More than 90 per cent of the existing pollution load in the Dommel and Aa basins, in 1977 totalling 2×10^6 p.e. – to which industry and population contribute about equally – is now subject to biological treatment. This has led to the fact that by the end of 1977 it can be said, that 'the Dommel and Aa rivers are clean' e.g. that their water nearly everywhere is at least of quality-class 3, which is a considerable achievement. Compared with the situation of about 10 years ago, when these rivers were in effect open sewers, black, without aquatic life, and the cause of serious

problems, the water is now clean again, and fish and other forms of aquatic life have returned.
In this context, the esthetical improvements effected should also be stressed. In the past, both rivers caused considerable odour problems and their water gave the appearance of being very polluted. At present, the observer does not recognize any noticeable visual pollution. It is further expected, that in the near future both rivers can be used to fill the increasing demand for opportunities for leisure in the region as, for instance, recreation on the banks of the rivers and game-fishing. All this constitutes a social benefit of the first order. The economic benefits are very difficult to detail, as by and large the only direct use that is made of the water is for agricultural purposes. Of course those areas, for example nature reserves, that depend on water of reasonable quality have gained much from the improvement effected, but again such benefits are very hard to quantify.
The costs in terms of funds expended for capital purposes are easier to specify. As already stated, up to 1978 the total amount invested in treatment plants, trunk sewers, pumping stations, etc., amounted to approximately Dfl 94 million for the Aa Water Board. There will be a substantial increase in future, as the construction of treatment facilities will have been completed. The emphasis will be on technical improvements, extension to existing plants, etc. How the capital expenditure has developed in time can be seen from figure 1, where the growth of

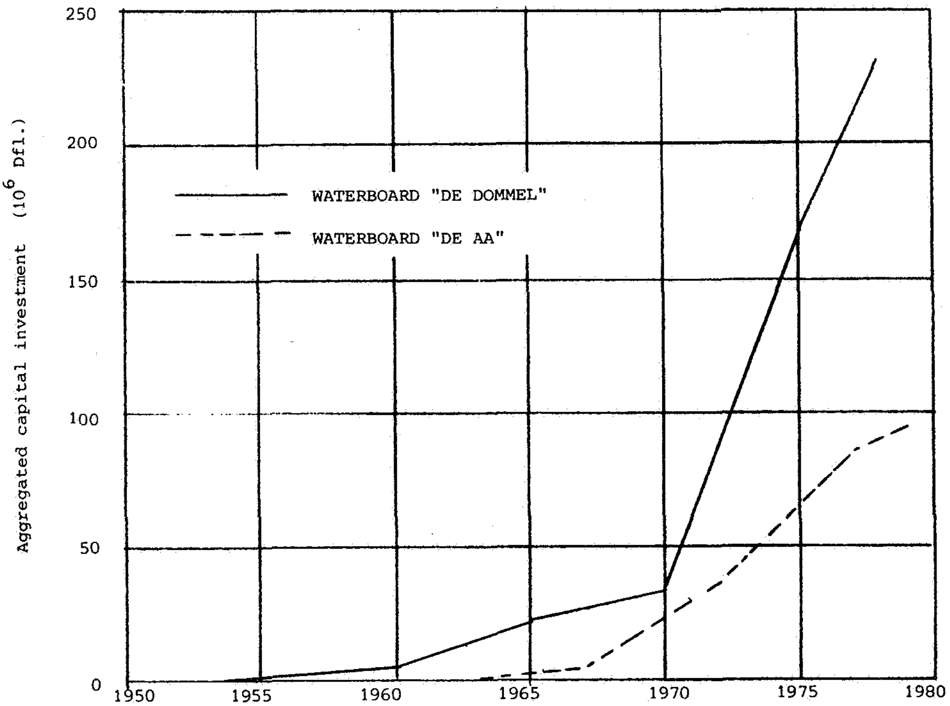

Fig. 1 Capital investments in waste water treatmentfacilities

the capital invested from 1950 onwards is given. The development in time of the rates charged per p.e. has already been shown in table 2. Both the illustration and the table reflect the considerable rise in the last decade.

What the additional costs have been for industry is very hard to estimate. The effect on certain industrial branches has been mentioned already, but it is hardly possible to indicate to what extent these developments have added to other negative trends already present for the industries concerned.

Reference

OECD-project: Management of Industrial River Basins. The catchment of the rivers Dommel and Aa, Case study. Contribution of the Netherlands, August 1978.

Allocation of water management costs

L. J. Locht

10 Allocation of water management costs

SUMMARY

A proposal for cost allocation and reimbursement is presented with reference to public finance theory in the Wicksellian tradition.
The proposal amounts to an adapted 'priority of use' device for the cost allocation to hierarchical tasks. With tasks and parties which are not hierarchical and called equitable, the proposal is an adaptation of the 'separable costs – remaining benefits' device to *ex post facto* conditions. This is embedded in a programme (EKWO) for decision making in two stages. First for cost-sharing on water management as such, then for the outlays of 'Water boards', after taking into account what has to be paid otherwise. The EKWO allocation device is operational. An application, in cooperation with decision makers, is given for a large drainage district with, as parties: government agencies, the built-up area, agriculture, roads, mining, landscape and recreation.

10.1 The problems setting

In the Netherlands, organizations for deciding on and executing regional water management are corporations. Many terms for them are current, the more general is '*waterschappen*'. These regional water authorities will be called water boards for brevity.

For centuries the tasks of the water boards were linked to those for which the landholders in the region were assumed to be financially responsible. Thus the matter of allocating costs to each water board and the 'central' government, was contested on the basis of who had to do the job. The cost allocation as job allocation was often fought out literally (Fockema, 1952). Now that the link between financial responsibility and the allocation of tasks has been dissolved, allocation of costs in monetary terms has an aspect of accounting for services provided to users outside the boards jurisdiction.

The set of rules that did evolve, were confined to the levies charged by the boards to the individual landholders. It has as a basis their protected area because dikes and discharges above all provide safety of residence. The penetration of the region with non-agricultural use led to changing over from protected area to protected assets. In fact the area basis was retained for agriculture and the unit amount of assets in built-up property was defined as equivalent to an agricultural hectare. With that, the shares of built-up property, as a group of users, and non-built-up property, as a group of users, depend on negotiating that unit of assets. Suburbanization is such that now, as an average, about half is paid by each of these groups. However, there are wide differences as well in the application of rules as in the actual charges. This does not upset the applied cost allocation rules in principle. Fatal for that set of rules is that the central government accepts responsibility for providing safety. That acceptance is not yet factually completed but it is established in principle by accepting it in full in other spheres. Consequently, providing safety is still a main job for the water boards, but the final financial responsibility is not. One conclusion is that some device for assigning these costs has to be developed to account for a claim on central government. Another point is that the logic of allocation to landholders according to protected area or assets is gone.

With the central government paying for dikes and the protection discharge, the levies on the landholders might have diminished. However, new tasks have developed and also water boards were originated in parts of the Netherlands where safety is not – or is scarcely – involved. Many water boards adapted to the new tasks by introducing a 'classification' of areas according to benefits in use and according to generated costs. That classification is added to the protected area as a sole criterion for the non-built-up areas. A diversity of procedures evolved, which were not the consequent adaptation to the new setting and the issue is confused.
Meanwhile, the amount of the yearly water board costs in the Netherlands surpasses the equivalent of two hundred million dollars.
The allocation of costs to groups of users or to who ever is going to pay for them, is the problem to be discussed in this paper. It will be dealt with as mainly separate and prior to that of the allocation to individual landholders.

10.2 The proposals setting

The allocation rules of the boards need the consent of the provincial government, hence it is assumed that public finance theory as an application of welfare economics is relevant. Policy makers usually have, however, another set of goals than those implicit in the formal welfare concept (Van den Doel, 1973). In order to adhere to one's discipline as an economist, and to provide a proposal that is acceptable, a structure of recommendations derived from welfare is presented stepwise. At each step the implications are mentioned and politicians can bring other preferences to bear and may bargain on the special issues. A test case has been carried out to perceive their impact. It showed that in this case they accepted the proposals from welfare economics in principle.

Optimality and equity are postulated as aims of the cost assignment. Equity has two aspects in referring to income differences as well as to fairness in the narrower sence. Lacking a formal definition of equity, it seemed necessary to derive its interpretation from the policy makers. Hence, the programme provided is not an objective solution; it is indeed a tool for deliberation starting from the economists' proposals. This limitation is explicitly mentioned in its abbreviated name in Dutch, EKWO (Economische benadering van de Kostenverdeling voor Waterschappen naar Overheidsmaatstaven). The abbreviation refers phonetically to the major aims implied: equity and optimum. It is usual nowadays to proceed from these aims (for references see e.g. Loughlin, 1977).

The statement given above about the limitations of economics stems from welfare being defined as a formal concept, following the excellent discussions by Hennipman (e.g. 1976). It implies that goods and services are taken into account to their consumers values; in that sense welfare is a narrow concept; it does not refer to social welfare, that is to say the policy makers' preferences as such are not included. Welfare is a wide concept indeed, embracing all goods and services which affect utility and are scarce, thus it is not limited to market goods. One should bear this in mind where costs and benefits are discussed: they are those of cost – benefit analysis as an application of welfare economics as defined above. For more references to public finance theory – especially the Wicksellian theory – see ANNEX I.
The best known device of welfare economics is that prices should be equal to marginal costs. This leads to optimum production including optimum growth of production (for references see Loughlin, 1977 and ANNEX I). The device as such cannot always be applied. There are physically joint costs – as for example for a dam providing electricity and irrigation – and economies of scale which procure economically joint costs. In applying the marginal cost rule with joint costs, the revenues will not cover total costs; a subsidy is then required (for an example see figure 1). If this has to come from taxes it may imply a levy on other production, thus interfering with the marginal cost rule (Oort, 1958). The optimality condition is therefore – and this is essential to our approach – restated as: cost allocation should not interfere with taking decisions according to the marginal cost rule. This implies that the parties 'can' agree on the cost allocation. This is – as discussed in ANNEX I – our formulation of the 'unanimity rule' and is consistent with the optimality rule.

10.3 Maximum allocation

Optimality requires that any actor whose cooperating in the water board is rational from the point of view of the marginal costs criterium, must be included in that

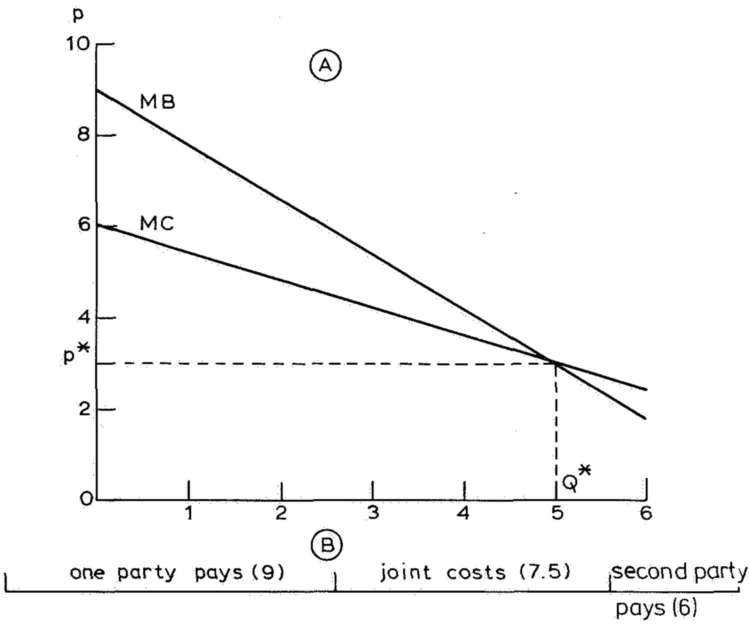

Figure 1 A: with marginal cost (MC) decreasing with quantity (Q), as in $MC = 6–0.6\,Q$, given the designed demand curve as marginal benefits (MB) the price according to the marginal costs rule (p^*) would be 3. Total revenues would be $5 \times 3 = 15$ and total costs – being the area under the MC curve – would be $5 \times 3 + \frac{1}{2} \times 5 \times 3 = 22.5$.
B: one party using three units would, according to the marginal cost rule, pay $3 \times 3 = 9$. The second party using two units would pay $2 \times 3 = 6$. The joint costs being in this case $22.5-(9+6) = 7.5$.

cooperation. This applies to individual users as well as to groups of users. The reformulated marginal costs rule therefore requires that possibilities those actors have if not cooperating in the water board, are upper constraints of cost allocation. Those are (applied to groups of users):

- to do without the utility; the group would lose the benefits in use (B use);
- doing without this cooperation but still producing the same facility as with excluding everybody else; the group would 'stand by oneself' and bear the consequent costs (C one);
- to provide for – the least expensive – other facility with the same use; the group would bear the alternative costs in the narrower sence (C alt).

This amounts to: the maximum for the levy to group i (L_i max) is the lesser of B_i use, C_i one, C_i alt. This is a well-known device in project appraisal where it is often presented as a matter of fairness (for references see Loughlin, 1977). After the execution of a project – the case dealt with here – it seems necessary indeed to state it as a matter of fairness because some groups often cannot withdraw from cooperation; a higher levy would therefore not induce those groups to a – for society – non-optimal decision. In the test case of this study, the device for the maximum levy as such was indeed accepted by the policy makers as a matter of equity. The proposed device does not require a so general policy statement: some groups actually could withdraw, for them the upper constraints hold solely from the point of view of optimality. For the other groups it would have been a sufficient equity condition that all should be dealt with after the same principles.

The cost reimbursement has consequences on net revenues of the users and on growth of production and/or prices of land. Under certain conditions those would be non-optimal if the charge was above the constraints mentioned. Seen in that way the proposed device for maximum allocation might have been stated as derived from optimality only.

10.4 Minimum allocation

The minimum allocation has to be deduced from the consequences to the board – as actor – of excluding the group of users (k) involved. In the project appraisal context, the consequence is that the board bears the costs for a project for $(i-k)$ parties. This amounts to k having to pay the total costs with all i parties included, less total costs with $(i-k)$ parties included. It is usual to call this difference 'separable costs' (C sep) to make clear that it refers to *ex ante* marginal costs (that is including investment costs) whereas marginal costs can also be marginal *ex post*. It is also called 'incremental costs', that is done to make clear the reference to the unit of the investment decision, which usually is equivalent with quite a number of physical units. The expression marginal costs could be thought to deal with one physical unit (for an example see fig. 2).
Another point of view for deriving minimum allocation is the induced growth of production of the parties including mobility to the region considered.
After execution of the project, the price structure may change or for example population can have moved out of the region. This may imply that C alt or B use drop below C sep, especially where the costs of the services do not vary with the number of users (group goods). It would be inefficient to adhere *ex post* to C sep and drive the rest of the users out by applying L_i min $= C$ sep in this approach with the groups. The standpoint taken here is, therefore, that merely from the point of view of optimality C alt and B use should be upper constraints for L min. To these constaints C one is added for the – unusual – case that C one $<$ C sep.

The generally applied device of L_i min $= C$ sep may be the reason that some authors (e.g. Loughlin, 1977) do exclude from the theory of cost allocation what the parties

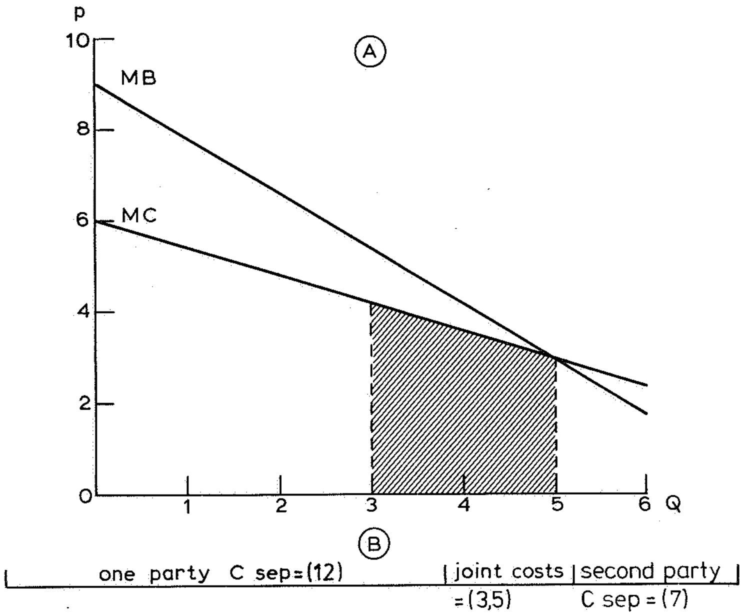

Figure 2 A: as figure 1A, with the shaded area being the incremental costs for including a second party using two units. If the *MC* curve refers to ex ante costs – including costs referring to investments – the incremental costs are the separable costs as well.

B: separable costs and joint costs with one party requiring three physical units and the second party requiring two physical units. The joint costs being now $22.5-(12+7) = 3.5$.

actually have to pay (the reimbursement). They confine allocation to something which is not used in project appraisal nor in reimbursement. What such an allocation aims at and therefore with what the equity has to be tested, is not clear. Some (e.g. Young et al., 1980) are of opinion that a levy below *C* sep is a subsidy of one party to another and therefore not fair. Of course this implies some special definition of subsidy. In our test case it did show up that having the other party pay more of the joint costs – than would be the case in a fictive project with a partner having more benefits – was felt to interfere less with equity than having a trapped party pay more than its benefits. It is also not in the Pareto-Wicksellian line to charge beyond the benefits.

10.5 Sharing costs

Consider a car driver (A), an ordinary hitchhiker (B) and one with a bicycle (C). Because their joining is 'incidental' it would be acceptable that B pays nothing and C only the extra petrol caused by having a bicycle on top, being the separable costs, say 20. This is usually called the 'incremental method' (Thursbey, 1972) and holds in a hierarchy of users. Let them discuss prolonging the trip for which the costs are say 250, the benefits in use for A are 100 and the costs for a railway ticket (alternative) for B as well as C also 100, their benefits in use being larger. They agree that each pays first his separable costs. With C this refers to the extra petrol – say again 20 – with A to the luxury of the car – say 80.

What should be shared additionally is called the joint costs being $250-(20+80) = 150$. They probably would first come with the notion of equal shares (50 each) because they have 'equal benefits of cooperation' (100). However, A would have to pay $80+50$ which is more than his benefits hence he will comment that he acquires a part of his benefits from his already allocated separable costs (80). This point will originate the notion of equal shares of the 'residual benefits of cooperation' (for A: $100-80 = 20$). 'Of cooperation' is added to show the difference with 'in use'; for B and C benefits of cooperation are their alternative costs and not their benefits in use. This notion of sharing joint costs in proportion to the residual benefits of cooperation is well known in project appraisal as: Separable Costs – Remaining Benefits (*SC-RB*), which refers to participants which are equitable partners.

10.5.1 *Equitable tasks and groups*

Because in this paper it is taken into account that a device is required that holds *ex post*, L_i min was proposed as the minimum allocation; it being the lesser of C sep, C alt, B use (and C one). This is one of the reasons that EKWO cannot be denoted as $SC-RB$, where C sep is used. In the example mentioned above, the difference between L_i min and C sep is not actual. The proposed device for cost sharing is:

$$L_i = L_i \min + (TC - \sum_i L_i \min) \frac{L_i \max - L_i \min}{\sum_i (L_i \max - L_i \min)}$$

where L_i is costs allocated to party i and $\left(TC - \sum_i L_i \min\right)$ are the joint costs.

Applied to the example mentioned, one derives for A, B, C respectively $L_i =$ (resp. 80; 0; 20)$+(250-100)\cdot(300-100)^{-1}\cdot$(resp. 20; 100; 30). So $L_i =$ resp. 95; 75; 80. In ANNEX III this is presented stepwise. Each gains an equal part – $\frac{1}{4}$ – of his benefits of cooperation. The difference with the $SC-RB$ formulation at this point implies only that if B use or C alt have dropped below C sep (and they still cooperate), the share of joint costs to those parties is zero instead of negative.

The device implies costs sharing in the narrower sense. It cannot be dealt with here with much more of the theory of that cost sharing as such (for cost sharing theories see the references in e.g. Murraro, 1972). Only two studies which criticize *SC–RB* will explicitly be discussed. Loughlin (1977) starts by stating that 'the objective of cost allocation is to distribute project costs equitably among the purposes served ... by providing proportional sharing of the savings resulting from multiple-purpose development' (citing Fed. Inter. Agency, 1950). He interprets this as: the savings should be proportional to 'the savings from inclusion of each purpose' instead of the savings for the participant himself as with *SC–RB*. To the present author, it is doubtful whether his interpretation of the quotation is imperative. What he is up to is illustrated in ANNEX III, where also shortcomings of his proportionality proposal are shown. Young, Okado and Hashimoto (1979) have two critical arguments. The first is that the possibility of coalitions between the partners is neglected. This is, however, a matter of definition of the parties – discussed hereafter – and not pertinent to the proposed EKWO programme. Their second argument is that if total costs show up to be different from what was originally estimated, no participants' allocation should be allowed to diminish: the method should be 'monotone'. The present author agrees under the condition, also mentioned by Young et al., that other cost magnitudes do not change. By way of their definitions they imply, however, that for each party C sep increases with the same amount as the total costs do. There is no formal objection to a decrease in some participant's levy if separable costs – of the parties – do change disproportionally. The sharing device that Young et al. (1980) propose themselves cannot take benefits into account. As stated in chapter 10.2 this runs counter to equity, hence it does not have to be presented here.

