COMMISSIE VOOR HYDROLOGISCH ONDERZOEK TNO
COMMITTEE FOR HYDROLOGICAL RESEARCH TNO

VERSLAGEN EN MEDEDELINGEN NO. 29a
PROCEEDINGS AND INFORMATION NO. 29a

POLICY ANALYSIS FOR THE NATIONAL WATER MANAGEMENT OF THE NETHERLANDS

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BACKGROUND PAPERS FOR THE

TECHNICAL MEETING 39

(JUNE, 1982)

VERSL. MEDED. COMM. HYDROL. ONDERZ. TNO 29a – THE HAGUE – 1982

AUTHORS

K. P. BLUMENTHAL	Rijkswaterstaat, The Hague.
G. BAARSE	Delft Hydraulics Laboratory, Delft.
E. VAN BEEK	Delft Hydraulics Laboratory, Delft.
P. K. KOSTER	National Institute for Water supply, Leidschendam.
F. LANGEWEG	National Institute for Water supply, Leidschendam.
P. J. A. BAAN	Delft Hydraulics Laboratory, Delft.
J. W. PULLES	Rijkswaterstaat, The Hague.
J. P. M. DIJKMAN	Delft Hydraulics Laboratory, Delft.
W. A. DORSMAN	Rijkswaterstaat, The Hague; at present: Municipality of Amsterdam.

POLICY ANALYSIS FOR THE NATIONAL WATER MANAGEMENT OF THE NETHERLANDS

PAWN-STUDY: POLICY ANALYSIS FOR THE WATER MANAGEMENT OF THE NETHERLANDS

With co-operation of:
- Rijkswaterstaat, P.O. Box 20907, The Hague, Netherlands,
- Delft Hydraulics Laboratory, P.O. Box 177, Delft, Netherlands.

Also published as:
- RIJKSWATERSTAAT COMMUNICATIONS Nr. 31;
- DELFT HYDRAULICS LABORATORY REPORT Nr. R. 999-7.

Contents

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 ambitions project, called 'Policy Analysis for the Water Management of 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 will take 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 for National Water Management of 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.

The PAWN-publication is a joint effort of CHO/TNO, Rijkswaterstaat and the Delft Hydraulics Laboratory.

General aspects of the policy analysis for the water management of the Netherlands (PAWN)

K. P. Blumenthal

1 General aspects of the policy analysis for the water management of the Netherlands (PAWN)

SUMMARY

A major study of the water management of the Netherlands entitled PAWN (Policy Analysis for the Water Management of the Netherlands) has been conducted during the years 1977 to 1979 incl. Approximately 125 man-years of direct contributions were required for this investigation, carried out in co-operation with the RAND Corporation of the United States and the Delft Hydraulics Laboratory.
After a description of the water-system of the Netherlands, the problems that initiated the study are dealt with. Next, the general approach used for the investigation, followed by some important conclusions are presented.
Subsequently, the various stages of the analysis and the features of the models used are explained in some detail. The final section of the paper contains a few concluding remarks.

1.1 Introduction

The Netherlands, owing to circumstances to be explained, have been obliged to conduct a major policy-analysis of the country's water management. The word 'major', in this connexion, means that something in the order of 125 man-years of direct contributions habe been invested in the study. The analysis will be further referred to as 'PAWN', standing for 'Policy Analysis for the Water Management of the Netherlands'.
The study proper lasted from April 1977 to December 1979, but has been preceded by nine months of feasibility study, and was followed by 2 years of reporting and conversion of models and skills from the RAND Corporation to the Netherlands. In-depth follow-up studies are being prepared. The study was commissioned by the Government of the Netherlands (Public Works Department) and has been carried out in close co-operation between Dutch Government experts, The RAND Corporation of Santa Monica, California, United States, and the Delft Hydraulics Laboratory. Inputs from various institutes have been solicited and received.

For the benefit of the ECE Seminar on Economic Instruments for the Rational Utilization of Water Resources, a series of contributions on the PAWN-study (mainly dealing with methodology) was submitted. They all cover parts of the analysis. The present contribution is meant to give a general outline of the entire analysis, thus providing a background for the other papers.

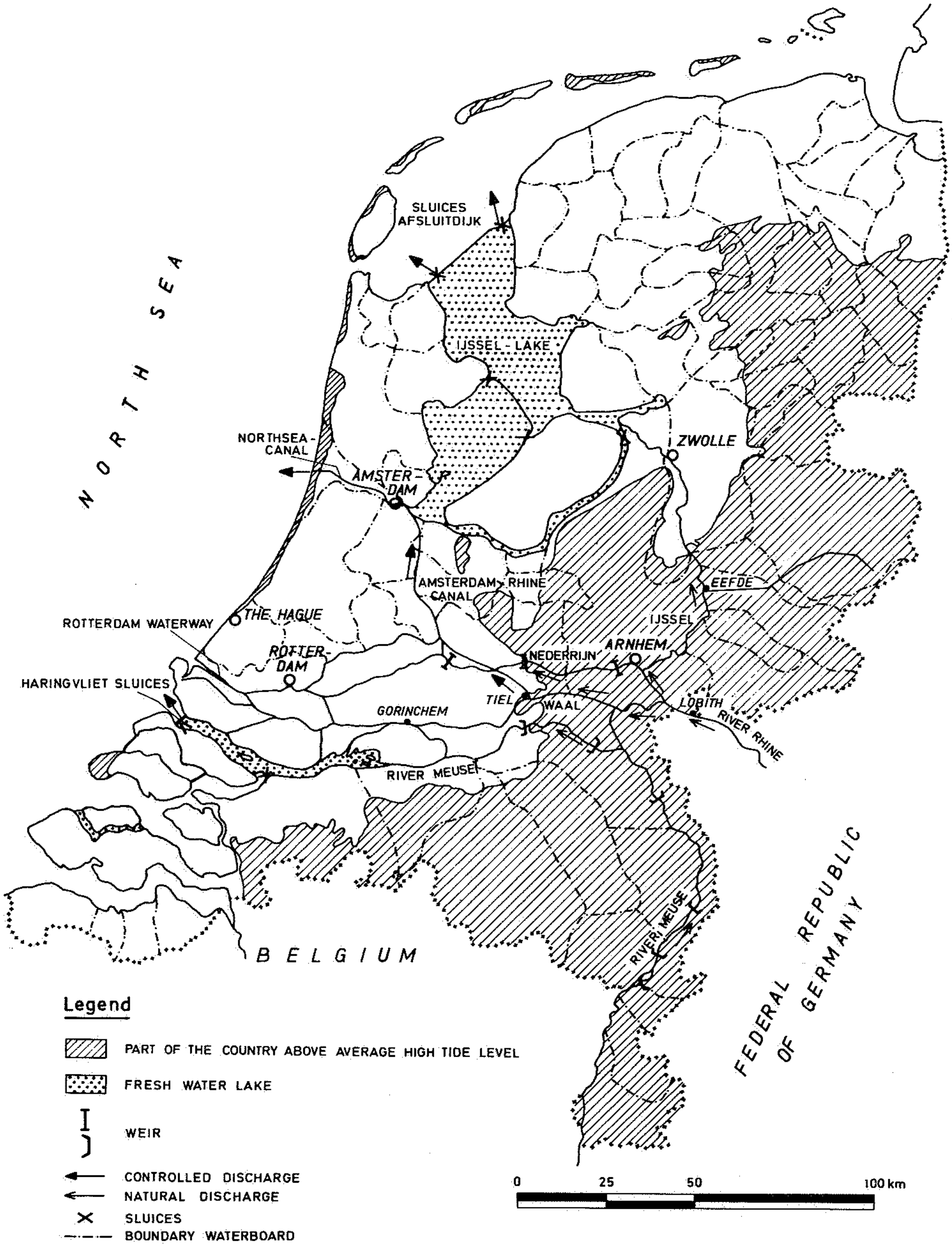

Figure 1 The Netherlands; Principal elements of the water-system

1.2 Description of the water system of the Netherlands

Obviously, a paper of such limited length covering such a vast study cannot escape sketchiness. This problem is aggravated by the necessity to describe, albeit briefly, the water system and water administration, in order to make possible an understanding of the rationale behind the analysis.

Figure 1 shows a small-scale, slightly stylized map of the Netherlands, giving only the main features that will be referred to. The shadowed part is above mean high-tide sea level, the rest is lower, up to 6 m below mean sea level. The so-called 'water-boards' (of which there are several hundreds, and approximately 100 large ones) have an important role in the water management system. In some parts (where this did not hamper the visualization of the main water system) their borders are shown on the map.
In an average year, the total fresh water supply to the Netherlands is $110 \times 10^9\,m^3$, of which $20 \times 10^9\,m^3$ evaporates. In a very dry year, supply may amount to less than a quarter of the figure given, while in some dry summer periods, it is much less than these figures would suggest. Of the supply, 67 per cent is given by the river Rhine, 8 per cent by the Meuse, 3 per cent by the small rivers crossing the borders in the east and south, and 27 per cent by local precipitation. As can be seen on the map, the Rhine, soon after entering the country, forks twice into, finally, three branches.

The natural division of discharges is: river Waal (going west) two parts against one part going north-east. Then two parts go west again through the river Nederrijn against one part going north through the river IJssel. The IJssel thus takes about 10 per cent of the total flow and carries it to the IJssel lake, formed artificially from the former 'Zuiderzee' by the construction of the enclosing dam 'Afsluitdijk'. The lake has been partially reclaimed, and its level is controlled by two large sets of evacuation-sluices in the Afsluitdijk. The lake has become fresh, and its levels are kept between N.A.P. − 0.20 m in summer and N.A.P. − 0.40 m in winter, thus creating a fresh-water reservoir with a capacity of over $0.5 \times 10^9\,m^3$. (N.A.P. = Normaal Amsterdams Peil, the national reference level; almost equals mean sea level.)

The natural division of flows is being artificially influenced at low flows by manipulation of the uppermost of three weirs in the 'Nederrijn' constituting the so-called 'Rhine canalization'. Shipping is improved by this canalization, but also, in times that it is most needed, more than the natural share of water goes to the IJssel lake. The bulk of the Rhine and Meuse flow, however, goes west. Formerly, it freely discharged into the Rhine estuary. This natural situation threatened the Netherlands, because natural and man-made influences caused the effect of seawater intrusion to penetrate gradually deeper into the country. This was especially grave in the Rotterdam Waterway, as here water is withdrawn for agriculture and for the drinking water supply of the low, western part of the country, which with a population of 5 million is the most important source of wealth in the nation, in terms of industry, trade, agriculture and intensive horticulture.

The construction of the Delta Works, the purpose of which was to provide safety against storm-surges for the low part of the Low Countries, partially solved the problem of salt intrusion. The biggest evacuation sluices in the world, in the Haringvliet estuary, are able to control the level of the northern estuaries in such a way that part, or if necessary almost all, of the river flow is led past Rotterdam, thus pressing back the threatening salt wedge. To be effective, this flow has to be more than 600 m^3/sec: this amount cannot be guaranteed at all times, as there are periods in which it almost equals the total momentary supply to the country. Another way for sea water to contaminate water-supply channels and reservoirs in the low parts is underground seepage. Rhine water (which by itself carries an artificial salt load and other pollutants) has to be used to flush these water bodies.

1.3 Statement of the problem, leading to the PAWN-study

Although fresh water supply is so abundant that, with a little care, the country would hardly run into shortages even in the driest times, the Dutch do have water resources problems due to the following circumstances:

- the sea, in direct or insidious ways, is constantly invading many water bodies with salt;
- the Rhine, the main source of fresh water, crosses the border heavily polluted by many inorganic and organic noxious and dangerous substances and also by salt and heat;
- the dense population and high industrialization is causing internal pollution problems;
- several of the previous items are responsible for the fact that many of our naturally eutrophic lakes are suffering from excessive and chronic eutrophication.

Groundwater presents a problem of a specific nature: it is saline or brackish in the low parts of the country; in the high parts where it is almost used to capacity it is of such quality that it is the preferred source for drinking water. Important items are, among others, the interaction between ground- and surface water, and the effect of ground water levels on nature preservation.

The instruments the country is using to combat these problems are, broadly speaking, the following:

- a large programme of construction of waste-water treatment plants, financed by taxes on polluted discharges (in PAWN terminology: 'technical tactics, financed by pricing tactics');

- infrastructural works carried out or planned, in order to distribute water quantities in a more sophisticated manner ('technical tactics');
- utilization of existing infrastructure for similar objectives ('managerial tactics');
- using existing, and creating new, legislation in order to manage water quality and quantity by, e.g. legal restrictions and/or pricing mechanisms such as taxes or subsidies ('pricing and regulation tactics').

In a country like the Netherlands, water management may have an enormous impact on the nation's economy and environment. Obviously, it is incumbent upon the Government to be reasonably sure that the country's resources in the water fields are used as beneficially as possible. Not only is the water system as such highly complicated, but also the governmental structure, being extensively decentralized, is an important feature. Water boards for instance, take care of local management. They are very old, very independent and still very powerful bodies. Eleven provincies as well as the municipalities play their parts, and of course the Government has the over-all responsibility.
Tendencies, like the increasing interrelation between regional and national interests and the growing determination to solve problems of water quality and the environment, call for an integrated approach. Legislation, while maintaining the principle of decentralization, aims at the possibility to carry out an integrated policy. Such legislation may provide the Government with the power to enforce standards; still, for a policy to succeed, it is essential that participants be persuaded of its effectiveness in the general interest.

1.4 The 'PAWN' general approach

The chief objective of PAWN was to design a number of over-all policies, assess their impacts on the various sectors of the economy and the environment and to present these impacts in such a way that they become visible and comparable, enabling policy-makers to choose between policies. It was foreseen that not all problems would be solved within the time limits, so a second objective of PAWN has been to transfer to the Netherlands those models, methods and skills that were developed in the United States. This will contribute to the ability to continue the study and tackle further problems and questions.
PAWN has developed a terminology of its own which cannot be altogether ignored. 'Tactic' has already been mentioned: a single measure to improve water management. There are four kinds of tactics, generally tackled by PAWN in two categories: Technical and Managerial (T/M)-tactics, and Pricing and Regulation (P/R)-tactics. Tactics of the same kind may be combined into a 'Strategy' and a combination of strategies is called a 'Policy'. PAWN operates on a national scale (regionally and locally the result can at best be used as a frame of reference), which means that a

PAWN-policy would be a national policy, comparable to e.g. foreign or economic policies.

The general method of PAWN is simple and may be explained in the flow chart of figure 2, 'Stages of Policy Analysis'. As a preliminary remark, it should be mentioned that the 'Sensitivity'-loop issuing from 'comparison of policies' belongs to PAWN, while the next loop 'decision making' lies essentially outside PAWN. Obviously, this loop will be an important feature of the post-PAWN process.

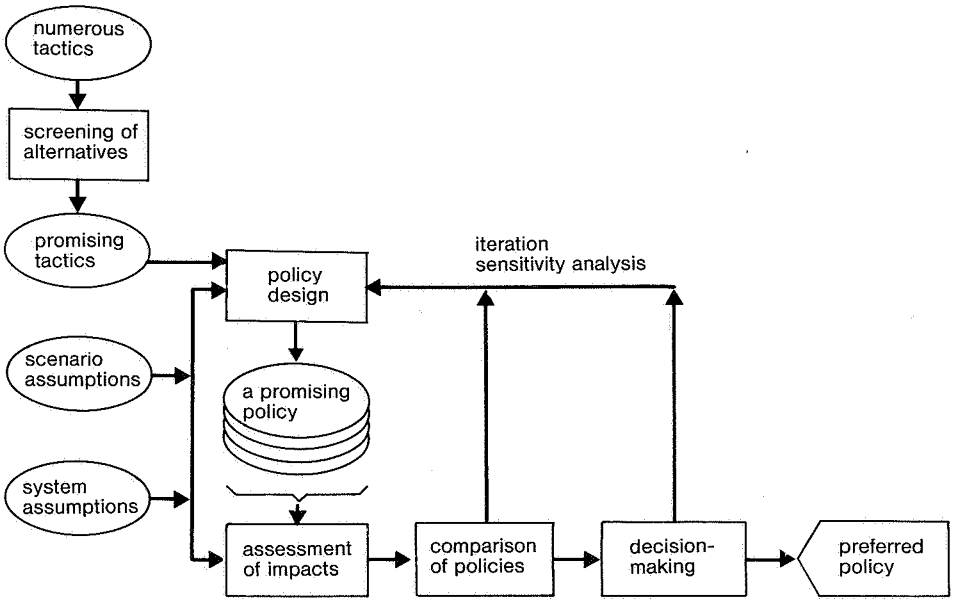

Figure 2 Stages of Policy Analysis

The study uses 'promising tactics' only because using all conceivable tactics would yield an unmanageable number of combinations. From the original 'numerous tactics', the promising ones are derived by a screening process; this will be dealt with in more detail later.

Now 'Policy Design' is done using 'promising tactics', together with scenario- and system-assumptions. 'Scenario' refers to factors outside the system (managers have no influence on them), 'system-assumptions' describe inside characteristics of the system. The process of Policy Design, as well as other stages of the analysis, is a complicated one. It can only be done by using a variety of models and analysis methods, several of which will be mentioned later. A model is used to show relationships explicitly and to predict consequences impacts). Some models are used in a single stage of the analysis; others are helpful in more than one activity. The models are designed to be operated on a computer. Of the policies designed by a process of applying standards and assumptions, promising policies are chosen, and these are kept for further analysis.

The next and very important step is the assessment of impacts of a policy, using a set of scenario and system assumptions. The various policies can then be compared; for this, score cards are used. For a number of policies, the impacts are shown per impact-category (e.g.: water shortage frequency; pollution; agricultural profits; etc.) each expressed in suitable units, which are not necessarily monetary. In this way – and also by using colours – rankings can be shown, but no choice is made. The score cards are, however, helpful in making choices, if desired.
The sensitivity analysis, finally, is done by changing standards and assumptions. Figure 2 suggests that this may upset policy design, and lead to new promising policies. In the actual PAWN-study, this did not occur, but much more sensitivity analysis will have to be done in the 'past-PAWN' period than could be accomplished in the study proper. What did not change were of course the impacts, thus influencing the comparison of policies. In the final analysis, a limited number of cases was compared, a 'case' being a policy under a set of various assumptions.

A good general impression of the PAWN-study is given in figure 3, the PAWN System Diagram. It shows the important sectors of the problem, the relations among them, and the major parts of the impact-assessment methodology. Each 'box' represents different models or sub-studies for assessing the full set of impacts, and the lines show

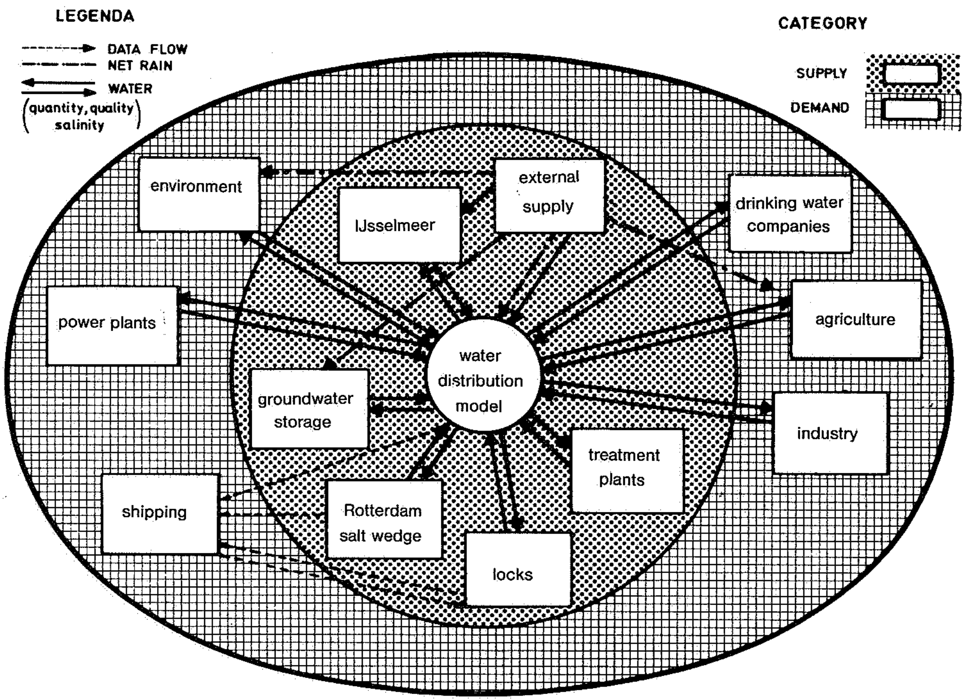

Figure 3 PAWN System Diagram

the relationships among them. It must be stressed that the methodology is not one big model, but a tool-kit of models combined with other techniques and with experience. The 'Water Distribution Model', however, did play a major part in screening as well as in impact assessment. For its sake, and for analyses purposes in general, the country was devided into 77 'PAWN-districts' that were treated as homogeneous units, from a water management point of view. Much effort was given to one specified model (not shown in the figure), called the Management Strategy Design Model, that is expected to be useful in the Policy Design stage. PAWN endeavours to draw its conclusions from comparisons between the present day (1976) context, and situations envisaged, with or without implementation of policies, for 1985 and 1990.
A detailed description of the various stages of the analysis is not possible within the space available for this paper. In the final section, however, they will briefly discussed again to give a general impression and to introduce the other PAWN-contributions that will dig deeper into much (though by no means all) of this material.

1.5 Some important conclusions of PAWN

First, however, a few things will be said about the results of PAWN, as these are certainly its most important feature. The results as such have come in such huge quantities, and present such an intricate pattern of interrelated possibilities and impacts that it seems hard even to give an impression. Therefore some very general conclusions will be given in the following seven items:

a As far as financial benefits or prevention of losses concerned, agriculture dominates all other sectors to such a degree as to make the others seem almost negligible (though appreciable sums are concerned with some of them too). To give a (randomly chosen) example: in an extremely dry year, the monetary value of the potential decrease of drought-losses in agriculture amounts to *f*2,000 million (crop value), the 'next best' being shipping with *f*100 million. For a more or less normal year ('expected value' in PAWN-terminology) the corresponding amount related to that particular year is *f*500 million for agriculture, with as second best electricity plants with *f*20 million (the difference in sequence is due to different steepnesses of the loss-curves in relation to dryness of the year).
b Sprinkling to augment crops, viewed askance by water managers (after its popularity increased abruptly during the exceptional drought of 1976) because of its potential water consumption, appears to be a very cost-effective measure. This generally takes the form of making other tactics or strategies much more cost-effective under a sprinkling scenario than without.
c Many Dutch water boards intend to improve their water management system by enlarging the area that will have access to water. Most of these 'Water board plans' prove cost-effective (and more so under a sprinkling scenario), and they too, often make other tactics look better. Sprinkling scenarios and most waterboard plans (as

well as several other tactics) are, by the way, only feasible on condition that the storage capacity of the IJssel lake be augmented by increasing the difference between summer and winter levels from 0.20 m to 0.30 m.

d The Netherlands are envisaging a set of future infrastructural works – some of them rather drastic – to improve the national water system (e.g. canalization of river branches, building of water transport canals, etc). As far as large projects are concerned, and under the assumptions made in the study, PAWN has shown none of those to be cost effective. Smaller projects generally need closer scrutiny than PAWN was able to provide.

e National tactics are possible (by redistributing water) to improve water quality. The effectiveness of these tactics, however, is very low and they are apt to inflict large losses on other sectors. Moreover, various environmental demands may require conflicting tactics. PAWN does not say that improvement of quality is not feasible, but refers it to regional or local tactics that are outside the PAWN-scope. On the other hand, the need for international measures aimed at quality improvement is a dominating factor in this field; the Rhine quality, however, was regarded by PAWN as a 'scenario assumption'.

f Eutrophication of lakes is one of the largest quality problems for the Netherlands. No single tactic will combat this phenomenon; only a mix of tactics, chosen individually for each lake, will be effective, and for some lakes only in a long-term perspective.

g As for environment and nature preservation, PAWN has shown that some tactics do better than others. This is largely a matter of the level at which standards are set. If these are very strict (or even of the 'Zero-effect' category) it is not surprising that they are difficult to meet, certainly in the socio-economic context of a densely-populated country like the Netherlands.

1.6 Description of the stages of the PAWN-study

In this chapter the various stages of the analysis and many of the models will be briefly mentioned.

1.6.1 *Methodology*

In visualizing the study, one should be aware that by far the greatest effort has been put into the development of methodology, and that this was done sector-wise (the various sectors to be read from figure 3). Exceptions to the sector-approach were:
- the Water Distribution Model, used in all stages of the analysis;
- the Management Strategy Design Model, used in policy design.

Whenever possible, the models for various sectors were linked to the distribution model; sectors for which this did not succeed were analysed by other methods. Linkage to the Distribution Model did succeed for the Lock Analysis Model (which in itself combines a Lock Operation Model and a Lock Salt Intrusion Model), and for the Electric Power Redistribution and Cost Model (EPRAC). Extensive studies on methodology were conducted for the sectors agriculture, shipping and water-quality. Much effort was put into the study of agriculture comprising, among others, the Sprinkler Design and Cost Model and the Sprinkling Optimization Model. The study on shipping contains the Low Water Loss Functions; the one on quality is largely based on the Algae Bloom Model, the Nutrient Model and the Dissolved Oxygen Model (OXYMOD).

1.6.2 *Screening of tactics*

The analysis stage of screening was done in three parts:
- individual water-board plans;
- Technical and Managerial tactics;
- Pricing and Regulation tactics.

The space allowed for this paper is not sufficient to deal in any detail with this topic, but it may be interesting in the present context that T/M tactics were analysed for six regions as well as on a national scale. Only eight tactics survived this screening, of which five are technical and three managerial. If they were all implemented, the total cost would amount to no more than *f* 500 million, or 50 million on an annualized basis. PAWN terminology calls them MAXTACS, and as such they are important in impact assessment, as some of the 'cases' do, and others do not, contain MAXTACS. In screening, the division of benefits between the Netherlands and neighbouring countries has been given some attention.

