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Policy Analysis of Water Management for the Netherlands

Vol. VII, Assessment of Impacts on Drinking-Water Companies and Their Customers

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PREFACE

For some time the Netherlands has had a problem with water quality, particularly salinity, eutrophication, and thermal pollution. Moreover, the future demand for fresh water is expected to exceed the supply. The growing demand for the limited supply of groundwater is leading to increased competition among its users: agriculture, industry, nature preserves, and companies that supply drinking water. The supply of surface water is sufficient except in dry years, when there is competition not only among such users as agriculture, power plants, and shipping, but also among different regions.

Facing such water management problems, the Dutch government wanted an analysis to help draft the first national water management law and to select the overall water management policy for the Netherlands. It established the Policy Analysis for the Water Management of the Netherlands (PAWN) Project in August 1976 as a joint research project of Rand (a nonprofit corporation),[1] the Rijkswaterstaat (the government agency responsible for water control and public works),[2] and the Delft Hydraulics Laboratory (a leading Dutch research organization).[3]

The primary tasks of the PAWN project were to:

1. Develop a methodology for assessing the multiple consequences of water management policies.
2. Apply it to develop alternative water management policies[4] for the Netherlands and to assess and compare their consequences.
3. Create a Dutch capability for further such analyses by training Dutch analysts and by documenting and transferring methodology developed at Rand to the Netherlands.

The methodology and results of the PAWN project are described in a series of publications entitled Policy Analysis of Water Management for the Netherlands. The series contains the following volumes:

- Volume I, Summary Report (Rand R-2500/1)
- Volume II, Screening of Technical and Managerial Tactics (Rand N-1500/2)
- Volume III, Screening of Eutrophication Control Tactics (Rand N-1500/3)
- Volume IV, Design of Long-Run Pricing and Regulation Strategies (Rand N-1500/4)
- Volume V, Design of Managerial Strategies (Rand N-1500/5)
- Volume VA, Methodological Appendixes to Vol. V (Rand N-1500/5A)
- Volume VI, Design of Eutrophication Control Strategies (Rand N-1500/6)

- Volume VII, Assessment of Impacts on Drinking-Water Companies and Their Customers (Rand N-1500/7)
- Volume VIII, Assessment of Impacts on Industrial Firms (Rand N-1500/8)
- Volume IX, Assessment of Impacts on Shipping and Lock Operation (Rand N-1500/9)
- Volume X, Distribution of Monetary Benefits and Costs (Rand N-1500/10)
- Volume XI, Water Distribution Model (Rand N-1500/11)
- Volume XII, Model for Regional Hydrology, Agricultural Water Demands and Damages from Drought and Salinity (Rand N-1500/12)
- Volume XIII, Models for Sprinkler Irrigation System Design, Cost, and Operation (Rand N-1500/13)
- Volume XIV, Optimal Distribution of Agricultural Irrigation Systems (Rand N-1500/14)
- Volume XV, Electric Power Reallocation and Cost Model (Rand N-1500/15)
- Volume XVI, Costs for Infrastructure Tactics (Rand N-1500/16)
- Volume XVII, Flood Safety Model for the IJssel Lakes (Rand N-1500/17)
- Volume XVIII, Sedimentation and Dredging Cost Models (Rand N-1500/18)
- Volume XIX, Models for Salt Intrusion in the Rhine Delta (Rand N-1500/19)
- Volume XX, Industry Response Simulation Model (Rand N-1500/20)

Four comments about this series of publications seem appropriate. First, the series represents a joint Rand/Rijkswaterstaat/Delft Hydraulics Laboratory research effort. Whereas only some of the volumes list Dutch coauthors, all have Dutch contributors, as can be seen from the acknowledgments pages.

Second, except where noted, these publications describe the methodology and results presented at the final PAWN briefing at Delft on December 11 and 12, 1979. For Rand, this briefing marked the beginning of the documentation phase of the project and the end of the analysis phase. Rand and the Rijkswaterstaat (RWS) considered the results to be tentative because (1) some of the methodology had not become available until late in the analysis phase, and (2) the RWS planned to do additional analysis.

Third, the RWS is preparing its Nota Waterhuishouding, the new policy document on water management scheduled for publication in 1982, by combining some of the PAWN results from December 1979 with the results of considerable additional analysis done in the Netherlands with the PAWN methodology. Because the understanding gained in the original analysis led to improvements in the data--and, in some instances, the models--used to represent the water management system in the additional analysis, the reader is hereby cautioned that the numerical results and conclusions presented in the PAWN volumes will not always agree with those presented in the Nota Waterhuishouding or its companion reports. (It has not been possible to indicate such differences in the volumes

since they are being written before the Nota is published.) Thus, the present series of publications puts primary emphasis on documenting the methodology rather than on describing the policy results.

Fourth, Vols. II through XX are not intended to stand alone, and should be read in conjunction with the Summary Report (Vol. I), which contains most of the contextual and evaluative material.