10.5.2 *Hierarchy of tasks or groups*

It seems that nowadays purposes are dealt with as equitables without arguing. This is, at its best, another presumed implication of equity. Our test case, however, pointed out that policy makers, given the choice, opt for hierarchy in groups of tasks with equitable tasks only within the levels. Because in this way equity does not refute the hierarchical approach, it is relevant to deliberate on what can be proposed from the economic point of view with regard to the set up of the hierarchy. Recall the basic notion that there should be no interference with decisions based on marginal costs. To do without the service is possible in some cases for individual members of the group, sometimes groupwise and sometimes not at all. The first refers to providing water for sprinkling, where a levy upon the users individually is possible (private goods). The second refers to infiltration, discharge, etc. (group goods). The third refers to provisions for safety; from the physical point of view, it may be possible to do without the facility; the institutional framework, however,

forbids this. Group decisions therefore approximate the optimal way if the joint element in costs of discharge and safety are allocated entirely to safety. At the planning stage, this implies *C* sep for all group goods together to be allocated to the group goods together.
With private goods the argument holds *mutatis mutandis* to allocate to its users the incremental costs with reference to facilities of the first (safety) plus second level (group goods). However, the created capacity is often different – e.g. in the take-off period – from actual use if the price is set in conformity with *C* sep for the group of users of private goods. *Ex post* marginal costs may therefore be first below *ex ante* marginal costs and at a later stage beyond them. The proposal is to separate the pricing of the private goods and to leave the board possibilities for flexible pricing policy on this issue. This amounts to allocating *C* sep over the years. Another point involved with private actors is that allocating *C* sep combined with the equity condition, stating that within the region each should pay the same price (p), would lead to non-optimal decisions in the case where marginal costs are decreasing; an illustration is given in figure 3.

The proposal therefore is, in conformity with the choice of the policy makers in the test case, to apply a hierarchy of (groups of) tasks, that hierarchy being: safety; common tasks; private goods and incidental services, with possibly equitable tasks within each level.

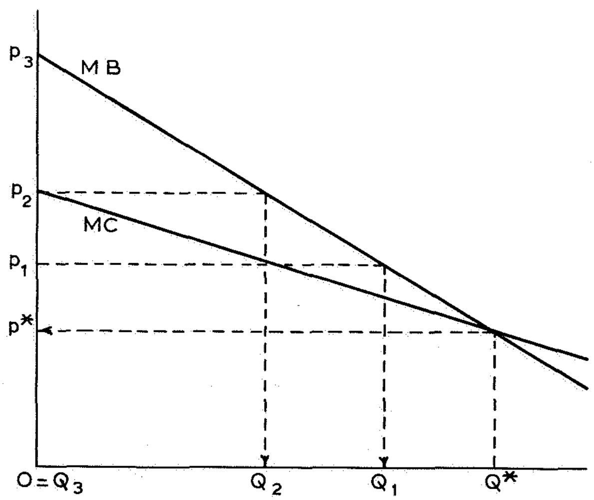

Figure 3 Contrary to figures 1A and 2A, here Q and MB and MC refer to one party only; the increase in Q refers to the number of individual farmers. Suppose the capacity (Q^*) is derived from ex ante marginal costs (MC) equal to marginal benefits (MB), the C sep for the party is the area under the MC curve limited by Q^*. Dividing C sep equally over Q^* would result in the levy p_1; from that 'price' would result Q_1. Dividing C sep equally over Q_1 would result in the levy p_2; from that 'price' would result Q_2. Dividing C sep equally over Q_2 would result in the levy p_3 which would finally eliminate the use of the facility.

In the scheme of procedures – ANNEX II – this proposal is implemented by:

- starting the calculation of costs for common tasks – procedure 2 – with a layout of the region as already providing for safety and starting the calculation for private goods and incidental services with a layout including provisions for safety as well as for common tasks.
- dealing with costs for safety as a basic facility and with private goods after actual pricing. This is presented in the right upper part of the scheme.

10.6 Groups and their responsabilities

The actual allocation job starts in EKWO (procedure 1 in ANNEX II) with agreeing on a table with the tasks of the board as one entry and the groups of users as the other entry. Basic tasks – in our test case, safety – and private goods and incidental services – as discussed in section 10.5.1 – and common tasks are discriminated. The definition of groups of users is, however, not yet clear; this will be discussed under the headings coalition and pollutor pays principle.

10.6.1 *Coalition*

In the test case of this study it was not clear whether agricultural areas, horticultural areas and nature conservation areas were groups apart. They have different requirements indeed but does that imply that they operate as parties apart in their cooperation? The same question arises with regard to roads and built-up areas and so on. Physical differences, as such, do not warrant economic delimitation. The proposal in EKWO is to delimit the parties according the economic condition and the equity condition. These conditions are:

- grouping has to be advantageous to each of the subgroups, their coalition has to be of mutual advantage (economic condition);
- grouping is to be accepted by the policy makers according to their concept of fairness (equity condition). This is especially important in the *ex post* context, where parties do not actually have other options. It may for example be felt to be unfair to permit some physical parties a coalition where other parties cannot enter, for instance as a consequence of its location within the region.

The programming for computing *C* sep and *C* one – discussed in chapter 10.7 – starts with delimiting any party that possibly can have an advantage in standing by itself. Normally this is delimiting – physical – parties according their requirements. The programme allows for the making of any coalition. Formally, it is up to the parties, as their policy, to require a calculation in coalition with some other participant(s). This possibility is an option in the programme (broken lines from procedures 4 and 7 to procedure 1 in ANNEX II). As an example, some coalitions have been tested on the economic conditions for the test case given (ANNEX IV). These aspects of the programme stand for the pretension of EKWO that grouping of users to parties is solved 'systematically'. The method thus deviates from usual applications of cost allocation, e.g. Howlett (1972). It is, therefore, that instead of the usual C single the notation C one is used, which can include a coalition.

10.6.2 *Pollutor pays principle*

In water board cost allocation in the Netherlands there have been up to now (section 10.1) arguments on who is provided with a facility. This may be the one that depends on it with its revenues or utility, or the one from which originates the requirement to have the facility. This problem is discussed elsewhere as victim pays or pollutor pays. For instance, uplands having a discharge that would effect revenues in the lowlands. It is the uplands where the requirements originate to have a water course for its water through the lowlands.

For a general discussion it may be referred to e.g. Macaulay and Yandle (1977) who argue that both have to pay and Locht (1972) discussing up to what level of requirements of the victim should the pollutor pay and how should damage be calculated. In EKWO the occupants of the areas are identified and each is not permitted to damage another. This implies eliminating or compensating for a – potential – harm. Deciding on whether harm would be implied, necessitates formulating to what level their requirements are actually met and whether they could do with less of a provision without harm. In the instance mentioned, of the uplands discharge through the lowlands, a water course in the lowlands is included in C one for the uplands. Some provision is also included in the uplands C sep but actually this will not count for much because the C one for the lowland will already include a substantial water course on its own account. In case of woods in the uplands, discharge will be spread rather evenly, hence the additional water will require only a very modest enlargement if any.

This approach can be interpreted as an application of the Pollutor Pays Principle (PPP) that is generally accepted with the definition: 'the pollutor should bear the expenses of carrying out the measures decided by public authorities to ensure that the environment is in an acceptable state' (for references see Locht, 1972). In our context, it is the environment of any party occupying an area, each having to avoid damage to the others. So here a wide view is taken of environment; this in conformity with Macaulay and Yandle (1977).

10.7 Application

The drainage district Oldambt has been the test case. Its water board has a task and area not too complicated. It is part of the Province of Groningen, the region best known as the origin of the large Dutch natural gas supply. A comprehensive discussion in the committee which provided for the application (see acknowledgements), led to a table of which the relevant part is presented as table 1. It showed up to be a necessity to have members of the office of the water board on such a team, for instance because the relevance of some tasks – as salinity abatement – for some users – as horticulture – depends on the locations within the region.
The criterion applied to delimitating groups at this stage was: differences in requirements. For brevity's sake some coalitions are already included in this presentation (landscape with recreation and fairways with safety).

Table 1 Conclusion from procedure 1 in first instance: delimitated tasks of the water board Oldambt with division according to basic, common and private plus incidental services and the parties distinguished for common tasks and private services (1 through 7)

	Basic	Common tasks				Private and incidental	
	safety of residence*	water discharge	ditto additional maintenance	accell. discharge	salinity abatement	water supply	incidental*
BUILT-UP AREA							
scattered (1)		x	x				
concentrated (2)		x		x			
AGRICULTURE							
farming (3)		x	x		x	x	
horticulture (4)		x	x	x		x	
MINING (5)		x		x			
INFRASTRUCTURE							
roads (6)		x		x	x		
waterways							
LANDSCAPE AND RECREATION (7)							
fishing					x		
woods		x					
nature		x					

*for brevity's sake these tasks are only dealt with in general in this paper. This is possible because it costs are allocated separately (procedure, Annex II)

10.7.1 *Allocation of water management costs*

With regard to the allocation in the hierarchy the general remarks in 10.5.2 must do here. We discuss below the allocation of costs of the common tasks which between themselves are equitable. In this case the groups involved with these tasks are also equitable. The calculus of cost magnitudes basic to this allocation, called procedure 2, would be tedious if it was not programmed for a computer. The exposé of Howlett (1972) of such programming for a complicated construction was the incentitive for EKWO. Preliminary research (Locht and Van Kleef, 1974) showed the possibilities to programme the calculation of the basic cost magnitudes. The breakthrough in operationality was provided by Van der Maarel (1979). He modelled the water management system with a network, the nodes representing areas with the party's actual environment and their requirements, and sections of water courses. Involved are the length of the sections, surface level, side slopes – related to soil – slope of the water surface. The physical output consists of width of water courses, required pumping capacity, etc. Although outside this author's competence, these aspects are mentioned to make it clear that programmes such as EKWO are only within reach if the modelling of the physical system is worked out. The available physical models are often too complicated to be efficient in a context where only cost allocation is involved. The model of Van der Maarel fits our questions. After introducing – accounting – prices the basic cost magnitudes are derived with the computer programme. It is recalled here – from chapter 10.2 – that accounting prices are used, being the prices that are relevant from the point of view of welfare optimum. These include a price for water inlet into the region and eventually for discharge out of the region, even when there are no actual prices. Of the other accounting prices only the time preference – 5 per cent per year – and opportunity costs for land – Dfl 1,000 per ha and year – are mentioned here. They are presented as backed-up propositions to the policy makers, who required a sensitivity analysis in these respects.

The programme provides the – yearly – costs in some detail, here cost is defined as related to investment as well as operation. Costs related to investment only, to be used later on, are also presented (table 2).

The programme will be enlarged to provide for applying the allocation device on the costs of water management according the formula discussed in section 10.5.1 (this is called procedure 3 in ANNEX II). This, however, is only possible after the

Table 2 Conclusion from procedure 2; costs of water management in Dfl 1,000 at selected – accounting – prices (time preference 5% per year; opportunity costs for land Dfl 1,000 per ha and year)

	Area (ha)	Operation and investment costs			Investment costs only		
		C sep	C alt	C one	C sep	C alt	C one
Scattered buildings (1)	549	205.3		2345.6	189.0		1305.7
Concentrated buildings (2)	370	141.5	1295.6	(1448.0)	128.6	1141.6	(846.0)
Farming (3)	17,095	3449.6		6389.6	3054.1		4657.7
Horticulture (4)	84	37.2	70.5	(425.8)	35.2	46.2	(281.4)
Mining (5)	213	69.4		1025.1	66.1		608.1
Roads (6)	492	174.9		2722.9	161.9		1509.1
Landscape and recreation (7)	624	89.5		2173.8	85.6		1198.6
Coop. of equitable tasks	19,439	7190.7			5391.5		

Table 3** Conclusion from procedure 3: judgement on benefits in use, deriving L_i min and L_i max and applying the allocation device (magnitudes in Dfl 1,000)

	Benefits in use	L_i min	L_i max	L_i max − L_i min	Allotment	Allotment + assignment*
Scattered buildings (1)	>	205.3	2,345.6	2,140.3	661.5	866.8
Concentrated buildings (2)	>	141.5	1,296.6	1,154.1	356.7	498.2
Farming (3)	>	3,449.6	6,389.6	2,940.0	908.7	4,358.3
Horticulture (4)	>	37.2	70.5	33.3	10.3	47.5
Mining (5)	>	69.4	1,025.1	955.7	295.4	364.8
Roads (6)	>	174.9	2,722.9	2,548.0	787.5	962.3
Landscape and recreation (7)	100.0	89.5	100.0	10.5	3.2	92.7
Sum		4,167.4	13,949.3	9,781.9	3,023.3	7,190.7

* with assignment is meant what the party is responsible for (L_i min), with allotment its share of joint costs being total costs (7,190.7) minus ΣL_i min (4,167.4). The share is (L_i max − L_i min)/Σ(L_i max − L_i min). Hence allotment is 0.309071 times (L_i max − L_i min)

** for table 4, see Annex IV

calculation of *C* alt and *B* use or the agreement that those are not actual constraints that is > *C* one. As is clear from tables 2 and 3, this was assumed to be the case for most parties, not for concentrated buildings, horticulture and landscape and recreation. The benefits for landscape and recreation are in fact a backed-up proposal to the policy makers. It is backed-up by relating their use in the region to a detailed study of the consumers surplus elsewhere (Locht, 1978). For agriculture *B* use > *C* one is backed up as well (in a way not discussed here). It can also be done with the usual approach (Help, 1978) of the Government Agency for Rural Reconstruction. In principle, however, EKWO is a tool for deliberations and the *onus probandi* for *C* alt and *B* use rests with the parties.

Because *C* alt and *B* use are relevant in reference to all costs for water management EKWO deals with that first (the left side of the scheme in ANNEX II).

What is derived from optimality with regard to choices holds on this level. The first policy check, called procedure 4, and the possibly required calculations either for coalitions or with other estimates of *B* use, is bypassed – and with that table 4 (see ANNEX IV) – at this stage of the discussion.

10.7.2 *Water board costs*

The major point is the involvement of the Government Agency for Rural Reconstruction of the Ministry of Agriculture. It provides for an improvement in infrastructure including that for water management. Only a part of the cost is passed on to the water boards. The reasons are either equity or the water board's re-imbursement possibilities.

The equity argument is that each should pay equally for equal services and generally no one should pay more than his benefits. Because for equal services revenues on the farms are wide apart e.g. related to the quality of the farmers, this amounts to a reimbursement to the water board which is considerably below total benefits as is illustrated in figure 4. Total benefits are in this case about Dfl 44,600. Assume this warrants the project in the cost benefit analyses. Because a reimbursement of this amount runs counter to equity – many farmers would have to pay more than their benefits or they would have to pay differently for equal services – one can reimburse much less, say Dfl 150 per ha per year amounting to Dfl 15,000 over the entire area. The bearing of costs by the Government Agency for this reason has of course to reduce only the farmers share in costs of water management. This point can be dealt with also from the Wicksellian – relative – unanimity condition (see ANNEX I).

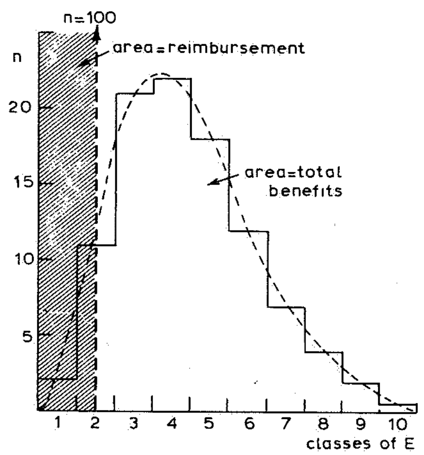

Figure 4 Total benefits of a project for equal services of farmers differing in farm management and acceptable reimbursement, if each should pay the same and only some pay more than there benefits. Here *n* is a percentage of the number of farmers and *E* is the real effect of the improvement in Dfl 100 per ha and year.

Among the purposes of the Agency is to provide in some instances for landscape and recreation usability. Their bearing these costs is only done with regard to investment costs and referring only to separable costs. This Agency, as well as others, has also policies with regard to other parties. That will not be discussed here; the implications of those policies are inserted in the third and fourth column of table 5 as the conclusion from procedure 5.

The cost estimates in earlier sections are estimates in replacement values; this is so in order to compare them with *C* alt and also with reference to *B* use. The water board's actual outlays – *ex post* – are far less. The total costs according to table 5 are about 4.5 million guilders per year, whereas actual outlays for equitable

Table 5*** Conclusion from procedure 5: deriving the share of the water board in the costs for water management in Dfl 1,000 respectively per cent

	Water management		Share of others (%)		Share of water board			
	assignment*	allotment**	assignment	allotment	assignment	allotment	total	share (%)
INVESTMENT COSTS								
scattered buildings (1)	189.0	368.2	50	60	94.5	147.3	241.8	8.11
concentrated buildings (2)	128.6	314.3	100	0	0	314.3	314.3	10.54
farming (3)	3054.1	662.4	50	60	1527.0	265.0	1792.0	60.09
horticulture (4)	35.2	6.7	50	60	17.6	2.7	20.4	0.68
mining (5)	66.1	175.2	100	0	0	175.2	175.2	5.88
roads (6)	161.9	436.5	100	0	0	436.5	436.5	14.64
landscape and recreation (7)	85.6	1.8	100	0	0	1.8	1.8	0.06
sum	3723.2	1965.1			1640.5	1342.9	2982.0	100.00
OPERATION COSTS								
scattered buildings (1)	16.3	293.3	0	0	16.3	293.3	309.6	20.57
concentrated buildings (2)	12.9	42.4	0	0	12.9	42.4	55.3	3.68
farming (3)	395.5	246.3	0	0	395.5	246.3	641.8	42.64
horticulture (4)	2.0	3.6	0	0	2.0	3.6	5.6	0.37
mining (5)	3.3	120.2	0	0	3.3	120.2	123.5	8.20
roads (6)	13.0	351.0	0	0	13.0	351.0	364.0	24.19
landscape and recreation (7)	3.9	1.4	0	0	3.9	1.4	5.3	0.37
sum	446.9	1058.2			446.9	1058.2	1505.1	100.00

* investment costs included in C sep (possibly in C alt)
** investment costs included in C one (possibly C alt)
***for Table 4, see Annex IV

tasks are about 2.5 million guilders (US $1 million). The main reasons are:

- investments were realized at much lower – nominal – prices and with loans in nominal terms;
- redemptions are according the terms of the loans. Thus for most of the land used for water management constructions there are no outlays anymore and the – economic – depreciation on other investments as well are often different from the redemption terms of the loans;
- some costs to society are not actually paid – yet.

Variants for dealing with the difference between replacement costs and actual outlays are presented to the policy makers (called procedure 6), one of them is given in table 6. Because most of the difference is related to investment this proposal is to reduce each participant's share in proportion to what the prime allocation for investment costs is. Because elsewhere in society such consequences of inflation, etc. accrue also to investors this seemed to be the least diversion from equal chances for growth (optimality), be it rough.

10.7.3 *Selection of chargeables*

The users are not always those who are going to be the 'chargeables' i.e. with the costs allocated to landscape and recreation.

Table 6 Procedure 6: allocation of costs of the Water board Oldambt for 1977

	Investment costs*	Operation costs*	Investment costs + operation costs	Overhead costs**	Total costs
BOARD OUTLAYS* IN 1977					2,648,859
basic task					112,164
tasks	653,355	1,443,949	2,097,304	439,391	2,536,695
ALLOCATION TASKS					
scattered buildings (1)	52,987	297,020	350,007 = 16.7%	73,327	423,334
concentrated buildings (2)	68,864	53,137	122,001 = 5.8%	25,560	147,561
farming (3)	392,601	615,700	1,008,301 = 48.1%	211,242	1,219,543
horticulture (4)	4,443	5,343	9,786 = 0.5%	2,050	11,836
mining (5)	38,417	118,404	156,821 = 7.5%	32,854	189,675
roads (6)	95,651	349,291	444,942 = 21.2%	93,217	538,159
landscape and recreation (7)	392	5,054	5,446 = 0.3%	1,141	6,587

* incidental services are already excluded; the derived shares - last column Table 5 - are applied
**overhead costs are distributed in proportion to the preceding column

Generally, water boards charge the owners of the areas concerned, the users – e.g. the lessees – paying indirectly. This choice is presented as being up for deliberation in procedure 7 of the programme.

Also involved are costs to society not actually paid for (as stated under the third reason given in section 10.7.2). One of the variants discussed with the policy makers was to deal with non-paid costs as a prepayment of one of the chargeables, the provincial government. On equity grounds, this was refused because in other spheres non-paid costs are not inserted either. It was preferred that actual charges with reference to such costs should be considered as a point of more general future policy. Another point involved in procedure 7 is that allocated costs to some party can show up to be not reimbursable purely because the board is lacking adequate power. One should reconsider whether the users are to be excluded from the project, or how to share the loss. This cannot be done as a proportional increase on the other shares because – in principle – that could imply a share exceeding the constraints. This procedure holds that L max for the party who refuses to pay is to be reduced. Hence at this stage an additional constraint on L max is imposed.