1.6.3 *Policy Design*

The stage of Policy Design was treated in the study in three separate parts:

a *Design of long-run pricing and regulation policies* that have the objective to reduce groundwater use. One of its most important tools is the Response Design Model (RESDM), which is a combination of two previous models: a Drinking Water Model and an Industry Response Simulation Model.

b *Design of Management Strategies* in which, again, three separate analyses have been made:
   - design of the 'MSDM'-Strategy, aiming at an optimal combination of tactics. Owing to time and priority limitations, MSDM has not yielded many satisfactory results. It did, however, provide a useful list of priorities of water use in the national system;

- an analysis on water management and thermal pollution;
- water management and water quality analysis, resulting in the conclusion, already mentioned, that a redistribution of the available water using the major infrastructure is unsuitable, as it would not substantially improve water quality.

c *Design of Eutrophication Control Strategies*, from which also conclusions follow that have been mentioned earlier.

1.6.4 *Assessment of impacts and sensitivity study*

The assessment of policy impacts is, in fact, the final stage of PAWN as it appears today: it does contain a sensitivity analysis section that may, however, be continued and deepened in future. The assessment was done primarily considering six 'cases', that cannot be described separately here. The differences lie in the difference between current policy and possible future policies, with or without MSDM strategy, with or without water-board plans, or high against low sprinkling intensity, including or not including MAXTACS, etc. The impacts are shown on score cards for the several sectors that were studied. The external supply scenario was limited to two alternatives: the extremely dry year (called 'DEX') and 1943, that is regarded as the 'expected benefits year'.

Apart from the six 'PAWN-cases' another six were studied consisting of special combinations of tactics suggested by the National Institute for Nature Management (RIN). This part of the analysis resulted in the relatively vague conclusions on the environment, that were mentioned in chapter 1.5, item g.

Finally six so-called 'Sensitivity Cases' were analysed, testing the robustness of results by changing assumptions that had earlier been regarded as fixed or as varying between strict limits. Effects were studied of management strategies, of increasing sprinkling by ground- or surface-water, of imposing groundwater quotas, priorities or charges, and of changing the Rhine salt load and Rhine BOD. Numerous 'score cards' illustrate these effects.

1.7 Concluding remarks

The material for this paper, as far as PAWN-proper is concerned, was entirely derived from the official oral presentation of results in December 1979. The material was available in the form of prints from over 500 overhead slides that were used in the presentation, of which about 20 per cent consisted of graphs and tables giving numerous data. And these, obviously, were only samples of the available complete results. It is expected that by the time the present publication will appear the full

RAND report on PAWN will have been published. For better understanding of PAWN, that report must be referred to, but it is hoped that the present paper, together with other PAWN contributions, will provide an impression of the character and scope of this unique policy analysis.

A methodology to determine consequences of variations in water management for agriculture

G. Baarse and E. van Beek

2 A methodology to determine consequences of variations in water management for agriculture

SUMMARY

Agriculture turned out to be a very important interest group to be considered in the PAWN-study (see Blumenthal, 1982), both with respect to quantity and quality of the available water. The interrelations between agriculture and the water management system are quite complicated. To describe the relevant processes, computer models were built to represent the three different levels of the water management system that were defined:

- user level;
- district level;
- national level.

The extent to which artificial water supply by sprinkling will be used in the Netherlands, is a key question with respect to total water demand and agricultural impacts. Separate modeling activities were carried out to determine the costs of sprinkling and to describe the way farmers operate their sprinkler systems. Also, a procedure was developed to compute (the distribution of) agricultural benefits or losses as a result of changes in crop yield.
The agricultural models were used for a number of different purposes. First a set of optimal sprinkler intensities was derived, reflecting the extent to which sprinkling should take place in order to maximize benefits to farmers. Various sprinkling scenarios were developed using these optimal intensities. Secondly, a great number of local plans to improve or expand surface water supply possibilities were evaluated, based on a cost-benefit analysis. These results and the agricultural models were then used in the different stages of the PAWN-analysis to compute costs, benefits and other impacts for many conceivable future situations and water management policies. The results confirmed the dominant role of agriculture, both with respect to water demand and impacts.

2.1 Introduction

Agriculture is by far the biggest single user of water in the Netherlands. Although over an entire year rainfall on cultivated areas exceeds the amount of water needed for crop evapotranspiration, considerable quantities of water should be supplied in summer periods to offset temporary shortages. This supply can take place from either surface or groundwater, thus creating a demand from water sources that (may) have alternative and competing uses. Apart from the shortage problem there is also a quality issue. In some parts of the Netherlands the chloride concentration of the water available to agriculture may exceed certain critical levels causing crop yields to be reduced. While the shortage problems mainly occur in the higher parts of the Netherlands (East and South), salinity is most important in the lower parts, where seepage of saline water contaminates the available ground- and surface-water (West and North).

The above considerations nominated agriculture a major interest group to be included in the PAWN-study. Hence a considerable effort was made to comprehend and model the aspects of agriculture relevant to PAWN. The main questions to be answered were:

- How do changes in water management affect the availability and quality of water consumed by agriculture?
- What are the consequences of these changes to agriculture in terms of physical crop yield and income?

This paper will describe in some detail the methodology that was developed to answer these questions. Chapter 2.2 provides some insights in the physical relations between agriculture and the different levels of the water management system. Chapter 2.3 deals with the basic models that were developed to reflect the relations described in chapter 2.2. In chapter 2.4 a number of additional modeling activities are discussed that support or complete the basic models. Chapter 2.5 aims at providing a coherent picture of how the agricultural models were used for different aspects and stages of the PAWN-analysis. Finally some illustrative results are presented in chapter 2.6.

2.2 Agriculture in relation to the water management system

The relation between agricultural water use and the influence of the water management system is shown in the diagram of figure 1.

Crop production is directly dependent on soil moisture, as it is the only source of water and nutrients-from-the-soil to the plant. Soil moisture can only be taken up by the root system of the plant if the soil moisture tension in the rootzone is within certain limits. Although the bulk of the soil moisture in the rootzone is provided by natural processes (rain, capillary rise) sometimes *artificial supply* will be necessary. This is done by irrigation, and in the Netherlands this usually means sprinkling from either surface water or groundwater.

As for the surface water system, it turns out there are actually two ways in which

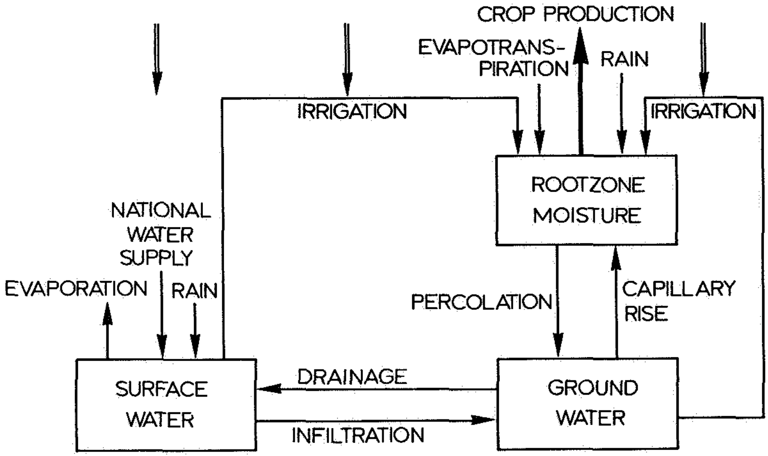

Figure 1 Agricultural water use and crop production in relation to the water management system.

surface water supply can help meet agricultural demands. Other than the artificial supply via sprinkling, there is a natural supply through the mechanism of infiltration from surface water to groundwater and the mechanism of capillary rise from groundwater to rootzone. All in all the system allows for three possible places for water managers to intervene. The natural water use from surface water is directly connected to the availability of a surface water system and the possibilities to maintain water levels in that system, which can be controlled by water managers. This also holds for surface water sprinkling. However, in this case water managers have additional options to stimulate, limit or prohibit the use of sprinklers by applying pricing and regulation tactics. The same is true for groundwater sprinkling. The double-lined arrows in the diagram of figure 1 indicate these places of possible intervention.

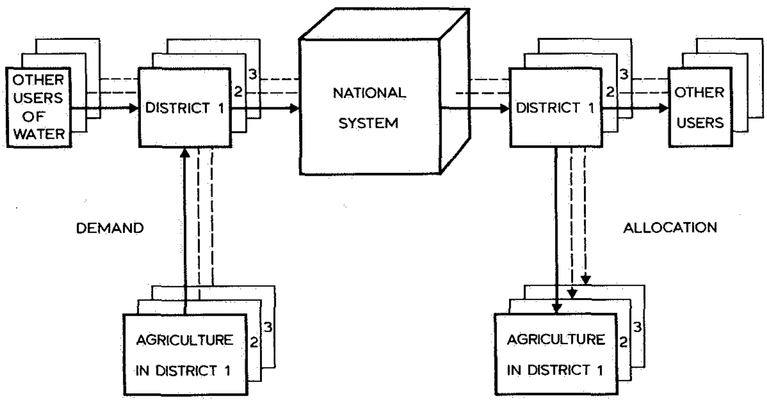

Figure 2 Agriculture and other users in relation to the water management system (surface water only).

One has to keep in mind that agriculture is not the only interest group to be considered. The diagram in figure 2 shows in a very simplified way how agriculture and other users are connected to the water management system.

As far as the representation of the water management system is concerned, three levels have been distinguished in PAWN:

- national level;
- district level;
- user level.

The role of agriculture within this system can be described as follows:

- agriculture requests water from a district for level control and surface water irrigation;
- the district combines the agricultural demand with other demands (industry, flushing) and requests water from the national system;
- the national water manager weighs the various district demands with other demands on the national level (shipping, cooling) and distributes water to the districts;
- each district allocates the water received from the national system to users within the district, one of which is agriculture;
- if less water is allocated to a user than requested, losses may result.

Note that two different phases can be distinguished here: a demand (or request) and an allocation (or delivery) phase.

2.3 Basic agricultural models

The following models were developed to represent the system as shown in the diagram of figure 2 of the previous chapter:

- the Water Distribution Model (DM) which describes the water management system of the nation;
- the District Hydrologic and Agriculture Model (DISTAG) which describes the water management system of the district;
- the Plot Models which represent agriculture.

First some definitions. A district is a part of the country that can be considered a hydrological entity with respect to its water supply and/or discharge situation. It consists of urban area, open water area, nature and cultivated area. In PAWN, 77 of such districts have been defined. Nature and cultivated areas were subdivided in so-called 'plots'. A plot is an area within a district having uniform properties with respect to crop type, soil type and irrigation condition (which can be one of three possibilities: no irrigation, irrigation from either surface water or groundwater). Including nature, 14 different crop types and 10 different soil types were considered. Plots typically have no specific geographical location within the district. As an example, a plot can be the collection of all non-sprinkled grass fields on peat in district X. In PAWN some 1250 different plots were defined for the current situation.

The above mentioned models are shown in context in the diagram of figure 3. This diagram is the model representation of figure 2 and follows the same pattern of data flows. Note, that also the models appear in a 'request' and a 'delivery' phase.

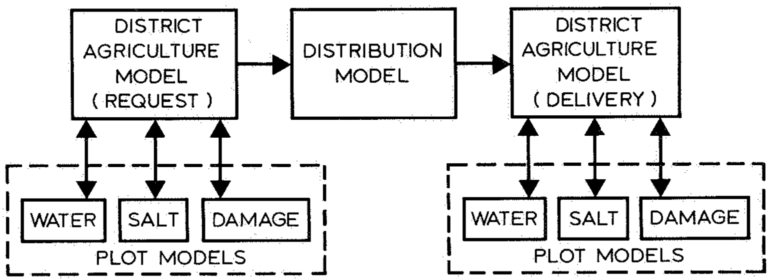

Figure 3 Models describing the water management system.

The models are operated in sequential timesteps covering a simulation period. Both timestep and simulation period can vary. In PAWN the main analysis was done simulating one-year periods with a timestep of ten days.

2.3.1 *The Plot Models*

Three different plot models were developed:

- the Plot Water Model to simulate the water flows in the plot;
- the Plot Salt Model to simulate the salt flows in the plot;
- the Plot Damage/Cost Model to determine the loss of agricultural production and costs of sprinkling.

THE PLOT WATER MODEL determines the water flows within a plot as a function of meteorological conditions, taking into account the interactions with the surface water system and groundwater flows. The core of the model is the computation of the soil moisture tension in the rootzone, thus linking soil moisture and groundwater flows with crop water consumption. For plots that can be irrigated also the required amount of sprinkling water is calculated.

The main inputs and outputs of the Plot Water Model are:
- inputs:
  - crop characteristics;
  - soil characteristics;
  - meteorological data;
- outputs:
  - actual versus potential evapotranspiration;
  - amount of sprinkling;
  - moisture content of rootzone and subsoil;
  - groundwater level.

THE PLOT SALT MODEL computes a salt balance based on the water flows generated by the Plot Water Model. As in Dutch agriculture most salt damage is caused by chloride (Cl^-), only that specific ion was considered. Hence chloride concentrations were associated with all relevant water flows. Moreover some diffuse salt loads (caused by fertilizers, pesticides) were taken into account. The Plot Salt Model yields a chloride concentration of the rootzone moisture for every timestep, which is used in the salt damage computation.

THE PLOT DAMAGE/COST MODEL calculates crop damages due to drought and/or excess chloride in the rootzone. If irrigation takes place it also computes the variable costs (labour and energy) of this irrigation.

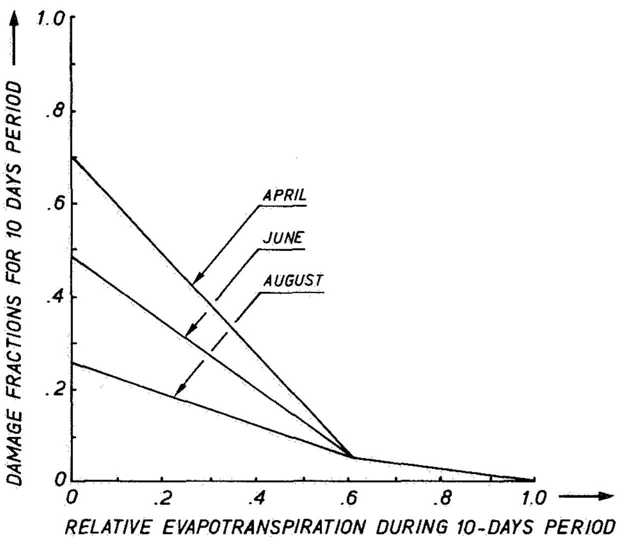

Figure 4 Quantity damage function for grass (damage fraction is related to total annual yield).

Drought damage is related to the relative evapotranspiration rate E-actual/E-potential (E-act/E-pot). If this ratio equals 1, then the actual yield Y-act equals the potential yield Y-pot for the considered timestep. If E-act/E-pot is smaller than 1, damage occurs. The yield reduction is a function of the ratio E-act/E-pot, the crop type and the stage of the growing season. An example of a quantity damage function for grass is given in figure 4.

Above a certain level of E-act/E-pot (> 0.6) the damage is assumed to be independent of the stage of the growing season (damage curves are the same for the different months). Below that level, the drought damage will become more severe, and also have an impact on the remainder of the growing season (plants may (partly) die). In this case, the amount of damage decreases for periods that are closer to the end of the growing season, because a bigger part of the grass crop will have been harvested/produced, so less remains that can be damaged. For other crops the curves may be quite different, depending on specific features with respect to the growth cycle (e.g. development of production over time, particularly critical periods). Salt damage occurs if the rootzone chloride concentration exceeds a critical level. Above that level damage is assumed to be linear with the extent to which the critical level is exceeded.

The variable costs of sprinkling (labour and energy) depend on the amount sprinkled, which is an output of the Plot Water Model. In the cost calculation sprinkling cost parameters are used that were produced in a separate analysis (see section 2.4.1).

2.3.2 *The District Hydrologic and Agriculture Model (DISTAG)*

In the request phase DISTAG calculates the total water demand or discharge by district. It does so by combining agricultural demands or discharges (generated by the Plot Water Model) with demands/discharges by other users. Moreover it takes into account a number of other things like urban run-off, evaporation of open water, flushing etc. DISTAG also calculates the chloride concentration of the district surface water volume.

In the allocation phase, DISTAG distributes the water received from the national system (the Distribution Model) among its users. For this a built-in set of priority rules is used. If agriculture gets less than requested, the consequences for the plot water and salt balance terms and crop yield are computed. As in the request phase calculation the implicit assumption is that the district will receive the water it wants, the allocation phase is only needed in case the district demand cannot be entirely met (if the total district demand is met, the computation that was done in the request phase remains valid).

2.3.3 *The Distribution Model (DM)* (see Baarse et al. 1982)

The distribution model reflects the national water management system. Rivers, canals and lakes are represented in the model by a network of (154) 'links' and (92) 'nodes'. The model is a simulation model in the sense that the water flows are calculated according to fixed rules for the water distribution. These rules depend on water supply, water demands, timestep considered, water quality etc. They are based on existing experience of the water managers and on a try and error optimization with the model. In the request phase the DM receives water demands from the districts and some other users on the national level (shipping, cooling). In the allocation phase the DM distributes the water among districts and users taking into account the distribution rules, constraints on capacities, quality standards etc.
The main outputs of the DM are:
- flows in links;
- water levels in links and nodes (storage);
- concentrations in links and nodes of some quality parameters;
- damage to agriculture (via DISTAG) and shipping.

2.3.4. *Relationship between the models*

The Distribution Model is the main program and uses the District Hydrologic and Agriculture Model as a subroutine. DISTAG itself uses the Plot Models as subroutines. As described before the data flows are reversible. In the request phase the order is: Plot Models – DISTAG – DM. In the allocation phase this is: DM – DISTAG – Plot Models.

2.4 Other agricultural modeling activities

The basic methodology and models as described before reflect the primary interactions between agriculture and the water management system and as such form the core of the agricultural analysis. In addition some other modeling activities have been carried out to support and complete the major tools:
- sprinkling cost analysis;
- sprinkler operation analysis;
- agriculture benefits analysis.

2.4.1 *Sprinkling cost analysis*

The current and future situation with respect to sprinkling plays a crucial part in the

agricultural analysis, as the amount of sprinkling affects:
- agricultural water demand;
- crop damage;
- costs of sprinkling to farmers.

Obviously these matters are strongly related, as the decision to invest in a sprinkler system is mainly based on a trade-off between costs of sprinkling and benefits that result from prevented damages. So the costs of sprinkling must be known to determine where sprinkling may be beneficial to farmers and hence if and where expansions of sprinkled areas should be expected.
Also in several other stages of the analysis it is important to be able to calculate the costs of sprinkling. Information about fixed and variable costs of sprinkling is needed in the cost-benefit analyses evaluating tactics that affect water management. Variable sprinkling costs must be known in making short run trade-offs between regions and different water users. Moreover the variable costs influence the way in which farmers operate their systems and hence have an impact on actual water use.
The sprinkling cost analysis deals with the question of determining fixed and variable cost parameters that can be applied on the plot-level. For this purpose two models were developed:
- Sprinkler System Design and Cost Model (SSDCM);
- Sprinkler System Allocation Model (SSAM).

Given a description of field size, water source (surface water or groundwater) and a number of performance requirements, the design part of the SSDCM specifies detailed system characteristics of appropriate sprinkling equipment. The cost part of the SSDCM then computes fixed costs (investment and maintenance) and variable cost factors (labour and energy costs per unit of water applied).

The SSDCM is based on the two currently most prevailing sprinkler systems in the Netherlands: the pipe-system and the reel-system. In total 8 different variations of these two systems have been considered.

The SSAM allocates relevant sprinkler systems to plots. Based on statistical data on crop types and farm sizes and a number of allocation rules, plots are identified with certain systems, after which weighted averages of the various required cost data are calculated. The result is a dataset of cost parameters that can be used to compute the fixed and variable costs of sprinkling by plot.

2.4.2 *Sprinkler operation analysis*

The sprinkler operation analysis tries to answer the following questions:

- What is (should be) sprinkling practice in the real world?
- How can this be modeled in the Plot Water Model?

Specifically the interesting question is: when does sprinkling take place and how much water is applied? The answer to this question is referred to as a sprinkling policy.

In the moderate Dutch climate substantial periods of drought hardly ever occur. This makes the practice of sprinkling rather complicated. To prevent drought damages a farmer should start sprinkling before his field dries out too far, because it takes quite a while to go round the entire field with the movable systems that are commonly used (several days to a week or more). However, sprinkling too soon decreases the possibilities to take advantage of rain. If rain falls on recently sprinkled fields, water might drain out because of the limited storage capacity in the rootzone. Apart from the fact this means a waste of water, energy and (often) valuable time, this situation may even cause damage by saturating the rootzone, given that water excess is at least as common as water shortage in the Netherlands.
On the basis of daily simulation, an attempt was made to select sprinkling policies that minimize the sum of sprinkling costs and drought damage under different climatological scenarios. Simplified versions of the selected policies have been implemented in the Plot Water Model in such a way, that the general behaviour matches the results of the more detailed daily simulation model.
It turns out that trying to prevent all drought damage by starting sprinkling long before the soil dries out to the point where damage begins, is generally not an optimal policy for Dutch circumstances.

2.4.3 *Agricultural benefits analysis*

As far as agriculture is concerned, applying certain tactics to the water management system will generally result in changes in marketable yield and a change in costs. The latter will normally consist of sprinkling costs and tactic costs. It is not directly clear how these results should be interpreted. The agricultural benefits analysis tries to determine the more detailed impacts on the following groups: producers (farmers), consumers and government. Because the ultimate impacts of tactics will in principle not be limited to the Netherlands only, a further distinction is made to Dutch and foreign impact groups.

The general approach is as follows. Changes in marketable yield are valued at a price (different price scenarios for different years have been considered) and will contribute to the farmer's gross income. Parts of these benefits are passed on to the government in the form of income tax. The farmer's sprinkling costs and his share of the tactic costs will partly be borne by the government because of tax deductions and credits. The

government may also bear a part of the tactic costs directly in the form of subsidies or because of reasons concerning national interest.
Increases in yield will lead to increases in market supply. For free market crops this may induce price changes, that cause part of the monetary benefits to be passed on to consumers. Moreover this may lead to a decrease in the income of producers that did not experience an improvement in production. Depending on the international market structure, the mechanisms involved here may pass on part of the benefits (or induce losses) to foreign producers, consumers and governments.

A Benefit Computation Model (BENCOMP) was developed to implement the above described agricultural benefits analysis. This model uses the results of the basic models as described in chapter 2.3. It compares agricultural damages by crop and tactic costs of a certain case to be analyzed with a base case. To calculate the desired price effects and benefit breakdowns it needs certain economic information like:

- elasticities of supply and demand by crop;
- Dutch and foreign share (both supply and demand) of relevant markets by crop;
- information on taxes and tax credits.

Unfortunately, very limited information about these subjects was (readily) available, so some rough approximations had to be used. Although some useful insights were obtained, the accuracy of the actual numbers yielded by this analysis is therefore not very high.

2.5 Agricultural analyses

The basic agricultural models and other modeling activities described so far were used for different purposes in several stages of the PAWN-analysis. The main applications were in:

- determining optimal sprinkler intensities;
- screening of waterboard plans;
- screening of technical and managerial tactics;
- impact assessment.

In this chapter some insights will be provided about these specific applications and the way they are interrelated.

2.5.1 *Determining optimal sprinkler intensities*

Optimal sprinkler intensities reflect the extent to which each crop in each district should have sprinklers in order to maximize the net benefits to farmers.

Increases in agricultural water demands largely depend on the additional crop area that will be sprinkled from either surface water or groundwater. Hence this question becomes a main issue in developing scenarios for future situations. To be able to realistically anticipate this, optimal sprinkler intensities were calculated, from which a number of different sprinkler intensity scenarios have been derived. In generating these intensities the following was taken into account:

- expected annual gross benefits of sprinkling per hectare;
- expected annual sprinkling costs per hectare (both fixed and variable);
- information on tax rates and tax credits;
- maximum sprinkler intensities.

The main tool used was the District Hydrologic and Agriculture Model (see section 2.3.2). DISTAG was run for a series of 19 years with both a sprinkled and an unsprinkled version of each plot (see section 2.3.1). The 19 years (1960/1978) reflect the period for which a complete set of meteorological data was available. By comparing the results for sprinkled and unsprinkled versions of the same plot, for each year the difference in yield reduction and the amount of sprinkling water applied could be determined. The average difference in yield reduction (over 19 years) represents the expected annual benefits from sprinkling. The average amount of water sprinkled was used to calculate the expected annual costs of sprinkling (using the results of the sprinkling cost analysis). Taking into account income tax payments on the benefit side and tax deductions and credits on the cost side, the net benefits to the farmers could be computed.

The optimal sprinkler intensity by crop and district is found at the point where total net benefits are at maximum i.e. where the marginal net benefits are zero. In most cases this means that the optimal intensity is either the maximum intensity or zero (sprinkling costs are always smaller than benefits or vice versa). However, sprinkling costs per hectare tend to increase as more of the same crop in a district gets sprinklers (more of the smaller fields have to be sprinkled, which is less efficient). Therefore it may happen that the optimum is between zero and the maximum intensity. The maximum intensities are based on practical considerations. Because of the scatter of fields on a farm, for certain parts it will not be cost-beneficial to sprinkle, even if a sprinkler system is available on that farm. Hence the total crop area in a district will never be completely sprinkled. The maximum differs by crop and location, and is assumed to be in the range of 60 to 100%.
In a comparison of the calculated intensities with real world observations, the results seemed reasonable for all crops except grass. It turned out that, on average, the calculated gross benefits of sprinkling grass should be twice as high to economically justify what seems to be happening in reality. There are a number of reasons why the benefits of sprinkling grass may in fact have been underestimated. For example:

sprinkling enables farmers to effectively apply fertilizer without having to wait for rain. In this way the growth retardation that normally occurs after mowing or grazing periods may be reduced, which will result in yield increases. These aspects have not been taken into account in the models. Also, there are reasons to believe that farmers invest in sprinklers for other reasons than strictly economical ones (buying insurance). Although it was considered a clear upper bound to accept the factor of 2 as 'real', the nature of the PAWN-analysis made it preferable in most cases to do so. This factor of 2 for grass benefits was defined and will be referred to as: *the grass 'multiplier'*.