10.8 Final remarks

The EKWO programme was tested on its sensitivity for the accounting prices for opportunity costs for land and the time preference. It showed up to be robust in these respects as can be seen in table 7. Results are presented there on an area basis. This should not be interpreted as a proposal of the research team to levy solely on an area basis.

The built-up area has been paying actually 14 per cent in this region; that is far

Table 7 Proposed levy for Oldambt, here, for comparison purposes, presented for 1977 in Dfl per ha per year; for the actual shares, see table 6

	With preferred acc. prices	With Dfl 800 per ha and year as opp. costs for land	With 3 %/year as time preference
Scattered buildings (1)	771	770	768
Concentrated buildings (2)	399	402	392
Farming (3)	71	71	71
Horticulture (4)	141	142	143
Mining (5)	891	886	903
Roads (6)	1,094	1,089	1,092
Landscape and recreation (7)	11	11	17

less than the national average – about 50 per cent. On an area basis, concentrated buildings would pay in the new approach the same as in the old one (399 and 396 resp.). Scattered buildings, however, have to pay much more; where this regards farmhouses, this would be compensated for in the lower levy on agricultural land. Roads did not bear a share up to now. For landscape and recreation much less would have to be paid, because of the lavish payment by other agencies for landscape and recreation in the investment stage, which as such is taken into account.

Coalitions were not asked for in procedure 4; the differences in subsidy rates on the investments and the different agencies involved will have been important in this respect. On the contrary, outside the test case, some further delimitations (of nature conservation and forests) were asked for. The programme is not prepared for that, it is only possible to lessen the number of groups. It could be illustrated that delimitations of relatively small areas result generally in an increase in the derived levy even if the requirements are more modest than when it was included in the larger group. Although no coalitions were asked for, it still was decided to calculate the levies with coalitions, as a research interest. The results are presented in ANNEX IV.

The 1977 derived shares as rates of outlays for equitable tasks are proposed to be used for the forthcoming years and until a party comes up with an argued request for reconsideration.

The 'policy team' has confidence in the proposal discussed. However, there are many water boards operating under much more complicated conditions than the one that was studied in the test case and many obstacles stand in the way of implementation. This is not surprising in a domain with such overwhelming traditions as those of Dutch water boards.

10.9 Acknowledgements

The idea to develop EKWO was first introduced in an advisory committee; the chairman C. Bijkerk is especially to be mentioned for his stimulating response. The preliminary studies were prepared for that committee.
The results motivated the Union of Water Boards to install a 'policy team' and a 'research team' and to vote funds. The secretary, vice-chairman and chairman of the research team, J. M. A. M. Mouwen, B. M. van Dam and the present author, are also members of the policy team. Other members of the policy team contributing to this study are: P. O. Lindenberg (chairman), P. H. Bon, J. M. de Graaff, K. Meinders, H. Visser, W. Westhoff. Other members of the research team are: H. Boer, J. A. Deurloo, H. A. van Kleef, A. J. G van der Maarel, C. G. Wagenaar, J. C. Woudenberg.
The report of the committee is available (Unie van Waterschappen, 1981). The paper presented is the sole responsibility of the author.

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Reference to public finance theory

1. In modern public finance theory, Wicksell (1896) is referred to as being its founder. Only recently this part of Wicksell's work received approval in the restatements of Buchanan, Musgrave and others (for references see Hennipman, 1974). Most of the theoretical points in the present paper are in conformity with Wicksell's theory indeed. We argued earlier for Wicksell's positions (Locht, 1972). Especially relevant here, are:

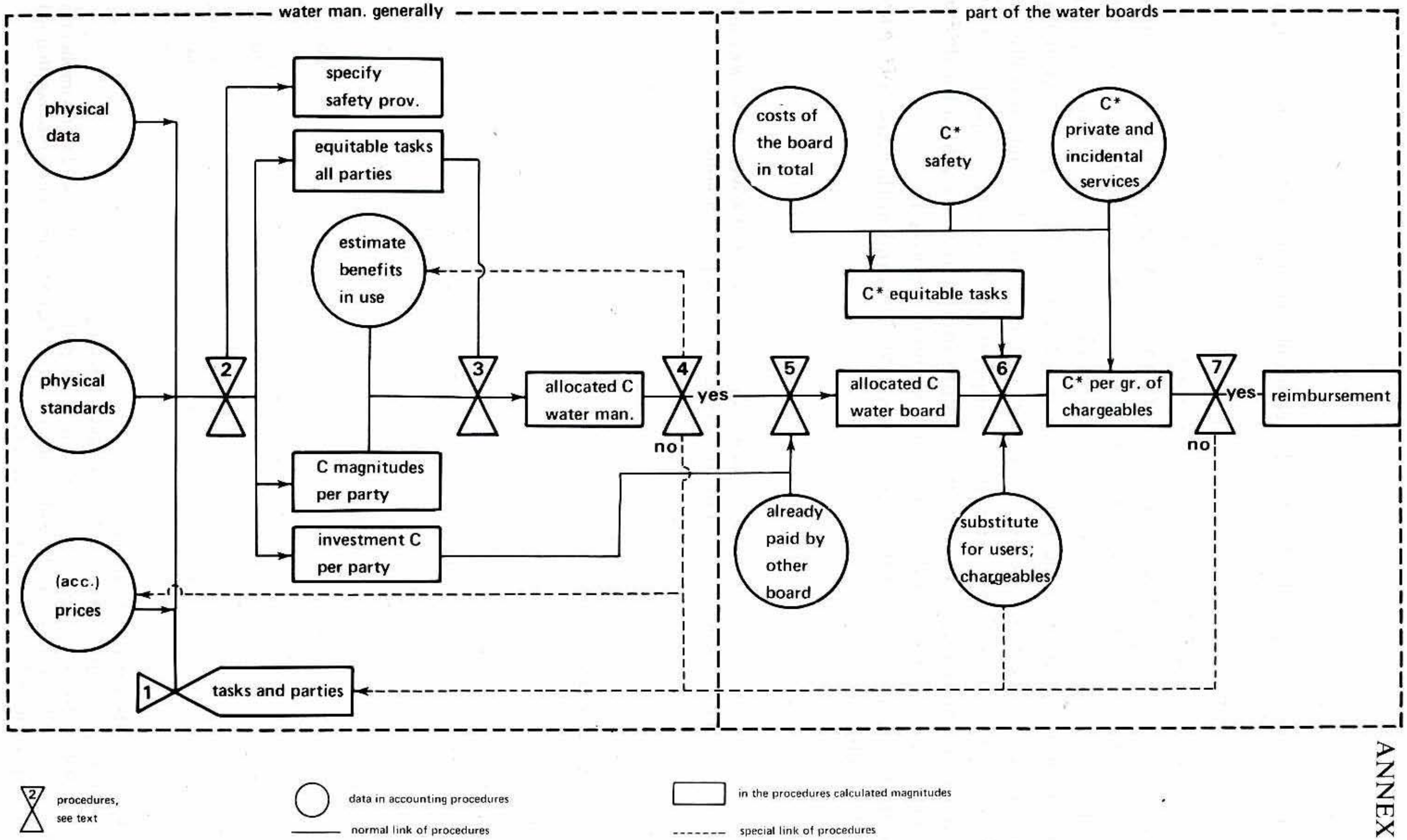
- utility of public goods is – in principle – not different from utility of other goods; this implies that individual preferences are – in economics – the sole criterion for government expenditures;
- this consumers sovereignty is not a reality but an implication of the welfare point of view;
- together with the marginal costs device, the inequalities in income – as an element of equity – should be considered;
- government behaviour is dominated by the preferences of the policy makers and their power; the utility model is not used as explaining reality but as reference for policy;
- the implication of interpersonal utility comparison is accepted.

2. Wicksell argued also against reimbursement after payment capacity in the context of fair distribution of costs, and for benefits as an upper constraint on reimbursement without the contention that any solution within the conditions is the only one economically warranted.

3. Our proposal is a cost allocation related to decisions about facilities on which all the parties 'can agree'. In this context the unanimity rule is implied that was proposed by Wicksell. In fact he proposed for practical reasons 'relative unanimity' as is involved here within the groups – e.g. the case we dealt with for water discharge for farmers. Above we used 'can agree' instead of 'will agree' because of the many practical difficulties (Van den Doel, 1973) and also because we are dealing with facilities already available for which the parties have all the reasons to behave as if their benefits are smaller than they actually are. The involvement in policies with regard to facilities of the parties is in the context of the water board much more direct than usual. This implies – in the present authors opinion – that many of the objections to the unanimity rule in general, are not relevant in our context.

4. The better known Pareto device that no party is permitted to lose, hence that benefits – in some way – are higher than allocated costs is consistent with the unanimity rule.

refer to procedures as discussed in the text



Discussion on the proposed allocation for equitable purposes and Loughlin's argument

1. For brevity's sake not our case study of the water boards but the hitchhikers example as presented in section 10.5.2, is used here. Table 8 presents the proposed allocation according to EKWO if only equitable goals are involved and L_i min = *C* sep. In that case EKWO does not differ from Separable Costs – Remaining Benefits (*SC-RB*), so allocation of joint costs of cooperation should be proportional to the residual savings of the party (L_i max − L_i min). This is presented in the left upper part of table 8. In the lower left part the comment of Loughlin is illustrated, that allocation of savings arising from cooperation should be proportional to the savings from party inclusion. The two columns on the right are added for discussion purposes; they illustrate a deficiency in Loughlin's approach.
For an illustration of the differences between *SC-RB* (and in this case also EKWO) and Loughlin, see figure 5.

Table 8 Allocation to equitable parties of total costs being 250 after EKWO (or *SC-RB*) and after Loughlin's argument on proportionality to savings from party inclusion

	A	B	C	Σ	A	(B C)
DATA						
1 benefits in use (B use)	100	>100	>100		100	>200
2 alternative costs (C alt)	>100	100	100		>100	200
SC-RB PROCEDURE						
3 L_i max (the lesser of 1 and 2)	100	100	100	300	100	200
4 L_i min (in case C sep)	80	0	20	100	80	20
5 remaining B of cooperation (3-4)	20	100	80	200	20	180
6 allocated joint costs SC-RB**	15	75	60	150	15	135
7 total allocated costs (4+6)	95	75	80	250	95	155
8 implied allocated savings (3-7)	5	25	20	50	5	45
PROPORTIONALITY TO SAVINGS PROCEDURE						
9 sum of L_i max over i-k*	200	200	200		200	100
10 costs over i-k* (TC-4)	170	250	230		170	230
11 justifiable costs for i-k* (lesser of 9 and 10)	170	200	200		170	100
12 savings from inclusion (3+11-TC)	20	50	50	120	20	50
13 same, as part of savings***	∿ 8	∿21	∿21	50	∿14	∿ 36
14 total allocated costs (3-13)***	∿92	∿79	∿79	250	∿86	∿164

* *k* refers to the party of the column.
** this is $(TC - L_i \min)(L_i \max - L_i \min)^{-1}(L_i \max - L_i \min)$.
*** Loughin's criterion is proportionality to savings from party inclusion (row 12). This implies (row 14) each to pay L_i max less that share of savings (3–13). In fact he later adjusts this, but that is beside the argument on his required proportionality.

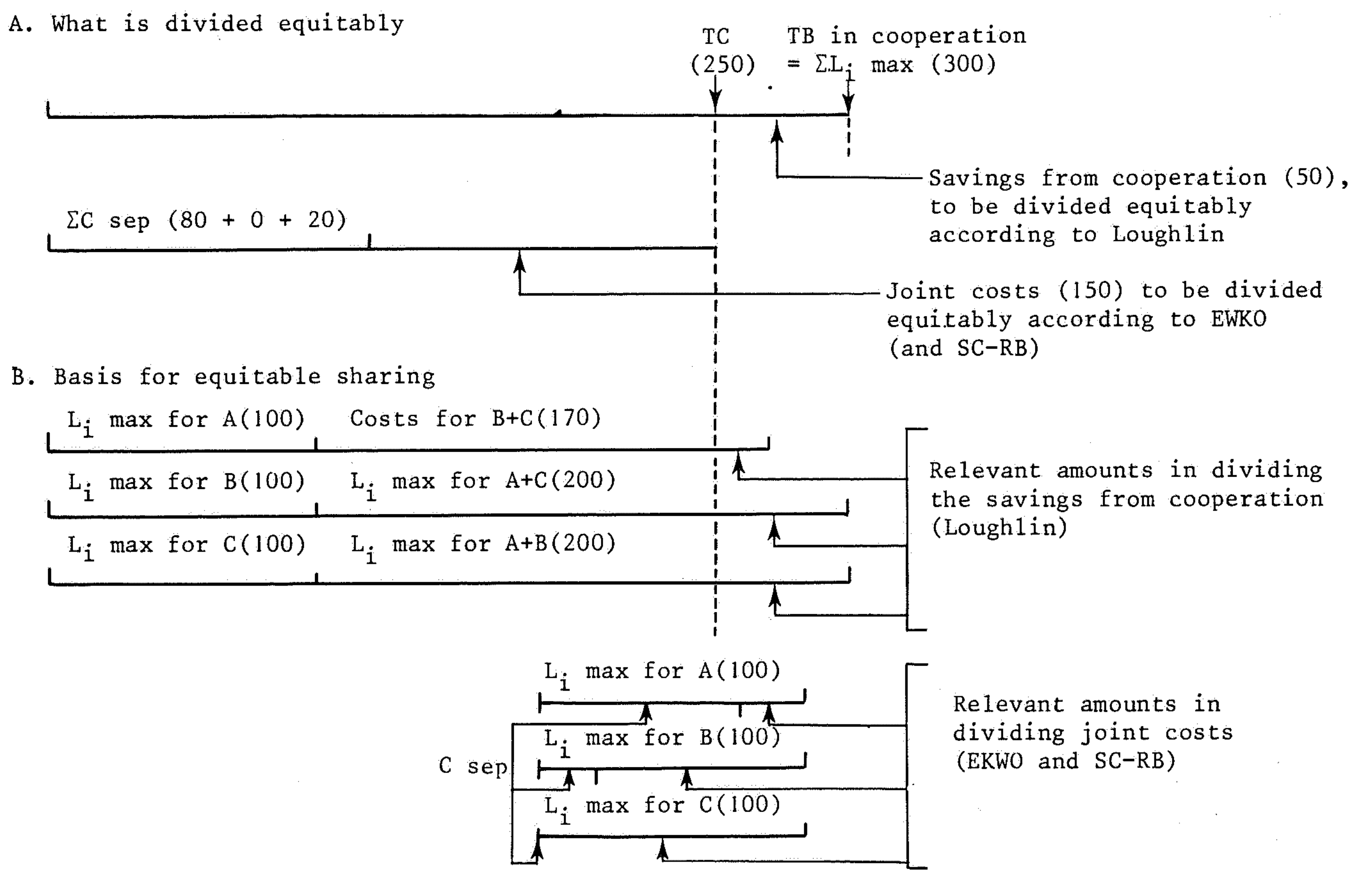


Figure 5 Illustration of the differences between the allocation of savings from cooperation proportional to savings from party inclusion and the allocation of joint costs of cooperation proportional to residual savings of the party.

Discussion of some groupings of parties or chargeables; possibilities in the procedures 4 and 7 respectively

SHARES OF COSTS OF WATER MANAGEMENT (grouping of parties; procedure 4); figures between brackets are the sum of the percentages of the parties without coalition

1. First approach to coalition	Built-up area (1+2)	Agriculture (3+4)	Mining (5)	Infrastructure (6+7)	
derived shares in %	15.15 [19]	62.52 [61]	5.43 [5]	16.90 [15]	
2. First approach improved	Built-up area (1+2)	Agriculture (3+4)	Mining (5)	Roads (6)	Landsc. and Recr. (7)
derived shares in %	15.48 [19]	62.96 [61]	5.57 [5]	14.70 [13.5]	1.30 [1.3]
3. Second approach to coalition	Built-up area (1+2)	Non-built-up area (3+4+6+7)	Mining (5)		
derived shares in %	17.91 [19]	74.46 [76]	6.63 [5]		

Remarks: The coalition in row 1 is - already in this procedure - not accepted (by 7); (6+7) is charged more with the coalition because the benefits are not anymore an actual constraint on 7. This is the reason for the improvement in row 2. The coalition in row 2 could hold - to the advantage of (1+2) - if the non-built-up areas would not threaten with the coalition in row 3. To each of these coalitions - especially to that in row 3 - mining would argue that it is not fair to have that wide parties with them apart. Besides - as discussed below - none of the coalitions would hold in procedure 7.

SHARES OF COSTS OF WATER BOARDS (grouping of chargeables; procedure 7); figures between brackets are the sum of the percentages of the chargeables without coalition

1. First approach to coalition	Built-up area (1+2)	Agriculture (3+4)	Mining (5)	Infrastructure (6+7)	
a. derived shares in %	19.46 [22.5]	48.49 [48.6]	7.85 [7.5]	24.09 [21.5]	
b. alternative for 1a*	19.07	48.89	7.88	24.17	
2. First approach improved	Built-up area (1+2)	Agriculture (3+4)	Mining (5)	Roads (6)	Landsc. and Recr. (7)
a. derived shares in %	19.95 [22.5]	48.94 [48.6]	8.06 [7.5]	22.80 [21.2]	0.26 [0.3]
b. alternative for 2a*	19.52	49.26	8.09	22.88	0.26
3. Second approach to coalition	Built-up area (1+2)	Non-built-up area (3+4+6+7)	Mining (5)		
a. derived shares in %	24.77 [22.5]	65.14 [70.1]	10.01 [7.5]		
b. alternative for 3a*	28.07	60.80	11.13		

*In the rows designed with 'a' the shares for other agencies are for (1+2) as for concentrated buildings (1) and for (3+4+6+7) as for agriculture (3+4). Alternatives are presented (row b) based on mixed rates for shares of other agencies in such a way that these shares have the same effect as those without coalitions.

Remarks: Party 7 will, also here, not accept the coalition (6+7), this leads to row 2. That would be to the advantage of (1+2) but might induce the others to treaten with the coalition referred to in row 3 that is advantageous to the non-built-up areas as one group. None of the coalitions hold, however, with regard to the additional condition: that those within a group being assumed equals are dealt with equally, because:

- the levy on all the non-built-up area (3+4+6+7) would be Hfl 91 per ha which is for farming (3) more than without coalition (71);
- the levy on all agricultural land (3+4) according to row 2 would be Hfl 73 per ha also more than 71;
- even in the best proposition for (1+2), that is row 1, the coalition would be unacceptable for concentrated buildings (2). On an area basis they would have to pay Hfl 526 per ha and without coalition only 392.

Effects of water pollution abatement policy on the development of technology

H.F.J. Peters

11 Effects of water pollution abatement policy on the development of technology

SUMMARY

The paper starts with a general discussion on the interaction of the application of production techniques congenial to the environment and the economy of production processes. In the next sections, technologies that are compatible with environmental needs and are also cost-saving are discussed. Some practical examples are given of the application of such production processes in a number of industries. This is followed by a brief discussion on government-supported investigations for the development of cleaner production methods.

11.1 Introduction

Factors stimulating the development of new technologies in production processes can largely be reduced to modifying production costs or price relativities. As the expenses for the protection of the environment form a larger proportion of the production costs, so will the newly introduced technologies be more compatible with the environment, so that less resources need to be used to comply with the constraints imposed by the prevailing environmental policy. The converse however, that production processes that are less hostile to the environment are more economic, does not hold. Increased energy consumption, less contaminated raw materials, lower quality of the product or more extensive safety facilities will often have an unfavourable effect on cost prices.
The development of technologies that are cleaner or more compatible with the environment will therefore especially be stimulated if they have a positive effect on total production costs or price relativities. An environmental policy aimed at succesfully boosting the innovation of production processes that are less harmful to the environment must therefore also take into account the policies on energy, raw materials and safety.

New or improved production technologies whose main effect is the reduction of water consumption or the recycling of waste water often belong to a category compatible with the policies on the environment, energy and/or raw materials. Such technologies have in common that pollution is combated at source, because less contamination arises. As a result expenditure for the treatment of waste water is reduced.

It is obvious that it will be the producer who, subjected to the burden of increasing disincentives as a result of the prevailing environmental policy (emission constraints in discharge licences, levies on the discharge of waste water), will initiate the development and introduction of those technologies that are more efficient economically. In cases where the producers are not in a position to do so, or when the financial risks associated with the development and testing of cleaner technologies are (too) large, the Government may take the initiative or provide financial support. Within the context of its environmental policy, the Government will also initiate projects for the development of pollution-reducing production methods in which the benefits for the environment are the decisive feature, but which in the first instance have a negative effect on production costs.

Below, some practical examples will be presented of technological innovation in production processes, which have largely come about as the result of the increasing burden in respect of the treatment of waste water, levies and more stringent constraints on the discharge of waste water deriving from the Surface Water Pollution Act 1970. Subsequently, a survey will be presented of some of the investigations stimulated by the Government for the abatement of water pollution by means of cleaner technologies.