The set of optimal sprinkler intensities presumably reflects an upper bound on future developments. It is therefore treated as a high scenario. The currently existing intensities are treated as a low (zero growth) scenario. A medium scenario was created by taking the average of high and low. All of these scenarios have been used in constructing PAWN-cases to be analyzed.

2.5.2 *Screening of waterboard plans*

In the current situation less than half of all cultivated areas in the Netherlands have access to surface water. Many local plans exist to expand and improve water supply possibilities. As these plans were put forward by the waterboards (institutional bodies responsible for local water management), they are referred to as waterboard plans. An inventory of these plans was made to obtain data about costs and affected areas by plan. In most cases there was no information about the economical consequences of the plan in terms of expected benefits, nor about likelihood of implementation. So in order to anticipate future situations, a formal and consistent procedure was needed to select plans that might be expected to get implemented.
The evaluation of the plans was done using results of the analysis of optimal sprinkler intensities. This analysis yields information about expected costs and benefits of sprinkling. The effect of a plan is, that a certain area can be supplied with surface water that could not be supplied before. As the net benefits of sprinkling were known, the total potential benefits of a plan could be found by multiplying additionally suppliable crop areas with a benefit per hectare and sum this over crops within districts affected by the plan. If the total potential benefits were large enough to offset the annual plan costs, the plan was considered promising and maintained for further analysis. If not, the plan was rejected.
There are a number of implicit assumptions involved with this procedure that cause the benefit estimates to be rather optimistic. Sprinkler intensities in newly suppliable areas were supposed to be optimal. The multiplier for grass was taken into account. Moreover it was assumed that the water needed for sprinkling could always be supplied from the main system.
In total 65 separate plans have been considered. Using the above assumptions, 46 plans

were screened in, adding about 40 % to the existing suppliable area. If the multiplier for grass is eliminated only 20 plans would be maintained.

2.5.3 *Screening of technical and managerial tactics*

In this part of the study a rather extensive list of technical and managerial tactics, all with respect to the national system, were investigated. The purpose was to reduce this list by selecting promising tactics for further analysis and setting aside others. The screening analysis focused on estimating an upper bound of the potential benefits of a certain tactic. This was done in a relatively crude way. If the upper bound of the benefits exceeded the estimated costs, the tactic was considered promising. If not, it was rejected.

The Distribution Model, describing the national system, was the main tool for this analysis. Agriculture, represented in the DM by DISTAG and the Plot Models, turned out to be the major impact group. The principle of analyzing the consequences of a tactic, is to simulate a situation with and without the tactic under consideration. Costs and benefits can then be estimated by comparing these two cases. Of course it is extremely important how the cases to be compared are specified. For this purpose scenarios have been developed, the main components being:

- climatological conditions (rain, evaporation);
- river discharges;
- sprinkling scenarios.

As for climate and river discharges the inputs to the models were derived from real world data. A number of actual years of different dryness were selected, that could be associated with certain probabilities. In total 4 different years were used: a 50 %-, 10 %-, 5 %-dry year and an extreme dry year (less than 2 %). Each of these years is referred to as an 'external supply' scenario. Surface water sprinkling scenarios were constructed by selecting one of the sprinkler intensities low, medium or high (see section 2.5.2) and applying these to the area suppliable with surface water. The latter is obtained by adding to the currently suppliable area a newly suppliable area that corresponds with a selected subset of the promising waterboard plans. Groundwater sprinkling scenarios could be constructed in a similar way by applying one of the sprinkler intensities low, medium or high to the remaining areas that are not suppliable with surface water. Note that in this way the implementation of waterboard plans will cause a shift from groundwater sprinkling to surface water sprinkling.
As screening dealt exclusively with the surface water system, all cases were run with a high intensity of surface water sprinkling and all promising waterboard plans implemented. Groundwater sprinkling was maintained at current level. In this way,

potential agricultural benefits from improvements of the national system were maximized.
In principle the benefits of a certain tactic were computed for the 4 different external supply scenarios. Apart from agriculture, benefits and costs of some other impact groups were taken into account, viz. shipping and power plants. Using the associated probabilities, an upper bound of expected benefits was then determined. By comparing this number with the annualized tactic costs, the tactic could be accepted or rejected. It turned out that the potential agricultural benefits always dominated these decisions.
As was remarked earlier, screening was done in a relatively crude way. In the agricultural benefit calculations the physical yield changes were valued at a constant price. Market effects and distributional aspects of benefits were not taken into account. Also, the interactions of surface water and groundwater were not considered here. A more detailed analysis was done in the impact assessment phase.

2.5.4 *Impact assessment*

Impact assessment is the final stage of the analysis. It is meant to provide a more complete and detailed overview of the consequences of combinations of promising tactics. The main procedures followed here were quite similar to screening. As far as agriculture is concerned there are two major differences. First, the benefit calculations were extended to include some market and distributional effects. This was done by means of the Benefit Computation Model (see section 2.4.3). Secondly, groundwater was now included in the analysis.

As in screening, the Distribution Model was the main tool to be used in impact assessment. In total more than 30 cases were run, reflecting the effects of different combinations of technical and managerial tactics, external supply and sprinkling scenarios (both surface water and groundwater) and groundwater policies.

As a limited set of technical and managerial tactics survived screening, all impact assessment cases were run with either no tactics or the whole set of surviving tactics (indicated as MAXTACS). Similarly most cases contained either all promising waterboard plans or no waterboard plans at all. External supply and sprinkling scenarios were used as in screening (see section 2.5.3). The groundwater policies dealt with imposing charges or restrictions on groundwater use, priority rules for different users, or a combination of these.

By comparing results of different cases a lot of information could be obtained. Specifically interesting for agriculture were:

- effects of increased sprinkling from surface water and/or groundwater;

- effects of tactics and waterboard plans in combination with increased sprinkling;
- trade-offs between use of groundwater and surface water by implementing waterboard plans;
- trade-offs in groundwater use by agriculture versus other users.

2.6 Some illustrative results

As an indication of the kind of results the agricultural models produce, a number of examples will be presented. Table 1 gives the sprinkled areas by crop group for a number of different scenarios, expressed as percentages of the total cultivated areas by crop group. The scenarios were derived in the way as described in the section about agricultural analyses (see sections 2.5.1 and 2.5.3). The situation with low sprinkling and no waterboard plans represents the current situation. The table shows that a substantial increase in sprinkled areas might be realized in future, although it should be borne in mind that the high scenario reflects a very optimistic view. Note, that a clear shift from groundwater to surface water sprinkling will take place if the promising waterboard plans are implemented.

Table 1 Sprinkled areas by crop group for different scenarios (as percentage of total cultivated area)

Water source	Surface water				Groundwater				Total cultivated area (hectare)
Waterboard plans	no		yes		no		yes		
Sprinkler intensity	low	high	low	high	low	high	low	high	
Grass	11	28	13	36	4	28	4	21	1 252 500
Arable crops	5	10	6	16	2	16	2	11	645 000
Horticulture	26	45	33	60	8	32	8	17	112 000
Total	10	23	12	31	4	24	4	18	2 009 500

Table 2 shows the limitations of the current infrastructure under severe drought conditions (the dryest 10-day period of the extreme dry year). Assuming a high surface water sprinkling intensity and the promising waterboard plans implemented, severe cutbacks would occur, as can be inferred from the numbers in table 2. The demand for level control is mainly due to natural infiltration from surface water into the soil. This part of the demand must be met in order to prevent water levels from falling, which is generally unacceptable.

Table 2 Total district water demand/supply situation in dryest 10-days period

Scenario: extreme dry year; high surface water sprinkling including waterboard plans; current national system

Use	Demand (m^3/s)	Supply (m^3/s)	Cutback (m^3/s)
Surface water sprinkling	329	206	123
Flushing	47	19	28
Level control	128	128	–
total	504	353	151

Table 3 Definition of cases

Case	Waterboard plans	MAXTACS	SW sprinkling	GW sprinkling
basecase (0)	no	no	low	low
1	yes	no	medium	low
2	yes	yes	midium	low
3	yes	yes	medium	medium
4	yes	yes	high	high

Table 4 Impacts with respect to agriculture
(All impacts relative to basecase 0)

External supply	extreme dry year				10 % dry year			
case	1	2	3	4	1	2	3	4
gross benefits	1083	1361	1601	2619	293	340	409	685
Sprinkling costs								
– variable	–93	–112	–141	–266	–56	–60	–78	–154
– fixed	–58	–58	–77	–140	–58	–58	–77	–140
waterboard plan costs	–22	–22	–22	–22	–22	–22	–22	–22
net benefits	910	1169	1361	2191	157	200	232	369
Dutch net benefits	891	1139	1330	2148	154	193	226	360
– producer	513	654	767	1243	89	111	131	210
– consumer	26	34	36	55	5	7	8	12
– government	352	451	527	850	60	75	87	138
Foreign net benefits	19	30	31	43	3	7	6	9
– producer	–131	–196	–202	–275	–22	–38	–41	–52
– consumer	246	370	380	521	42	73	76	99
– government	–96	–144	–148	–203	–17	–28	–29	–38
Δ Groundwater use ($10^6 m^3$/year)	–	–	167	347	–	–	105	262
net benefits without grass multiplier	578	787	898	1378	59	98	107	146

(All numbers in 10^6 Dfl unless otherwise indicated)

Table 4 shows some results of impact assessment. Four cases have been compared with a base case (case 0) for two different external supply scenarios (extreme dry year and a 10 % dry year). A description of the cases is given in table 3. The cases either have all promising waterboard plans or none at all and the same is true for the set of technical and managerial tactics (MAXTACS).
All of the numbers in the table reflect differences compared to the base case. Apart from total gross and net agricultural benefits, a breakdown by Dutch and foreign producers, consumers and government is given. Also the table contains information about changes in groundwater use by agriculture and the effect of the grass multiplier.

The effect of increased sprinkling is quite obvious. Note the differences in benefits and variable sprinkling costs between cases 1 and 2, that are entirely caused by improvements to the national system (MAXTACS).
The total foreign share of net benefits seems to be quite limited. Benefits that foreign consumers may experience are compensated by losses to foreign producers and government. However, the economical assumptions on which these numbers are based intend to give an upper bound of the Dutch share and hence a lower bound of the foreign share. An upper bound of the foreign share might yield numbers that are about five times higher. This is still a relatively small part of total benefits.
The results prove to be very sensitive to the grass multiplier. Net benefits will be reduced by more than 60 % if the multiplier is eliminated.
It must be realized that the extreme dry year is indeed very extreme. All of the numbers are quite a bit lower for the 10 % dry year.

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A cost minimization analysis of the future drinking water supply in the Netherlands

P. K. Koster and F. Langeweg

3 A cost minimization analysis of the future drinking water supply in the Netherlands

SUMMARY

Within the framework of a policy analysis for the water management in the Netherlands (the PAWN-study) a simple, linear programming model has been developed to analyse the production and transportation costs of the future drinking water supply in the Netherlands.
The main variables in this analysis are the extractable quantities of groundwater, the priorities in allocating groundwater to different users and the future need for drinking water. Using these variables, several policy alternatives have been established from which decision-makers can choose the one they favour.
A cost-minimal solution may be obtained for each policy alternative using the linear programming model. In this model, investment functions are used to determine the fixed and variable costs coefficients of different types of drinking water projects by applying the 'unuity' method (calculating the average unit costs). New projects are allocated using the integral costs, existing projects are allocated using the variable costs.
The results of the analysis will be presented in terms of the quantities of groundwater to be extracted as a trade-off function of groundwater v.costs, since groundwater is considered to be the main source for drinking water supply. In this presentation, the present policy will be indicated as described in the structure plan for the future drinking and industrial water supply.

3.1 Introduction

The Rijkswaterstaat is carrying out a policy analysis of the water management in the Netherlands (PAWN) as is shown in several papers. Drinking water supply is one of the sectors to be considered in water management. For this reason a cost minimization model for this sector was developed to be integrated in the PAWN systems model. The policy on drinking and industrial water supply itself, however, is embodied in the Structure Plan (Structuurschema Drink- en Industriewatervoorziening) and the Policy Paper (Beleidsnota Drink- en Industriewatervoorziening) of this sector. The Structure Plan embodies the governmental policy on the development of the water supply and the incorporation of this development in water management and physical planning. The Policy paper contains the objectives and constraints of the policy on the production and supply of drinking water and industrial water.

Within the framework of water management, policies on drinking and industrial water supply should be judged in terms of the objectives and constraints set in the Policy Paper for this sector. The general objective is to promote a water supply adopted to the need of water for the use of health, well-being and prosperity of the population in a socially acceptable way. This general objective is elaborated into five sub-objectives, namely,

- The promotion of an uninterrupted supply of a sufficient amount of water under sufficient pressure and of good and constant quality for domestic consumption and, within this sector, for human consumption and sanitary purposes in order to contribute to the health of the population and the hygiene.
- The promotion of the supply of an acceptable amount of water of desired quality to the economical sector in order to contribute to economical development and through this, to the prosperity of the population.
- The promotion of the extraction and production of drinking water using sources resulting in reliable products in terms of public health.
- The promotion of such development of the water supply that it will take place in a way acceptable for the national economy.
- The infrastructural works and extraction activities should satisfy ecological constraints and are to be integrated in water management and physical structures.

An analysis of the costs of the future drinking water supply is related to only one of the objectives and, therefore, it cannot be the sole basis for policy in this sector. However, some information on the other objectives can be obtained from cost analysis. The amount of groundwater used in drinking water supply can be used as an indicator for the reliability related to public health. In general, groundwater is considered to be the most favourable source in this respect. The other objectives should be handled in a similar way as costs. For this reason the analysis of costs is only an example of the means that systems analysis can provide to investigate different policies on drinking water supply.

3.2 The model for cost minimization of drinking water supply on a national scale

In order to obtain cost minimal solutions for the future drinking water supply a simple linear programming model was used. The main problem, however, was to schematize the national drinking water supply system in such a way that it could be used in a model without losing touch with reality. For this purpose, the users of water are considered to be concentrated at eleven provincial demand points. The water demand at each point is representative for the water demand within the provincial borders. The internal distribution of water is not taken into account.

For the production of drinking water, 31 projects of the following types are distinguished:

- 11 projects using groundwater as a source;
- 4 projects using river water for artificial infiltration in the subsoil;
- 3 projects using bankfiltration;
- 10 projects using surface water as a source combined with open reservoirs;
- 3 projects using surface water with limited possibilities for storage.

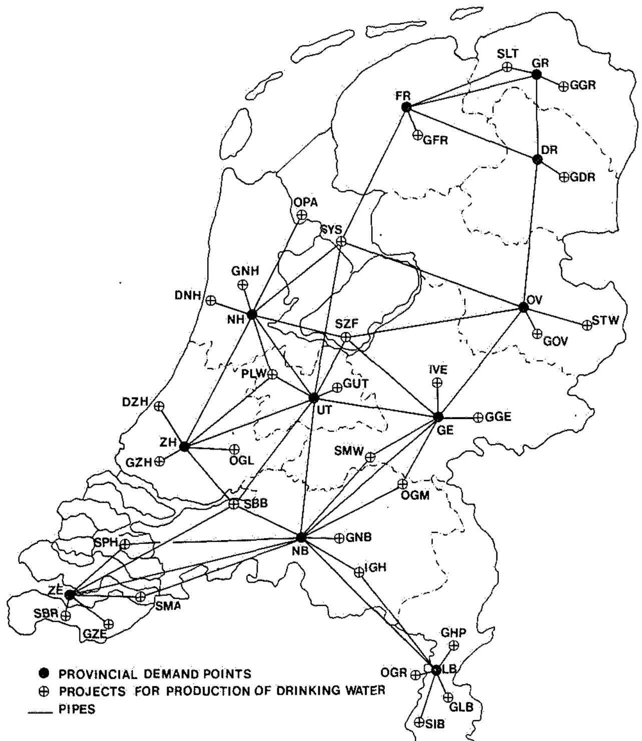
They are defined at a national scale which means that a project may consist of several spatially spread units. The extraction of groundwater, for example, is considered to be concentrated in one point although in reality groundwater is extracted using several pumping stations across the province. The purification to drinking water in principle takes place at the projects.

The drinking water projects and the demand points are linked by transportation pipes for drinking water or (semi) treated water. The demand nodes are also linked by transportation pipes in order to allow interregional transfer of drinking water. Totally, 74 pipes are used in the model of which 48 are connecting projects with demand points. In this way a network of pipes, demand points and projects is formed as a representation of the drinking water supply system (see figure 1). Meeting constraints (set *a priori*) the model selects elements out of the network leading to cost-minimal solutions at a fixed point in time.

The model computes the total costs of production and transportation at a fixed point in time. The production costs are related to the extraction, storage and purification of water in the projects mentioned. The costs of transportation include only transportation along the main pipeline system. The costs of distribution within the provincial demand nodes are not taken into account. Both the production costs and the transportation costs are separated into fixed and variable costs. The fixed costs consist of interest and depreciation on investments. The variable costs are related to maintenance, energy and use of chemicals.
The fixed costs of all projects including the existing ones are obtained from investment functions. The following types of functions are used:

- pumping stations for groundwater : $I_0 = 4.9 \times CAP^{0.53}$
- bank filtration projects : $I_0 = 7.0 \times CAP^{0.53}$
- projects for artificial infiltration : $I_0 = 7.0 \times CAP^{0.53} + 0.5 \times CAP$
- purification and storage of surface water : $I_0 = 7.1 \times CAP^{0.73} + (0.59T + 3.45) \times CAP^{0.53}$

The initial investment I_0 (in million Dutch guilders) is given at the 1977 price-level. The



DEMAND POINTS AND GROUND WATER PROJECTS	
PROVINCIAL DEMAND POINTS:	
NH = NOORD - HOLLAND	OV = OVERIJSSEL
ZH = ZUID - HOLLAND	GE = GELDERLAND
ZE = ZEELAND	UT = UTRECHT
FR = FRIESLAND	NB = NOORD - BRABANT
GR = GRONINGEN	LB = LIMBURG
DR = DRENTE	
G ADDED TO THE ABBREVIATION OF THE PROVINCIAL STANDS FOR A PROVINCIAL GROUND WATER PROJECT (SEE TABLE 1 FOR CAPACITIES).	

OTHER PROJECTS TO PRODUCE DRINKING WATER	
OPEN RESERVOIRS:	LIMITED STORAGE RESERVOIRS
SLT = LETTELBERT-RESERVOIR (50)	GHP = HEEL-PANHEEL-RESERVOIR (50)
STW = TWENTE-RESERVOIR (57)	PLW = LAKE STORAGE AMSTERDAM (60)*
SMW = MAAS-WAAL-RESERVOIR (100)	OPA = STORAGE ANDIJK (20)*
SZF = FLEVOLAND-RESERVOIR (100)	ARTIFICIAL RECHARGE
SBB = BIESBOSCH-RESERVOIR (500)*	DNH = DUNE INFILTRATION NOORD-HOLLAND (150)*
SPH = PHILIPSLAND-RESERVOIR (150)	DZH = DUNE INFILTRATION ZUID-HOLLAND (110)*
SMA = MARKIEZAAT-RESERVOIR (200)	IVE = INFILTRATION VELUWE (500)
SBR = BRAAKMAN-RESERVOIR (16)*	IGH = INFILTRATION GROTE HEIDE (20)
SIB = ITTEREN-BORGHAREN RESERVOIR (60)	BANKINFILTRATION
	OGL = BANKINFILTRATION LEK (50)
SYS = IJSSELMEER-RESERVOIR (500)	OGM = BANKINFILTRATION MAAS (50)
	OGR = BANKINFILTRATION ROOSTEREN (25)

(50) THE MAXIMUM CAPACITY OF A PROJECT IN 10^6 m^3 PER YEAR

* EXISTING PROJECT

Figure 1 Network structure used in the analysis.

capacity of the projects is measured in million cubic metres per year and the time of residence in open storage reservoirs (T) in months. Due to the costs of interest during construction and management costs, the initial investments were raised by 10 to 15 per cent.

The fixed costs of the projects per m^3 are estimated by means of the unuity method. The unuity (also called the average unit cost) can be calculated by the following formula (see Hall, e.g., 1970):

$$I_0 = \sum_{i=1}^{n} \frac{AF_i}{(1 + r)^i} \times UN$$

in which AF_i = the production in year i
r = interest or discount rate for which 9 per cent is used
n = period of depreciation for which 40 years is used and
UN = unuity

Almost independent of the discount rate and the rate of increase of the production, a period of about 10 years is optimal in an economic sense for a project to reach its full capacity. In some individual cases, adjustments had to be made to this generally applied rule.

For transportation pipes, the optimal period to reach full capacity is in the order of the planning horizon of the Structure Plan, which is about 25 to 30 years. Based on this, transportation costs are estimated and divided into three types:

- high transportation costs of 1 cent per m^3 per km for pipes in soft soils and many or expensive river crossings;
- medium transportation costs of 0.75 cent for pipes in soft soils and few river crossings or pipes in sandy soils with expensive river crossings;
- low transportation costs of 0.5 cent for pipes in sandy soils and few river crossings.

For groundwater, the average distance to the demand points is fixed at 10 km.

The variable costs of projects are taken into account by adding 0.05 guilder to the unuity. The total costs of transportation are calculated by adding 0.15 cent per m^3 per km to the unuity for energy costs. Using these figures, it can be shown that the total production costs of bank filtration projects are about 0.35 guilder per m^3. The production costs of surface water treatment and storage are about 0.70 guilder per m^3. The production costs of groundwater projects are about 0.25 guilder per m^3.

The model selects capacities of projects and pipes on the basis of linear relationships between total production costs and capacity in such a way that the total water demand is met at minimal costs. Constraints on the capacities of projects and pipes are also met in the cost minimal solutions. If no further allocation rules are applied, projects are chosen regardless of the present situation. Ignoring the present situation does not seem to be realistic, therefore, an additional allocation rule is used by which present projects are allocated to a solution on variable costs. In calculating the total costs of the solution, the fixed costs are added afterwards. The fixed costs in general are based on depreciation to renew a project or a pipe.

3.3 Strategies and scenarios

Scenarios are related to variables influencing the behaviour of the system but which do not belong to the system. To estimate future demand for drinking water, scenario assumptions should be made concerning variables such as growth of population, specific use of water *per capita*, industrial growth and specific water use in industry. The Structure Plan for the future drinking water supply distinguishes two scenarios for the demand: a low one and a high one. In the present analysis, an average growth of demand is assumed to be the average of the low and high scenario.

The priority by which consumers are getting access to groundwater is another scenario variable. Those uses consist of extractions by water companies, industry, agriculture and well point systems. The demand used in the analysis is given in table 1. The drinking water demands consist of the total demands of the water companies per province. The other demands are only related to the groundwater extractions. The last column in table 1 shows the estimated total extractable quantities of groundwater per province according to the Structure Plan. The industrial and agricultural demands for surface water are not taken into account since the analysis is focused on the priority of access to groundwater.

Two scenarios are investigated in the analysis, each using an average growth of demand. Scenario A gives priority to water companies to extract groundwater. Scenario B attaches the lowest priority to water companies which means that all other demands for groundwater are to be met first.

Strategies aim to improve the systems behaviour to one or more objectives. A combination of several strategies and scenarios leads to a policy alternative. Strategies to be considered are related to the amounts of groundwater to be extracted, the use of open reservoirs and artificial recharge of aquifers in the drinking water system and to what extent new production methods such as bank filtration are to be introduced in the system. Table 2 shows the policy alternatives considered in the analysis.

The medium strategy for groundwater to be extracted equals the Structure Plan estimates given in table 1. The low strategy is put at 50 per cent of the Structure Plan estimates, the high strategy at 150 per cent. The medium strategy on surface water projects aims to consolidate the present situation. The high strategy adds a large potential capacity of about 1,500 million m^3 per year of storage reservoirs to the present capacity.

Table 1 Average scenario for water demands in the years 1990 and 2000 and the extractable quantities of groundwater (in million m^3 per year)

demand points	1990				2000				estimated total extractable quantities of ground-water
	drinking water	industry	agricul-ture	well point system	drinking water	industry	agricul-ture	well point system	
Groningen	54	18	1	2	63	20	1	2	65
Friesland	61	19	2	2	73	20	2	2	131
Drente	39	21	16	3	46	23	19	3	200
Overijssel	96	30	50	4	119	32	58	4	175
Gelderland	171	82	87	4	205	85	97	4	395
Utrecht	92	15	7	13	104	15	8	13	136
Noord-Holland	217	9	8	2	247	10	9	2	89
Zuid-Holland	328	26	1	7	384	27	1	7	135
Zeeland	40	0	0	1	47	0	0	1	6
Noord-Brabant	195	62	147	49	233	65	165	49	440
Limburg	109	42	90	12	128	44	104	12	195
Total	1 402	324	409	99	1 649	341	464	99	1 967

Table 2 Policy alternatives considered in the analysis

alternative	scenario	strategies									
		groundwater			surface water		artificial recharge			new methods	
		low	medium	high	medium	high	low	medium	high	no	yes
I	B		X			X			X		X
II	B	X				X			X		X
III	B			X		X			X		X
IV	A		X			X			X		X
V	A		X		X		X			X	
VI	A		X		X		X				X
VII	A		X		X			X		X	
VIII	A		X		X			X			X

The strategies for artificial recharge are especially aimed at the dune region because of environmental impacts. The high strategy assumes a capacity of 260 million m^3 per year. The medium strategy reduces this capacity to 50 per cent and in the low strategy no artificial recharge will take place in the dune region. A strategy on new production methods introduces a total potential capacity of bank filtration of 125 million m^3 per year.

3.4 Results of the analysis

By means of the cost minimization model, the minimum total costs for production and transportation are calculated on an annual basis for the years 1990 and 2000. These cost computations are made for each of the eight policy alternatives mentioned in table 2. Separate computations are carried out for extreme policies in which the total demand for drinking water is met by surface water or groundwater only.
Using surface water only leads to the highest costs of a drinking water system. In that case, the yearly costs are about 1,300 million guilders for 1990 and about 1,500 million guilders for 2000. The cheapest solutions occur if groundwater is used to a very large extent for the production of drinking water. The cost minimal policy alternative for the year 1990 uses groundwater only at a yearly cost of about 650 million guilders. For the year 2000, a cost minimal policy alternative uses more than 70 per cent groundwater to meet the demands at a yearly cost of about 800 million guilders. Some policy alternatives show minor inconsistencies in the development over time for which no adjustments are made since the effects on costs are marginal.
Figure 2 shows the yearly costs as a function of the percentage of the demand met by the use of groundwater. Figure 3 shows to what extent projects and pipes are used to meet the demands for the year 2000 at minimum costs if only groundwater or surface water is

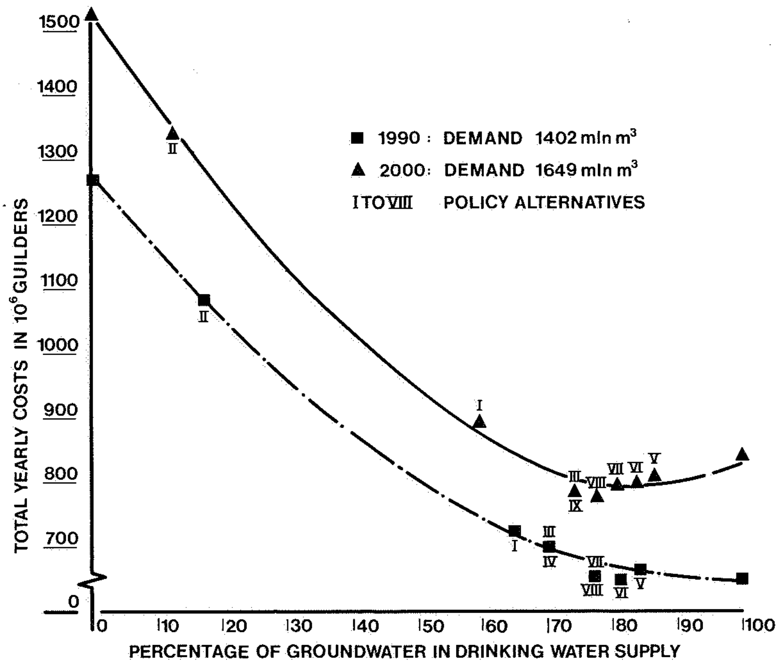


Figure 2 Relation between minimum total production and transportation costs and the percentage of groundwater in drinking water supply.

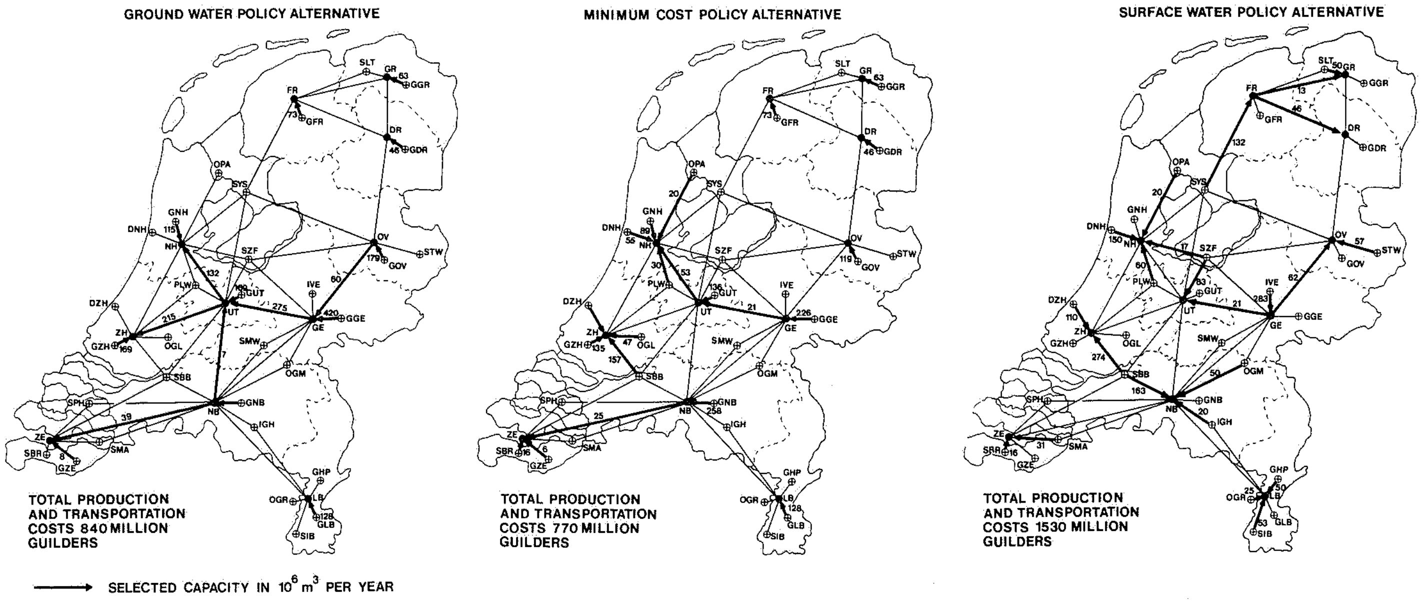


Figure 3 Distribution of drinking water in the national system for 3 policy alternatives in the year 2000.

used for drinking water supply and in case of a cost minimal policy alternative, compared with the eight alternatives considered.

The present policy in the Netherlands is more or less equal to policy alternative I. The costs of drinking water production and transportation, however, can be reduced by 10 or 20 per cent if a cost minimal solution is sought. To reach this the amount of groundwater used in drinking water supply has to be increased which may lead to abandoning present surface water projects. In that case, the costs involved are considered to be sunk costs. This assumption may not be valid if these projects cannot be written off within the planning period. An increase of groundwater extractions may also be unacceptable to other interests such as agriculture and the environment, or may be physically limited due to the quantity or quality of the groundwater to be extracted (for instance salination). These aspects are not taken fully into account in the cost analysis presented.

For reasons mentioned before, the analysis given cannot be the sole basis for the policy on drinking water supply in the Netherlands. It has to be considered as a first attempt to show the potential role of systems analysis in policy making. A full analysis of the drinking water supply system, in terms of the objectives mentioned, should be made to create an effective instrument for policy making.

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Minimum cost allocation of groundwater to drinking water companies and industries

P. J. A. Baan

4 Minimum cost allocation of groundwater to drinking water companies and industries

SUMMARY

Groundwater is a valuable and reliable source of water in the Netherlands. The last 20 years groundwater withdrawals have increased, which caused a lowering of the groundwater level. It is expected, that in future groundwater demand will rise further. Therefore in PAWN policies and measures were studied, which would lead to a more rational utilization of groundwater.
Models were developed to simulate the responses of the various user groups (industry, drinking water companies and agriculture) to groundwater policies and measures and to determine the impacts of these policies. This paper focusses on the responses of industry and drinking water companies.
Industry can switch from groundwater to other sources (surface water, drinking water) or apply recirculation. Surface water projects can replace groundwater for drinking water production, however, it results in much higher drinking water prices. So the costs for both industry and drinking water production increase substantially in cases of severe restrictions on groundwater use.
The PAWN results indicate, that agriculture should get priority in groundwater use over industry and drinking water companies. This conclusion, however, is sensitive to the increase in forecasted groundwater demand and the way the benefits to agriculture are estimated.

4.1 Introduction

Groundwater is a valuable and reliable source of water in the Netherlands. Often – especially in the highlands – it is of excellent quality, so it can be used to produce good quality drinking water and process water at low costs. Because of its low and constant temperature groundwater is also used for cooling purposes. Another use is in agriculture for irrigation during dry periods.
Over the last 20 years the amount of groundwater extracted in the Netherlands has increased considerably. This caused a lowering of the groundwater level which has negative impacts on the natural environment. This and the general scarcity of good groundwater requires a more optimal allocation of groundwater among the users. The PAWN-study paid attention to these problems as part of the Policy Design stage (see Baarse and Van Beek, 1982a). The aim was to find policies which would lead to a more rational utilization of groundwater and possibly a reduction of groundwater use.

This contribution deals only with groundwater tactics on the intake side of industries, drinking water companies and agriculture. Tactics on effluents, industrial processes etc. are not considered. The emphasis of this paper will be on industries and drinking water companies.
Agricultural extractions vary strongly over the seasons and over the years. In the analysis however an average extraction is used. Extractions of drinking water companies and industries show relatively small variations within the year and also from year to year.

To get an idea about the order of magnitude of groundwater withdrawals in the Netherlands table 1 is presented which gives groundwater extractions by industry and drinking water companies for some selected years and the average agricultural extractions based on 1976 irrigation capacity. The table shows that drinking water extractions are growing rapidly. Since about 1972 industrial groundwater use decreased however. The main reasons for this are imposed effluent charges and a more efficient energy management of the industries. The economic recession during that period also played a role.

Table 1 Fresh groundwater extractions in the Netherlands (million m^3/year)

Year	1967	1972	1977
Drinking water companies			
– with infiltration	601	729	863
– without infiltration	–	596	719
Industry	427	425	355

Average agricultural withdrawal based on 1976 irrigation equipment capacity: 85 million m^3/year

4.2 Objective of the analysis and used tools

The objective of the analysis was to determine a long run pricing and regulation policy for groundwater in the Netherlands. The implementation of such a policy will cause drinking water companies, industries and agriculture to respond e.g. with changes in amount of groundwater used. These responses have been analysed in the study.

The groundwater policies that were investigated in the study contained the following elements:

- charges;
- quota;
- priority rules among users.

A charge is an amount to be paid for every cubic meter of groundwater extracted. If a charge is imposed it only applies to agriculture and industry, and not to drinking water companies.

The quota indicates the amount of groundwater that can be extracted. It is expressed as a fraction of a reference quota that is considered a 'reasonable' maximum. The reference quota by region was provided to PAWN by the responsible governmental agency RID.

The priority indicates which of the groundwater user groups (industry, drinking water companies or agriculture) is allowed first to satisfy its demand from groundwater while the other groups only can take what is left of the quota. In PAWN it is either the combination of industry and drinking water companies or agriculture that is given priority.

The long-run industrial responses are mostly technological. Examples are:
- recycling of cooling water;
- substituting surface water or drinking water for groundwater.

Examples of responses of drinking water (DW) companies are:
- changing the price of drinking water;
- building new surface water projects (reservoirs, pipelines);
- importing drinking water from a neighbouring region.

To design pricing and regulation strategies and to learn about their possible consequences, we must predict the responses of industries and DW companies. In the analysis it is assumed that industries and DW companies will choose the responses which will minimize their costs.
The primary tool for carrying out the analysis was the Response Design Model (RESDM). RESDM is a linear programming model, that determines the least-cost allocation of groundwater between industries and drinking water companies.
RESDM was constructed by combining the two sectoral models IRSM (Industry Response Simulation Model) and RIDDWM (RID's Drinking Water Model). A description of the models and some results will be discussed in the following chapters, starting with IRSM.

4.3 Industry Response Simulation Model (IRSM)

IRSM was created to predict the responses of industry to imposed groundwater charges. It selects, for each firm in its dataset, a least-cost process response to the

groundwater charge. Alternative responses considered are for example:
recycling groundwater, substituting surface water, buying drinking water (see figure 1). An alternative is also to pay the charges without reducing the groundwater intake. IRSM contains data from industries in different sectors:

- food and luxuries;
- chemicals;
- paper;
- textiles;
- basic metals;
- metal products;
- remaining industries.

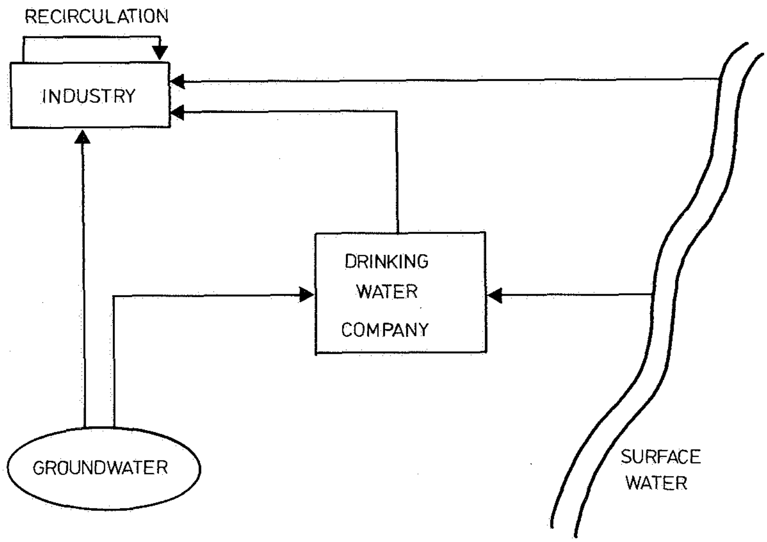

Figure 1 Possible sources of water intake by an industry.

Charges on effluent discharges will also induce industries to recirculate its process water. Recirculation will increase until the marginal cost is equal to the effluent charges. As the effluent charges on process water in the Netherlands are already rather high it is not likely that more recirculation of water due to charges and restrictions imposed on groundwater use will happen. In IRSM it is therefore assumed that more recirculation of process water is not possible.

Effluent charges on waste cooling water however are in the Netherlands low or zero. For this reason recirculation of cooling water can take place at relatively low costs. In IRSM the cost estimate for recirculation cooling water is a lower limit.

IRSM can also be used to predict the responses of industries to regional restrictions on groundwater intake (quota). This is done by imposing a fictional groundwater charge to induce industries to decrease their groundwater intake. The charge itself is not taken into account when the cost increase is determined. If the charge, applied in a particular region, is high enough, the industries will reduce their groundwater intake to the desired level.
IRSM focusses on predicting the long run response of the industries. Short term responses like stopping production are ot considered.
Future growth of groundwater demand by industries is estimated by using growth factors. These growth factors are based on official estimates of the growth in gross added values of production by sector. To account for a reduction in specific use of groundwater due to technological innovation the estimated production level for the year 1990 is reduced by 10-20 %.

4.4 Findings

Low charges (say under Dfl. 0.20/m^3) imposed on industry lead to long run cost increases which are nearly equal to the short term ones (paying the charges for the full amount of groundwater intake). At higher charges the long run cost increase is substantially lower than the short term one. How much depends mainly on the price of drinking water.
Charges of up to 0.50 Dfl./m^3 will lead in the long run to large reductions in groundwater intake (to about 50 %). At higher charges the intake is further reduced, but at the expense of an increased drinking water demand. However this additional amount of drinking water is mainly produced from groundwater, so that the overall groundwater savings to the nation do not increase much further.

A restriction policy (quota) can lead to the same reduction in groundwater intake as caused by charges. However, government must gather much information to determine, which industries economically can be restricted (IRSM may be of help in this task). In case of quotas the cost increases are not borne by all groundwater withdrawing industries. Only those, who are restricted will face extra costs.
In theory, auction markets for the amount of groundwater available in each PAWN district should bring about the same responses as charges. An imposed charge, equal to the market clearing groundwater price, should result in the same reductions in groundwater intake.

4.5 Drinking Water Model (RIDDWM) (see Koster and Langeweg, 1982)

RIDDWM is a linear programming (LP) model which was developed by the National

Institute for Water Supply (RID). It minimizes the cost of producing drinking water for the Netherlands, subject to available groundwater and meeting drinking water demands of households, the commercial sector, and industry. Just like IRSM, RIDDWM deals with the long run responses.
The model considers one drinking water company and one groundwater source in each of the twelve provincial regions considered. It contains a menu of 20 potential surface water projects (reservoirs, infiltration plants), that could provide drinking water companies with more surface water.
RIDDWM considers the following cost elements in its optimization:

- groundwater extraction costs;
- surface water project costs;
- surface water transportation costs;
- drinking water transportation costs.

Economies of scales are not taken into account.

Because groundwater has in general an excellent quality it is the cheapest source of drinking water. The treatment which is necessary to bring the quality up to drinking water standards is limited. Because of the more expensive treatment of surface water, (average) drinking water price will increase in case less groundwater is available. This will also happen when the demand for drinking water increases.
Except for costs drinking water companies prefer groundwater also for reasons like reliability, constant quality and national health. The aspects are however not included in the model and therefore the importance of groundwater for the drinking water companies might be underestimated.

4.6 Response Design Model (RESDM)

RESDM was created by combining IRSM and RIDDWM to one model. Its basic structure resembles that of RIDDWM (being a Minimum Cost Optimization Model) but it is greatly enlarged by the addition of numerous 'vectors' representing the range of possible industry responses in each PAWN district.
In RESDM one single 'composite' industry was created for each PAWN district with composite responses and cost increases based on the individual industries in the district. Just like RIDDWM, RESDM minimizes costs subject to available groundwater, specified capacities of surface water projects and meeting drinking water demands. The costs in RESDM consist of the drinking water production costs and the cost increases to industry that arise due to the necessity to reduce its groundwater intake.

The two user groups draw on the same available amount of groundwater. The interests

of both user groups are weighted in that way that the sum of the cost to produce drinking water and the cost of industry's responses is minimized for the Netherlands. RESDM determines also regional shadow prices of groundwater. The shadow prices are the savings in total costs which will occur when one additional unit of groundwater would become available in that particular region. These shadow prices are the same as the groundwater charges which should be applied to obtain the desired levels of groundwater intake. In this way restrictions in groundwater use can be translated into charges.
When reductions in groundwater intake are needed, industry has the possibility to switch to drinking water. This will increase the drinking water demand and, because the demand is always met, the total drinking water production costs. The model weights the additional drinking water production costs against other possibilities to reduce groundwater intake. Translated to reality this optimization of total costs implies that industry should be charged with the *marginal* drinking water prices for the additional demand.

Currently common practice is however that drinking water prices are based on average costs. Because water companies select their water sources in order of unit costs – which means groundwater first – marginal costs are always higher than or equal to the average costs.

RESDM is not able to simulate cost minimization based on average drinking water prices. This however can be done by using an iterative procedure between IRSM and RIDDWM.

4.7 Some results of the analysis

This chapter will describe some examples of the analysis which PAWN has done with the described tools:

- comparison between marginal cost and average cost pricing for drinking water;
- determination of responses on various groundwater policies.

4.7.1 *Marginal cost versus average cost pricing*

As described in chapter 4.6 average cost pricing means that when industries switch from own extractions to drinking water those industries will in some way be 'subsidized' by the other users in the drinking water pool. To achieve a total cost minimum marginal cost pricing should therefore be applied for the additional demand of industries.

In table 2 a comparison is presented between the two pricing methods. As can be seen in the table it is not worthwhile switching to marginal cost pricing when the quota is 1.0. The reason for this is that for the predicted situation for 1990 the extracted amounts of groundwater are hardly limited by the quota.

Table 2 Comparison of average cost pricing with marginal cost pricing for DW (DW/IND priority; no charge; withdrawals based on estimates for 1990)

Quota	1.0		0.5		
DW-pricing	MC*	AC**	MC*	AC**	
Total costs	656	656	846	856	mln. Dfl./year
GW-intake industry	441	439	245	213	mln. m^3/year
GW-intake DW-comp.	1110	1112	774	806	mln. m^3/year
total GW-intake	1551	1551	1019	1019	mln. m^3/year

* MC = Marginal Cost pricing
** AC = Average Cost pricing

Reduction in the availability of groundwater (for environmental reasons) will result in severe limitations on groundwater withdrawals. In that case, marginal cost pricing looks worthwhile. In the example in table 2, 10 million guilders per year are saved when the quota is reduced to 0.5 (on a total cost increase of 200 million guilders per year). No savings in groundwater intake will take place because the amount saved by industry is compensated by the additional extraction of drinking water companies. Use of marginal cost pricing depends, however, also on other factors, not considered in PAWN, such as implementation problems.
Because marginal cost pricing looks as good as – or better than – average cost pricing, the following examples will be based on marginal cost pricing.

4.7.2 *Responses on groundwater policies*

Table 3 shows some responses on a number of groundwater policies that were analysed. It compares six different policies in terms of groundwater use and related costs or benefits to industry, DW companies and agriculture. Responses by industries and DW companies are based on RESDM-results. Agricultural benefits pertain to sprinkling from groundwater. Both the groundwater used by agriculture and the related benefits reflect an average situation. As was explained earlier, a groundwater policy consists of a quota, a charge and a priority rule. The effects of changing each of those elements will now be briefly discussed.

Table 3 Some results of the analysis of ground water policies

Case	1	2	3	4	5	6
Quota	1.0	1.0	1.0	1.0	0.25	1.5
Charge (Dfl/m^3)	–	–	0.20	0.20	–	–
Priority	IND/DW	AGR	IND/DW	AGR	IND/DW	IND/DW
Ground water use (10^6 m^3/yr)						
– DW companies	1 110	1 081	1 128	1 106	250	1 240
– Industry	441	380	282	259	167	482
– Agriculture	208	386	169	257	85	306
Total	1 759	1 847	1 579	1 622	502	2 028
Total DW demand (10^6 m^3/yr)	1 442	1 454	1 458	1 466	1 528	1 428
Costs to industry and DW companies (10^6 Dfl/yr)	656	685	725	733	1 170	596
Agricultural benefits (10^6 Dfl/yr)	55	103	25	40	28	83
Revenue from charges (10^6 Dfl/yr)	–	–	90	103	–	–

The effects of changing the quota can be demonstrated by comparing cases 5 and 6 to case 1. The quota of 0.25 (case 5) reduces total groundwater extractions by more than 1,250 million cubic meters a year, but increases costs to industry and DW companies with more than 500 million Dfl./yr and reduces agricultural benefits by more than 25 million Dfl. Total drinking water demand increases by almost 90 million cubic meters. Although this severe restriction may be very desirable for the environment, industry and DW companies would have to pay an extremely high price for it. A quota of 1.5 increases total groundwater extractions with 250 million cubic meters costs to industry and DW companies by 60 million Dfl. and provides extra benefits to agriculture in the order of 30 million Dfl. Of course, relaxing the quota will have negative impacts on environment. From the comparison of cases 1 and 3 it follows that a charge of Dfl. 0.20 significantly reduces industrial and agricultural extractions (industry by as much as 160 million cubic meters per year). Drinking water demand and use of groundwater by DW companies increase by about 18 million cubic meters. Logically, costs to industry and drinking water companies go up and benefits to agriculture go down. However the total losses to industry/DW companies and agriculture of about 100 million Dfl. are almost compensated by the revenue from charges of 90 million Dfl. Similar observations can be made by comparing cases 2 and 4.

Comparing cases 1 and 2 shows that shifting priority to agriculture reduces groundwater use of both industry and DW companies (in total by about 90 million cubic meters). However, agricultural extractions increase with about 180 million cubic meters. Drinking water demand goes up due to an extra demand by industry. The extra costs for industry and DW companies are about 30 million Dfl. But agriculture gains almost 50 million, which suggests that agriculture should be given priority.
The same conclusions seem to hold if a charge of Dfl. 0.20 is imposed on both industry

and agriculture (cases 3 and 4). Extra costs to industry and drinking water companies if priority is shifted are 8 million Dfl. But agriculture gains 15 million and also revenues from charges increase by 13 million. Again, shifting priority to agriculture causes the total groundwater extraction to increase. This effect will be substantially stronger in a dry year, as agricultural water use directly depends on climatological conditions.
One should be careful in concluding from these examples that agriculture should in fact always have priority. The results for agriculture in terms of groundwater use and benefits are based on a high sprinkling scenario. In the paper about agriculture (see Baarse and Van Beek, 1982b), it was explained that some optimistic viewpoints were taken with respect to the high sprinkling scenario and the benefit computation of grass (which is by far the most important crop). Also, the indications are that the conclusions would change if demands by industry and DW companies will deviate from those, that were assumed in these examples.

The conclusions might also be affected by the low cost estimates for recirculation cooling in IRSM (and RESDM). This reduces the shadow prices of groundwater to industry in the models. Besides drinking water companies value groundwater higher than corresponds with the computed shadow prices for quality reasons.

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Consequences for shipping of water-withdrawals from the river Rhine in the Netherlands and the method used in the PAWN study to estimate the financial implications

J. W. Pulles

5 Consequences for shipping of water-withdrawals from the river Rhine in the Netherlands and the method used in the PAWN study to estimate the financial implications

SUMMARY

When relatively large quantities of water are withdrawn from the River Rhine in the Netherlands, the available water depths for shipping at the withdrawal points are reduced. Under certain circumstances this can create a handicap for shipping. In the PAWN study the financial consequences of these water withdrawals have been investigated. This paper gives an outline of the approach followed.

5.1 Introduction

In the Netherlands there are three places where the interests of shipping meet those of quantitative water mangement:

a In the low parts of the Netherlands, locks very often form a separation between fresh and saline water bodies. At every lock cycle, a quantity of fresh water is lost to the sea and, more seriously, an amount of salt enters the fresh water body. This increases the salinity of the water system behind the lock, which in turn increases the damage to certain agricultural crops.

b In the higher regions of the Netherlands there are a number of canals. In general, these canals are fed with the run-off from the surrounding drainage basins. During a drought, shipping is badly affected and also some agricultural damage often occurs. By cycling the shiplocks, water is lost from the canal system. If the supply is inadequate, the level of the canal will drop; this will decrease the available loading depth for the ships and consequently the quantity of cargo they can carry. The drop in water level can be diminished by reducing the number of lock-cycles per day. Usually this means that a shiplock is only cycled, when it is completely filled with ships. This reduces the amount of the water lost per day, but usually it increases the delay time for ships at the locks, and as a consequence constitutes a constraint for shipping.

c The third category where water management creates consequences for shipping (and vice versa) occurs at the main rivers. In times of drought, the main rivers such as the Rhine are virtually the only source water in the Netherlands. Relatively large withdrawals from these rivers and their tributaries are required to satisfy the needs of agriculture and power plants (cooling water). However, these withdrawals are creating negative effects for shipping. In an alluvial river, an equilibrium exists between the amount of water flowing in the river and the amount of sediment transported by the water. Also there is a relation between water depth and flow in the river. By taking water from the river, the water level will drop some decimeters almost instantneously and also the sediment-carrying capacity will diminish. As a direct consequence, the shipping depth available at the withdrawal point will diminish as soon as the withdrawal is initiated, and if the withdrawal is continued for a considerable period – say one to two months – the available water depth will diminish further by the deposition of sediment. Such reduced water depths can decrease the loading depth of the ships. If this happens, the quantity of cargo carried per trip will decrease. For the same quantity of goods to be transported, more trips are necessary, thus creating extra costs.