11.2 Technologies which are both compatible with the environment and economically efficient

In many cases such developments relate to the optimization of water management. Often significant savings of water can be effected by very simple measures. Examples are the dry removal of spilled matter, the cleaning of machinery and floors by means of high pressure hoses, the installation of automatic stopcocks, etc. Also the change-over from the parallel current system to the reverse current system in washing-plants is worth mentioning.

Another important method for improving the efficiency of the water management system is to keep flows consisting of contaminated water separate from other flows. Such measures however often require very extensive modification of the sewage network. Examples of this type of action are: the segregation of clean cooling water and of uncontaminated rain water, the substitution in steam-water-vacuum systems of condensers based on the mixing principle by surface condensers by which the pollution of cooling water by contaminated condensed water is avoided.

Some of the technologies developed are so complex that production processes must be completely modified. Also use is made of advanced techniques, for instance membrane filtration, which is aimed not only at the recycling of water but also the recoupment of raw materials or by-products. Other methods which allow the recycling of water make use of the ion-exchange principle.

Also in respect of cooling water important savings of water can be attained. Mention can be made of conversion to air cooling or the recirculation of cooling water by means of cooling towers. Finally in some cases re-use of raw or treated waste water is resorted to.

11.2.1 *Some examples*

• COOLING WATER

For many industrial processes cooling systems are required for the removal of excess heat. Water is an excellent medium for the transport of thermal energy. For this purpose, surface water and to a smaller extent groundwater and drinking water are often used.
Earlier, mention was made of the segregation of uncontaminated cooling water from other waste water flows; this allows (subject to certain conditions) the direct discharge of such cooling water into surface water, or its re-use after passage through a cooling tower. Such measures may be worthwile for plants connected with the municipal sewerage network, as well as for industries discharging directly into surface water. Recirculation of cooling water may be desirable or necessary in view of the quality of the receiving water. As far as groundwater is concerned it should, if at all possible, only be used for preparing drinking water and for purposes for which high-quality water is required. Recirculation of cooling water may also be resorted to on account of restrictions in the supply of cooling water of the requisite quality or for reasons of cost.
Cooling water used in conjunction with cooling towers usually has chemicals added to it to condition the water. Such chemicals are eventually discharged with the cooling water. By making a proper choice, the drawbacks for the environment connected with the use of such chemicals can be reduced to the maximum possible extent.

• PULP AND PAPER INDUSTRY

The rehabilitation of discharges of waste water by the pulp and paper industry can be effected by internal measures, if necessary followed by external treatment. Internal action includes *inter alia*: the recirculation of waste water rich in fibres (primary cycle), the recovery of fibres from the waste water by means of flotation, sedimentation or filtration and the recirculation of the reconditioned waste water. The degree to which such recycling can be effected depends to a considerable extent on the prevailing conditions and the type of paper produced. Recycling results in an increase in the concentration of sulphates in the process water; in particular their conversion by sulphate-reducing organisms into H_2S results in a significant increase in corrosive properties, which in turn gives rise to special requirements for pipelines and machinery. In addition, requirements in respect of the quality of paper produced also result in restrictions on the degree of recycling. By internal measures, a number of concerns have managed to effect full recycling, so that discharge of waste water is completely or nearly completely obviated. If recycling is not quite complete, purification of the remaining waste water, usually containing substances that degrade well biologically, is most suitably effected by aerobic treatment.

An investigation by the National Institute for Drinking Water Supply has revealed that water use per unit of product has been reduced from 80 m^3/ton in 1968 and 60 m^3/ton in 1971 to 50 m^3/ton in 1974; it is expected that these figures go down further to 37.5 m^3/ton in 1980, 21.5 m^3/ton in 1990 and 13 m^3/ton in the year 2000.

The pollution engendered by the pulp and paper industry amounted to 2.4×10^6 p.e. in 1969 and 1.2×10^6 p.e. in 1975; in 1980 it will be reduced to about 0.4×10^6 p.e.

- FOOD INDUSTRY

A large number of industrial branches belong to this sector, namely slaughtering meat products, dairy products, canning, sugar, margarine, edible oils, starch, soft drinks industries, breweries, etc. In these industries in particular a multitude of technical measures have been taken during the last 10 years resulting in an important reduction in the water pollution engendered. Concurrently, a considerable decrease in water use has been effected in these industries. Tables 1 and 2 show the improvement made.

Table 1 Annual water pollution by the food industry (excluding the potato-starch industry)

Year	1969	1975	1980
Pollution (10^6 p.e.)	8.10	3.5	2.7 (est.)

Table 2 Annual water-use in the food industry (10^6 m^3/annum)

Year	Groundwater $Cl^- < 300$ mg/l	Surface water (excl. cooling water)	Drinking water	Total
1967	169	61	33	263
1972	188	22	35	245
1976	165	6	30	201

The sugar beet industry may be mentioned to illustrate the progress made. The bulk of the water it uses consists of surface water. An important measure that resulted in a significant reduction of the contamination and volume of water discharged was the recycling of the water used for the transport and cleaning of the sugar beet. Prior to its re-use, the water is treated to prevent the content of organics in it from exceeding the allowed quantity.

A considerable part of the water to be discharged consists of water from open condenser systems. This water, which in addition to being of elevated temperature is also contaminated by oxygen-binding substances, can be recirculated by making use of cooling-ponds. However such basins take up considerable room. Condensers of the mixing type can be replaced by surface-condensers, which allow the separate disposal of contaminated condensed water from the cooling water. By means of cooling towers, the latter can be recirculated.
These and other measures have been realized in several plants in the Netherlands. They have reduced water pollution by the industry from 2.5×10^6 p.e. in 1969 to about 0.1×10^6 p.e. in 1980. The water-use per ton of sugar beet processed, that in 1972 still amounted to 6.5 m^3/ton, went down to only 3,5 m^3/ton in 1975. At present its value is no doubt much lower still.

• CHEMICAL INDUSTRY, OIL REFINERIES

Compared with other industries, the waste water problems of the chemical industry require perhaps even more an approach tailored to the individual production unit. It is not however possible within the context of this paper to detail the actions taken or to be taken in this sector. In principle it can be said that in this case also there is a close connexion between measured to reduce water pollution and action to limit water-use. In many cases however very complex and expensive modifications of the production processes are required.
In this respect it is worthwile mentioning the important results that have been obtained in the production of chlorine. In the past, this branch of the industry accounted for the largest emission of mercury, a pollutant belong to the class of black-list substances. An essential step is the segregation of the flux of mercury-polluted water from the remaining waste water. By this means the quantity of water to be treated is reduced very considerably. A large producer of chlorine in the Netherlands has developed a process for the removal of mercury from waste water. This separation is effection by means of ion-exchange. The mercury extracted can be used again. Another main producer near Rotterdam enlarges the production capacity of chlorine by introducing the so-called 'membrane-process' in which no mercury is used.

The waste water generated by oil refineries is primarily characterized by the presence of oil. The nature and the quantity of the waste water discharged is very much dependent on the age of the plant and its type. Almost invariably, older refineries use much more water than more modern ones; in the latter, water saving and cleaner production techniques are used. As expected, the pollution engendered and the quality of water used will in general be higher for plants of a more complex nature than for production units in which only simple refining takes place.

The methods used for the optimization of water management and the reduction of pollution are many and varied. Examples are:

- the separation of waste water into flows not contaminated by oil (such as cooling water) and polluted flows;
- the application to the maximum extent possible of air-cooling instead of water cooling;
- recirculation of cooling water by means of cooling towers;
- the use of surface condensers instead of open condensers;
- the re-use of some waste water flows for purposes that do not demand high quality process water.

By separating the total flux of waste water into flows differing in nature and degree of pollution, treatment methods specific to such partial flows can be applied. In the case of oil-refineries, such techniques may consist of simple oil-separators, physico-chemical treatment and/or aerobic biological treatment. The specific water consumption of oil-refineries may amount to 0.1 to 0.5 m^3/ton of oil for plants converted for pollution abatement purposes and to upwards of 1.5 m^3/ton of oil for old unconverted refineries. Cooling water is not included in the values mentioned.

11.3 Government supported projects

In this context, the investigations to reduce the water pollution engendered by the potato-flour industry may be mentioned. The measures required for this purpose are so drastic that the production processes applied in a converted plant bear little resemblance to the methods traditionally used in the starch industry. The steps include the conversion of the production process to low water consumption, the extraction of proteins and other subsidiary products from the effluent issuing from the production process, and the recycling, after passage through a treatment installation, of the waste water deriving from the transport and cleaning of potatoes.
Increasingly policies for the reduction of pollution are primarily aimed at

abatement at source. For this purpose, investigations will have to be made into the development of products that are less contaminating and into production processes and techniques that are compatible with the environment. In this context, low water use and recycling of water are essential. Such research will have to be carried out by the industries concerned themselves. In a number of cases, a government subsidy for such projects is provided. Examples of such support are the development of anaerobic treatment for full-scale application, the extraction of chromium from the waste water of tanneries and the subsequent re-use of the chromium, the removal of organic substances from the waste water of tanneries, the development of alternative processes for fortifying mixed yarn and the printing of textiles, the development of a process for the elimination of zinc from the waste water of the rayon industry. Many of these projects are also concerned with the reduction of water consumption by installations making use of the processes concerned.

Investigations directed towards the abatement of pollution at source or to the development of products that are more congenial to the environment find special favour with the Government, if additionally they provide benefits in respects of savings of energy or raw materials. The projects must also be innovating or stimulate innovation. Generally speaking, projects are considered that result in process-integrated facilities or measures affecting the composition of products that prevent or restrict pollution. In addition, projects concerned with the re-use of waste or waste-water or with the introduction of new treatment techniques will find favourable consideration.

Systematic evaluation of land consolidation projects in The Netherlands

H. Bosma

12 Systematic evaluation of land consolidation projects in The Netherlands

SUMMARY

A new system for the evaluation of land consolidation projects has been developed in the Netherlands by the Government Service for Land and Water Use. Land consolidation projects are multi-purpose projects and comprise a number of measures among which the improvement of water management is an important one.

The effects of land consolidation projects – which are generally complex projects – are numerous and vary greatly in character. In consequence, the methods to measure these effects differ greatly also and the units in which these effects can be measured likewise vary.

The evaluation system is now being put into practice. Its objective is first to make a thorough comparison between proposed land consolidation projects and second to make possible a comparison between land consolidation projects and other Government investments. This paper describes briefly the way of measuring the manifold effects of land consolidation projects adopted in the evaluation system. Some remarks are added as to the usefulness of the system, its point of departure, the gaps still existing in it and the way it should be applied in order to obtain the most valuable results for the policy makers.

An example of practical application of the evaluation system is also briefly discussed.

12.1 Introduction

In the Netherlands, as everywhere else, water and water management play an important role in human life. Plans in the field of water and water management usually serve many purposes. Often such plans are incorporated in, comprehensive, multipurpose plans as, for example, in the field of physical planning and rural development.

Today land consolidation projects (LCP's) in the Netherlands consist generally of a number of measures aimed at rural development. In most cases, measures to improve water management are an important part of LCP's in the Netherlands. Recently a system has been developed for the evaluation of LCP's. This paper deals with:

- the need for an evaluation system (section 12.2);
- the purpose and possibilities of the system (section 12.3);
- the measuring of the various effects of LCP's (section 12.4);
- some general observations as to the character of the system and its usefullness for the policy makers (section 12.5);
- an example of practical application of the system (section 12.6);
- some final remarks (section 12.7).

12.2 The need for an evaluation system for land consolidation projects

An LCP is a project for developing a part of the rural area in such a way that it can perform optimally the functions allocated to it. The allocation of functions to parts of the rural area is the task of physical planning.
Land consolidation can thus be considered as realizing and putting into effect the purpose given to the rural area by physical planning.

The Netherlands has a high population density and a high income level. That means that land is scarce. It is therefore essential that every part of the territory should be used efficiently, whatever its function. Land consolidation, therefore, is an important instrument of the Government with regard to the rural areas and especially agriculture.

Land consolidation in the Netherlands is the responsibility of the Government Service for Land and Water Use, which is part of the Ministry of Agriculture and Fisheries. The current capacity of the Service is to develop about 40,000 hectares per annum. As the Netherlands count about 2,500,000 ha of rural area, once every 60 years the whole rural area of the Netherlands could be (re) developed. The Service's budget is now about 400 m guilders a year.
The high population density and high prosperity lead to keen competition for space in the rural area, for many purposes such as agriculture, outdoor recreation, nature conservation and others. There is also competition for a share in the Government budget between land consolidation and other tasks of the Government.

LCP's vary considerably. Generally, they consist of a combination of the following measures:

- improvement of the situation with regard to parcelling;

- improvement of water management for agriculture;
- improvement of the road network to ensure a better opening-up of the area;
- measures to safeguard or to enhance landscape and natural values;
- facilities for outdoor recreation.

As LCP's consist of many and different measures their effects are also numerous and varied in character. Moreover, it should be borne in mind that an effect that is favourable for one purpose, for example, agriculture, can well be unfavourable for another purpose, for example landscape protection.
It is therefore difficult to get a clear view of the effects of a LCP as a whole and also to judge whether these effects justify the costs of the LCP.
A thorough evaluation of LCP'S is therefore essential and difficult. An evaluation is essential, first, to ascertain what the effects of the LCP's are for the many functions competing for space in the rural area, to make it possible to weigh these effects against the cost of the projects, and second, to be able to compare the effectiveness of investment in LCP's with that of other Government investments. An evaluation is difficult because of the complexity of the LCP's and the variety of the effects they produce.

12.3 Purpose and possibilities of the evaluation system

The purpose of the evaluation system is to provide help for the policy makers when they have to decide whether an LCP should be carried out or not. This is achieved by describing the various effects of the LCP: (a) as objectively and as far quantified as possible; (b) in a strictly uniform way for every LCP.
The effects of LCP's vary widely in character and are measured – if they can be measured at all – in different units. It is not possible to reduce them into one denominator. Consequently, it is impossible to present the results in a simple cost/benefit ratio or internal rate of return for the LCP as a whole. This implies that unequivocal and strictly objective conclusions cannot be drawn from the evaluations.
The evaluation results themselves cannot lead directly to a conclusion; nor are they meant to do so. The purpose of the evaluation is to provide better information upon which policy makers can base their decision.

From the preceding, it follows that the evaluation system will be most suited for comparing similar projects, in this case LCP's. This is of course what is most urgent for the Government Service for Land and Water Use. For the comparison of an LCP with another type of Government investment, the evaluation system can of course be very helpful, but in such cases additional information will be necessary and the conclusion drawn will be subject to more restrictions.

12.4 The measuring of the effects of land consolidation projects

12.4.1 *General remarks on measuring effects*

In the framework of the Seminar, it looks natural initially to dwell first and foremost on the effects of the improvement of water management. However, there is a close connexion between the effects of improvement of water management and those of other measures, especially the effects of improvement of parcelling. Both measures have their effects, but the effect of both measures taken simultaneously is greater than the sum of the effects of both measures when taken separately.

An effect of an LCP is the influence it has upon the realization of an objective of government policy. An effect that can be considered as a (partial) realization of an objective is a positive effect. An effect that conflicts with an objective is a negative effect.

Usually the most important effects of an LCP are:

- the economic effects, especially for agriculture;
- the effects on values of nature;
- the social effects, especially those on working and living conditions of the rural population;
- the effects on landscape;
- the effects of road network improvement;
- the effects on outdoor recreation.

For an evaluation of an LCP all these effects must be measured if possible. This applies both to positive and negative effects. Measuring effects is far more difficult than measuring costs. Therefore, this paper does not dwell at length on measuring costs, but concentrates on measuring effects.
The evaluation system for LCP's assesses the effects in two phases. The first phase is the delimitation of effects; the second phase is the measuring of effects. The principal starting points for the delimitation of effects are:

- effects are defined from a national-economic viewpoint;
- only effects caused by the LCP are taken into account;
- indirect or multiplier effects are not taken into account;
- if additional private investments are necessary for the realization of effects, these private investments must be included in the evaluation.

Effects are defined from a national-economic viewpoint. The LCP is considered as a project of society as a whole. Costs are made by the Government, which is a member of society, effects are in first stage enjoyed by others, for example farmers, who are also members of society. Only really used production factors and really produced goods and services are considered costs and effects. Income and money transfers from one member of society to another such as subsidies, taxes, land purchases and sales do not enrich or impoverish society as a whole and are not considered costs or effects for this purpose.

Only effects caused by the LCP are taken into account. This sounds obvious enough, but in practice this is not so very easy to realize. On average the execution of an LCP takes about 10 years. During these 10 years there will probably be more changes in the area concerned than the execution of the LCP alone. Technological and biological developments in agriculture will continue, provinces and communities may reconstruct roads; natural values and scenic beauty may be lost. If one wants to measure only the effects caused by the LCP, it is necessary to eliminate the effects of these autonomous developments. This is realized by making a forecast of the situation in the area in about 10 years, when the LCP will have been carried out, and another forecast of the situation in the area at the same time, but not supposing that the LCP has not been carried out. By comparing both forecasts – or rather developments – the net effect of the LCP can be measured. This looks simple, but it is one of the most crucial aspects of the evaluation. Effects of the LCP depend as much on the situation with the LCP as on the situation without the LCP. The latter situation is not so easy to assess, however. Many problems, often very fundamental ones, are involved in assessing this situation without the LCP. These problems will not be treated here, as this would exceed the scope of this paper.
Indirect or multiplier effects are not taken into account. In investment evaluation the problem of how to deal with these effects often arises. For several reasons, which cannot be detailed here, the evaluation system for LCP's in most cases neglects these possible effects.
If additional private investments are necessary for the realization of the effects, these private investments must be taken into account. The effects of the LCP are then, essentially, the result of both Government and private investment. If private investments is not taken into account, the profitability of Government investment may be grossly over-estimated.

As stated before, the effects of LCP's are of very different character. The ways to measure them and even the possibilities of measuring them, are accordingly different. In the sections 12.4.2 to 12.4.7 inclusive a brief description is given of how the effects are measured and how it is tried, if the effects are not measurable to describe them in such a way that comparison between different LCP's as to each type of effect can be as clear as possible.

12.4.2 *Measuring the economic effects*

The economic effects of an LCP will, in general, be the economic effects on agriculture and as the effect on agriculture is defined, the increment in remuneration of the farmer due to the LCP. The remuneration of the farmer is the turnover of the farm less all cost, including those of hired labour, but excluding any remuneration for the labour of the farmer and his family.

As stated in section 12.4.1 the effect to be attributed to the LCP is the difference between the remuneration of the farmers with the project and the remuneration of the farmers without it. For both situations a forecast must be made. Strictly speaking, such a forecast should be made for every farm in the area. This is impossible for practical reasons and for reasons of principle. Therefore, agriculture in the area is characterized by a limited number of economic farm models, in a certain proportion.
The situation with and without the LCP 10 years ahead is then represented in the same way. For that purpose, two preliminary questions must be answered:

(a) How will the future farm size distribution and number of farms be as compared with today? This is mainly determined by the number of farmers leaving agriculture for reasons of age or change of occupation. The Dutch Agricultural and Economic Research Institute forecasts the number of famers leaving.
(b) What modernization will take place during the next 10 years? This is a difficult question. An answer to it must be sought in co-operation with the Agricultural Advisory Service.

The number of farmers leaving agriculture is determined principally by demographic and general economic factors. The influence of an LCP on this aspect is limited. On the other hand, modernization of farms depends to a considerable extent on the implementation of the LCP.
The farm models mentioned above are designed on the basis of optimal circumstances as to division of land, distribution of plots and water management. The remuneration of the farmer is optimized given these circumstances. If circumstances are suboptimal, data concerning these circumstances can be introduced into the model. With the use of linear programming, the actual remuneration of the farmer under these suboptimal circumstances is assessed.
Thus it is possible to calculate the remuneration of the farmers both in the situation with the LCP and in the situation without it. By subtracting the last amount from the first, the increase in the remuneration of the farmers caused by the LCP is obtained.

The effect of LCP's can be attributed to the measures that together form the

LCP's. With respect to these effects, the measures can be broadly divided into two categories:

- improvement of parcelling;
- improvement of water management.

Measures improving parcelling are for example:

- joining of parcels;
- enlargement of parcels;
- diminishing distance between parcels and farm buildings
- better opening-up;
- resettlement.

The primary effect of these measures is the saving of labour and machine hours.

Measures improving water management are for example:

- the digging or improvement of water conduits and ditches;
- sub-surface drainage;
- the construction or renewal of pumping plants.

The primary effect of better water management is improved productivity of the soil. In the Netherlands most soils are too wet and the improvement of water management is usually aimed at achieving a lower groundwater level, especially during the cold season. In early spring, land with a lower groundwater level will be firmer, so that cattle and machinery can move on it earlier without damaging the soil. Moreover, as in drier soils, the temperature will rise earlier in the season, growth of grass and other crops will start earlier. On the other hand, these effects will make it possible to use the land until later in the season than if it had a higher groundwater level. Thus the effect of a lower groundwater level corresponds with a lengthening of the productive season.
The longer productive season will mean higher productivity of the soil. This means higher production, provided more labour and machine hours are available to put this higher productivity into effect. As has been stated above, in an LCP extra labour and machine hours become available as an effect of improved parcelling. The combination of different measures leads to a larger profit than would have been possible if these measures had been taken separately.

Now that the character of the effects of LCP's for agriculture has been described the question arises how these effects work on the remuneration of the farmer. The economic farm models mentioned on the preceding page are the basis for the calculation of the number of labour and machine hours saved.
As has been stated there it is possible for every set of circumstances with respect to parcelling and water management to calculate the remuneration for the farmer that is possible. By calculating the remuneration of the farmers in the area concerned with the LCP and the remuneration without the LCP, and then subtracting the

latter amount from the first, it is possible to assess the increment in remuneration of the farmers caused by the LCP.

Among the 'circumstances' mentioned above the productivity of the soil is of course a very important one, and more especially the productivity of the soil in relation to groundwater level. The productivity of various soil types in relation to the groundwater situation is given in tables 1a and 1b. This table is based on studies as to the yields of different crops on different soils under different groundwater conditions. For every groundwater level a 'depression' is calculated that is the difference between the actual yield of crops on that soil compared with the yield on that soil with an ideal groundwater level. By comparing the 'depressions' in an area with the execution of an LCP with those without the LCP, it is possbile to measure the effects of the LCP on the productivity of the soil.

Another possibility to enlarge a farmer's remuneration as a consequence of an LCP can be the modernization of the farm. A cubicle cowstable, for instance, can only be economically used if at least 60 percent of the farm area is adjacent to it. In crop farming, better accesibility of plots can lead to the growing of more root crops which are usually more remunerative than cereals.

12.4.3 *Measuring the effects on natural values*

As has been stated, there is keen competition in the Netherlands for space in the rural area for all kinds of uses because of the high density and high income level of the population. In many LCP's, the clash of interests of the steadily intensifying agriculture and those of natural environment play a predominant role. The evaluation of the effects on natural values is therefore a very important aspect. The starting point for the measuring of effects on natural values is the objective of Government policy as to the natural environment. This can briefly be described as 'a maximally differentiated natural environment'. This differentiation can diminish by the vanishing of communities and species. Rare and vulnerable elements (communities or species) will vanish first. Their conservation or settlement is the most crucial for maintaining differentiation; therefore, a higher value is conferred to these elements than to other, less rare or less vulnerable elements.
As with other effects, the effect of an LCP on natural values is defined as the difference between the situation with the LCP and the situation without it. Two forecasts of possible developments of natural values in the area should thus be made. Making such forecasts is a difficult task because there is only scanty experience in this field. Moreover, these forecast must be based upon the actual situation, and the question arises how the actual situation should be determined. The obvious answer is that an inventory should be made of the natural elements

Nr.	Code	Description of soil	Ground water class																			
			II		III		V		VI		VII		VIII		II		III		V		IV	
			Type of depression (Wa = excess of water; Dr = drought)																			
			Wa	Dr	Wa	Dr	Wa	Dr	Wa	Dr	Wa	Dr	Wa	Dr	Wa	Dr	Wa	Dr	Wa	Dr	Wa	Dr
1	hV	Clayey earthy peat soils	28	0	18	0	12	2	6	4	4	6	4	6	15	0	10	0	8	2	6	0
2	aV	Clay-poor earthy peat soils	32	0	20	0	10	4	2	8	2	10	2	10	15	0	8	0	4	4	4	0
3	kV	Peat-soils with a clay cover	26	0	16	2	8	6	2	14	2	16	2	16	12	0	6	2	4	6	2	2
4	zV	Peat-soils with a sand cover	28	0	14	0	6	4	0	8	0	10	0	10	10	0	4	0	2	4	0	0
5	vW	Peaty soils	32	0	20	2	10	4	2	12	2	16	2	16	15	0	8	2	4	4	4	2
6	kW	Peaty soils with a clay cover	26	0	16	2	8	6	2	16	2	20	2	20	12	0	6	2	4	6	2	2
7	zW	Peaty soils with a sand cover	28	0	14	2	6	4	0	12	0	16	0	16	10	0	14	2	2	4	0	2
8	K1 z	Clayey soils with a subsoil of peat (tilth: 'zavel' and light clay)	24	0	14	0	8	4	2	8	2	12	2	12	11	0	6	0	4	4	2	0
9	K1 k	Clayey soils with a subsoil of peat (tilth: clay)	26	0	16	2	10	6	4	10	4	14	4	14	13	0	8	2	6	6	4	2
10	K2 z	Clayey soils with a subsoil of peat (tilth: 'zavel' and light clay)	24	0	14	2	8	6	2	12	2	16	2	16	11	0	6	2	4	6	2	2
11	K2 k	Clayey soils with a subsoil of peat (tilth: clay)	26	0	16	4	10	10	4	16	4	20	4	20	13	0	8	4	6	10	4	4
12	K3, 4 z	Clayey soils with an intermediate layer of heavy clay or a subsoil of heavy clay (tilth: 'zavel' and light clay)	26	0	16	4	10	12	4	18	4	20	4	20	13	0	8	4	6	12	4	4
13	K3, 4 k	Clayey soils with an intermediate layer of heavy clay or a subsoil of heavy clay (tilth: clay)	28	0	18	6	12	14	6	22	6	26	6	26	15	0	10	6	8	16	6	6
14	K5 z	Other clayey soils (tilth: 'zavel' and light clay)	24	0	14	0	8	0	2	2	2	4	2	4	11	0	6	0	4	0	2	0
15	K5 k	Other clayey soils (tilth: clay)	26	0	16	0	10	2	4	4	4	6	4	6	13	0	8	0	6	2	4	0
16	BL 1	Brick soils and loam soils (loamy sand)	26	0	14	0	6	0	0	2	0	4	0	4	10	0	4	0	2	0	0	0
17	BL 2	Brick soils and loam soils (sandy loam)	28	0	16	0	8	2	2	4	2	6	2	6	12	0	6	0	4	2	2	0
18	BL 3	Brick soils and loam soils (silty loam)	30	0	18	0	10	4	4	6	4	8	4	8	14	0	8	0	6	4	4	0
19	S	Extremely fine, clayey sand	24	0	12	0	6	2	2	6	0	10	0	10	9	0	4	0	4	4	2	0
20	EEZ	Sandy soils A1 horizon 80 cm	28	0	14	0	6	0	0	0	0	2	0	4	10	0	4	0	2	0	0	0
21	EZ	Sandy soils 50–80 cm	28	0	14	0	6	2	0	4	0	8	0	10	10	0	4	0	2	2	0	0
22	cZ	Sandy soils 30–50 cm	28	0	14	2	6	6	0	14	0	20	0	20	10	0	4	2	2	6	0	2
23	tZ	Sandy soils 15–20 cm	28	0	14	4	6	12	0	24	0	30	0	30	10	0	4	4	0	12	0	4
24	Z	Sandy soils 15 cm	24	2	10	8	2	20	0	36	0	40	0	40	6	2	2	8	0	20	0	8
25	kZ	Sandy soils with a clay cover	24	0	14	4	6	12	2	24	0	30	0	30	10	0	4	4	2	12	2	4

Table 1b Arable farming – Yield depression in % of yield in ideal groundwater situation

Nr.	Code	Description of soil	Ground water class																	
			III		V		VI		VII		VIII		II		III		V		IV	
			Type of depression (Wa = excess of water; Dr = drought)																	
			Wa	Dr	Wa	Dr	Wa	Dr	Wa	Dr	Wa	Dr	Wa	Dr	Wa	Dr	Wa	Dr	Wa	Dr
1	hV	Clayey earthy peat soils	36	0	24	0	8	0	4	0	4	0	40	0	28	0	20	0	12	0
2	aV	Clay-poor earthy peat soils	36	0	24	0	8	4	4	8	4	8	40	0	28	0	20	0	12	0
3	kV	Peat-soils with a clay cover	36	0	24	4	8	8	4	12	4	12	40	0	28	0	20	4	12	0
4	zV	Peat-soils with a sand cover	28	0	20	0	4	4	0	8	0	8	32	0	20	0	12	0	6	0
5	vW	Peaty soils	36	0	24	4	8	12	4	20	4	20	40	0	28	0	20	4	12	0
6	kW	Peaty soils with a clay cover	36	4	24	8	8	16	4	24	4	24	40	0	28	0	20	8	12	4
7	zW	Peaty soils with a sand cover	28	0	20	4	4	12	0	20	0	20	32	0	20	0	12	4	6	0
8	K1 z	Clayey soils with a subsoil of peat (tilth: 'zavel' and light clay)	32	0	20	0	4	4	0	12	0	12	32	0	20	0	12	0	8	0
9	K1 k	Clayey soils with a subsoil of peat (tilth: clay)	36	0	24	4	8	8	4	16	4	16	36	0	24	0	16	4	12	0
10	K2 z	Clayey soils with a subsoil of peat (tilth: 'zavel' and light clay)	32	2	20	4	4	12	0	20	0	20	32	0	20	0	12	4	8	0
11	K2 k	Clayey soils with a subsoil of peat (tilth: clay)	36	4	24	8	8	16	4	24	4	24	36	0	24	0	16	8	12	4
12	K3, 4 z	Clayey soils with an intermediate layer of heavy clay or a subsoil of heavy clay (tilth: 'zavel' and light clay)	36	0	24	8	8	20	4	28	4	28	36	0	24	0	16	8	12	0
13	K3, 4 k	Clayey soils with an intermediate layer of heavy clay or a subsoil of heavy clay (tilth: clay)	40	4	28	12	12	24	8	32	8	32	40	0	28	0	20	12	16	4
14	K5 z	Other clayey soils (tilth: 'zavel' and light clay)	32	0	20	0	4	0	0	0	0	0	32	0	20	0	12	0	8	0
15	K5 k	Other clayey soils (tilth: clay)	36	0	24	0	8	0	4	4	4	4	36	0	24	0	16	4	12	0
16	BL 1	Brick soils and loam soils (loamy sand)	32	0	20	0	4	0	0	0	0	0	32	0	20	0	8	0	4	0
17	BL 2	Brick soils and loam soils (sandy loam)	36	0	24	0	6	0	4	0	4	0	36	0	24	0	12	0	8	0
18	BL 3	Brick soils and loam soils (silty loam)	40	0	28	0	8	0	4	4	4	4	40	0	28	0	16	0	12	0
19	S	Extremely fine clayey sand	28	0	20	0	4	4	0	8	0	12	28	0	20	0	8	0	4	0
20	EEZ	Sandy soils A1 horizon 80 cm	28	0	16	0	4	0	0	2	0	4	28	0	16	0	10	0	6	0
21	EZ	Sandy soils 50–80 cm	28	0	16	0	4	2	0	4	0	12	28	0	16	0	10	0	6	0
22	cZ	Sandy soils 30–50 cm	28	0	16	4	4	12	0	20	0	20	28	0	16	0	10	4	6	0
23	tZ	Sandy soils 15–20 cm	28	4	12	16	2	28	0	32	0	32	28	0	12	4	8	16	4	4
24	Z	Sandy soils 15 cm	24	12	8	24	0	48	0	48	0	48	24	0	8	12	2	24	0	8
25	kZ	Sandy soils with a clay cover	32	4	20	16	4	28	0	32	0	32	32	0	20	4	12	16	8	4

present. It is clear, however, that such an inventory is only feasible if severe restrictions are made as to its scope. These restrictions can be:
- not to include in the inventory all kinds of elements;
- not to cover the whole plan area.

It will be clear that covering all elements in an inventory is impossible. As to covering the area, in practice the whole area is covered by the inventory but the intensity depends on the natural values apparently present in the different parts of the area.

The notion 'ecotope' has been chosen as a basis for evaluation and inventory. An ecotope is defined as a part of the area where a certain biological community occurs or can be expected to occur, for instance, young pinewood, verge of a road, heather moor and so on. After an inventory has been taken of the size of the different ecotopes presently in the area, a forecast is made of that size in about 10 years time with and without the LCP. Depending on the character of the ecotopes, the size is expressed in hectares (for example old deciduous forest), in hectometers (hedges) or units (old oak trees).

The resulting enumeration of differences in sizes of the different ecotopes with and without the LCP is not yet a sufficient basis for evaluation. Four additional data should be added. First, not every ecotope has the same value (as stated herefore). Biologists have made a list of the values of the ecotopes in the Netherlands. These values are applied to the ecotopes of the area concerned. Second, not only the size, but also the quality of the ecotopes should be taken into consideration. This quality aspect refers to the fact that an ecotope is defined as a part of the territory where certain communities and species find their natural home. It is possible, however, that not all of these species or communities are present because of the impact of human activities. This aspect can be brought into the evaluation by splitting up the ecotopes in two: a well-developed one and a less-developed one.

A third aspect is that the ecotope method is a botanical one. Additional attention for other components of natural life is necessary. Among animals, vertebrates lend themselves best to introduction into the evaluation because on that category of animals most knowledge is available. For meadow birds, it is now possible to give a forecast of the effect of certain measures on the number of nests built.

At last point is that the relations between the different ecotopes should be taken into account, that is, both the relations between the ecotopes within the area of the LCP and the relation with ecotopes outside that area.

12.4.4 *Measuring social effects*

Many of the effects mentioned have in fact also social aspects. In that sense, one could say that they indicate the impact of the LCP on the social climate in the area, and that it is not necessary to calculate separate social effects. However, there are two social effects that are not reflected in the other effects and are yet very important. These two effects should therefore be treated separately. These effects are the reduction in working hours for the farmer and his family and the effect of the LCP on employment in the area.

As for reduction in working time, as stated before better parcelling has the effect of saving labour and machine hours. Part of the labour saved is used on the farm to realize the production growth made possible by the enlarged productivity of the soil as a consequence of improved water management. Another part of the labour saved is at the disposal of the farmer and his family, or reflects a diminishing of the amount of hired labour. The labour saved for the farmer and his family is usually considered as a benefit because of the long and heavy work in agriculture, especially in dairy farming.

The effect on an LCP on employment is fourfold:

- the execution of the works to realize the LCP demands a certain amount of labour (about one man-year for every Dfl 100,000 to 150,000 spent);
- as the LCP gives the farms a firmer economic basis, fewer farmers will have to leave agriculture than without the LCP;
- as stated already, some hired labour will no longer be necessary, which means a diminishing of employment in that sector;
- the employment effect outside the agricultural sector due to mulitplier effects.

12.4.5 *Measuring the effects on outdoor recreation*

Facilities for outdoor recreation are made available with the intention that they shall attract visitors. So at the basis of an evaluation of these facilities is the number of visitors that is expected to visit them. The next problem is whether it is possible to express the value of these visits in money terms. For some types of outdoor recreational facilities, it is indeed possible to calculate a money value for expected visits. However, for the type of facilities provided in LCP'S this is not possible. Therefore, the evaluation system tries another way to supply policy makers with useful information. First a survey is made of the general level of outdoor recreational facilities in the area. Next an estimate is made of the cost per visit to the facilities provided for by the LCP. The cost per visit together with the already existing level of facilities can be of some help for the decision-makers, although in fact no comparison between costs and effects is given.

12.4.6 *Measuring the effects of road network improvment*

Measuring of the effects of road network improvement has turned out to be very difficult. This is especially so in the case of roads that have not merely an agrarian function, but also serve more general traffic aims. Improvement of roads can be obtained in two ways:

- broadening of the surface to ensure a greater capacity and more safety. No evaluation method is available on this point; especially the safety aspect is very difficult to grasp.
- reinforcement of road construction in view of the growing use of heavy vehicles such as bulk milk lorries and heavier lorries for carrying products like potatoes and sugar beets.

In an LCP, roads are reinforced so as to be able to carry modern vehicles. Without the LCP, road owners will usually not reconstruct the roads or at least not so thoroughly, because they cannot afford the investment cost. In consequence, however, without the LCP maintenance costs will be higher than with the LCP. The result of the LCP is diminished maintenance costs. This can be measured, although it is not easy to make a forecast of the development without the LCP on this point.

12.4.7 *Measuring the effects on landscape*

Scenic values are often specific for one area. Evaluating them against general standards is therefore very difficult and a truly satisfactory method has not yet been developed. For the time being, evaluation is carried out along the following lines. In the area where an LCP is designed the elements which are characteristic for its scenic qualities are defined. Then the influence of the LCP on these elements is determined. This influence cannot be expressed in quantitative terms: it is only possible to indicate whether this influence is positive or negative, heavy or light.

12.5 Some observations on the character of the evaluation system and its applicability

The purpose of the evaluation system is to provide help for the policy makers for their decision if an LCP should be carried out or not. The usefulness of the evaluation system for this purpose depends on:

- its general characteristics;

- the points of departure chosen;
- the gaps still present in the system;
- the way of application chosen.

General characteristics: as stated in section 12.3 the effects of LCP's vary widely in character and are therefore measured in very different units: the system does not confer weights to these different units; this is left to the policy makers. In consequence, the evaluations cannot lead to one unequivocal conclusion. Another consequence is that the system is best fit for comparing LCP's.

Points of departure: the most important point of departure of the evaluation system is that the Government and European Economic Community (EEC) policies are accepted as data. This implies that the prices the farmers receive for their products are considered as the prices the evaluation must be based upon. This point of departure is not generally agreed upon. One difficulty is, however, to find a good alternative for official EEC prices. Insofar as the system is used for the evaluation of LCP's which in effect means the comparing of similar projects, the exact price level chosen is slightly less crucial because possible distortions will all work in the same direction.

Gaps still existing in the system: lack of knowledge still causes some gaps in the system. Studies are under way to fill out these gaps where possible.

Way of application: the usefulness of the evaluation depends to a considerable degree on the way it is applied. A correct way of application can greatly enhance the value of the result obtained.

Two examples may be given.

When an LCP is evaluated, this evaluation leads to a judgement on the project as a whole. However, if the project as a whole is profitable, it does not follow that every part of the project is also profitable. To check if there may be unprofitable parts, it is necessary to evaluate at least two variants of the project, which differ as to the level of investment or other measures for the different objectives. By comparing costs and effects of these variants, less attractive aspects of these variants can be spotted.

A very considerable increase in usefulness of the evaluation can be obtained by starting the evaluation process right from the beginning of the planning of the LCP. It is thus possible to adjust the project on the basis of preliminary evaluation results.

12.6 An application of the system

In table 2 a survey is given of the results of the evaluation of an LCP with the system described heretofore. The results are presented in the form of a balance sheet. This evaluation refers to an LCP in the southern part of the Netherlands of about 1,400 hectares. Two variants for the LCP are taken into consideration. Variant A is primarily aimed at achieving economic benefits for agriculture. Variant B pays more attention to values of nature and landscape, especially in the eastern part of the area of the LCP. The survey has five columns: In the first column are listed the types of effect brought about by the LCP. The second gives a description of the indicators of effects (or costs) that are measured in further detail. The third column gives some indications as to the development in the area without the LCP, while the fourth and fifth column give the results of the measuring of the effects of two variants of the LCP that were evaluated. As the development without the LCP is the reference level for measuring the effects, it is not strictly necessary for the evaluation to describe it extensively. However, some knowledge of the development without the LCP can be useful, for example to get an impression of the relative effect of the LCP on the development of the area.

Table 2 Survey of costs and effects of the land consolidation project Velden

Type of effect	Description of costs and effects	Some data on development without LCP	*Alternative A* (Compared to development without LCP)	*Alternative B* (Compared to development without LCP)
Economic effects	Investment for agriculture including roads for agricultural purposes		Dfl 5,215,000	Dfl 4,240,000
	Remuneration of farmers	Dfl 1,500,000 p.a.		
	Increase in remuneration of farmers		Dfl 817,000 p.a.	Dfl 725,000 p.a.
	Decrease in maintenance costs roads for agricultural purposes		Dfl 7,000 p.a.	Dfl 6,000 p.a.
	Internal rate of return for above mentioned investment		15.6 %	17.1 %
Effects on values of nature	Changes in size and number of ecotopes and other elements of natural environment	Some deterioration	Some decrease in highly valued ecotopes. Some increase in moderately valued ecotopes.	Similar to A, but fewer losses in the eastern part of the area
	Variety of species and communities	Steady	Some deterioration	Some deterioration
	Relation with surrounding areas	Steady	Some deterioration	Some deterioration

Table 2 (continued)

Type of effect	Description of costs and effects	Some data on development without LCP	*Alternative A* (Compared to development without LCP)	*Alternative B* (Compared to development without LCP)
Social effects	Hours available for leisure for farmers		10,000 hours p.a.	8,000 hours p.a.
	Employment of hired labour		– 2 jobs	– 2 jobs
	Employment for farmers		+	+
	Employment created by execution of works		60 man-years	50 man-years
	Indirect employment		p.m.	p.m.
Effects on outdoor recreation	Investment costs		Dfl 200,000	Dfl 200,000
	Maintenance costs		Dfl 20,000 p.a.	Dfl 20,000 p.a.
	Number of visitors	150,000 p.a.	0	0
	Average cost per visitor:			
	– walking		Dfl 0.15	Dfl 0.15
	– cycling		Dfl 0.25	Dfl 0.25
	– horse riding		Dfl 0.80	Dfl 0.80
	– touring by car		Dfl 0.15	Dfl 0.15
Effects on landscape	Investment		Dfl 580,000	Dfl 585,000
	Effects on elements of landscape	Deterioration	Improvement	Similar to A, but with more conservation of small-scale landscapes in eastern part of area
Effects of the improvement of	Investment		Dfl 1,150,000	Dfl 1,150,000
	Decrease in maintenance		Dfl 17,000 p.a.	Dfl 17,000 p.a.
excluding roads with a purely	Comfort for drivers	Moderate	Fair	Fair
agricultural function	Road safety	p.m.	p.m.	p.m.