All three relations between shipping and water management have been investigated within the PAWN study; however, this paper deals with the last aspect only. The other categories will be discussed in the official documentation of the PAWN study, which will be published in 1982.

5.2 General description

The stretch of the River Rhine from Basel to Rotterdam is one of the main transportation arteries of western Europe. In 1976, 150,000 loaded ships with a carrying capacity of 175 million tons passed the Dutch-German border. The river is most heavily used between Duisburg (Federal Republic of Germany) and Gorinchem (Netherlands). Intense use is made of the Rhine by ships making trips originating in or destined for: Netherlands; Belgium; Federal Republic of Germany; France; and Switzerland.

The maximum loading-depth for the various ships depends on the minimum depth of water along the route they take, and on the keel clearance required for safety reasons. The minimum shipping depth on a shipping route sometimes is determined by locks, canals, tributaries, etc., which a ship has to traverse before or after using the Rhine river. On other occasions, the depth of water along the river itself can be the limiting factor in the loading of ships to capacity. The maximum loading depth depends also on the stretch of the river used. For instance, for ships that travel from Rotterdam to the Ruhr area, the depth-limitations usually occur in the stretch of river from the Dutch border to the Ruhr area. However, for ships destined for Mannheim, depth-limitations occur in the fetch from Bingen to Mannheim. When the water depth along the main stem of the Rhine river is the limiting factor, the magnitude of the minimum shipping depth and its position is strongly dependent on the discharge of the river. Under the present circumstances controlling depths for shipping purposes seldom occur along the main stem of the river or its tributaries in the Netherlands; constraints generally occur in canals and in the part of the basin in the Federal Republic of Germany. However, this would change if rather large quantities of water were withdrawn from the river in the Netherlands.

The most important locations which at this moment are considered for such withdrawals are Tiel at the Waal and Eefde at the IJssel (figure 1). The analysis of the effects of these withdrawals is rather complicated. Firstly, the shipping sector itself is very hard to model due to the diversity of the ships and of the goods to be transported. Secondly, the river-flows and the water-withdrawals vary over time. Lastly, the effects of withdrawals in one time period can have repercussions in future periods, due to the consequences of the sedimentation. Therefore, the damage was estimated in the PAWN study by using various models. These can roughly be divided into two categories:

a models related to shipping itself;
b models related to water-withdrawals and sedimentation.

5.3 The shipping section

The diversity in the shipping fleet (sizes and types of ships), and the kind of goods to be transported and the large variety in the locations between which ships are travelling make use of a modelling-approach unavoidable. Use has been made of an existing model that has been developed by the Netherlands Institute of Transport in close co-operation with the Rijkswaterstaat. This model has been modified for the PAWN study. Before the model could be run, the results of three preliminary studies had to be available:

a An analysis of the waterborne transportation structure: from a survey, a relation was developed between the total quantity of goods transported (tonnage) and the number of ships by type and size. This relation was established for each origin and destination combination, and for each type of cargo. For the average load factor – the same kind of relations were developed. These relations formed the basis for the model calculations.
b The development of the relationship between water depth and load-factor: for this study the shipping fleet was divided into four types (push barges, towed vessels, motor driven dry-cargo vessels and motor driven tankers) and into seven classes according to the size of the ship (tons). For each class and type of ship, the distribution of the maximum draught was determined. Next, relations between draught and load-factor were established by sampling. By using both relations, the effect of depth-constraints on the total carrying capacity (tons) by type and class of ship could be determined.
c An inquiry into shipping-costs and features of shipping-operations: from an inquiry among the inland-shipping companies, the shipping costs for 1976 were obtained.

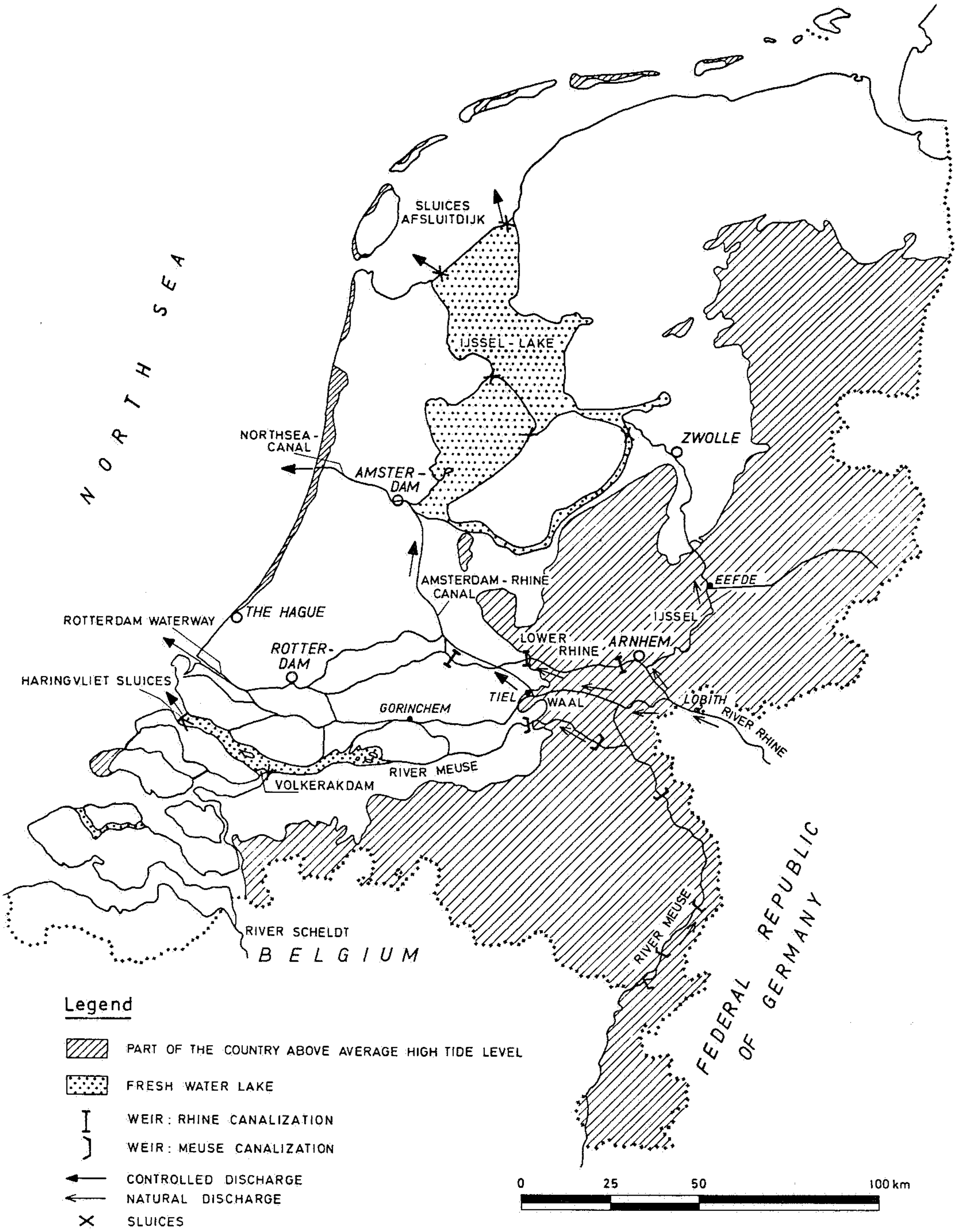

Figure 1 The Netherlands; principal elements of water-system.

These costs were broken down into a number of components. With these data, the cost per hour for travelling and waiting were determined for each type and class of ship. These relations were established for variable costs, as well as for total costs.

In the latter case, elements such as investment were included. Also information about the various phases that can be distinguished in a single trip was obtained from these inquiries. One complete passage of a ship can be divided into a number of elements. The most important of these are: 'waiting for loading', 'loading', 'travelling', 'waiting for unloading', 'unloading', and sometimes 'empty travel'. The time required for the phases 'waiting for loading', 'loading', 'waiting for unloading', and 'unloading' was obtained from the inquiry for each kind of cargo and for each type and class of ship separately. Also the effect of high and low water levels on the duration of these phases was analysed. The time required for travelling and for travelling empty is calculated by the model.
From the results of these preliminary analyses and from the characteristics of the network of water ways, the model calculates the total time spent on a passage, its total cost and the number of ships required, split up according to each combination of origin and destination, the type of cargo and the type and class of ship. It does this by determining the cheapest shipping route for each type and class of ship and by taking in account the constraints of the network, such as maximum allowable ship sizes, speed limits lock capacities, etc. The number of ships that travel empty is calculated as a function of the number of loaded ships. The computations are performed in two steps. First, results are derived on the the basis of 'normal' circumstances e.g. it is assumed that a situation without any depth-limitations on the river prevails. In the second step, the model checks for a given hydrological situation if there are draught limitations for certain ships on the various routes. If there are, the ships affected are unloaded until they can pass the bottleneck and the off-loaded cargo is assumed to be transported by extra ships of the same type and class. The costs incurred for these additional trips are due to the hydrological constraints prevailing at that moment.

In a later stage of the study, it was ascertained whether the ships required to carry the off-loaded goods were in fact available. When the total carrying capacity of ships of a certain type and class was inadequate to cope with the extra demand, a correction was made. The cargo which could not be transported by the kind of ship concerned, were loaded on ships second-best on the list of cargo rates. The extra costs incurred for this operation were taken into account. This redistribution process was continued until all available ships were used. The goods which were then left over, were assumed to be put in storage at a certain cost per week.
The analysis was made for four discharge situations at Lobith and also for a number of water withdrawals at different rates superimposed on them. The four cases are given the financial consequences for shipping due to the changes in the natural hydrological situation; the superimposed cases give the influence of man. The analysis was

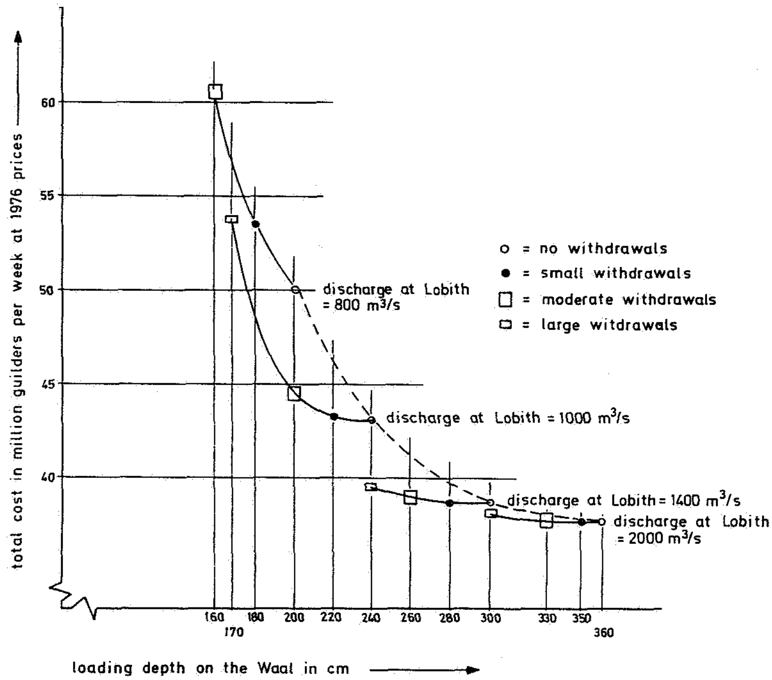

Figure 2 Relations between waterlevel and total costs for the year 1976

performed for two periods of time, namely 1976 and 1985: for the 1985 situation a change in the total volume of goods transported, changes in the shipping network, the fleet size and in the distribution of the types and classes of ships were taken into account. As stated before, the variable and the total costs were determined by the model. Figure 2 presents the relations developed between waterlevel and total cost for the year 1976. Most decisions concerning the management of the water resources concerned have to be made at short notice. The total carrying capacity of the shipping fleet cannot be adapted quickly to the ever varying circumstances imposed. For this reason, the variable cost concept was mostly used in the PAWN study. These costs are roughly one third of the total costs.

As the Rhine is an international river, the burden of the extra shipping costs is distributed over a number of nations. For this reasons, division into a Dutch and a foreign share was made. Both parts have been taken into account when the effects on the various interests concerned with the Dutch water management system were compared.

5.4 The models related to the water withdrawals and sedimentation

In order to determine the fresh water needs from the rivers for the sectors agriculture, power plants, and drinking water supply, various models were developed. These models, or their results, were combined in one model, the Distribution Model. This model calculates, *inter alia*, the size of the withdrawals from the river at the locations Tiel and Eefde.

The direct consequences of these withdrawals are obtained from the hydraulic relations between stream flow, rate of withdrawal and water depth. From these results and the calculations mentioned in the previous chapter, the costs of the direct consequences can be obtained.

For the determination of the indirect consequences resulting from the sedimentation-process, two approaches were followed, depending on the method assumed to cope with the condition resulting from the diversion of significant quantities of water. The cases considered are:

a The situation with dredging: here the assumption is made that adequate time is available to dredge away the sediment which is deposited due to the abstraction of water, before it reaches the locations at which a controlling depth for shipping may develop. In practice, this is usually the case. By the application of sedimentation models in use by the Rijkswaterstaat, simple relations have been developed. These relations provide an estimate of the quantity deposited as a function of the rate of withdrawal and its duration. With these functions and various specifications of the dredging vessels, (such as capacity, loading depth, cost per hour etc.) dredging-cost functions could be developed. Such functions give per time-step the relation between dredging costs and the withdrawal rate. The total cost resulting from the withdrawal of water is the sum of the dredging costs, and the costs due to the lowering of the water level as discussed in this section. This sum has to be balanced against the benefits acquired by the sectors to which the water diverted has been allocated.

b The situation without dredging: the Rhine in the Netherlands is an alluvial river and for that reason very sensitive to interference with its natural behaviour. Dredging must be done very carefully as otherwise scour or deposition at unwanted locations might occur. Due to the risks involved, there is a tendency in the Netherlands to avoid dredging as much as possible. In order to determine the consequences for shipping of the extra decrease in water depth due to sedimentation, a special set of loss-functions were developed. They are based on the loss-functions as described in chapter 5.3. As the consequences for shipping of the presence of a sandbar may extend over one or more years, future fiver flows have to be taken into consideration. This is done byn making use of the statistical distribution of river flows and a mathematical formulation of the behaviour of a sandbar, subject to varying hydraulic conditions. By this process, expected sedimentation loss-functions were obtained. The losses derived by means of these functions should again be added to the losses due to the lowering of the water level.

5.5 Conclusions

The results of the analyses of the effect on shipping of water withdrawals were used as input to the Distribution Model. With this model, the consequences for shipping of the various changes in the water management system were compared with the benefits gained by the other user-groups.

The consequences for shipping were calculated using 1976 prices. The higher costs for energy have not yet been taken in account. The repercussions on this score are subject to further analysis.

5.6 Remark

In preparing this paper, the author made use of information supplied to him by Mr. W. de Ruiter of the Rijkswaterstaat and the Netherlands Institute of Transport.

The relation between water management and power production and the way its consequences are investigated in the PAWN study

J. W. Pulles

6 The relation between water management and power production and the way its consequences are investigated in the PAWN study

SUMMARY

In this paper the consequences of power production for water quality are discussed. To diminish the environmental ill-effects of heat discharges by power plants, standards are set. In the PAWN study the financial consequences of these standards for power plants are investigated via a modelling approach.
This paper contains a broad description of this approach and some results of the relevant part of the study.

6.1 Introduction

Until the last two decades, the cooling of power-plants with surface water was hardly a problem. However the growth in the demand, the centralization of power production and the growing concern for the environment has changed this situation. To minimize the environmental damage of power production in the Netherlands, standards on the discharge of cooling water are set.
In the PAWN-study the effects of these standards on the power companies are investigated. Also the effects of improvements in the water management system have been studied.

6.2 Effects of the power production on water management

The power production in the Netherlands is done by several independent power companies, which are mainly provincially organized. Together they had in 1979 a production capacity of 15,300 MW. The greater part of this capacity is cooled with a once-through system. Only for 1,350 MW there is an option to use cooling towers. Roughly 400 MW can be generated by systems which do not need surface water cooling, such as gas turbines and district heating. Of the remaining 14,900 MW, 5,200 MW was cooled by rivers, 1,500 MW by lakes, 3,100 MW by large canals, 2,900 by estuaries, 1,000 MW by the sea and 1,200 MW by city canals and cooling ponds.
The cooling capacity of the above-mentioned water bodies depends on the standards which are set for these categories. For the rivers and large canals, the cooling capacity is strongly related to the flow through these water systems. And, therefore, the level of

power production at those locations becomes dependent on the way these waterflows are managed in the water management infrastructure.
Power plants located on large bodies of water such as the main lakes, estuaries and the sea are hardly dependent on the passing flows. The available water surface mainly determines the cooling capacity. In general, in these cases technical measures can be applied to avoid severe environmental damage. For these reasons, in the PAWN study the main emphasis has been laid on the investigation of the problems around power plants located along rivers and large canals.

6.3 Environmental aspects of power plants cooling

The withdrawals and the discharges of water for cooling purposes have a number of environmental ill-effects. Two main stages can be distinguished:

- a considerable amount of water (roughly 40 m^3/s at a production level of 1,000 MW) is withdrawn from the various watercourses. This amount passes the condensors of the power plant.' All the organisms which are in this water endure a sudden temperature shock of several degrees, while mechanical damage also can occur. The residence time is rather short;
- the amount of water withdrawn, together with the absorbed amount of heat is discharged in the original watercourse. In so doing, the remaining ambient water undergoes a temperature rise. Here the exposure to this rise is much longer. For some bottom organisms near the power plant, it is even a permanent rise.

For both stages in the cooling process in the Netherlands standards are set. Due to the short exposure in the first situation the standards here are less stringent than in the second case.

Since 1979 the following standards are effective in the Netherlands:

a The maximum temperature anywhere in the cooling-system is not permitted to exceed 30° C. An exception to this rule is made for cooling towers. Here higher temperatures are allowed.
b The maximum temperature difference between the intake water and the water discharged may not exceed 7° C in summer and 15° C in winter.
c the maximum temperature increase above the so-called 'natural temperature', averaged over the cross-section of the river may not exceed 3° C. Furthermore, no heat discharge is allowed if the oxygen content falls below 5 mg/l unless intensive aeration is performed by the power-plant.

The second standard can usually be met by taking technical precautions at the power plant. For this reason, the effect of this standard has not been investigated in the

PAWN-study. About the third standard two remarks can be made: first, the concept 'natural temperature' means, that the effects of all heat-discharges together (also the upstream ones) may not exceed the 3° C. This makes the standard rather stringent, as the Rhine for instance is already at this moment crossing the eastern border with an excess temperature of 2° C. The second remark is that this standard is only effective for rivers. For two large canals, this standard is not yet in force. However, as the circumstances for these canals are roughly the same as for the rivers, we have investigated in the PAWN-study the effects of this standard when also applied to canals.

6.4 The approach

In order to evaluate the effects of the standards on power plants, in essence two models were used; namely: the Water Distribution Model; the Electric Power Redistribution and Cost Model (EPRAC). The distribution model determines the flows of water in the water managerial network (see figure 1). It also calculates the thermal linkage between the power plants under the following assumptions:

- The excess temperature decays exponentially as a function of link flows and link surface area.
- Complete mixing of water in a node or link is assumed.
- An instantaneous steady-state approximation is used in developing thermal linkages.

At the end of its calculation the distribution-model passes a set of matrices on to the EPRAC-model. These matrices contain information on how each power plant influences the other and how the excess heat crossing the border influences the water temperature at the various power plant locations. With this information, the EPRAC model determines how much heat still can be dumped into the various watercourses without exceeding the standard.

The Electric Power Redistribution and Cost Model is a linear programming optimization model. It determines the optimal electrical production over the various available production units by the hour. At the same time, it meets the power demand in five regions of the Netherlands, while taking into account the restrictions in power transfer which are set by the national powergrid. The model contains several assumptions; the main ones are:

- It assumes that when a thermal constraint tends to be violated, power can be produced by another Dutch power-plant. This means a deviation from the optimum situation; so a less efficient power unit comes into production and more fuel is needed for the same electrical output.

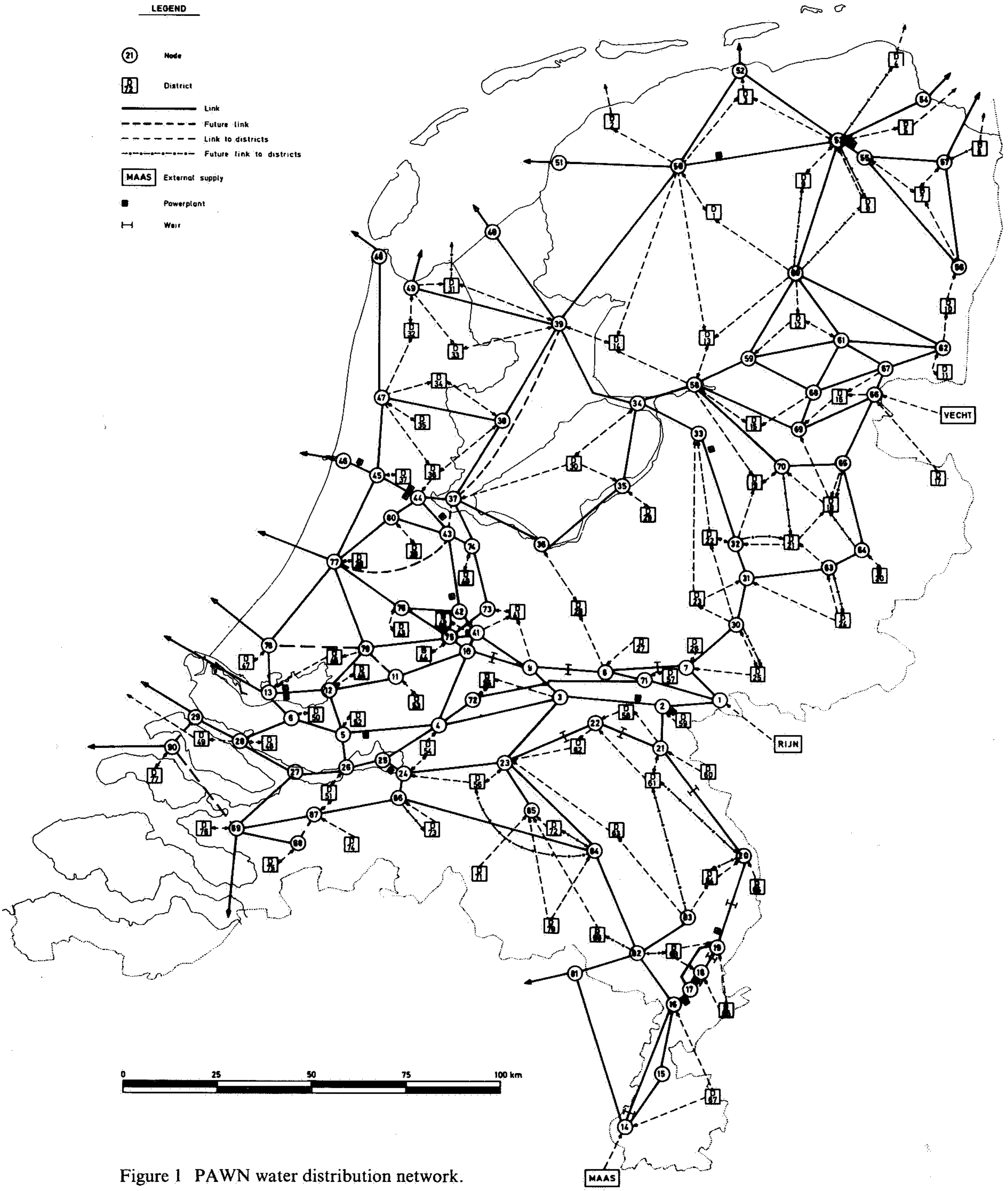

Figure 1 PAWN water distribution network.

- It uses only fuel costs as a proxy for these extra generating costs.
- It uses linear relationships between energy input and electrical output for each unit.
- It uses linear relationships between the rejected heat and the electrical output for each unit.
- It ignores the starting and stopping costs for each unit.

With this model for each situation two cases are calculated. One without any thermal constraints and one with thermal constraints.
The above-mentioned modelling approach is a strong simplification of the real world. These simplifications were necessary in order to keep the whole set of PAWN-models in a manageable form. Some comparisons have been made for the non-constraint case with a much more complicated model, which is in use by power companies. This model, however, could not handle the linkage to the water management system. The results of this comparison were that, although there were some differences between the outcome of the two models, these differences were sufficiently small that the EPRAC model could be used for the analysis, making some provisions.

6.5 Results of the analysis

In the large set of cases which were analysed within the PAWN-study, it turned out that it was always possible to supply the national power demand with the Dutch power production units. (Calamities excluded). The enforcement of the standards as such never made it necessary to buy electricity abroad. This is caused by the fact that thermal limitations usually occur in the summer period when the demand for electricity is low.

The financial consequences of the existing standards for the power-companies vary over the years, depending on the hydrological circumstances. On the average these costs were several million dutch guilders per year. Imposing the stricter set of standards (that is applying the 3°C standard for both rivers and canals) increases these costs respectively with some tens of millions of dutch guilders per year. By changing the water distribution in the network, it is possible to decrease the above-mentioned costs to the power companies. However, the decrease in benefits for agriculture and the increase in costs for shipping were much much larger than the decrease of power plant costs. Therefore, these changes in water distribution were left out of consideration. Also, some technical improvements to the water management system for power plant reasons only were investigated. Here the costs of these measures outweighed the benefits for the power companies. Therefore, these measures were screened out.