The economic effects of the LCP are essentially benefits for agriculture in the form of higher remuneration for the farmer. This benefit is related to the investments in improvement of parcelling and in improvement in water management, including that part of the investment in the road network which is considered essential for the realization of agrarian benefits. It is not possible to make a very sharp distinction between roads with purely agrarian functions and others, but a reasonable separation is possible. If part of the roads is considered to be serving agrarian purposes and included in investment for agricultural purposes, the benefits of these roads in the form of decreased maintenance costs should also be taken into account when measuring the benefits of this investment. The increase in remuneration of the farmer is built up from the effects of improved water management and those of the improved parcelling situation. In this case it can be shown that the factor improvement of water management accounts for about 25 per cent of benefits for agriculture. It has already been pointed out that this effect can only be reached if extra labour is available. This extra labour becomes available to the farmer as a consequence of better parcelling as a result of the LCP.

The social effects measured are of two kinds. First are, man hours-saved by the LCP for the farmer and his family and not used in the farm. As these man-hours are set free and at the same time income increases, this effect is regarded as a positive effect or benefit. The second social effect is the effect on employment. In this case, for the hired labour two jobs are lost. Employment for farmers is influenced positively. The execution of the LCP provides employment for a number of man-years. Indirect employment is thought to be positively influenced.

The facilities provided for *outdoor recreation* in this LCP consisted of some supplementary provisions to round off existing facilities, for example, some shortcuts in walking trails so as to make it possible to make a round trip. These provisions were not expected to lead to a higher numer of visitors; they had the effect of a qualitative improvement of existing facilities. Cost per visit include maintenance costs.

The effects on values of nature: especially in the evaluation of these effects it is essential to take into consideration the development without the LCP, as this development, too, is expected to lead to diminishing natural values. The qualitative statements given in the survey are a summary of a list giving the increase or decrease in size or number of some 40 types of ecotope.

Effects on landscape: as with natural values, the development without the LCP shows diminishing values.

Effect of improvement of road networks: it will be noticed that the very important aspect of road safety cannot yet be adequately treated.

12.7 Final remarks

In the foregoing, an outline has been given of the system for the evaluation of LCP's being used by the Government Service for Land and Water Use in the Netherlands. This system is the first of its kind in use in the Netherlands.
The evaluation of LCP's in the Government Service for Land and Water Use is a task of the provincial officers of the Service, not of the specialists at the Service's Head Office. A special feature of the system is, therefore, that it has been devised

for use by engineers not highly specialized in evaluation. This has two consequences. First, that the system is not very sophisticated theoretically; this as opposed to many evaluation methods used by specialists. Second, the use of the system on the provincial level can be supposed to contribute more to the spreading of cost- and effect consciousness in the Service than the use of sophisticated and perhaps in that sense more perfect, systems by specialists at the Head Office.

Experience up to now suggests that results of evaluations according to the the system just described can be of great value in choosing the right direction in which to develop LCP's.

Water, water management and nature conservation

G. J. Baaijens and J. G. de Molenaar

13 Water, water management and nature conservation

SUMMARY

After briefly outlining both the past and the present situation with regard to water management in the Netherlands, a review is given of the ecological significance of water in ecosystems. Three ways in which water exerts its influence in ecosystems are distinguished. The operational function is defined as the set of requirements which must be met before a species, or a bioscenocis, can establish itself. The conditional function encompasses those regulatory mechanisms which maintain operational functions at a sufficient level. The positional function is the driving force behind the conditional functions. Some consequences of (changes in) water management for these various functions are given and illustrated with a few examples. It appears that especially the positional function of water is usually neglected in land and water management. Because of this, nature conservation faces often insurmountable problems. Suggestions are put forward to improve this situation.

13.1 Water and environment

13.1.1 Traditional hydrological systems in The Netherlands

Man's impact on the hydrology of the Netherlands was and still is tremendous. Conveniently a distinction may be made between the western part, lying at about sea level or below (peat and clay districts) and an eastern part, well above that level (sand, loess and chalk districts). Water management differs widely in these two regions.

13.1.2 Western region

The parts lying above sea level (dune ridges, salt marsh bars) or above high water level along the rivers (early holocene river dunes or *donken*; levées) were occupied at an early date. The perils of marine transgressions were met by raising artificial mounds (*terpen*, *woerden*); later on by the construction of dikes. Dike building was fairly widely under way by 1000 A.D. The invention in the tenth century of simple tide-operated sluices closing automatically with the floods and drawing with the ebbs, greatly facilitated impoldering and drainage of the clay soils along the sea and the tidal rivers.

Peat soils were reclaimed at a later date. The process started from the edges near the dune ridges, river levées or from peat streams which drained radially from the blanket bogs. These marginal peat soils were rather rich in nutrients as compared to the oligotrophic central domes. Since the peatland was well above high water level, dike building was not a prerequisite for occupation, although occasionally dikes were raised to prevent flooding from the water draining the higher central part of the bogs. Drainage of the reclaimed areas was promoted by digging regularly-spaced, parallel ditches carrying surplus water into a larger – often natural – watercourse. Groundwater levels were lowered, facilitating agricultural land use but, on the other hand, promoting compaction and oxidization. Eventually, drainage by natural means was impeded.
In due time, reclamation activities extended into the less nutrient-rich but more elevated oligotrophic cores of the bogs. Although these parts must have stood several metres above sea-level, they too ultimately lay near that level, making natural drainage impossible. Some early reclamations were, in fact, abandoned. Most of them, however, could be kept more or less sufficiently dry with the help of wind-powered watermills introduced at the end of the fifteenth century.
While agriculture became more and more difficult, a growing demand developed for peat as a fuel in the rapidly expanding industrial cities in the western part of the Netherlands. Peat cutting became more profitable than agriculture but was limited to the layers above groundwater level. When somewhere around 1530 dredging came into use, it became possible to exploit peat deposits below the water level. While the volume of extractable peat was greatly enlarged, the resulting lakes formed a serious threat to the remaining land. Dikes, roads and villages were eroded by wave action. The Haarlemmermeer, for instance, which covered some 2,600 ha in 1530, exceeded 16,000 ha in the year 1700. The construction of better windmills, the menace presented by the growing lakes and higher prices for agricultural products led to the impoldering and subsequent drainage of both natural lakes and former peat excavations. This process started in the middle of the sixteenth century and has continued up to the present day (IJsselmeerpolders).

Apart from wind conditions or high water levels outside, the actual ditch water level in the polders was determined by:

- compromising between conflicting demands such as that for grassland and for arable land;
- gradual and unequal subsidence of drained peat as a result of oxidization and consolidation;
- increasing seepage of brackish water from the subsoil as a consequence of lowering the groundwater table; etc.

For many centuries the water level was as a rule highest in winter and lowest in summer. During dry periods water was frequently extracted from the rivers. In grassland, the ditch water level was usually maintained between 0 and 30 cm below the soil surface. Drainage means (ditches, canals) were (and are even more so today) mostly highly artifical, although old creeks, rivulets and the like frequently constituted the basic elements.

13.1.3 Eastern region

The higher grounds in the east and south were drained by brooks, rivulets, etc. In early days they were only slightly modified to meet man's demands. Deforestation and excavation of high moors resulted in hydrological changes which made it necessary to widen and deepen them slightly. Sometimes new brooklets were created by interconnecting depressions without superficial drainage and linking these up with existing drainage channels.
In low lying grassland along rivulets and brooks a system of ditches was dug to control the groundwater level. Especially downstream grassland was designedly flooded with comparatively nutrient-rich water. Such grassland was often completely devoid of ditches, because they would hamper the sedimentation of fertilizing silt. In the southwestern part of the province of Drenthe, for instance, thousands of hectares were fertilized in this way even up to the 1940s. The water level was controlled by weirs and small dikes. The weirs were not lowered until about June, sometimes even not before the end of July.

Obviously, most control measures were aimed at preventing rapid discharge and maintaining high groundwater levels as long as possible. Because of the undulating terrain and limited technical and organizing means, however, there existed a wide variety of groundwater levels and fluctuation patterns. Man adjusted his pattern of occupation and agricultural land use to these different conditions. Meadows and pastures were selected in the brook valleys. The arable land was usually situated well above groundwater level and remained without artificial drainage, as did the vast majority of the extensively sheep-grazed heathland. The latter which regionally constituted up to 80 per cent of the agricultural area, formed an enormous hydrological reservoir. It was of great importance in maintaining high summer groundwater levels in the low grasslands in the brook valleys.

13.1.4 Present situation

In the last few decades agricultural practice has changed dramatically. Creating conditions favourable for mechanization is now considered at least as important as

maintaining maximum growth conditions. As a result, lower winter groundwater levels are aimed at, i.e., not exceeding 30 or 40 cm below soil surface. This corresponds to even considerably lower water levels in the ditches. Consequently too low a summer groundwater level is risked. On the higher grounds, river water or groundwater is extensively used for sprinkling or irrigation to reduce desiccation. In the polders, water from the Rhine and Meuse is used to maintain a high ditch (and ground-) water level and to replace the increasing quantity of saline seepage water resulting from deeper drainage. Retention of rainfall surplus is no serious objective anymore.
In particular, the introduction of fertilizers promoted the call for deeper drainage of wet meadows and pastures in all parts of the country. In the eastern part, the reservoir function of the heathlands was thus no longer needed. The extensive agricultural use of these vast areas came to an end at the same time and largely due to the same cause. They were subsequently extensively drained and turned into highly productive arable and grasslands. Consequently, high peak discharges became more frequent. As a result of this, extensive flooding occurred along the brooks which now became too small; consequently nearly all water courses were straightened, widened and deepened. More or less natural and meandering rivulets and brooks are quite a rare phenomenon nowadays, even in nature reserves.
In these higher parts of the country, the past decade of relatively dry years has focused attention on the need of water again. The rivers Rhine and Meuse are already extensively used for supply, while further schemes are prepared to open up even the remotest areas for this supply.

13.1.5 Public water supply

Public water supply, becoming important about a century ago, is one of the most rapidly growing amenities today. The main sources are surface water and groundwater.

Surface water is mainly extracted from the Rhine and Meuse. During periods of high discharge, water from these rivers is stored in natural lakes and artificial reservoirs and after purification distributed in the western part of the country. Although vast areas in, e.g., the former tidal area (the Biesbosch) are changed considerably, and reservoirs are planned in such important areas as Twente, the southwestern part of the province of Groningen, etc., further detail here cannot be explored.
Since the middle of the last century the dune area along the coast has been used intensively for groundwater extraction. Ultimately, when withdrawal exceeded replenishment, the fresh water lense shrunk considerably. Since the 1940s water from the Rhine and Meuse has been pumped into the dunes both in order to restore

the fresh water lense and to meet the expected increase in demand for water for domestic and industrial purposes.
In the higher parts of the country groundwater is extracted on a large scale. Estimates are that at the end of this century about one-third of the rainfall surplus will be used for public water supply. Considerable lowering of groundwater levels does, and will, result from this activity. Again, the Rhine and Meuse are the main source for recharge as well as for creating water reservoirs.

13.2 Ecological consequences

13.2.1 *Introductory remarks*

Life on our planet cannot exist without water. Its action, however, or to put it differently, its role in nature is very complex. In studies on the ecological effects of changes in water management it may be convenient to distinguish three aspects of the function of water. The hydrological regime directly determines the amount of water available for plant and animal life. In this sense it is operational. Next, water is conditional to quite a lot of other operational factors such as soil temperature, oxygen content, nutrient status, and fluctuations in these parameters. Furthermore, other conditional factors are largely dependent on the water regime, like humus formation and breakdown, nutrient cycling, leaching and other aspects of soil formation. Specific characteristics of water, such as its high specific heat and high latent heat of fusion, its capacity as a solvent, etc., are very important in regulating fluxes in nutrients, oxygen, heat, etc., to and from organisms. In open water, mechanical aspects of water movements are energetically operational.
In turn, soil factors and plant life co-determine the characteristics of the water regime. As far as this interdependent system finally enables the existence of particular organisms, it is to be considered as the hydrological part of their ecoystem. Such organisms fit into this system, i.e., they take part in its selectory and regulatory functions. In passing it may be remarked that the concept of ecosystems is taken in this respect as the abstract formulation of interdependent relations.
The time lag between input and outflow of water in a land section highly influences, *inter alia*, the chemical composition of stored and discharged water. This is largely reflected, for example, by the share of calcium in the ionic composition of water. Calcium in turn conditions, *inter alia*, P- and N-economy and its presence often indicates the presence of other constituents which act more or less similarly.
Although there are numerous agents through which biocenoses exert influence on each other, water is very important among them. It forms the link between the communities in, e.g., a catchment area. Both operational and conditional character-

istics on a given spot are thus determined by communities upstream and downstream. Similar to the concept of fields in physics, an ecological field can be described in which sources and sinks of the hydrological system fulfil a positional function. For a further elaboration of the concepts the reader is referred to Van Wirdum (1979); Both & Van Wirdum (1979) and Van Leeuwen (1979).

The three functions of water briefly outlined above are, of course, well known. In most ecological studies they are, however, rarely distinguished. In particular there is a tendency to neglect the positional function. This holds even for studies of areas where environmental conditions are subject to changes, and especially, it seems, in planning schemes. Although it is claimed that today much allowance is made for the interests of nature conservation and management, in amelioration schemes and schemes for domestic water supply – to name two of the most outstanding examples – a remarkable short-sightedness is still shown on this point. Nature conservation, therefore, finds itself facing often insurmountable problems. Some of these are discussed below.

13.2.2 Operational functions

The change in operational factors primarily concerns quantitative changes in water supply and fluctuation patterns of groundwater. In aquatic environments current patterns and velocity may be affected. Nutrient levels are, as a rule, changed too – sometimes directly (input of Rhine water in the dunes, for example) but usually by changes in conditions and/or positions.

Since plants are among the organisms affected most directly, most attention is focused on this group or, rather, phanerogams and vascular crytogams. Various attempts have been made to classify plants according to their requirements for water. Numerous scattered data can be found in floras. As early as 1554 Dodonaeus presented a compilation of excellent observations. Most work is based on the relation between occurrence and the depth of the groundwater level. Ellenberg (1974) and some other authors seem to be exceptions, relating the occurrence to classes of soil humidity ('*Feuchtzahlen*'). However, in attributing individual species to one of these classes, a more or less direct connection with the relative depth of the phreatic level seems to have been decisive.

In the Netherlands the first classification was made for a number of dune plants (Goethart et al., 1924). It appeared that the occurrence of 65 species out of the 91 studied was limited to places where the phreatic level was found not deeper than 60 cm. The authors added valuable information about the 'ecological range', i.e., minimum and maximum groundwater levels. Recently, Londo (1975) published a compilation covering, in this respect, the entire flora of the Netherlands. He distinguished eight categories. For practical purposes this number is usually reduced to three (cf. e.g., De Molenaar et al., 1978): true hydrophytes, phreatophytes and aphreatophytes. Hydrophytes are plants confined to open water bodies. Phreatophytes generally occur only in soils where the influence of the groundwater is manifest in the rhizosphere. Aphreatophytes do not necessarily require this condition. The phreatophyte spectrum of the flora of the Netherlands, comprising about 1,400 species, is given in table 1. Although the relation with groundwater tables is not the only decisive factor for plant species, this table nevertheless reveals something about the vulnerability of the Dutch flora.

Table 1 Phreatophyte spectrum of the flora of the Netherlands (Pteridophyta and Spermatophyta; based on Londo, 1975)

			number of species	*percentage*
hydrophytes	('water plants')		72	5
phreatophytes			429	31
obligatory	('marsh plants')	176		
obligatory s.s.		102		
non-obligatory *		150		
aphreatophytes			853	61
halophytes	('salt plants')		50	3
			1,404	100

* species usually dependent on high groundwater levels; in moist (micro-)climates and/or soils with a high moisture capacity they may, however, occur well above the sphere of influence of groundwater.

As a rule aphreatophytes will not be affected by lowering the groundwater table; some exceptions are discussed below. The two other groups, however, are essentially quite sensitive. The actual reaction of individual species in a given case will, of course, depend on the primary conditions in their habitat and the degree of lowering, changes in fluctuation pattern, etc.

Since the turn of this century most plant species displayed a decline in their occurrence. This decline is comparatively strongest in the hydrophytes and phreatophytes. Within these two groups, species of particular interest for nature protection (e.g. rare species and/or species limited to environments with comparatively little variation and irregularity in nutrient levels and hydrology) appear to be most threatened (De Molenaar et al., 1978).

It must be emphasized that changes in water management do not only affect hydrophytes and phreatophytes. Aphreatophytes may be affected. This is most obvious in situations where aphreatophytes are drowned (storage lakes in the dunes, to cite one example). But decline and extinction may also be observed in those plants which heavily depend on stable gradients from dry to wet, fresh water to brackish

water, peat to clay, etc., even if these plants are limited to the 'dry' part of the gradient. Changes in conditional and positional functions apparently lead to changes in operational functions even in situations where water is not a direct variable.
When one looks at plant communities, decline is even more striking. On alliance level, 54 percent of the non-halophytic plant communities of the Netherlands are confined to situations with a high groundwater table. Of the basal units, i.e., plant associations, 96 – of which 14 are endemic – are characteristic for wet and moist conditions. About 80 percent of them are more or less threatened by lowering of groundwater tables, changing of fluctuation patterns, eutrophication, intake of allochthonous water in dunes and polders, etc. For more detail, reference can be made to the compilations given by De Molenaar et al. (1978) and De Molenaar (1980), or the invaluable work of Westhoff et al. (1970; 1971; 1973).

Similarly to plants, animals can be arranged with respect to their relation to groundwater. Many faunas present valuable though scattered information on the subject, while occasionally a more fundamental approach is attempted. Bonnet (1964), for instance, was able to classify Rhizopodes as to their demand of water, and similar efforts have been made for groups such as Nematodes, Mites and Collemboles (e.g. Overgaard Nielsen (1949), Weiss-Fogh (1948) and others). It is not surprising that these studies pertain to soil inhabiting organisms where migration, if any, is usually vertical.

In aquatic habitats, changes in operational functions such as current pattern, discharge patterns, velocity, osmotic value, etc., affect quite a number of animals. The majority of animal species, however, both in terrestrial and aquatic habitats, is predominantly influenced through changes in conditional and/or positional functions.

13.2.3 Conditional function

Since nature, rate and extent of physico-chemical and micro-biological processes in the soil are determined by water, changes are likely to occur following deeper drainage. Usually the availability of nutrients increases, because denitrification becomes less prominent and mineralization is promoted when soil water content denitrification is lowered. In grassland on peat soils, for instance, lowering of the groundwater table (ditch water level 80–100 cm below soil surface) may result in an additional supply of nitrogen ranging from some 100 up to about 600 kg per hectare per year (Schothorst, 1974, 1977: table XI) out of which only about half is used by the plant cover (Schothorst, 1977), as well as a considerable amount of other mineral constituents such as calcium, sulphate, etc. (Steenvoorden & Oosterom, 1975). With such levels of 'fertilizing', the occurrence of pronounced (terrestrial) eutrophication on the spot and in the surroundins needs no further adstruction. The phenomenon may also result in eutrophication, through leaching, of nearby and distant surface water (c.f. Kolenbrander & Van Dijk, 1974; Van Dijk & Kolenbrander, 1976; De Boer, 1977; nitrogen eutrophication norms: see Leentvaar in De Molenaar, 1980). This phenomenon is caused by oxidization of organic matter, a process which largely depends on soil water content, i.e., soil water levels and fluctuation pattern. Apart from eutrophication, this results in gradual lowering of the soil surface.

Oxidization was the main factor in soil subsidence before 1850 in peatlands. It is estimated that the subsidence rate amounted to about 1 mm annually, and drainage was adapted to this rate. Since 1850 to 1874, the technical tools were improved (steam-powered watermills!) and in agriculture more emphasis was laid on dairy farming. Consequently, more attention was paid to the grassland conditions. On peat soils, drainage was improved and engine pumping gradually replaced the work of windmills.
A better control of water tables (and usually at a deeper level) became possible, both in ditches and in the soil. This resulted in increasing oxidization and, because of the decreasing upward pressure of groundwater, in consolidation. Subsidence rate increased to 2 to 4 mm annually.
Since the 1950s even deeper groundwater levels (never exceeding 35 cm below soil surface on the lowest places) are propagated.
Subsidence rate consequently increased ranging now from 10 mm up to even 40 mm annually. The last value – an average value over ca 20 years – was reached in the Twiskepolder. This polder represents a valuable example – due to highly uneven oxidization and shrinkage resulting in a very uneven surface; agriculture is now no longer possible.
Subsidence rate is highest during the first four or five years after lowering the water table, as advocates of deeper drainage soothingly put forward. Compaction is predominant in this period. Oxidization, however, although also greatly enhanced in the first years continues – be it at a lower rate – until ultimately the groundwater level is reached. Long before that time the groundwater table is, of course, lowered again and evidently oxidization will not stop until the mineral subsoil is reached. Common sense prevails in many farmers constituting the polder-boards, so usually after a few years ditch levels are lowered annually at the same rate as before amelioration works. As a result yield depressions soon reach the same level as previously. This is clearly demonstrated in the Zegveld area, where ditchlevels were considerably lowered in the mid-sixties. Yield depressions are again at the same level as before. Ironically, the vegetation may be altered in a way hardly liked by farmers. This is demonstrated in nearly all experimental plots. While less appreciated grass species made up some 10 % before the water level was lowered, they may amount up to 90 % afterwards, as appeared from one of the few documented cases (Anonymus, 1973).

When drained too deep, peat may dry up irreversibly. This was a matter of great concern in former days, but it is largely bagatalized nowadays. The danger is, however, well demonstrated each year in the peat reclamation areas of Groningen and Drenthe, which form the 'dust-bowl' of the Netherlands. In a few days time up to 700.000 kg of soil particles per hectare, mainly consisting of dried and fragmented peat, may be blown away by storms, causing apart from agricultural losses an eutrophication threat to nearby oligotrophic areas. A raise of the water table is not seriously considered in these regions used almost exclusively as arable land.

Even when groundwater levels are not maintained at a level as low as in the peat reclamation areas the phenomenon may, however, be observed. It is estimated that in the province of Zuid Holland about 2000 ha of the peat soils is too dry (Van Wallenburg, 1966).

In mineral soils too lowering the water table usually results in an increased availability of nutrients by decomposition of organic matter, increasing nitrifying activity, chemical, physical and biological ripening of the deeper soil layers, etc. In clay soils it has been estimated, for example, that about 30 kg of nitrogen extra becomes available by reducing the number of days in spring during which a groundwater level of 30 cm below surface is surpassed to zero (Sieben, 1964). As a rule the larger amount of nutrients also leads to more dynamic, i.e., less stable conditions negatively affecting the natural environment.

Occasionally lowering the water table may result in more stable and less dynamic situations. Examples may be found in soils where groundwater levels fluctuate strongly and where plants may receive some additional nutrients by periodic upward movement of soil water. In nutrient-poor wet heath dominated by *Erica tetralix* and with a thin humus layer, for instance, deeper drainage may result in a shift in vegation to the effect that *Calluna vulgaris* becomes predominant. A slightly different example illustrating the opposite effect generally resulting from lowering the groundwater table is presented by moist, oligotrophic to mesotrophic grassland of the Cirsio-Molinietum type. When the groundwater table is lowered, the comparatively dry representatives deteriorate to a higher degree than the wetter ones. In the latter ones the effects of increased fluctuations are counterbalanced to some extent by the effects of desiccation (Both, 1976).

Most modern floras, regional or national surveys of plant communities, etc., give more or less consistent general data on the nutrient requirements of plant species and communities (in terms of eu-, meso- and oligotrophic) and refer to the acidity and salinity of their habitat. For the Netherlands the Werkgroep Biologische Waterbeoordeling (1977) enumerated aquatic microphytes indicating various levels of water quality and added an indicative classification of aquatic macrophytes as

Table 2 Status of the flora of the Netherlands for species mentioned in Ellenberg (1974), with respect to the availability of nitrogen in the soil during the vegetation period (De Molenaar, 1980)

	number of species	percentage of total	change in occurrence in this century (percentage of species)		
			increased	unchanged	decreased
Indicative for low nitrogen content	46	4.6			
Intermediary group	146	14.3	2	18	80
Preference for low nitrogen content	126	12.5			
Intermediary group	95	9.4	3	43	54
Indicative for moderate nitrogen content	124	12.3			
Intermediary group	96	9.5			
preference for high nitrogen content	119	11.8	4	53	43
Indicative for high nitrogen content	92	9.1	11	43	46
Indicative for excessive nitrogen content	33	3.3	21	15	64
Rest group	129	12.8	–	–	–

to nutrient requirements. Ellenberg (1974) published a review of the central European higher plant species in nine classes according to the mineral nitrogen supply during the vegetation period. He does the same, *inter alia*, for the relative acidity of the soil ('*Reaktionszahle*') and its salinity ('*Salzzahle*').
Interesting information is obtained by combining Ellenberg's classification with data on the relative abundance of plant species in the Netherlands (compiled by the Rijksherbarium at Leiden) in the years 1900 and 1971 (table 2).

Table 2 shows that approximately 80 per cent of Dutch flora is vulnerable to eutrophication. A similar survey of the vegetation alliances of the country (excluding alliances of rock, wall and saline soil vegetation) based on Westhoff & Den Held (1969), shows that also about 80 per cent of these are vulnerable to eutrophication (De Molenaar, 1980). Regarding hydrophytes, again about 80 per cent is vulnerable to eutrophication and saprobiation, out of which about 70 per cent is rare and/or threatened (De Molenaar, 1980).

It is likely that for the fauna a similar picture could be worked out (see for evidence literature cited in De Molenaar, 1980). Studies on biological qualification of brooks and rivulets (Moller Pillot, 1971, Werkgroep Biologische Waterbeoordeling, 1977) show indeed that the number of aquatic animal species (macrofauna)

Table 3 The status of five 'weidevogel' species in the Netherlands (compiled in De Molenaar, 1980)

A: The breeding population in the Netherlands as percentage of Europe.
B: Decrease in numbers of breeding couples following intensifying of drainage and exploitation in two grassland areas in the Netherlands, formerly considered excellent 'weidevogel' biotopes.

Species	*A* *percentage*	*B* *percentage*
black-tailed godwit	90*	70– 75
ruff	75	80–100
lapwing	50**	80– 90
redshank	50	70– 80
snipe	40	90–100

* including the Icelandic subspecies this is 80 per cent; the Netherlands' population approximates 50 per cent of the world population.
** excluding Schleswig-Holstein (no data).

and the diversity of animal life forms decrease exponentially with increasing pollution. This effect is accelerated by regulation of such streams. Much attention has been paid to the fate of a group of limnocolous birds confined to wet and moist grasslands designated in Dutch as '*weidevogels*'. The occurrence of these weidevogels in the Netherlands is of international importance (table 3; column A). They offer a clear example of the importance of water for non-aquatic animals, i.e., the impact of changes in conditional and positional functions of water.
Intensifying grassland exploitation, made possible by lowering the groundwater level and the highest rate of application of fertilizers and manure in the world, lead to a rapid decline in both number of species and individuals per species (table 3; column B). It is feared that in the long run outside nature reserves, 11 species will vanish, including stork, corn-crake and shoveler.

13.2.4 Positional functions

Finally positional functions may be affected. They provided the basis for the diversified plant and animal life which formerly characterized the Netherlands. Van Leeuwen (1967) listed the areas which, from a point of view of species diversity and complexity of biotic communities, presented the best the Netherlands could offer, and provided a sound theoretical base for the explanation of their occurrence. It is now understood that water, both quantitatively and qualitatively, is a prerequisite in establishing the stable gradients on which Van Leeuwen delineated the foci, i.e., the areas where complexity reached its summit, and where many extremely rare plants and animals could be found (figure 1). These areas represent the expression of regulatory forces both upstream and downstream.

Landscapes characterized by gradual transitions.

Narrow zones with gradual transitions connecting widely differing environmental conditions.

Downstream areas of the rivers Scheldt, Rhine and Meuse with gradients from fresh water to seawater and diminishing tidel influence in eastward direction.

Relatively small areas in the western part of the Netherlands comparatively rich in transitions between fresh and haline conditions.

Areas with many different and stable transitions in nutrient status, moisture, etc. displaying a wide variety of species, including many rare ones. (Paramount among these was the area in the southeast of the province of Brabant).

Landscapes entirely without or only with abrupt changes in environmental conditions.

Most important landscapes of this type

Most important geese- and waterfowl-areas

Most important "weidevogel"-areas

Areas with comparatively large relicts of heathland, highmoor, wandering dunes and uniform planted woods; important regulators for stable gradients and in itself important for birds of prey, curlews, black grouse, etc.

Figure 1. Map showing the areas in the Netherlands with the most valuable natural environmental conditions.

It will be clear that if, for instance, groundwater is extracted from an area which acts as a reservoir, i.e., a regulator for downstream areas, the influx into the latter diminishes or may even cease to exist. The same happens if downstream areas are drained – reclamation of the IJsselmeerpolders leads to lowering of the water tables in the Veluwe area, etc. The effect will hardly be felt on the high parts of the Veluwe itself, where groundwater levels are very low, but the more so in those areas around it where levels are so high as to influence vegetation. Wells and rivulets may run dry, or the period of dryness may be prolonged; seepage areas may turn into areas where downward movement of water prevails, etc. Even if no actual seepage occurs, vegetation may be influenced because lateral movement from one community to another diminishes. Generally speaking, the effect is worst when its cause lies upstream: as a rule downstream biocenoses are by nature more adapted to dynamic circumstances. Gradients are shortened when groundwater is extracted downstream, but at least the relative position of the ecosystems involved remains the same. Positional relations may even be completely reversed when upstream localities are used. Water winning activities near Emmen in the province of Drenthe caused a lowering of the groundwater table *in situ* of about 8 m. This area, formerly an important 'source' in regulating hydrological conditions on both sides of the Hondsrug, is now a large 'sink' draining the area it used to control. Its effects can be noticed on isohypse maps over a distance of some 40 kilometres.

Similar cases may be observed elsewhere, actually nearly everywhere where Van Leeuwen drew his 'magic circles', as well as outside these regions. In the nature reserve 'Meinweg', for instance, one of the finest rivulets is threatened by water winning activities while a small quagmire is already rapidly deteriorating; in the oldest nature reserve Naardermeer, the steady supply of iron-rich groundwater from the Utrechtse Heuvelrug, important for the regulation of phosphate levels in the lake, diminished resulting into eutrophication, etc. Agricultural drainage may lead to similar phenomena – the pitiful history of the nature reserve 'Schraallanden langs de Meije' is a clear example. This reserve was a fine example of once common, but now extremely rare, mesotrophic hayfields of a peculiar type not found outside the Netherlands. It does not stand alone, however; literally hundreds of similar cases could be added.

Time, of course, is a very important though often overlooked factor. In a particular forest area in the Winterswijk area, described by Meijer Drees in the 1930s, all species except one could be found by the senior author some 40-odd years after the water table was lowered approximately 30 cm, though obviously at different stations. The bottom of a former rivulet is now occupied by species normally found on its edges. Most species have apparently shifted downwards, while other species eke out a bare existence in former whirlpools which now contain stagnant water. The flora of this particular area is even, seemingly, richer than it was before. Up to now only one species was lost while several new ones have invaded. Particularly on humus-rich or clay soils or in undulating terrain it may take years before stabilization – which means also the loss of a number of phreatophytes – ultimately takes place.

Usually research on positional action is limited to the area 'between the mountains and the sea', to paraphrase the fittingly descriptive title of an eminent Dutch textbook on local geology. Terrestrial ecologists usually draw the limits of their professional occupation at the beach, while it is remarkable though understandable that the ecological field is usually described land-inward and not the other way round. Estuarine ecologists tend to have more interest in the impact from terrestrial systems on the life of the sea, and the importance of influx from the land is amply described by them. Recently, attention has been focused on a rather unexpected way in which terrestrial ecosystems may exert influence on marine life. Marshes, moors, fens, in short: anaerobic ecosystems may have a function as a safety-valve in the nitrogen cycle by reducing the input of this nutrient into the sea. While in former days pedologists worried about shortages of nitrogen caused by denitrification, anxiety now arises about a possible imbalance through extensive draining of wetlands, i.e., by reducing the area in which denitrification takes place. It has been estimated that the difference between nitrogen fixation and nitrogen losses amounts to nine million tons annually on a world scale. The meaning of this figure may become clear when realizing that nitrogen fixation in the oceans amounts to only 10 million tons. It is feared that the addition of an approximately equal amount to the sea will lead to plankton blooms, ultimately causing oxygen depletion in the sea and the atmosphere (Delwiche, 1977).

13.2.5 Review

In figures 2 and 3 some aspects of changes in the water regime caused by agricultural and domestic water supply demands, respectively, are tentatively summarized. The starting point, a more or less undisturbed system, is the same; however, some remarks must be made. Simplification is evident; within the different zones distinguished, micro-differentiation caused by relief, differences in parent material, soil formation, etc., leading to a wide variety in plant and animal life, is omitted. The schemes are only two-dimensional, depicting half a cross-section of a catchment area. Lastly, the influence of time is also omitted.

13.2.6 Original situation

Zone	(cf. figures 2 and 3)	I	II	III
(1)	mean groundwater level	low	near surface	*ib.*, periodically flooded
(2)	fluctuation of groundwater level	large	very small	small
(3)	principal direction of groundwater movement	downward	upward and lateral	*ib.*, periodically reversed by flooding
(4)	nutrient load of groundwater and open water	small (oligotrophic)	intermediate (mesotrophic)	high (eutrophic)
(5)	soil types	mineral	± rich in organic matter	*ib.*, inter-calcated mineral layers
(6)	species diversity	low	very high	± low
(7)	ecosystem strategy with regard to water	resistance to drying	resilience	resistance to flooding

13.2.7 Changes caused by agricultural demands

Principal measures: drainage of wet and moist soils especially in winter. In the summer, an additional watersupply is provided by intake of Rhine water (not depicted) and for sprinkling from groundwater.

13.2.8 Changes caused by extraction of groundwater for public water supply

Principal measures: drilled wells. Occasionally compensatory measures (introduction of water ultimately derived from Rhine and Meuse) are taken to meet agricultural demands. Such measures, however, as to their effects comparable to the effects described above, are not considered in this scheme. Wells are thought to be on the higher ground – contrarily to the oldest wells but in agreement with recent developments.

13.3 Ecological functions and physical planning

We would like to repeat that the three functions of water in ecosystems outlined above are, of course, well known but rarely considered separately. While changes in operational functions and, although to a lesser degree, conditional functions soon become apparent, changes in the positional function of water are most

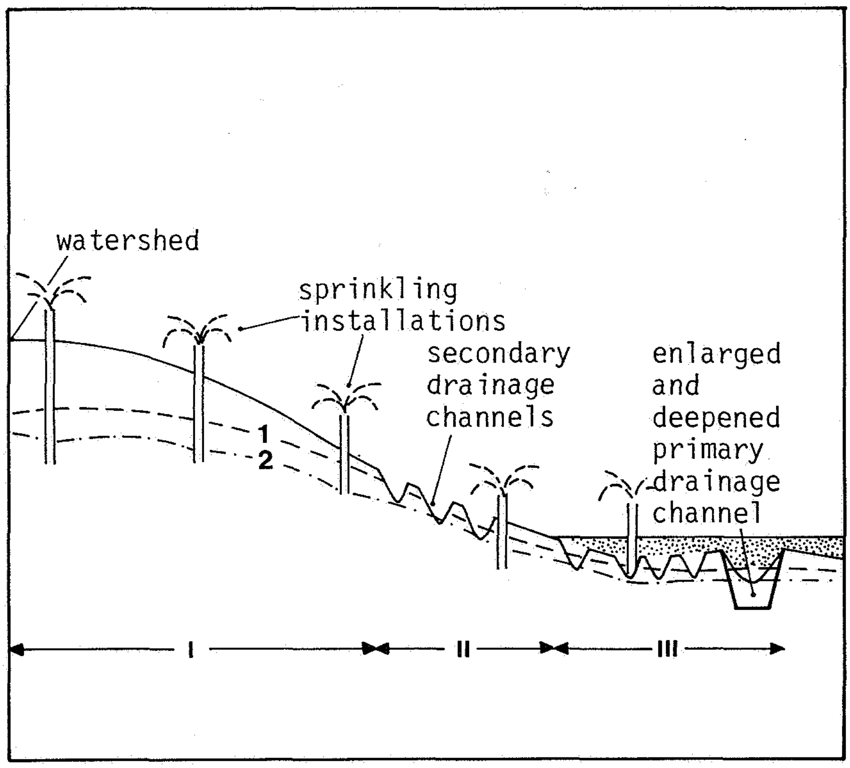


Figure 2. Changes caused by agricultural demands.
1: Mean groundwater level before agricultural amelioration.
2: Mean groundwater level after agricultural amelioration.

Zone I

1. Groundwater level: lowered as a result of lowering in zones I and II and by using groundwater (sometimes surface water) as a source for sprinkling;
2. Fluctuation of groundwater level: enlarged by sprinkling activities;
3. Principal direction of groundwater movement: local sinks caused by extraction of groundwater for sprinkling hence disturbance of streaming pattern;
4. Nutrient load: higher through leaching of fertilizers and manure; leaching promoted by sprinkling; ultimately even hypertrophic situations;
5. Soil types: not influenced as a rule, though content of organic matter may be raised by fertilizing activities and sprinkling;
6. Species diversity: seemingly raised by use of fertilizers in a primarily nutrient-poor environment; ultimately, however, sometimes even lower than in the primary situation;
7. Ecosystem strategy: resistance.

Zone II

1. Mean groundwater level: heavily lowered by draining and occasionally by using groundwater for sprinkling;

2. Fluctuation of groundwater level: enlarged;
3. Principal direction of groundwater level: seepage diminished or may cease to exist; ultimately downward because of lowering of groundwater level in zone III;
4. Nutrient load: cf. zone I; moreover enlarged by breakdown of organic matter and use of surface water introduced from Rhine and Meuse for sprinkling; ultimately even hypertrophic situations;
5. Soil type: degradation of organic matter hence tendency towards mineral soils;
6. Species diversity: lowered very much;
7. Ecosystem strategy: shifts to resistance.

Zone III

1. Mean groundwater level: heavily lowered, no more flooding;
2. Fluctuations of groundwater level: enlarged but near the (straightened) drainage channel sometimes diminished;
3. Principal direction of groundwater movement: seepage zone may be shifted towards this zone, flooding is prevented, downward movement may occur;
4. Nutrient load: cf. zones I and II;
5. Soil type: cf. zone II; physical, chemical and biological ripening in mineral soils;
6. Species diversity: heavily lowered;
7. Ecosystem strategy: resistance, but more is needed.

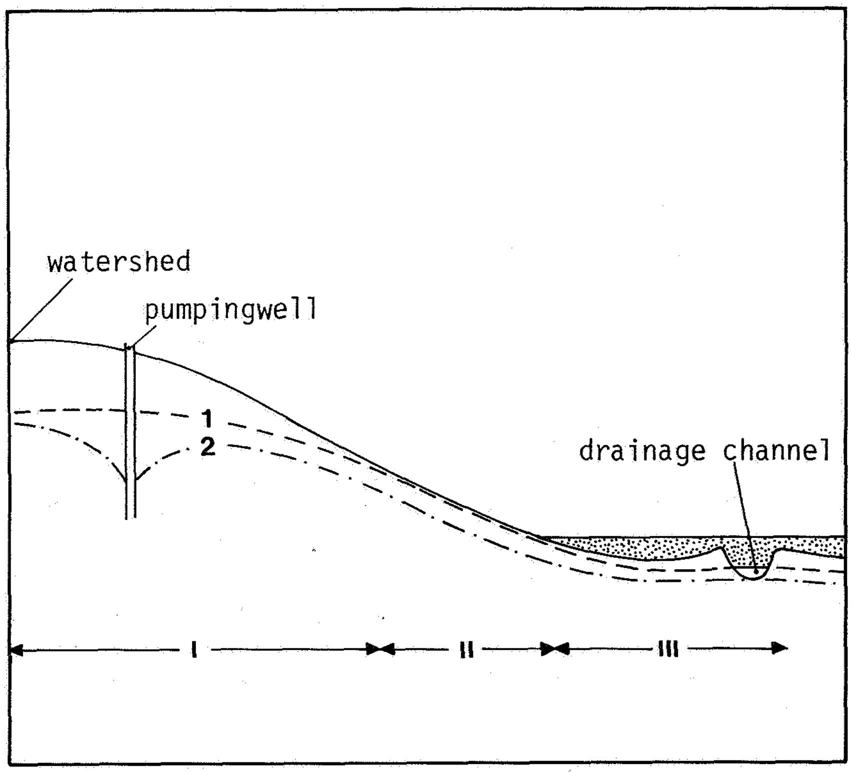


Figure 3. Changes caused by domestic water supply demands. 1: Mean groundwater level before groundwater extraction. 2: Mean groundwater level after groundwater extraction.

Zone I

1. Groundwater level: extensively lowered;
2. Fluctuation of groundwater level: usually not enlarged in this zone since demand for water does not show a marked periodicity in most areas. An exception has to be made for those regions where large recreational facilities are located;
3. Principal direction of groundwater movement: heavily influenced, directed towards the drilled wells hence shift of watersheds;
4. Nutrient load: retention time is altered, hence some influence is to be expected. Data, however, are still lacking;
5. Soil type: not changed;
6. Species diversity: remains the same apart from areas with buildings, roads, etc.;
7. Ecosystem strategy: remains the same.