The different improvements of the water management system for the other sectors, such as agriculture and shipping, had no important effects on the costs to the power companies. In the most extreme cases, these costs increased 2,5 per cent.

Some of the above-mentioned conclusions depend heavily on certain scenario assumptions which have been made in the PAWN-study. The increases in the costs of energy which we see today, will increase the damage to the power plants roughly proportionally. The consequences of these kind of changes are subject to further study.

A model describing the water distribution in the Netherlands/the screening of water management tactics

G. Baarse, E. van Beek and J. P. M. Dijkman

7 A model describing the water distribution in the Netherlands/the screening of water management tactics

SUMMARY

An important tool developed in the PAWN-study is the Water Distribution Model (DM). It simulates the operation of the national water management system of the Netherlands based on a network representation of links and nodes, taking into account a great many of the specific features of this complex system (flow capacity constraints, operation of locks and weirs, flushing of lakes and canals, salt intrusion etc.).

The most important surface water user groups are directly considered in the DM, viz.

- agriculture;
- shipping;
- power plants;
- environment.

Separate modeling efforts have taken place to reflect the consequences of water management tactics for these user groups. These models – or the model results – have been integrated in the DM. In this way the DM is able to calculate in detail the overall consequences of water management tactics in terms of costs and benefits to different users and distribution and concentrations of a number of important pollutants.
In screening three different kinds of measures have been considered:

- screening of Pricing and Regulation tactics (P/R-tactics);
- screening of waterboard plans;
- screening of Technical and Managerial tactics (T/M-tactics).

As the first two parts have been described in other contributions, this paper focusses on the screening of T/M-tactics. The effects of the tactics were simulated under various conditions using the DM. Mainly based on the calculations of expected net benefits, promising tactics were then selected for further analysis.
Only a limited number of investigated T/M-tactics were found to be promising. Interestingly, not one of the larger projects that were suggested in the past, was included in the list of promising tactics.

7.1 Introduction

As described in the paper on the general aspects of the PAWN-study by Blumenthal

(1982) three major stages were distinguished in PAWN:

- screening;
- policy design;
- impact assessment.

This paper deals with the screening process and the main tool used for that: the Water Distribution Model (DM). Separate papers have been devoted to the stages policy design by Baarse and Van Beek (1982a) and assessing impacts also by Baarse and Van Beek (1982c).
Some definitions. PAWN uses a hierarchy of three levels of measures to improve water management:

- tactics;
- strategies;
- policies.

A tactic is a single measure to improve water management.
A strategy is a mix of tactics of the same kind. Two main categories have been considered:
- Technical and Managerial strategies (T/M-strategies);
- Pricing and Regulation strategies (P/R-strategies);

A policy is a mix of different strategies. It represents a national policy for the Netherlands.

Screening deals with a relatively quick and crude evaluation of a great many conceivable tactics. Policy design is the part of the analysis that specifies alternative water management policies to be investigated. Impact assessment is the stage in which the impacts of various selected policies are estimated. This is done for a variety of different impact categories under different circumstances, as to provide decision makers with the best possible insights in the consequences of certain decisions.

In chapter 7.2 of this paper the main features of the Dutch Water management system and the way this is modeled in the DM will be discussed. Chapter 7.3 focuses on the different user groups and how they are represented in the DM. The actual screening process is described in chapter 7.4, while in chapter 7.5 some results are given of the screening of technical and managerial tactics.

7.2 The water management system of the Netherlands and the way it is represented in the Water Distribution Model (DM)

A discussion about the water management in the Netherlands requires a definition of the boundaries of the system under consideration. In the PAWN-study the system

boundaries coincide with the fysical boundaries of the country, its subsoil and the atmosphere. Waterflows and flows of pollutants (including heat) pass these boundaries as inputs and outputs. Examples are: river discharges, rain, seepage, deep groundwater extractions, while pollutants in incoming rivers and salt intrusion in the Rotterdam harbour are examples of input flows of other matter.
Examples of outputs of the water management system are again the flows in rivers, but also the use of water by agriculture, industry, drinking water companies, evaporation of water, infiltration into subsoils etc..
The inputs of water (water availability) are variables that may have important impacts for the country as a whole. For example: dry summers cause agricultural damage and low river discharges cause low water levels and hence shipping losses, while an increase of the salt intrusion in the lower rivers, may cause damages to the sensitive horticulture crops in the Mid-West.
Among the numerous infrastructural works that are elements of the water system one may find weirs, sluices, locks, pumping stations, canals, pipelines, reservoirs. They all are intended to meet one or more of the goals of an integrated water management policy e.g. realizing desired flow capacities, level control, quality control, enabling ship traffic etc..

In the PAWN-study this complete system was simulated in a computer model: the so-called Water Distribution Model (DM). The advantages of such a simulation model are obvious; any technical or managerial tactic can be evaluated by simulating the impacts of that tactic on the water management system and on the water related activities (agriculture, industries, shipping, etc.).
The distribution model distributes the water according to fixed rules which are specified in advance. These rules are based on hydraulic properties, existing experience of Dutch water managers and on an empirical optimization with the model itself but they are not optimizing the water distribution in a mathematical way. An optimization model has been built for the policy design stage, but for computational reasons this model had to be based on a much more simplified representation of the Dutch water management system and was therefore only appropriate for a limited number of PAWN's purposes. (see Baarse and Van Beek, 1982a).

Simulation of the water management system was realized by defining a network of 92 nodes and 154 links (see figure 1). Links represent either individual waterways or a combination of waterways. Nodes indicate places where canal and/or riversections meet, but can also represent the main lakes (often used as reservoirs). Given the structure of nodes and links the model computes flows and waterdepths in links, levels and storage in nodes and furthermore the concentrations of quality parameters such as chloride, BOD, phosphate and some others.

The network used in DM distinguishes two levels in the water distribution system, viz.

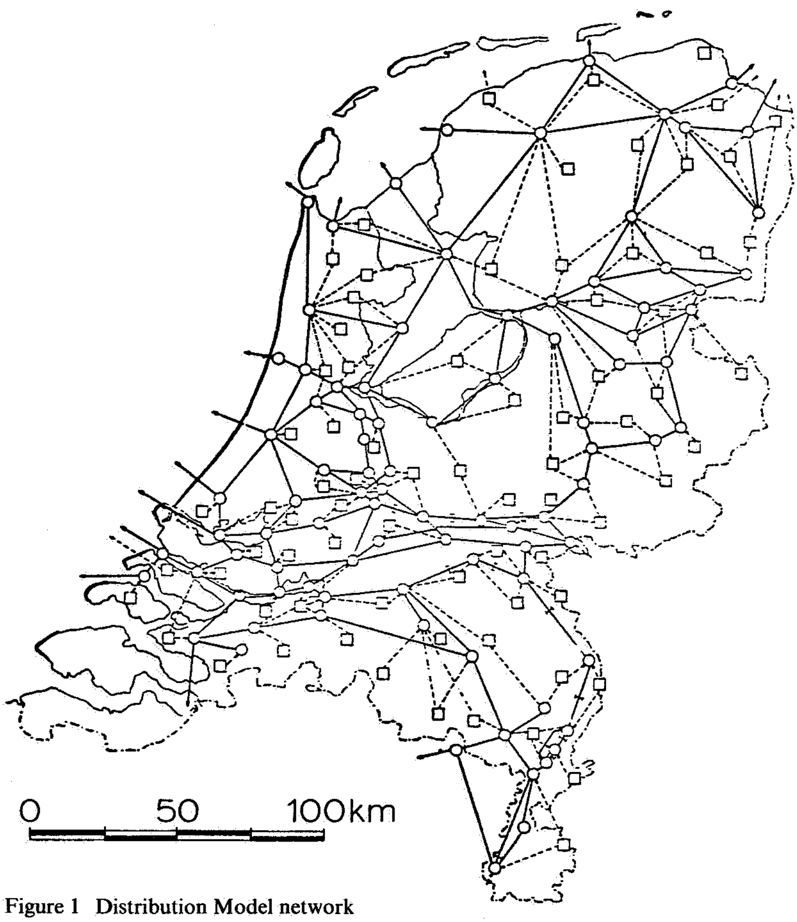

Figure 1 Distribution Model network

the national and the regional distribution network. The national system contains 50 of the 92 nodes and 70 of the 154 links. The regional system links most of the 78 districts, considered in PAWN, with the national system.
Districts extract water from and discharge water to the nodes of the network according to so-called discharge and extraction keys. These keys tell the program to allocate fixed percentages of the total district demand or surplus to specific intake or outlet points. Limits imposed by capacities of sluices, pipelines and pumping stations are reflected by upperbounds on magnitudes of flows passing the intake/outlet points.

Some particularly complicated phenomena have been implemented in the DM by applying results of separate modeling efforts. Examples are:

- salt intrusion in Rotterdam harbour area;
- water distribution in Southern Rhine delta (rivers around Rotterdam).

The Rotterdam salt wedge has been subject to a detailed analysis. Based on actual measurements, physical model tests (in the Delft Hydraulics Laboratory) and a theoretical modeling approach, a simple Salt Wedge Model has been integrated in the DM, describing the relation between river discharges and salinity levels at various locations.

The water distributions in the Southern Rhine delta area is very hard to be computed because of the complex geometry of the system and the interactions of tidal influences and river discharges. A set of distribution rules for the flows in various river branches under different conditions was derived by using results of the detailed IMPLIC-model (an existing model used by Rijkswaterstaat). These distribution rules were then implemented in the DM.

After specifying a number of scenario-type conditions, the DM calculates in detail the consequences of water management tactics, strategies and policies in terms of benefits and costs for user groups like agriculture, shipping and powerplants, and the distribution and concentrations of a number of important pollutants. The integration of these different aspects is possible because separate user models or the results of those models have been connected to the DM. How this was done will be described in more detail in the next chapter.
The time depending water management problem is simulated in timesteps of 10 days. The normal simulation period is one year. Although the model only considers 36-timesteps in one year, the computing costs are quite high because of the complexity of the system under consideration and the many different aspects taken into account. A single DM-run simulating one year takes about 5 CPU-minutes on an IBM 370/168.

7.3 User groups considered in the distribution model

The water user groups that are directly considered in the DM are:

- agriculture;
- shipping;
- power plants;
- environment.

7.3.1 *Agriculture*

The agricultural modeling efforts and the hierarchic structure of the Plot Models (representing agriculture), the District Aggregation Model (representing regional water management) and the DM (reflecting the national system) have been described in some detail in the paper about agriculture by Baarse and Van Beek (1982b).

As indicated in this paper, the agricultural models are an integral part of the DM. In a logical order, the most important internal data flows per timestep are:

- Agriculture → DM:
  - water demands or discharges;
  - salt concentrations of discharges;
- DM → Agriculture:
  - water available for agriculture;
  - salt concentration of available water;
- Agriculture → DM:
  - drought damages;
  - salt damages;
  - fixed and variable sprinkling costs.

These data flows are generated by individual crops and/or by district. The DM aggregates the information on water demands/discharges, damages and costs in several ways (over time, region, the entire Netherlands) thus providing all kinds of useful summary outputs.

7.3.2 *Shipping* (see Pulles, 1982a)

Three topics directly related to shipping have been considered in the DM:
a analysis of low water losses;
b lock analysis;
c dredging cost analysis.

a ANALYSIS OF LOW WATER LOSSES

In case of water shortage, the water level at specific locations may fall beyond the minimum level required to enable ships of certain sizes to sail. There are several things one could do in such an event, e.g. reduce ship loads, transfer to smaller ships, temporary storage, all of which will bring about losses.

In a separate modeling exercise the extent of these losses was determined for various conditions. This was done on the basis of a transportation matrix reflecting 93 origins and destinations and a variety of ship classes and commodity-groups. The results of this analysis were processed to obtain direct relations between low water shipping losses and water depths at some predetermined critical locations (the so-called low water shipping loss functions).
These shipping loss functions have been integrated in the DM. The logical order of computation in the DM is:

- water depths by timesteps are calculated at the critical locations;
- shipping losses are calculated by applying the low water shipping loss functions;
- low water shipping losses are aggregated by timestep and for the total simulation period.

The result is a summary table of low water shipping losses by timestep and location.

b LOCK ANALYSIS

Related to locks that operate between fresh and salty waters, there are two phenomena of importance for water management: salt intrusion via the lock and loss of fresh water for flushing purposes and lock operation. For the locks operating between fresh waters (in the highlands) only the loss of fresh water during lock operation is of importance. Another aspect of lock operation is formed by the delays for ships that pass. There are a number of tactics that the lock manager can apply in order to obtain an 'optimal' lock operation. Technical tactics (e.g. air bubble screens, selective withdrawal systems, etc.) as well as managerial tactics (e.g. reducing the number of lock cycles by increasing the number of ships per cycle, stop locking during high tide, etc.) are at his disposal. These tactics mostly reduce the salt intrusion and the flushing amount, but often increase the waiting time for ships. So besides fixed costs for technical tactics, and variable energy costs for its operation, 'waiting costs' for the ships must be considered. These aspects were investigated in a separate lock analysis using a lock operation model that, if necessary, was combined with a model to compute salt intrusion at locks.

The results were then implemented in the DM. Trade-offs between shipping delays and salt intrusion are not made within the DM. Based on the stand-alone lock analysis, relations between the amount of flushing and the corresponding salt load were directly applied in the DM with no feedback on shipping. For the freshwater locks this is different. In case of water shortage the DM will change the lock operations as a result of which shipping delay costs will be incurred. For that purpose, direct relations between water available for lock operation and delay costs for shipping were developed and implemented in the DM.

c DREDGING COST ANALYSIS

At a specific location on one of the most important shipping routes (the river Waal at Tiel, see figure 3) considerable withdrawals may take place to feed the important Amsterdam-Rhine canal. As a result, sedimentation will occur downstream of this intake point. As it turned out, low water losses to shipping would exceed the costs of dredging, required to avoid the low water losses. Based on an existing sedimentation model and some simplified versions of it, a relation was derived between the amount of water withdrawn and the resulting sedimentation, and hence the costs of dredging required to avoid shipping losses. This relation was then applied in the DM.

7.3.3 *Power plants*

Power plants need considerable amounts of water for cooling. The allowed absolute temperatures and temperature increases of the surface water bodies used for this purpose, are subject to rather strict constraints, mainly to protect environment. This may cause difficulties in summer periods, when water flows are small and natural temperatures high. In order to meet the thermal standards, it may be necessary to shut down certain power plants and start or increase power production at other (less constrained) plants. As in a normal situation the most efficient power generating units are used, this means an increase in power production costs.
The above mentioned effects are analyzed in PAWN, using two models, viz. the DM and the Electric Power Redistribution and Cost Model (EPRAC). Use and results of the latter model are described by Pulles (1982b). The DM computes thermal consequences of power generation, based on the water flows in the network and a set of dummy heat discharges for each existing power plant.

These results are then processed by EPRAC, which computes the least-cost allocation of power production subject to the thermal standards. There is no feedback to waterflows in the DM, so the optimal allocations of power production are subject to pre-calculated patterns of water flows. The justification is, that generally the redistribution of power seems to be less costly than the redistribution of water.
Note, that in contrast with the other user groups described so far, the final consequences in terms of power production costs are not computed in the DM, but in the EPRAC model (post processing).

7.3.4 *Environment*

As far as environment is concerned the DM has been used to compute concentrations of certain pollutants at nodes and links of the national network. The pollutants considered were:

- chloride;
- temperature (thermal pollution);
- phosphate;
- nitrogen;
- BOD (Biological Oxygen Demand);
- chromium.

The modeling approach is simple. Concentrations of pollutants are calculated based on one-dimensional flows in a steady-state condition, assuming complete mixing and zero diffusion. For the non-conservative pollutants (e.g. thermal, BOD) exponential decay rates were taken into account.

The accuracy of the approach is limited because of the simple way of modeling the very complex mechanisms and interactions involved and a severe lack of consistent data. With the exception of chloride the results can only be used to get some rough indications about the overall situation with respect to pollution and the potential effects of national water management tactics.

7.4 The screening of water management tactics

As solutions to the water management problem in the Neterlands many tactics have been proposed. Because it was not possible for PAWN to consider all those tactics in great detail it was necessary to select a list of the more promising tactics. This has been done on the basis of simple selection criteria like feasability, cost-benefit estimates etc. Three different kind of tactics have been considered in screening:

- Pricing and Regulation tactics;
- waterboard plans;
- Technical and Managerial tactics.

7.4.1 *Screening of Pricing and Regulation tactics*

Pricing and Regulation tactics aim at providing incentives for a more efficient water use. Examples of such tactics are charges on water intake, subsidies on water saving equipment, and licenses that restrict withdrawals or equipment. A detailed description how Pricing and Regulation tactics have been screened can be found in a contribution of Dorsman (1982). In this paper only a summary of the results is given. This will be done on basis of the source of the water:

- surface water;
- groundwater;
- drinking water.

Pricing and Regulation tactics on *surface water* are only worthwhile for the target groups drinking water companies and agriculture. The net quantities used by industries is small and hence the effect of tactics on that group limited as far as quantities are concerned. Withdrawals by drinking water companies can be controlled directly. Controlling withdrawals of farmers is not practical since the numerous extractions would require a very expensive administration to monitor those withdrawals. Therefore it seems more practical to control access to surface water by totally forbidding farmers to withdraw water. No recommendations could be made by PAWN on Pricing and Regulation tactics for discharges into surface waters as essential data for the analysis were not available.

Fresh *groundwater* is a scarce source in some areas of the Netherlands. Given the limited number of withdrawers and the significant amounts withdrawn it is feasible to control the use of groundwater by drinking water companies and industries (this is already done in the Netherlands). For farmers it seems more appropriate to control access to water rather than to monitor the amounts withdrawn. It looks worthwhile to investigate the effects of pricing and regulation tactics on groundwater extractions in more detail in order to reallocate the water among drinking water companies, industries, agriculture and the environment.

Reducing the amounts of *drinking water* withdrawn by the users is only possible to a limited extent. Without jeopardizing public health households will not be able to reduce their drinking water intake by more than 10 per cent. Potential savings by industries may be somewhat higher but are also quite limited.

7.4.2 *Screening of waterboard plans*

As a first step in the screening of Technical and Managerial tactics, a great many local plans to expand or improve surface water supply possibilities were evaluated (the so-called: waterboard plans). This was necessary in order to make realistic assumptions about the extent to which cultivated areas have access to surface water in future situations (needed for the surface sprinkling scenario). This procedure and the results were described in the paper about the agricultural analysis written by Baarse and Van Beek (1982b).

7.4.3 *Screening of Technical and Managerial tactics*

The emphasis in the screening process was on Technical and Managerial tactics (T/M-tactics). Technical tactics involve a change or expansion of existing water management infrastructure (e.g. building or improving canals, building a pumping station). Managerial tactics pertain to changes in the way the existing infrastructure is used (e.g. operation of weirs, setting lake levels). All T/M-tactics considered relate to the national water management system, as represented by the Distribution Model. Hence, there is a strong relation between the screening of the T/M-tactics and the use of the DM. Screening is meant to provide a list of 'promising' tactics for further analysis. Therefore it uses:

- a list of conceivable tactics;
- criteria.

A list of conceivable tactics was obtained using all kinds of existing plans and ideas. It

was primarily based on the insights and experiences of people concerned with national and local water management.
The main criterion for selection was the net benefit of the tactic under consideration. But also feasibility was taken into account. A tactic is considered promising, if:

- the upper bound of benefits equals or exceeds estimated costs;
- the tactic is not dominated by others (tactic 1 is dominated by tactic 2 if tactic 2 achieves the same goals better at equal costs or as well at lower costs than tactic 1);
- the tactic appears to be feasible (in a technical sense and/or from the viewpoint of administration).

Screening focussed on determining consequences (costs and benefits) of tactics. The performance of a tactic is very much affected by all kinds of conditions concerning the state of the system in which the tactic functions. To the extent these conditions are not within control of the water managers, they were treated as part of a scenario, the main components being:

- external supply;
- agricultural sprinkling;
- context variables;
- miscellaneous.

The external supply scenario consists of variables that reflect the climatological conditions (rain, evaporation, temperature) and the waterflows that enter the Netherlands via rivers. External supply scenarios were constructed by using the real world data of some selected years that were associated with certain probabilities. In total four different external supply scenarios were used. An average (50 %-dry) year, a 10 %-dry year, a 5 %-dry year and an extreme dry year (less than 2 %). It should be noted, that the external supply scenarios are treated as something that can happen in any situation, so the various external supply scenarios were generally not used in the circumstances of the actual years from which they were derived.

The agricultural sprinkling scenario indicates the amount of installed sprinkling capacity by crop and location, for both surface water and groundwater. This scenario is combined with a specification of the area that is suppliable with surface water and the area that can use groundwater. For both surface water and groundwater three different scenarios were used: 'low' which reflects the current situation, 'high' which indicates an optimistic forecast (high growth) and 'medium' which is the average of low and high.

The set of scenario variables referred to as 'context' consists of variables whose values are largely determined by the time frame under consideration. This usually means they depend on socio-economic developments. Examples are:

- shipping fleet and goods to be transported;
- inventory of power plants and expected power demand;
- surface water and groundwater demands of drinking water companies and industries;
- pollution discharge inventory.

PAWN considered two contexts: 1976 and 'future'. Context 1976 is as close to the current situation as possible, given the practical constraints with respect to data gathering. The future context is based on projections for different activities in 1985 and 1990. As there is no exact future date that the various projections can be associated with, the future context should be regarded as a conceivable situation in a relatively near future. In screening only context 1985 was used.

The 'miscellaneous' part of the scenario consists of variables whose values will be primarily determined by decision makers other than those concerned directly with water management. Examples are:

- Rhine salt dump by other European countries;
- treaty about river Meuse with Belgium;
- implementation of various existing plans affecting water management infrastructure;
- pollution standards.

For each of these variables a best guess was made that was considered the reference value. In screening only these reference values were used. In impact assessment a small number of variations were investigated.

Given the list of conceivable tactics the main steps to be carried out were:

- estimating annual costs of tactics;
- determining upper and lower bounds of expected annual benefits;
- comparing annual costs and upper bound of expected annual benefits; if costs exceeded expected benefits, the tactic was set aside.

Although a far from easy task, estimating costs of tactics boiled down to gathering and processing lots of information on investment and operating costs of all kinds of structures and actions, derived form scattered sources.
The main effort in the screening process was in determining expected benefits from tactics. This was done using the Distribution Model. The principle of estimating expected benefits from tactics is to compare 'cases', i.e. simulation-runs with the DM under specified conditions, with and without the tactic under consideration.
As was explained earlier, the results of this comparison will be very much affected by the specified scenario. All screening runs have been based on the high agricultural

sprinkling scenario for surface water, in order to maximize potential agricultural benefits from improvements to the national surface water system. Groundwater sprinkling was kept at its current (low) level. For the same reason all runs were made with context 1985. This will maximize the potential benefit from tactics for other user groups, like shipping and power plants.

As for external supply all four different scenarios were used i.e. the 50 %-, 10 %- and 5 % -dry year and the extreme dry year (less then 2 %). These scenarios have been indicated by the acronyms D50, D10, D05 and DEX respectively (D stands for dry, EX for extreme). Based on the results of the four different years, upper and lower bounds of expected benefits were calculated. The way this was done is illustrated in figure 2.
Not knowing the curve of figure 2, but only having some points on that curve, there are two extreme viewpoints one could take. An upper bound approach would be to assume that the benefits belonging to a certain scenario occur on the entire interval between that scenario and the next less dry scenario. Similarly, a lower bound is found if the benefits of a certain scenario are extended to the next more dry scenario.

Using this approach, upper and lower bounds on expected benefits from tactics were determined by integrating the upper and lower bound curves of figure 2. The upper bound served as the criterion to accept or reject the tactic. The lower bound provided some additional information about the range of uncertainty. Moreover it provided a

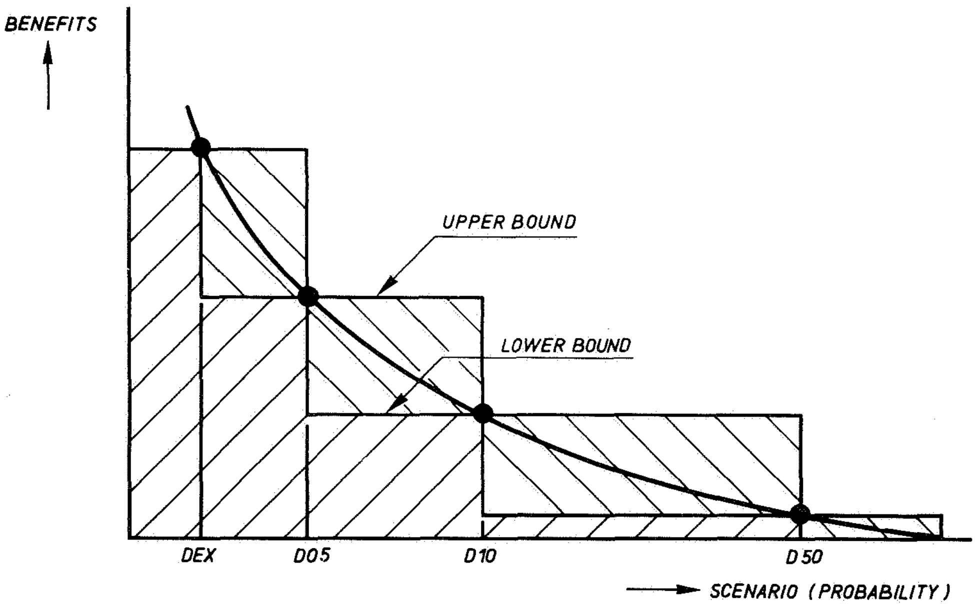

Figure 2 Determining upper and lower bounds of expected benefits

means to further classify promising tactics. E.g. for some tactics the lower bound on expected benefits exceeded the costs, so these tactics have been considered very promising.

7.5 Some results of screening Technical and Managerial tactics

In total 32 different T/M-tactics were considered in screening. Most of them aimed at creating benefits for agriculture by either expanding surface water supply possibilities via the national network or decreasing chloride concentrations of available water to reduce salt damages. Others specifically aimed at providing benefits to shipping or power plants.

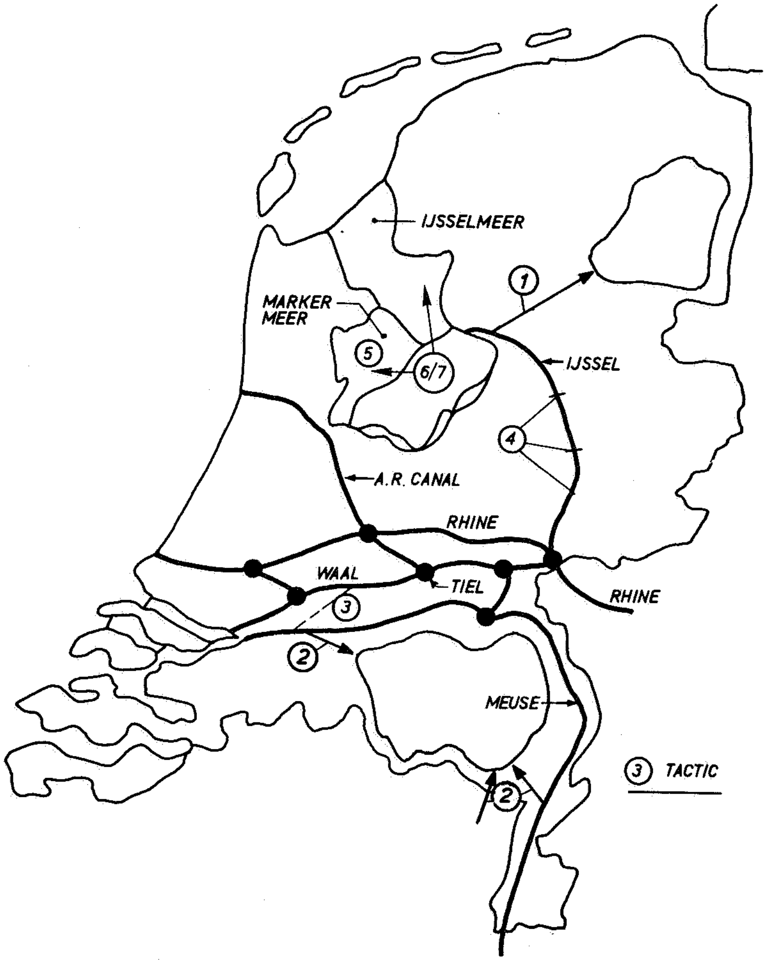

Figure 3 A simple representation of the Dutch water management system and location of some tactics

As it turned out, only 9 T/M-tactics survived screening. It is striking that none of the large projects considered were found to be promising. The set of 9 is referred to as 'MAXTACS'. As such it has been used as part of several national water management policies to be analyzed in impact assessment (see Baarse and Van Beek, 1982c).
A moderate number of investigated alternative tactics (about 8) also had positive expected net benefits, but were dominated by MAXTACS and therefore rejected.
For a selective sample of the 32 T/M-tactics considered, some results have been presented in tables 1 and 2. Table 1 provides a short survey of the main features of the selected examples. Table 2 summarizes the results. For geographic locations see figure 3.

Tactic 1 aims at increasing surface water supply possibilities to the North-East highlands region by expanding capacities of the local canal system. Several alternative routes were investigated, all of which seemed to be promising. However, they were dominated by the selected example.

Tactic 2 is meant to reduce drought damage in the South-East highlands by supplying water from the river Meuse; in this region agricultural losses are very high. Various combinations of tactics were evaluated and found to be promising; one of these was chosen for further analysis.

Tactic 3 is supposed to provide benefits for power plants. Indeed this seems to be the case, but it hurts shipping in such a way that the overall benefits turn out negative. In contrast with the other tactics considered here, this conclusion is based on an analysis for the extreme dry year (DEX) and the 10 % dry year (D10) only. Yet the conclusion to find this tactic unpromising seems obvious.

The IJssel canalization (tactic 4) is supposed to make shipping on the IJssel independent of the river discharge thus providing the possibility to send more water to the West. In this way shipping on IJssel and Waal can benefit, and also agriculture in the Mid-West by reducing the intrusion of the salt wedge. Even though the shipping benefits indicated in table 2 are a clear upper bound and some possible negative effects on IJsselmeer storage were neglected, this tactic seems quite unpromising.

Tactic 5 tries to save water of the IJsselmeer by limiting the amounts of flushing water for quality control of the Markermeer early in the year. The consequences of the (slight) decrease in quality of the Markermeer seem to be negligible. As there are no other costs involved to offset the benefits, this tactic is considered very promising.

Tactics 6 and 7 serve the same purpose: increase the amount of water available in IJsselmeer and Markermeer to be used in dry summers. This can be done by either raising the target level (increase storage) or reducing the minimum level (allow more water to be taken out). Both tactics are promising, but tactic 6 dominates tactic 7 because of its higher net benefits.

Table 1 Main features of selected tactics

Tactic	Kind	Description	Purpose
1	technical	expand throughput capacity to North-East highlands by improving 'Hoogeveensche Vaart' route	reduce drought damage to agriculture by increased surface water supply
2	technical	expand transport capacity to South-East highlands by way of the existing network of waterways	reduce drought damage to agriculture by increased surface water supply
3	technical	provide means to send more water from Waal to Meuse for cooling of 'Amer' power plant	reduce costs of power generation redistribution to meet thermal standards
4	technical	canalization of IJssel	reduce damage to shipping on Waal and IJssel/reduce salt damage in Mid-West
5	managerial	change flushing strategy of Markermeer	save more water for use in dry summer periods
6	managerial	increase summer target level of IJsselmeer and Markermeer	increase availability of water in dry summers
7	managerial	decrease minimum level of IJsselmeer and Markermeer	increase availability of water in dry summers

Table 2 Results of selected tactics

Tactic	User group	Annual benefits*		Annual costs	Conclusion**
		UB(10^6 Dfl)	LB(10^6 Dfl)	(10^6 Dfl)	
1	agriculture	13.4	4.3	4.4	0
2	agriculture	20.1	6.3	7.2	0
4	agriculture	3.7	0.8		
	shipping	16.6	5.9		
	total	20.3	6.7	60	X
5	agriculture	12.5	2.6	0	00
6	agriculture	18.5	5.3	5	00
7	agriculture	2.8	0.8	2	0*
		DEX(10^6 Dfl)	D10(10^6 Dfl)		
3	power plants	5.1	1.6		
	shipping	−9.1	−5.8		
	total	−4.0	−4.2	0.7	X

* UB: Upper Bound; LB: Lower Bound

** Legend: 0 promising (LB < costs < UB)
00 very promising (costs < LB)
X Unpromising (costs > UB)
0X dominated by other tactic (7)

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Screening of pricing and regulation measures for water allocation in the PAWN study

W. A. Dorsman

8 Screening of pricing and regulation measures for water allocation in the PAWN study

SUMMARY

This paper explains how in the PAWN study the list of many potential pricing and regulation measures for the reallocation of water was reduced to a manageable size, containing only measures that were to be studied further. Criteria for selection were feasibility, significance of the measures' benefits for at least one user group, cost-effectiveness, economic efficiency and dominance by other measures.
How these criteria were used and what the results have been is briefly described.

8.1 Introduction

In the extensive study on water management in the Netherlands, called the PAWN study, many policies for water management have been studied, each consisting of a combination of single measures (called tactics). Since there were hundreds of measures and thousands of possible combinations, a selection was needed of those measures that were going to be studied further and combined into alternative policies. This selection, called screening, was a first step in PAWN.

The measures considered by PAWN were various. Some would change the physical water management, given the present infrastructure; others would add to or modify the infrastructure. These technical and managerial measures would affect the supply to water user. Other measures would affect the water demand. They were called pricing and regulation measures. This paper explains how pricing and regulation measures were selected (screened) for further study.
Before the actual screening method and results will be described, chapter 8.2 discusses the subject of the seminar and tries to make a link with the PAWN-study.

8.2 Rational utilization of water resources

The objective of the ECE Seminar in 1980 was to discuss economic instruments for rational utilization of water resources. It may be very useful to describe what is meant by rational use of water resources. The word 'rational' may be interpreted in many ways. However, most definitions include something like purposeful or motivated. Rational utilization of water resources can therefore be promoted by formulating the goals to be persued. Also, it is important to distinguish whose goals are persued, in other words, who has to behave rationally. A single water user's goal may be to sprinkle his garden, while the nation as a whole has many, often competing, objectives for water utilization. The individual users' point of view may be different from the national viewpoint.

Potential goals or objectives for a nation that can be promoted by water use are public health, national income, environment protection, certain types of equity, etc. From this short and incomplete list of goals, it appears that rational water use not merely means reducing water use. Stimulating some uses can be very rational. In the recent past, the Dutch Government prescribed that new houses should have a shower, thereby increasing water use for the purpose of public health. In general, using water can be very rational as opposed to letting it run into the sea. This means that even if there is an apparent surplus of water, it can be very useful to list the possible objectives that this water might serve. Further analysis may show that it can be used in a thus far unknown, beneficial manner, and that instruments for stimulating such use should be looked for. Economic incentives can be of value in cases when public priority of goals differs from private priorities. Indeed, it may appear that there is no surplus but, rather, scarcity.

If water is scarce, demand exceeds supply. Often, water is wanted by numerous users with different and conflicting objectives (like drinking water, waste disposal, plant and animal life). If a country wants to use scarce water rationally, a rational way of allocating this use is necessary. A first step would be to identify the different objectives for water use and the potential users. This is necessary in order to decide what allocation or what instruments for allocation are desirable, what goals will be reached and to what extent, and what goals will be foregone (opportunity costs).
In most cases there are other costs involved, too. Water has to be transported to and from the place where it is used, and often purified. For these activities scarce production factors (building materials, energy, labour) have to be mobilized, and it is a very legitimate question whether the purpose for which the water is used is worth these costs.
From this short discussion it may be concluded that, for a rational use of water resources, it can be very helpful to realize what and whose goals are considered, and to distinguish use of water (e.g. taking it away from others) from use of other production factors (for transport and purification).

8.3 Method for screening of measures

By comparing the goals, to be reached by water management, with the actual situation, problems can be identified. In PAWN, problems were listed by user-group, whose goals, however, were not always stated explicitly.

To solve these problems, many measures are possible which can be grouped in four categories: a measure can be classified as 'technical' if it primarily involves having some public agency, such as the Rijkswaterstaat or a local water board, add to or modify the nation's water infrastructure (e.g., build a new canal or lock). A measure is 'managerial' if it would have a public agency operate the given infrastructure in some different way (e.g., alter weir setting patterns). It is a 'pricing' measure if it concerns the prices users pay, or may be required to pay in future, for some aspect of water use (e.g., for access to water, for quantity consumed, or for discharge of polluting substances). Finally, it is a 'regulation' measure if it principally affects restrictions on users. In practice, these distinctions are not always straightforward. Therefore, as additional help in delineating the limits, the further assumption is adopted that pricing and regulation measures together encompass all measures which rely in large part on persuasion or coercion of users, or on advice from or bargaining amongst them. On the other hand, measures in which the important decisions are governmental and in which users thus have only a passive role, are technical and managerial.
Since it is not possible to analyse all possible measures for solving the stated problems, a selection has to take place to shorten the list that will be studied in detail. This was called screening in PAWN. The selection criteria are listed below.

First, a measure should be feasible. That is, it should satisfy a number of practical considerations about its implementation, administration and acceptibility. A second group of criteria is that measures should provide significant benefits for some major interest, that is it should do some good for at least one user group or part of a user group (the viewpoint of individuals). A third criterion is that a measure should be cost-effective in the sense that its benefits should exceed its costs, at least in so far as the two are computable in comparable terms. Fourth, it is also desirable that a measure should lead toward, rather than away from, economic efficiency of water use. Economic efficiency is achieved when scarce water resources are allocated according to value in use, and hence high value users get higher priority than low value users (the national viewpoint). Finally, a fifth criterion is that a measure should not be dominated by some other one. That is, there should be no other measure that is better in all important respects, e.g. provides the same benefits for less costs.

We did not require that a measure should satisfy all of these criteria simultaneously in order to qualify for further study. We first asked for each measure whether it would be feasible or not. If not, it could be rejected immediately. If feasible, we next considered whether it was attractive by at least one of the next three criteria, that is, did it provide significant benefits for at least one user group or part of a user group. Was it cost-effective and did it promote economic efficiency. If not, it could be rejected since it was not desirable from the perspective of any user. If positive, we then considered whether it was dominated by some other measure. If positive, it could be rejected. If negative, the measure could be accepted for further study.

8.4 Pricing and regulation measures

The rest of this paper deals with pricing and regulation measures for reallocating water. Examples of such measures are a tax on water intake or on equipment for water withdrawal, subsidies on water saving equipment, and licences that restrict withdrawals or equipment. These measures are often alternatives to technical or managerial measures. In other cases, they are necessary supplements. Therefore, evaluation of pricing and regulation measures alone has to be incomplete. Still, some conclusions can be drawn about what measures may be beneficial in what situations.

We discuss incentives for reallocation of water use, not for rational use of other production factors related to water use. This means that we do not assess the issue of how to decide to build a transport pipe or to purify water. Other papers deal with this issue. Also, we do not discuss measures to protect river beds, streams, etc. We concentrate on measures that affect intake of, not discharge into, water as this latter topic is discussed elsewhere. The paper is about both pricing and regulation measures, because they have many features in common and it is hard to give preference to one type over the other, without further information. We repeat that pricing and regulation measures are directed to private institutions or persons (as opposed to government authorities like local water management boards).

Pricing and regulation measures for controlling water allocation have to be specific on various topics. First, water sources have to be specified; is it groundwater, drinking water or surface water that is to be controlled, in which canal or river, etc. Second, water users that will be affected have to be specified by area, user-group, etc. Third, it is necessary to specify what exactly is going to be controlled: access to water, amount withdrawn, equipment for extraction/use of water, or other factors, like level or type of production. Fourth, the type of policy instrument needs to be specified: a price (one time or annual fee, price per unit of water, subsidies) or a quota (to be allocated by the government on basis of set criteria or by an auction market). Finally, one should distinguish between permanent measures and those that will only be used in exceptional circumstances.

8.5 Pricing and regulation measures on water intake in the Dutch context

In this chapter we illustrate the conclusions that were drawn in PAWN about pricing and regulation measures on water intake. To understand these conclusions, it is necessary to have some insight of the water management problems on water quantity and salinity in the Netherlands, (see also Blumenthal, 1982).
Briefly, there is a scarcity of surface water and groundwater in the eastern and southern parts of the Netherlands, in some areas only in dry summers, in other areas in most

years. Competing water users are environment, industries, drinking water companies, agriculture and shipping. In the western and northern parts of the Netherlands, fresh groundwater is very scarce, and surface water contains salt which causes damage to agricultural crops and drinking water quality. Sources of the salt are sea water intrusion, seepage of saline groundwater and the river Rhine. On some lowland waterways there are water level problems for shipping in dry years.

Measures for reallocating surface water were selected (screened) in PAWN by the following arguments. No significant benefits in terms of relieving shortage and salinity would be gained by controlling industrial surface water intake, as in general, the water taken in is discharged at almost the same place. [Pollution caused by industries' discharges can be controlled better by discharge oriented measures than by intake oriented measures]. Only in one or two situations in which large quantities of water are discharged at considerable distance from the intake point, or if very large factories consume large net quantities, measures are appropriated. Intake by agriculture in the lowlands does not contribute significantly to salinity problems there. The salinity in the lowlands is combatted by flushing the canals with large quantities of fresh water. The amounts of water taken in by farmers for sprinkling the crops are quite small compared to the quantities used for flushing. Therefore, large scale control measures on water intake by agriculture in the lowlands are not appropriate from the salinity viewpoint. In the highlands, however, scarcity is the major problem and farmers' extractions are quite significant, so control measures have to be studied. As there are numerous withdrawers, each taking only a fraction of the total agricultural withdrawals, it would require too much administration to monitor the exact amounts withdrawn by each farmer.
Controlling equipment for water withdrawal is not feasible either as the equipment is portable and numerous. Therefore it is more appropriate to control access to water. One can forbid farmers to withdraw water at all during a certain period, e.g. via a licence. Water companies form a limited number of large withdrawers, whose quantities withdrawn can be monitored. Other user groups do not extract large quantities of surface water (households, commercial institutions) or pricing and regulation measures are not feasible (shipping, environment).

Groundwater is used by environment, water companies, industries and farmers. Given the limited number of withdrawers and the significant amounts withdrawn, controlling the amounts withdrawn by drinking water companies and industries is feasible. For farmers, controlling access to water is more appropriate (one can see sprinkling or irrigation) than monitoring the amounts withdrawn, given the large number of small withdrawers. As an alternative, the size of the farmers' equipment may be controlled, as it is fixed to the well.

Controlling the amounts of drinking water withdrawn by its users is only possible to a

limited extent. Without jeopardizing public health policies or without installation of very costly equipment, households will not be able to reduce their drinking water intake by more than 10 per cent, on an average. Potential savings by industries may be somewhat higher but they are also limited.
The identified problems did not warrant pricing and regulation measures, beyond those existing, to stimulate water intake. Measures for stimulation, studied in PAWN, are of a technical and managerial nature.
In PAWN, no final choice was made for specific policy instruments ('how to control') e.g. between pricing and regulation. However, some observations can be made. Allocating quantities of water to the highest bidder via an auction market seems administratively very complicated. But other pricing systems may be as good as, or better than, regulation schemes. For example, putting a fixed price on each unit may help allocating the units to those within a user group who value the water most. Without this instrument, the government may have only limited information about the value of the water to the users. On the other hand, authorities need some aggregated information before they can set a price that results in a desirable level of total withdrawals within a region. If the desired extractions are specified in many small areas, finding prices that produce this requires much information, and regulations seem more appropriate. In general pricing not only results in a modified distribution of water but also of money, which is important for the political feasibility of a measure.

The above conclusions on controlling the amounts withdrawn are valid for the long run (year round). For a short period (e.g. one or two weeks), controlling the exact withdrawals requires a lot of administration.
Given the results summarized in this chapter, PAWN analysed the effects of policies including prices and quotas on groundwater for industries, drinking water companies and agriculture, and quotas on surface water for drinking water companies and agriculture.

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Design of policies for the water management of the Netherlands

G. Baarse and E. van Beek

9 Design of policies for the water management of the Netherlands

SUMMARY

Policy design is the stage in the PAWN-study that specifies alternative water management policies. A policy consists of a mix of four kinds of measures:

- technical (e.g. building of new canals, pumps);
- managerial (e.g. alternative ways to operate weirs, locks);
- regulation (e.g. restrictions on water withdrawals);
- pricing (e.g. charges on water withdrawals).

The specification of technical measures will be described in another contribution. Pricing and regulation measures prove to be promising tools to achieve certain goals with respect to groundwater use. A model was developed (the Response Design Model – RESDM) to predict the responses of industries and drinking water companies to pricing and regulation measures on groundwater withdrawals.

To design promising managerial measures for the water management infrastructure the Management Strategy Design Model (MSDM) was built. The results of the model indicate that there are only few possibilities in the water management system in the Netherlands which allow optimization by managerial measures and that the 'optimal' solution differs only marginally from the current operation practice. For extreme dry conditions a priority list for the allocation of water among the various users and regions was developed.

9.1 Introduction

As described in the paper on the general aspects of the PAWN-study (see Blumenthal, 1982), three major stages were distinguished in PAWN:

- screening;
- policy design;
- impact assessment.

The screening process and some of the results are described in the papers about the Water Distribution Model/Screening by Baarse et al. (1982), about agriculture by Baarse and Van Beek (1982b), whereas in the next paper impact assessment will be addressed by Baarse and Van Beek, (1982c).

Some definitions. PAWN uses a hierarchy of three levels of measures to improve water management:

- tactics;
- strategies;
- policies.

A tactic is a single measure to improve water management.
A strategy is a mix of tactics of the same kind. Two main categories have been considered:

- Technical and Managerial strategies (T/M strategies);
- Pricing and Regulation strategies (P/R strategies).

A policy is a mix of different strategies. It represents a national policy for the Netherlands.

Screening deals with a relatively quick and crude evaluation of a great many conceivable tactics. Policy design is the part of the analysis that specifies alternative water management policies to be investigated. Impact assessment is the stage in which the impacts of various selected policies are estimated. This is done for a variety of different impact categories under different circumstances, as to provide decision makers with the best possible insights in the consequences of certain decisions.

As defined above a water management policy consists of a mix of four kinds of strategies:

- technical (e.g. building of new canals, pumps);
- managerial (e.g. alternative ways to operate weirs, locks);
- pricing (e.g. charges on water withdrawals);
- regulation (e.g. restrictions on water withdrawals).

In the screening stage the emphasis was on investigating the technical tactics. The combination of all surviving national tactics was called the 'MAXTACS'-strategy. Another technical strategy considered in PAWN is the implementation of waterboard plans which deal with local improvements and/or expansions of the surface water supply possibilities (see Baarse et al, 1982).

As described in the paper on screening of pricing and regulation tactics, Dorsman (1982) concluded that those tactics looked very promising for groundwater withdrawals and that this should be investigated further. How this was done in PAWN is described in chapter 9.2. In chapter 9.3 attention will be given to the design of managerial strategies and to the main model used for this purpose: the Management Strategy Design Model. Because only a limited set of strategies seemed promising enough to be passed on to the impact assessment stage little attention will be given in this paper to the combination of the different kinds of strategies.

9.2 Design of long-run pricing/regulation strategies

The objective of the analysis was to determine long-run pricing and regulation strategies to achieve certain goals with respect to groundwater use e.g. optimal allocation of groundwater among users, reducing groundwater extractions to protect environment. Tactics investigated were:

- pricing: imposting a groundwater charge on use of groundwater;
- regulation: imposing quotas that limit the amount of groundwater that can be withdrawn;
- priority rules among users;
- some combination of these.

A more detailed description on how these strategies were designed can be found in another paper about this topic (see Baan, 1982). This chapter will give a summary of that paper.

The three 'technical' usergroups of groundwater in the Netherlands are drinking water (DW) companies, industries and agriculture (technical as opposed to users like environment, ecology etc.).
Possible responses of those groups on groundwater tactics as mentioned above are:

- DW companies:
  - building new surface water projects (reservoirs, pipelines);
  - importing drinking water from a neighbouring region;
  - changing the price of drinking water;
- industries:
  - recycling of cooling water;
  - substituting surface water or drinking water for groundwater;
- agriculture has only one realistic response besides stopping sprinkling;
  - switching to surface water (if possible).

To predict the responses of industries and DW companies the Response Design Model (RESDM) was developed. This model assumes that industries and DW companies will choose those responses that will minimize their costs. The linear programming approach used for RESDM determines the least-cost allocation of groundwater to industries and DW companies only. The agricultural groundwater withdrawals are treated as part of the scenario.

When reductions of groundwater intake are required, industry has the possibility to switch to drinking water. This will increase the drinking water demand and hence the total drinking water production costs. The model compares the additional drinking water production costs with the costs of other possibilities to reduce groundwater intake and determines a least-cost solution. The minimization of total costs implies that industry should be charged with the marginal drinking water prices for the additional demand. Currently common practice is however that drinking water prices are based on average costs. Because water companies normally select their water sources in order of increasing unit costs – which means groundwater first – marginal costs are always higher than or equal to the average costs.

Analysis on this difference in pricing schemes showed that for the present situation it is not worthwhile switching from average-cost to marginal-cost pricing. The reason for this is that the extracted amounts of groundwater are hardly limited by the quota as they exist now. If severe limitations are imposed on groundwater withdrawals (for environmental reasons) marginal-cost pricing looks worthwhile. Not considered in the analysis however, are possible implementation problems.

Changing the quota to 25% of the presently accepted amounts reduces the total groundwater extractions by more than 1250 million cubic meters a year (from 1759 to 502 mln m^3/yr). However the increase in costs to industry and DW companies is extremely high; they have to pay more than 500 million Dfl/year for additional investments etc..
A charge of 0.20 Dfl/m^3 on industrial and agricultural extractions reduces the groundwater extractions by those users by 180 mln m^3/year. DW companies however will increase their extractions by 18 mln m^3/year. The total costs to industries and DW companies and the reduction in agricultural benefits (totally 100 mln Dfl/year) are almost compensated by the revenue from the charge of 90 mln Dfl/year.
If priority is shifted from industry/DW companies (which had priority in the examples of the second paragraph of this chapter) to agriculture the additional benefits to agriculture exceed the extra costs for industry and DW companies. This suggests agriculture should be given priority.

There are several reasons to be very careful with the above mentioned results. The agricultural benefits should be considered upperbounds, whereas the costs for recirculation of cooling water used in RESDM may have been underestimated. Important is also that for quality reasons, drinking water companies will value groundwater higher than RESDM has done.

9.3 Desing of management strategies

The performance of a water management infrastructure (existing or modified) can only be analysed if it is specified how this infrastructure is (or should be) operated under different conditions (time, climate, river discharges). To design promising management strategies PAWN developed the Management Strategy Design Model (MSDM).

MSDM designs strategies for a combination of a specified infrastructure (represented as a network of links, nodes, pumping stations, sluices etc.) and a menu of other tactics like pricing/regulation tactics. The designed strategies are based on a total cost minimization of the tactics costs (only the variable operating components) and the direct economic losses to the users of the water (agriculture, shipping etc.). While optimizing, it takes into account constraints on capacities (pumps, canals etc.), standards and requirements (e.g. for quality) and bounds on lake levels, levels of canal sections etc.

The core of the model consists of a linear programming algorithm which minimizes the total cost during a particular timestep by allocating the available water among the users. Optimization over time is taken into account by including an 'insurance value' of stored water (expected value in future uses) as part of the objective function. The insurance value is estimated by multiplying the likelihood that stored water will be used by the value it has in that particular use (e.g. for shipping). It depends on the period of the year considered and the amount of water already available (marginal value of stored water).
The tactic costs and user losses that are considered in MSDM are:

- agriculture (drought- and salt-damage, sprinkling costs);
- shipping (sedimentation/dredging costs, delays at locks, low water losses, storage of goods not shipped);
- energy costs for pumping;
- operating costs for salt-intrusion abatement equipment (e.g. bubble screens).