Zone II

1. Groundwater level: (more or less) extensively lowered;
2. Fluctuations of groundwater level: enlarged;
3. Principal direction of groundwater movement: seepage diminishes, and may cease to exist; shift to downward movement;
4. Nutrient load: stable input of nutrient diminishes, but eutrophication due to breakdown of organic matter may completely obscure this effect; hence local tendency towards oligotrophy; usually, however, towards eutrophy or even hypertrophy;
5. Soil type: tends to mineral soils due to breakdown of organic matter;
6. Species diversity: heavily lowered;
7. Ecosystem strategy: tends towards resistance.

Zone III

1. Mean groundwater level: slightly lowered because of lowering of the hydraulic head;
2. Fluctuation of groundwater level: slightly enlarged;
3. Principal direction of groundwater movement: not altered; flooding may occur less extensively;
4. Nutrient load of groundwater: cf. zone II;
5. Soil type: cf. zone II;
6. Species diversity: usually not much changed;
7. Ecosystem strategy: not changed; sometimes, however, water shortage may occur hence ruderals move in.

decisive in the long run. Nevertheless, there is a marked tendency to neglect the latter, especially, it appears, in, *inter alia*, amelioration schemes, planning schemes for domestic water supply, etc. Although objectionable, this tendency is quite understandable since politicians are very reluctant when it comes to large-scale and long-term management which is what maintaining the positional function of water amounts to. Hence ideas or even substantial knowledge about positional relations are usually labelled as 'far-fetched' instead of far-sighted'. Conservation is considered a luxury, especially when economic growth stagnates, instead of, as Moore & Bellamy (1974) rightly put forward: 'the sensible utilization of natural resources'.

It will be evident that if we continue in this way, it cannot be avoided that our natural environment faces absolute disaster – and this is hardly a doomsday

prophecy. A more aggressive policy is required from those politicians and civil servants responsible for conservation of natural environment and natural resources. To start with, it seems appropriate – in view of the immense interest of positional relations – to designate areas in which activities will be restrained to a level which no longer threatens survival of individual species and communities. It seems logical that for this action, areas ought to be designated where the Netherlands show some unique features. Roughly speaking these areas will have to encompass a full positional sequence, i.e., a complete catchment area. Outstanding among our natural habitats are, from an international point of view, wet heathlands, the dune area, the marshy areas and the lowland rivulet systems. To a certain extent some of these are protected, but not in such way as to ensure permanently favourable conditions. Examples are to be found, *inter alia*, in the southwest of the province of Drenthe and the adjacent northwest part of the province of Overijssel, the eastern Achterhoek and Twente, the Dommel area, the area between the Meinweg-reserve and the river Roer, the area south of Bergen op Zoom, the dunes, etc.
Secondly, a scheme has to be developed in which necessary measures to safeguard these areas are enumerated. Of course allowance has to be made for those activities which, in the short run, have little or no alternatives elsewhere. Consequently, a timetable has to be added to enable everyone concerned to know when his presence is no longer wanted, or his activities should have reached a level which no longer endangers the continuity of the environment or its inhabitants, respectively. Lastly, an authority should be installed to ensure proper management and land use. For the planning and realization of such a scheme great imagination and large amounts of skill are required from policy makers, geohydrologists, agriculturalists, engineers, farmers, water boards, etc. The Research Institute for Nature Management is quite willing to fulfil its part of the job.

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Ten years of the Pollution of Surface Waters Act

Government Institute for Waste Water Treatment

14 Ten years of the Pollution of Surface Waters Act

SUMMARY

After a brief description of the main characteristics of the act, a detailed treatment of the various instruments provided by the Act for the control of water quality is given. Next, a critical review of some of the features of the Act is presented. This is followed by a discussion on some of the international aspects pertaining to the abatement of water pollution. Finally, the main elements of the amendment to the Act, introduced into Parliament, are dealt with.

14.1. Introduction

On 1 December 1980 it will be ten years since the Pollution of Surface Waters Act (*Wet Verontreiniging Oppervlaktewater* – WVO) came into force. Before dealing with the experiences acquired with the WVO during those ten years, a short summary of the main features of the system of the WVO is presented.

14.2 Short description of the WVO

The basic principle of the Pollution of Surface Waters Act is that it is prohibited to discharge waste, polluting or deleterious matter, in any form whatsoever, without licence into surface water. The Act is based on the principle of administrative decentralization of the control of surface water quality. In the Act a distinction is made between State waters – under the control of the central Government – and other watercourses. The control of the quality (as well as of the quantity) of State waters lies in the hands of the Department of Transport and Public Works. The control of the quality of the other watercourses is exercised by the provinces in question, which in turn may delegate this duty to purification boards, water boards and certain other public bodies. All open water that is of major importance for the management of the hydrological system of the country (big rivers, estuaries, lakes, canals and the North Sea) is considered to be State water.

As far as the control of water quality is concerned, a further distinction can be made between passive control – maintaining and/or improving as far as possible a reasonable quality of surface water by means of licenses, levies, regulations, prohibitions and supervision – and active control – by means of making the requisite arrangements to prevent and/or reduce the pollution of surface water by the treatment of waste water. The arrangements may be directed towards purification installations and other – sometimes temporary and provisional – arrangements, such as aeration. So far the Government only excercises a passive control of water qaulity; its expenses are defrayed by pollution charges. The regional authorities (purification or water boards, provinces) are in charge of both the active and the passive control of water quality. The WVO has the explicit character of an enabling act; for State waters and for the other watercourses, further arrangements have to be made. In the former case such arrangements are promulgated by means of a Royal Administrative Decree; in the latter case the provincial governments, after obtaining Royal Consent, have to take similar action.

In order to achieve a smooth introduction of the Act and to adjust gradually the arrangements so far in existence the Act includes some transitory provisions. Among other things, the provision is made that within four years of the introduction of the Act the controlling bodies must be in a position to introduce the system of control set out in the Act.
At the end of this transitory period, during which the provinces amply availed themselves of the discretionary power to delegate control, the following situation had arisen: three provinces (Friesland, Groningen and Utrecht) retained the active and passive control of water quality in their own hands; the other eight provinces had delegated this control to water or purification boards in their area.
By virtue of the Act the authorities have the following instrument at their disposal to control surface water quality:

- licenses;
- levies;
- the statement of inadequacy;
- penalties;
- water quality plans.

14.2.1 *Licences*

Anybody discharging waste into surface water must apply for a licence. Such a licence will be granted by the authority responsible subject to certain conditions, for instance that the waste water, before discharge into open water, shall be purified as far as possible, or that certain emission standards have to be met. The introduction of licensing by the legislator is a consequence of the application of the principle that pollution abatement has to start at source, either by prevention or control of pollutants.

14.2.2 *Levies*

In the Act the authority controlling the quality of the surface water concerned is authorized to impose assessments (levies) upon the licence holders. The instrument of assessment derives from the implementation of the internationally accepted 'polluter pays' principle. The quantity and/or the quality of the waste water discharged is taken as a basis for the assessment.

The Act states in detail how the Government has to determine the assessment: for oxygen-binding substances the unit 'population equivalent' (p.e.) is used, by which is understood the average demand on oxygen by waste water deriving from one inhabitant during 24 hours. For other substances, their weight discharged into surface water per unit of time is used.
The Act states explicitly that all funds originating from the assessments have to be spent actually and exclusively on the abatement of surface water pollution (allocational assessment). The amount of the assessment per p.e. is established every year. The rate is based on the cost for the year concerned of the authority's programme of action and depends on the cost of the operation and maintenance of the purification plants and appurtenances, servicing of loans, administrative expenses, etc.
As far as the pollution assessment on dwellings is concerned, it has been decided that they will be assessed for 3 p.e. People living singly may on application be assessed at 1 p.e.

For industrial waste water, it is far from simple to establish the waste load. This may be done by measuring, sampling and analysing the waste water of a given facility, but since the former method is rather expensive – especially for the smaller industries – the population equivalent (p.e.) is estimated by means of a table of coefficients shown in the regulations for waste water. This table is based on the experience that for various types of industry or industrial processes, the quantity and the nature of the waste load that is discharged into surface water on an average day is approximately proportional to parameters such as the number of people employed, quantity of raw material processed, quantity of final product produced, etc.

The levies for discharging into non-State waters vary according to the pollution authority concerned and generally speaking are in excess of those for State waters. This is due to the fact that in the assessment for non-State waters, in addition to the costs of the installations (cost of construction and operating cost), those for passive control are also taken into account. The costs for passive control of the water quality of State waters are defrayed from levies.
The Government does not construct and operate treatment installations, but from

the levies imposed makes financial contributions (up to 60 per cent) towards the cost of their construction. According to the terms laid down by the discharge permit, those who are responsible for the pollution of State waters have to operate the treatment installations.

14.2.3 *Statement of inadequacy*

The Government and the provincial authorities can issue a so-called Statement of Inadequacy to those who are in default of having taken the necessary measures for the pollution abatement of surface water. It is issued in conjunction with an assessment. This aims at exempting a water or purification board that has performed its duty adequately from being obliged to accept heavily polluted water from another region, where the controlling authority has failed to do its work properly. So far, however, statements of inadequacy have not yet been issued.

14.2.4 *Penalties*

An offence against the Pollution of Surface Waters Act can be commited in two ways:

- discharging waste water without a licence (illegal discharges);
- discharging waste water with a licence, without paying due regard to the conditions of the licence.

Acts in contravention of the Act are now considered to be economic offences (Act of 5 June 1975, Government Gazette 353). The penalties and measures listed in the Economic Offences Act, which are more severe than the sanctions imposed by the general penal law, can be applied in the case of contravention of the Pollution of Surface Waters Act.

14.2.5 *Water quality plans*

As far as the programmes of the various controlling authorities for the improvement of surface water quality are concerned, the Act does not contain any special instructions for the co-ordination of the various authorities' actions in order to arrive at a methodical approach to the abatement of water pollution. The Act does, however, impose a duty on the Minister of Transport and Public Works to present every 5 years a Prospective Multi-annual Programme. On 7 February 1975 this programme was issued for the first time and presented to Parliament. As far as the content of the programme is concerned, the Act does not lay down any further conditions. The programme is prepared in consultation with the controlling authorities, partly on the basis of regional water quality projects. This is possible because – although the Act does not give explicit directives in this respect – the regulations of all provincial governments provide for the preparation of water quality programmes.

14.3 Criticism of the Pollution of Surface Waters Act

In the past surface waters were often used as a convenient means for removing and transporting waste matter, with the result that the aquatic environment was being polluted. After the introduction of the above Act this is definitely now a matter of the past. It is evident that such a comprehensive programme of rehabilitation, which intends according to the objectives of the Act to deal with the backlog of pollution left behind by several generations in a period of 15 years (1970-1985), thereby subjecting one generation to heavy financial sacrifices, will meet with resistance and criticism.
As far as difficulties encountered in the execution of the Act are concerned, a distinction should be made between management and financial problems; the latter have to be split up into financial problems for industry and for individuals.

A criticism levelled at the law concerns its decentralizing features which sometimes give rise to confusion and make it difficult to gain an over-all perspective. A striking example often mentioned is the province of South Holland where quality control was delegated by the provincial government to 14 (mostly small) water boards.
At the time the Act was conceived, a deliberate choice was made for a decentralized approach to the control of surface water quality; one of the reasons for this was the existing complexities in the control of the interrelated system of canals and other water-ways in the Netherlands. If, however, in practice (issue of licences, assessments, etc.) the system does not show a certain uniformity in the conduct of affairs by the various controlling-authorities, decentralization may easily give rise to criticism. This is why the Government attaches increased importance to a well co-ordinated effort by the various public bodies involved to ensure coherence in the implementation of the Act. For this reason, on 20 September 1973 the Co-ordinating Committee for the Administration of the Pollution of Surface Waters Act (CUWVO) was set up, representing the national Government, provincial governments, water and pollution boards and municipal corporations. The CUWVO set to work energetically and established six working committees (legal administrative problems; fiscal problems of the assessments; technological problems of the assessments; cost of treatment installations; establishing water quality groups; discharge of non-oxygen-binding matter), in which representatives of industry also participate.

Criticism of the assessments issued for domestic waste water is mainly levelled at the levies for individual dwellings. As the magnitude of such assessments is gradually increasing, resistance to them is growing, since they are not related to the degree of pollution caused (number of members of the family, consumption of water). Single people especially find it unreasonable to pay just as much as a big family. In order to meet these objections to some extent, almost every authority controlling water quality decided to fix the assessment on a dwelling at 3 p.e. instead of $3\frac{1}{2}$ p.e. in view of the fact that the average occupation has decreased. Moreover, on request, the assessment for single people may be reduced to 1 p.e. An assessment according to the real occupancy of a dwelling would conform closer to the pollution effected, but it would obviously meet with practical objections (excessive cost of administration and collection). As a matter of fact, as regards also sewerage tax (municipal) and the removal of solid household refuse, a system of average cost per dwelling is applied.

At an early date the CUWVO will report on the possibility of basing the determination of pollution levies for individual dwellings on water consumption and of having the charge collected by or with the assistance of the drinking water supply companies.

Initially, the policy of the authorities controlling the quality of surface water was aimed at limiting the discharge of oxygen-binding substances into surface water by constructing installations for the treatment of waste waters.
Now that the abatement of water pollution by oxygen-binding substances is proceeding rapidly, more interest is shown in the reduction of water pollution by non-oxygen-consuming substances. The CUWVO is drawing up a rehabilitation programme for discharges of this kind of substances and for this purpose has made a rough inventory on the basis of an inquiry among authorities controlling surface water quality. It turned out that the chemical, metallurgical and metal-processing industries in particular discharged relatively large quantities of non-oxygen-binding substances. Abatement measures include actions taken to remove as far as possible the causes of water pollution and to reduce present pollution.
For oxygen-binding substances table 1 shows the situation in 1969, 1975 and 1980, and also the prognosis for 1985. Under the heading industry, the pollution remaining after treatment by the plant itself – if any – is shown.

As is also stated in the first Prospective Multi-annual Programme, interest in the reduction of water pollution due to substances that are not biologically degradable has grown in the past few years. The listing in table 2 presents for the years 1975, 1980 and 1985 the emission at source and the discharge into surface water of some non-biodegradable substances. The final column shows the quantity of non-biodegradable substances entering the Netherlands *via* the rivers Rhine and Meuse.

Table 1 Emission at source and discharge into surface water of oxygen-binding substances in the Netherlands (10^6 p.e.)

Emission at source	1969	1975	1980	1985
Household	12.5	13.3	13.8	14.2
Industry (incl. recreation)	33.0	19.7	14.3	9.7
Total	45.5	33.0	28.1	23.9
Eliminated in publicly-owned treatment stations	5.5	8.7	12.8	19.5
Discharge into surface water	40	24.3	15.3	4.4

The substances mercury and cadmium have been placed on the black list internationally. The figures for 1985 for phosphate are based on the assumption that phosphate in detergents will be fully substituted by other substances and that, as a result of de-phosphatizing measures, the emission of phosphate by sewage treatment plants will be reduced by one third.

Table 2 Emission at source (ES), discharge into surface water (DSW) and transfrontier entry of some non-biodegradable substances in the Netherlands (ton/year)

Substance	1975		1980		1985		1978
	ES	DSW	ES	DSW	ES	DSW	Transfrontier input by way of Rhine and Meuse
Mercury	4.8	4.6	0.84	0.70	0.45	0.41	20
Cadmium	31	29	15	15	11	10	200
Zinc	1,700	1,500	1,100	900	570	300	10,000
Copper	210	150	170	120	150	90	1,300
Nickel	85	80	50	45	45	40	1,000
Chromium	400	350	150	110	120	100	2,600
Lead	370	300	270	200	90	50	1,800
Phosphate (as P)	32,000	29,000	28,000	24,000	16,000	12,000	57,000
Mineral oil	16,000	13,000	12,000	8,000	5,500	3,500	23,000

Much attention continues to be paid to the investigation of technical means for the further abatement of water pollution. This includes both the possibilities of reducing water pollution at source and an examination of methods and techniques of sewage treatment. As to the steps taken and to be taken, a distinction is made between measures taken by industry and those taken by the authorities.
For the greater part, the purification of waste water mainly polluted by oxygen-binding substances is performed by the authorities by means of sewage treatment installations. As a result of the projects realized in the last 5 years, the biological

treatment capacity available increased from 11 million p.e. to 17 million p.e. Some delay in the implementation of the programme has occurred, mainly due to problems of a planning and technical nature, and also due to the fact that the quantiy of sewage to be treated proved to be less than predicted. The programme is based on the attainment of a total biological treatment capacity of 25.3 million p.e.

14.4 International consultation

Since about 1970 the quality of surface water has become increasingly a matter of international concern. This has resulted in the conclusion of international agreements for the reduction and prevention of water pollution. Consultations are being held on standards of emission in the framework of a number of international arrangements on discharging pollutants, such as the Oslo Convention (1972) on dumping sewage into the North Sea, the London Convention (1973) on dumping into the Northern Atlantic Ocean, the Paris Convention (1974) on discharging sewage into the coastal waters of Western Europe and the draft Strasbourg convention. Various substances have been classified in lists of different colours (black, grey) according to their potential harmfulness to the aquatic environment. For substances on the black list discharge must be prevented entirely; for substances on the grey list discharge must be restricted and regulated as far as possible. The classification of substances and families of substances is dealt with extensively in the Prospective Multi-annual Programme.

As far as supra-national action is concerned, the action programme for the environment of the European Community should be mentioned. It has resulted in EEC directives on emission standards and water quality standards, which are binding for all member countries. Reference is made to the directive on the discharge of dangerous substances into the aquatic environment (4 May 1976), the quality of surface water being used for drinking water (16 June 1975), the quality of water for swimming purposes (8 December 1975), the quality of surface water for fish-life (18 July 1978) and the quality of surface water being used for the cultivation of molluscs (19 June 1979).
These directives give imperative rules to the Governments of member countries, which have to adjust their national legislation to comply with these measures. The directives relate to the following four topics:

- the methodology to be used for measurements and monitoring;
- surveys for the discharge of certain substances;
- licensing;
- rehabilitation programmes and their implementation.

14.5 Legislation

At the beginning of 1978 an amendment to the Pollution of Surface Waters Act was presented to Parliament dealing with the following items.

14.5.1 *Indirect discharges*

The amendment aims to bring indirect discharge of certain pollutants mentioned in the general administrative orders within the terms of the Pollution of Surface Waters Act.

14.5.2 *Emission limits*

These limits have to be established by a general administrative order and state the maximum permissible discharge of certain substances.

14.5.3 *Water quality programmes, quality objectives and Prospective Multi-annual Programme*

This amendment purports to establish the juridical basis for a system of water quality programmes, in which the main lines of the policy to be followed and the objectives aimed at within a certain period of time must be mentioned. The Prospective Multi-annual Programme serves as a basis and provides guidelines for the content of the programmes to be set up by the regional authorities.

14.5.4 *Survey of discharges and determination of the water quality*

As to certain substances mentioned in the general administrative orders (black-list substances), every three years an inventory of the discharges must be prepared by the Minister of Transport and Public Works for State waters and by the provincial authorities for the remaining watercourses. In a general administrative order, directives concerning the measuring methods employed to establish the quality of surface water may be made.

Another activity in the legislative field concerns the introduction of a draft bill on the management of water resources. Its aim is to provide the legal basis for the introduction of instruments required for ensuring the development of a coherent policy and control for the administration and management of surface water and groundwater. Present legislation is felt to be inadequate for the purposes envisaged.

The draft bill deals, *inter alia*, with the following topics.

- *Planning*

A system of planning is proposed that should ensure that the management of water resources conforms to the Pollution of Surface Waters Act, the Ground Water Act and the directives for water quality control stated in the draft. These so-called 'water management plans' are prepared by the Minister of Transport and Public Works as far as State waters are concerned and by the provincial authorities for the remaining watercourses, in close consultation with those charged with the control of these waters.

- *Note of intent*

The policy of the Government with regard to the entire water system should be laid down in a note on the management of water resources, which serves as the co-ordinating framework on a national level.

- *Water agreement*

Parties charged with the control of water and involved in the mutual discharge or diversion of water can be obliged in certain circumstances to come to a so-called 'water agreement'.

- *Licensing*

The draft includes measures for the initiation of a system of licensing for all cases in which water is supplied, discharged or diverted.

- *Registration*

Anyone supplying, withdrawing or discharging water has the duty to inform the authorities charged with the control of the water of the quantities of water concerned.

14.5.5 *Consultation on a national level*

As to this topic, the draft provides a legal framework for the activities of the existing Interdepartmental Co-ordinating Committee on Water Management.
By means of this bill, the Dutch Government intends to create the machinery to meet and satisfy as far as possible the demands of a modern industrial society for an adequate supply of water of reasonable quality.

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3. Observations of Groundwater Levels
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9. Measurements and improvement Works in Basin of Brooks
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