The main difference between MSDM and the other network model in PAWN – the Distribution Model (DM) – is that MSDM optimizes its allocation of water while DM only applies fixed management rules (optimization versus simulation).
To avoid a tremendous computational burden MSDM considers a much more simplified network than DM and also the extent of detail to which the user groups are taken into account is much less.

Because of technical limitations of the model (e.g. the determination of the insurance value for stored water proved to be very different) and time limitations in PAWN, MSDM is only used for some specific conditions. The model has been run for single timesteps of 10 days only and not for subsequent timesteps covering an entire year (like the DM). For that timestep parameters like river flows, rainfall, evaporation and initial lake levels were varied parametrically. Based on the results of these calculations three different kinds of management strategies were developed:

- the 'MSDM-strategy' (overall optimization);
- a thermal pollution strategy;
- water quality strategies.

9.3.1 *The 'MSDM-strategy'*

By means of exercising MSDM a priority scheme was developed for the allocation of water among the various uses when there is a shortage of water:

priority 1: Supply level control requirements for boezems [a local sub-system of connected water bodies (canals, small lake with a single, specified water level] and lakes; flush locks and boezems up to specified levels (minimum required flushing for water quality reasons);

priority 2: Supply water to farmers for irrigating their crops;

priority 3: Trade off shipping losses due to low water on the Waal and the IJssel (see figure 1), the dredging cost (or other sedimentation cost) due to withdrawals at Tiel, and salt damage to agriculture due to the Rotterdam salt wedge in the Nieuwe Waterweg, by simultaneously adjusting the weir at Driel and withdrawals at Tiel;

priority 4: Use water from the IJsselmeer and Markermeer for cooling the power plants Velsen and Bergum to the thermal standard;

priority 5: Use water for additional flushing of locks, boezems and ditches;

priority 6: Raise the IJsselmeer and Markermeer to their target levels to meet the possible future needs for water;

priority 7: Use water for flushing the Markermeer.

This ordering of water uses corresponds with the relative economic values that water has in the various uses.

In dry periods these rules mean that the optimal water allocation is rather straightforward. The only exception is priority 3 where a trade-off has to be made between shipping losses, dredging cost and salt damage to agriculture on specific places in the Netherlands. It was possible to isolate these aspects from other uses and a simplified MSDM was developed which concentrated on the above mentioned trade-off.

With this simplified MSDM a great number of years were simulated and the results were compared with the presently used water management strategy in the Netherlands. It appeared that the additional benefits of the MSDM-strategy were rather small.

9.3.2 *The thermal pollution strategy*

The MSDM-strategy optimizes the overall water management in the Netherlands. By doing so it shifts huge quantities of power to be generated from presently used units to cheaper power plants (see the paper on power production by Pulles, 1982b). The thermal pollution strategy tries to reduce this effect somewhat by allowing more extraction from the lakes to cool the power plants at Velsen and Bergum (see figure 1) at the expense of the available storage of water. However, also this strategy proved to give hardly any additional benefits compared with the present strategy. The expected costs and benefits of these strategies are also very small compared to the total power generation costs.

9.3.3. *Water management strategies for water quality*

It was tried to find national water management strategies which would reduce pollutants concentrations. These strategies however proved to impose heavy costs on other sectors like agriculture and shipping. Moreover the success of these strategies in reducing the concentration of the pollutants was very limited. The conclusion therefore is that in general water management strategies are ineffective and costly ways of

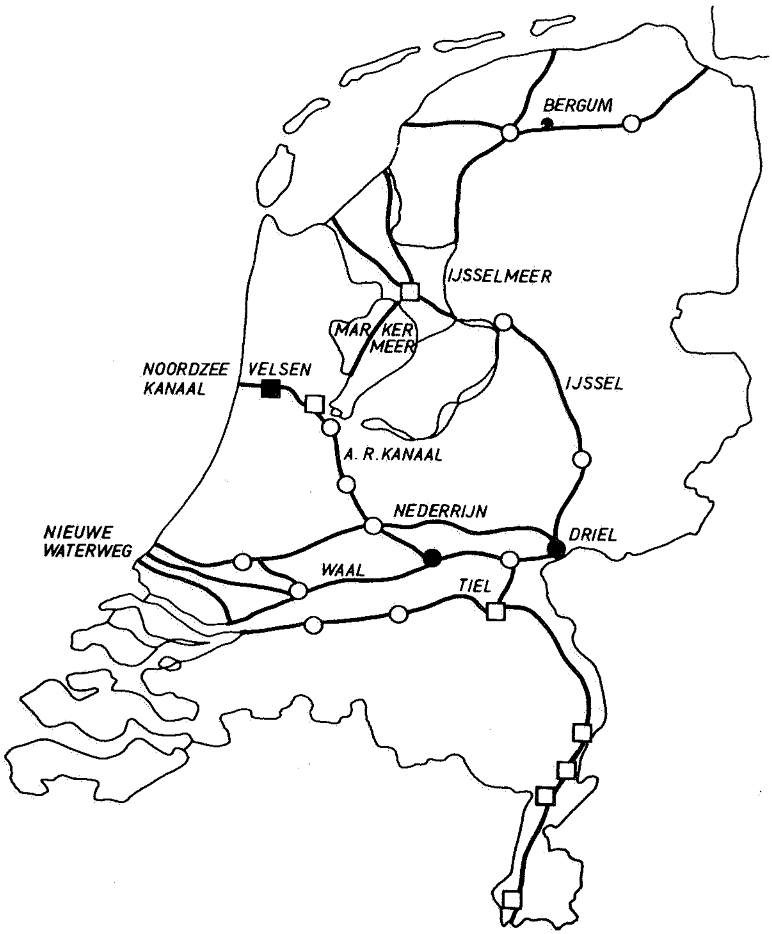

Figure 2 Simple representation of the Dutch water management system.

improving water quality in the major infrastructure. Local water management tactics however may be effective in some areas. Other tactics like pricing/regulation on discharges might be much more succesfull in fighting pollutants concentrations.
Besides the above mentioned management strategies for water quality, PAWN developed also strategies to fight eutrophication. The results proved to be very important for the water management in the Netherlands but because the subject falls to much outside the scope of this ECE-seminar it was not treated in this paper.

9.4 Concluding remarks

The strategies which resulted from the screening and policy design stages can be summarized as follows:

- technical strategies: MAXTACS and waterboard plans;
- management strategies: MSDM-strategy and thermal strategy;
- pricing/regulation strategies: strategies with respect to groundwater use.

So, the number of different strategies to be considered in the impact assessment stage was quite limited and hence the combination of these strategies to policies was a relatively easy task. Examples of how this was done and the performance of those policies in the impact assessment stage will be described in the paper devoted to impact assessment by Baarse and Van Beek (1982c).

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Assessing impacts of water management policies

G. Baarse and E. Van Beek

10 Assessing impacts of water management policies

SUMMARY

Impact assessment is the final stage of analysis that was considered in the PAWN-study. It is the stage in which the impacts of various selected water management policies are estimated. A water management policy is some set of measures to improve water management, that represents a national policy for the Netherlands.
Basically, impact assessment deals with determining impacts on different impact categories for different 'cases' to be analyzed. Main impact categories are the user groups (e.g. shipping, agriculture) and the national impact categories (e.g. public health, financial aspects). A case is defined as a mix of some water management policy and a set of scenario type assumptions, that affect its performance and impacts. Quite a number of scenario variables have been considered in constructing these cases, e.g.:

- external supply (climatological conditions and river discharges);
- agricultural sprinkling scenario (extent to which sprinkler systems are available to agriculture);
- context variables (variables that reflect socio-economic developments).

The results indicate that on a national scale agricultural impacts dominate others. However locally, the impacts on shipping and power plants may be substantial. It turns out that putting severe restrictions on groundwater use will have a very large impact on the costs and quality of drinking water production and at the same time increase the drinking water demand by industries.

10.1 Introduction

As described in the paper on the general aspects of the PAWN-study by Blumenthal (1982) three major stages were distinguished in PAWN:

- screening;
- policy design;
- impact assessment.

The screening process and some of the results are described in the papers about the Water Distribution Model by Baarse et al. (1982), and Agriculture by Baarse and Van Beek (1982b). Policy design is addressed in still another contribution from Baarse and Van Beek, (1982a). Impact assessment is the topic of this paper.

Some definitions. PAWN uses a hierarchy of three levels of measures to improve water management:

- tactics;
- strategies;
- policies.

A tactic is a single measure to improve water management. A strategy is a mix of tactics of the same kind. Two main categories have been considered:

- Technical and Managerial strategies (T/M strategies);
- Pricing and Regulation strategies (P/R strategies).

A policy is a mix of different strategies. It represents a national policy for the Netherlands.

Screening deals with a relatively quick and crude evaluation of a great many conceivable tactics. Policy design is the part of the analysis that specifies alternative water management policies to be investigated. Impact assessment is the stage in which the impacts of various selected policies are estimated. This is done for a variety of different impact categories under different circumstances, as to provide decision makers with the best possible insights in the consequences of certain decisions.

In contrast with screening, impact assessment involves a more detailed and complicated analysis of the effects on various impact categories. However, this is done for only a limited number of policies, that are of a national nature. A way of presenting impact assessment results is by using a scorecard, which summarizes the effects of alternative policies for various impact categories under different circumstances (scenarios). To the extent possible, the impacts are expressed in comparable units that are often, but not necessarily, monetary.

In this paper the various impacts and impact categories will be described in chapter 10.2; chapter 10.3 will provide some information about the construction of 'cases' that were considered in impact assessment (a case is a combination of a policy and a number of scenario type assumptions that affect its performance and impacts). In chapter 10.4 some results will be presented.

10.2 Impacts and impact categories

The following impact categories were considered in the impact assessment stage of PAWN:

- *user groups:* – agriculture;
  - industries;
  - drinking water companies;
  - shipping;
  - power plants;
  - environment;

- *entire nation:* – financial;
  - economical;
  - public health;
  - social/distributional.

For the different user groups, extensive modeling efforts were made to be able to reflect and analyze the effects of water management policies. The main tool used in the analysis was the Water Distribution Model, providing an overall description of the water distribution in the Netherlands and linking different users together. All of these modeling activities have been described in other papers concerning the PAWN-study.

The relevant impacts by user group that were dealt with are:

- *Agriculture:*
  - gross and net benefits (prevented crop damages);
  - fixed and variable costs of sprinkling;
  - costs of waterboard plans (local plans to expand or improve surface water supply possibilities);
  - breakdown of net benefits by producers (farmers), consumers and government, both Dutch and foreign.

- *Industries:*
  - use of surface water, groundwater and drinking water;
  - change in costs of water supply to industry.

- *Drinking water companies:*
  - use of surface water and groundwater;
  - change in costs and revenues of drinking water production;
  - change in price of drinking water.

- *Shipping:*
  - costs due to low water losses;
  - costs due to delays at locks;
  - dredging costs (to prevent low water losses);
  - annualized fixed costs of long run fleet proxy.

[The long run fleet proxy is an estimate of required fleet capacity to carry a specific amount of goods under certain conditions, given a specified water management policy.]

- *Power plants:*
  - extra costs of power generation if thermal standards are exceeded.

- *Environment:*
  - extent of violation and violation frequency of water quality standards;
  - environmental impacts of implementing tactics (building new infrastructure);
  - changes in groundwater level (damage to nature).

The impacts considered on the national level were mainly derived by combining selected impacts on the user level, such as:

- *Financial:*
  - total Dutch net benefits;
  - total investment and operating costs of tactics.
- *Economical:*
  - direct and indirect effects on employment, sales and trades.
- *Public health:*
  - violation of water quality standards;
  - percentage of groundwater in drinking water produced (groundwater is preferable to surface water as a drinking water source because it generally is of a better and more constant quality).
- *Social/distributional:*
  - uneven distribution of selected impacts among users and regions.

10.3 Construction of cases to be analyzed

In the impact assessment stage of PAWN more than 30 'cases' were investigated. A case is defined as a mixture of some water management policy and a number of scenario type assumptions that affect its performance and impacts. Typically, a water management policy will contain the following elements:

- managerial strategy;
- technical strategy;
- price- and regulation strategy.

A managerial strategy specifies the way in which the national water manager should operate the national system under various conditions. In impact assessment, three different management strategies were used. One is meant to reflect current practice, the other two resulted from the policy design stage. Of the latter two, one is the optimal strategy from an overall (least-cost) point of view, although the actual results are not very different from the current policy. The other strategy reflects a least-cost solution to comply with the thermal pollution standards at some critical locations.

The technical strategy involves two major elements: tactics concerning the national system and waterboard plans. Only a limited number of national tactics survived screening. In impact assessment either this whole set of national tactics (called 'MAXTACS') was supposed to be implemented or no tactics at all. Waterboard plans deal with local improvements and/or expansions of the surface water supply possibilities. In a pre-screening exercise, a set of promising waterboard plans were derived, using the agricultural models (see Baarse and Van Beek, 1982b).

Again, in impact assessment this set of plans was supposed to be implemented as a whole or not at all. It should be noted, that the modeling structure is capable of handling any subset of national tactics or waterboard plans one wants to specify. However, given time and budget restrictions the number of cases to be analyzed in PAWN had to be limited.

The price- and regulation strategy focuses on the use of groundwater. This policy consists of three elements: groundwater restrictions, groundwater charges and priority rules for different users. Several combinations of these have been considered in impact assessment.

The following scenario type assumptions are involved in specifying a case:

- agricultural sprinkling scenario;
- external supply scenario;
- context variables;
- miscellaneous.

The agricultural sprinkling scenario indicates the amount of installed sprinklers by crop and location, for both groundwater and surface water. This scenario is combined with a specification of the area that is suppliable with surface water (depending on the waterboard plans that are implemented) and the area that can use groundwater. For both surface water and groundwater three different scenarios were used: 'low' which reflects the current situation, 'high' which indicates an optimistic forecast (high growth) and 'medium' which is the average of low and high.

The external supply scenario consists of variables that reflect the climatological conditions (rain, evaporation, temperature) and the water flows that enter the Netherlands via rivers. External supply scenarios were constructed by using the real world data of some selected years that were associated with certain probabilities. In total four different external supply scenarios were used. An average (50 % -dry) year, a 10 %-dry year, a 5 %-dry year and an extreme dry year (less than 2 %). It should be noted, that the external supply scenarios are treated as something that can happen to any policy in any situation, so the various external supply scenarios were generally not used in the circumstances of the actual years from which they were derived.

The set of *scenario variables referred to as 'context'* consists of variables whose values are largely determined by the time frame under consideration. This usually means they depend on socio-economic developments. Examples are:

- shipping fleet and goods to be transported;
- inventory of power plants and expected power demand;
- surface water and groundwater demands of drinking water companies and industries;
- pollution discharge inventory.

PAWN considered two contexts: 1976 and 'future'. Context 1976 is as close to the current situation as possible, given the practical constraints with respect to data gathering. The future context is based on projections for different activities in 1985 and 1990. As there is no exact future date that the various projections can be associated with, the future context should be regarded as a conceivable situation in a relatively near future. The acronyms: 'CON76' and 'CON85' indicate the two different contexts that were used.

Then 'miscellaneous' part of the scenario assumptions consists of variables whose values will be primarily determined by decision makers other than those concerned directly with water management. Examples are:

- Rhine salt dump by other European countries;
- treaty about river Meuse with Belgium;
- implementation of various existing plans affecting water management infrastructure;
- pollution standards.

For each of these variables a best guess was made that was considered the reference value. Most impact assessment cases were run using these reference values. For some of these variables a few variations have been investigated. However, again because of time and budget constraints, the number of sensitivity cases to be analyzed in PAWN had to be limited.

10.4 Results

In view of all the variables and scenario elements involved, a limited number of cases have been analyzed in PAWN (about 30). Many more policy-scenario combinations may have to be investigated to obtain additional information or to deal with questions that were not yet addressed. Hence, this part of the analysis cannot and should not be regarded as 'finished'.

The cases that were analyzed provided a big flood of information. By comparing results of different cases in a sensible way, useful insights could be obtained about the effects of:

- increases in sprinkling from surface water;
- increases in sprinkling from groundwater;
- waterboard plans;
- national tactics;
- managerial strategies;
- groundwater charges, quota and priority rules;
- combinations of these.

In tables 1 to 3, some selective results have been presented. Table 1 starts out with a definition of the cases that were used in tables 2 and 3. The cases are defined in terms of some variables describing the water management policy (waterboard plans, MAXTACS, groundwater quota, charges and priority) and in terms of the surface water and groundwater sprinkling scenario. Where relevant, the external supply scenario is indicated in tables 2 and 3. All of the cases used the optimal managerial strategy (see chapter 10.3) and have been considered in 'context 85' (see chapter 10.3). The 'miscellaneous' scenario variables were always at their reference values (see chapter 10.3).

A case either has all promising waterboard plans or none at all; also it has all promising national tactics (MAXTACS) or none. Sprinkling scenarios for surface water and groundwater can be low, medium or high. The groundwater policy needs some explanation.

The quota indicates the amount of groundwater that can be extracted. It is expressed as a fraction of a reference quota that is considered a 'reasonable' maximum (opinions differ widely on this subject). The reference quota was computed for different regions by the responsible governmental agency. Note, that this reference quota is not a single number, but a vector of numbers, indicating extractable amounts by region. The fraction expressing the quota that is actually used in a specific case is a single number. A charge is an amount of money to be paid for every cubic meter of groundwater extracted. If a charge is imposed, it only applies to agriculture and industry, and not to drinking water companies.

The priority indicates which of the groundwater user groups (industry, drinking water companies or agriculture) has the first claim in satisfying its demand from groundwater. It is either the combination of industry and drinking water companies or agriculture that is given priority (indicated in table 1 by IND/DW or AGR). As long as the groundwater sprinkling scenario is low (current) PAWN does not explicitly set a priority, because the existing agricultural demand is assumed always to be met, regardless of any quota.

Table 1 Definition of cases

Case	Waterboard plans	MAXTACS	SW* sprinkling	*GW*** sprinkling	*Groundwater policy* quota	charge (Dfl)	priority
basecase (0)	no	no	low	low	1.0	0	–
1	yes	no	medium	low	1.0	0	–
2	yes	yes	medium	low	1.0	0	–
3	yes	yes	medium	medium	1.0	0	IND/DW
4	yes	yes	high	high	1.0	0	IND/DW
5	yes	yes	high	low	0.25	0	–
6	yes	yes	high	high	1.0	0.20	IND/DW
7	yes	yes	high	high	1.0	0.20	AGR
8	yes	yes	high	high	1.0	0	AGR
9	yes	yes	high	high	1.5	0	IND/DW

* SW: Surface water
** GW: Groundwater

10.4.1 *Observations on table 2*

Table 2 represents a summary of some impacts for the cases 1 thru 5, for both an extreme dry year and a 10% dry year. It provides a breakdown of tactic costs and benefits/losses by user group, resulting in a total Dutch net benefit. Moreover the following impacts are shown:
- change in total groundwater extraction;
- percentage of groundwater in drinking water;
- violation frequency of some pollutants at national nodes;
- minimum level attained at IJssellake.

The change in groundwater extraction gives some indication of the potential impacts on environment. The percentage groundwater in drinking water is something to be considered from a viewpoint of national health. Violation frequencies indicate the extent to which pollution standards are violated. They are expressed as a percentage of the maximum possible number of violations. This maximum is the product of nodes and timesteps (at most the standards can be violated at all nodes in any timestep, yielding a violation frequency of 100%). Note though, that the number is ambiguous: e.g. a violation frequency of 50% could mean that 50% of the nodes are always violated, or 100% of the nodes are violated half the time.

The IJssellake is by far the biggest reservoir in the national system. It plays a crucial role

Table 26 Summary of impacts for cases 1 thru 5 (impacts relative to basecase 0)

External supply	extreme dry year					10 % dry year				
Case	1	2	3	4	5	1	2	3	4	5
Costs:										
MAXTACS	–	50.0	50.0	50.0	50.0	–	50.0	50.0	50.0	50.0
Waterboard plans	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7
Total	21.7	71.7	71.7	71.7	71.7	21.7	71.7	71.7	71.7	71.7
Dutch benefits/losses:										
Agriculture	912.7	1160.7	3151.7	2169.7	1900.7	175.7	214.7	247.7	381.7	354.7
Shipping	−18.7	2.6	1.6	−12.7	−9.2	0.1	0.5	0.6	0.3	0.3
Thermal penalty	−7.2	−4.7	−5.0	−4.3	−2.1	−2.9	−1.4	−1.4	−1.6	−0.4
DW production costs	–	–	–	–	−514.0	–	–	–	–	−514.0
Total	886.8	1158.6	1348.3	2152.7	1375.4	172.9	213.8	246.9	380.4	−159.4
Total Dutch net benefit	865.1	1086.9	1276.6	2081.0	1303.7	151.2	142.1	175.2	308.7	−231.1
ΔGW extraction (10^6 m^3/yr)	–	–	167	347	−1138	–	–	105	262	−1138
GW in DW (%)	77	77	77	77	16	77	77	77	77	16
Violation frequency at national nodes (%)										
BOD	40	39	39	40	40	49	49	49	49	49
Phosphate	51	52	52	51	52	55	54	54	54	54
Chloride	69	69	69	69	69	54	54	54	54	54
Minimum level IJssellake (cm)	−37	−45	−47	−49	−49	−20	−23	−23	−25	−25

(numbers in 10^6 Dfl unless otherwise indicated)

DW: Drinking Water
GW: Groundwater

in the water supply of a considerable part (more than half) of the country. The minimum level attained in a simulation period indicates the risk of shortage if conditions became more severe. The minimum acceptable level is −40 (cm). Below that level, severe difficulties will arise with various important intake points that use gravity (level difference) to let in water (water can no longer be withdrawn). Also there may be serious consequences for shipping, environment, safety (e.g. stability of dikes).
Comparing the benefits/losses of cases 1 thru 5 shows a very obvious effect of sprinkling scenarios on agricultural benefits. Judging from cases 1 and 2, implementing MAXTACS may have quite an impact on agriculture and also on shipping (although it hardly makes a difference for shipping in the 10 % dry year). As sprinkling from surface water increases, shipping costs also increase, indicating a competition between agriculture and shipping. Case 5, with the very low groundwater quota (0.25 times reference quota), shows a big reduction in groundwater extraction, but at the same time the fraction of groundwater in drinking water is very much reduced. The benefits drop compared to case 4, due to increased costs of drinking water production and a reduction of agricultural benefits.
As for the violation frequencies, the different policies seem to have no effect whatsoever. This confirms the general feeling that the effectiveness of national tactics to deal with pollution problems is limited. The reason is that the pollution problems are either very local, or they are mainly caused by the 'imported' pollution of the river Rhine, which is by far the biggest source of river water to the Netherlands. All of the violation frequencies are quite high: the imposed standards turn out to be very strict compared to what seems to be possible in reality. The minimum IJssellake levels indicate the severity of the extreme dry year scenario and the potential problems with the lake level if surface water sprinkling is increased.

10.4.2 *Observations on table 3*

Table 3 lists a number of specific impacts with respect to some groundwater policies. It shows the groundwater extractions by user group and the way drinking water is composed of groundwater and surface water. Also the number of surface water projects that should be implemented to meet the drinking water demand is given, which could be interpreted as a negative impact on land resources and environment. Finally the change in production costs for both drinking water companies and industries and the effect on the price of drinking water are presented.

The very limited quota of case 5 clearly affects groundwater extractions and production costs. It also requires a big number of surface water projects to be carried out. Cases 6 and 7 show the effect of imposing charges on industry and agriculture. Indeed, the costs for industry increase and extractions are reduced. For agriculture the change in groundwater extraction because of the charge is more than compensated by

Table 3 Impacts of various groundwater policies

Case	4	5	6	7	8	9
GW extractions (10^6 m^3/yr):						
– by agriculture*	625	275	508	760	1136	915
– by DW companies	1102	250	1128	1106	1081	1240
– by industry	450	167	282	259	380	482
Total	2177	692	1918	2125	2597	2637
DW production (10^6 m^3/yr):						
– from GW	1102	250	1128	1106	1081	1240
– from SW	330	1278	330	360	373	188
Total	1432	1528	1458	1466	1454	1428
GW in DW (%)	16	74	77	75	77	87
SW projects for DW	18	8	6	8	6	3
Change** in DW production costs (10^6 Dfl)						
– by DW companies	–	478	7	17	18	–59
– by industry	–	36	62	60	2	–1
Total	–	514	69	77	20	–60
Change** in DW price (Dfl/m^3)	–	0.43	–0.01	0.02	0.04	–0.07

GW: Groundwater
DW: Drinking water
SW: Surface water

* extractions in extreme dry year
** changes relative to case 4

changing the priority rule in case 7. Case 8 shows a big increase in agricultural extractions if priority is given and no charges are imposed. Case 9 shows the consequences of relaxing the quota to 1.5 times the reference quota: total groundwater extractions increase and production costs decrease.

An obvious question that might arise is, why the total groundwater extractions in cases 4, 6, 7 and 8 are quite different although the same quota were applied. This is caused by the agricultural extractions. In applying the quota to agriculture, the *average* groundwater extractions are considered. However in a dry year these extractions will be (and are allowed to be) way above average. So total actual extractions depend on the share of agriculture and the year considered. Table 3 reflects agricultural extractions in an extreme dry year. So in cases where the relative share of agriculture is large, the total extractions also become large (e.g. case 8).

10.5 General remarks

A few general remarks might be helpful in interpreting these results.

- It should be borne in mind that the extreme dry year is indeed very extreme. Hence the effects shown occur only in very rare instances.

– Agriculture is very dominant in the overall benefits. However, this is caused to a great extent by the assumptions about the sprinkling scenarios. As was explained in the paper of Baarse and Van Beek (1982b) about agriculture, some quite optimistic viewpoints were taken here with respect to the high scenario and the benefit computation of sprinkling grass. Moreover it should be realized, that developments concerning sprinkling are not in the hands of the water managers but reflect autonomous decisions of farmers (although in future these developments could be limited or stimulated).

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