This volume assesses the impacts of a number of water management policies developed by PAWN on drinking-water companies (DW companies) and their customers (households, commercial entities, and industrial firms). DW companies are a major user of groundwater in the Netherlands, and since many of the policies directly or indirectly strive to conserve groundwater, the impacts on the DW companies take on greater significance. This volume should be considered a companion volume to Vol. IV: the methodology employed to analyze the combined effects of water management policies on the three major users of groundwater--DW companies, industry, and agriculture--is discussed more fully there; this volume presents the impacts on DW companies assessed with that methodology, along with a more detailed discussion of the assumptions underlying its representation of DW companies.

We believe this volume will be of particular interest to three types of readers: officials at the state and provincial levels in the Netherlands who are concerned and responsible for deciding among competing uses of groundwater throughout the country; directors of the Dutch DW companies, who find it increasingly difficult to meet demands for DW in the face of the decreasing availability of groundwater; and research analysts who are interested in understanding and further developing the methodology to assess impacts of water management policies on DW companies and their customers.

NOTES

1. Rand had had extensive experience with similar kinds of analysis and had been working with the Rijkswaterstaat for several years on other problems.
2. The Rand contract was officially with the Rijkswaterstaat, Directie Waterhuishouding en Waterbeweging (Directorate for Water Management and Water Movement), but numerous other parts of the Rijkswaterstaat contributed to the analysis.
3. Delft Hydraulics Laboratory research was performed under project number R1230, sponsored by the Netherlands Rijkswaterstaat.
4. Each water management policy involved a mix of tactics, each a particular action to affect water management, such as building a particular canal or taxing a particular use. Four kinds of tactics were considered: building new water management facilities (infrastructure) or applying various treatments to the water (called technical tactics); using managerial measures (called managerial tactics) to change the distribution of water among

competing regions and users; and imposing taxes or quotas to affect the quantity or quality of water extracted or discharged by different users (called price and regulation tactics, respectively). A mix of tactics of the same kind is called a strategy. Thus, the overall policy could be conceived as a combination of technical, managerial, pricing, and regulation strategies.

SUMMARY

The objectives of the PAWN study are to develop a set of alternative water-management policies for the Netherlands and to assess the impact of those policies on several sectors within the economy. Even more important than these two objectives is a third--to establish an appropriate methodology and tools with which to develop the policies and assess their impacts. This volume assesses the principal impacts of a number of PAWN policies on drinking-water companies (DW companies) and their customers (households, commercial entities, and industrial firms) and describes the methodology used. The volume is one of three that directly assess the various impacts of PAWN policies.

Drinking water in the Netherlands is obtained mainly from groundwater (GW), the purest and least costly water available. However, in areas where not enough GW is available to meet the DW demand, the deficit is made up with surface water (SW), which usually requires extensive treatment because many SW sources are heavily polluted. Treatment and transportation costs make SW more expensive than GW; treatment also makes SW a distant second in terms of taste.

By law, DW can only be provided by DW companies, whose pricing and production activities are regulated by the state and the province or municipality in which each is located. The law requires DW companies to produce enough DW to meet all demands and to maintain the quality of the water above a prescribed level.

DW companies' problems are mounting. Demands for DW are rising steadily, but it is hard to obtain GW and expensive to extract, treat, and transport SW. Since a high proportion of GW is what usually gives DW its purity and good taste, maintaining that high quality in the face of increasingly inadequate supplies of GW and added SW is difficult. Since several PAWN policies limit or discourage the use of GW, the question of their impact on DW companies takes on greater significance.

THE IMPACT ASSESSMENTS

We carried out impact assessments on DW companies of ten of the PAWN impact-assessment cases defined in Vol. I. (As we shall see later, some of these cases differ only in ways that are irrelevant for GW extractions and DW production; so here we treat only six district cases.) A case is defined by certain input values, of which only those shown in Table S.1 are important for our analysis of DW companies and their customers. These parameters are:

- GW quota: RID (Rijksinstituut voor Drinkwatervoorziening, or State Institute for DW Supply) estimated the maximum safe amounts of GW that could be extracted annually within each

province. These extractable amounts were deemed safe in that they would not cause undue damage to agriculture and the environment due to the dropping of the GW level. When GW quota is 1.0, no more than the RID extractable amounts can be taken by industry, DW companies, and agriculture combined, in an average year. (In drought years, agriculture will take more, but industry and DW companies are not asked to cut back.) When GW quota is 0.25, only one-fourth of the RID extractable amounts can be taken, and similarly for a quota of 1.5.

- GW charge on industry and agriculture: One method proposed for reducing GW extractions is to require that industries and farmers who extract GW pay for the privilege. While we have examined cases in which DW companies also must pay (see Vol. IV), this is contrary to Dutch proposals. In the cases shown here, DW companies are exempt from any GW charge, although they do pay pumping and transport costs for the GW they extract.
- GW priority above current sprinklers: The model used in our analysis, RESDM (Response Design Model), considered the combined responses of industries and DW companies to various GW-conservation tactics. RESDM did not, however, consider the effect of agricultural GW extractions. Sometimes agricultural extractions had to be introduced as a reduction in the amount of GW available to industries and DW companies. In most cases, we let industries and DW companies take as much as they wished, up to the quota, with the remainder available for agriculture. In other cases, we let agriculture take the average amount it would need, up to the quota, and industries and DW companies could take only what was left. (In all cases, we permitted currently installed GW sprinklers to continue to operate, even if their extractions caused the quota to be violated. Such violations were small and rare.)
- Waterboard plans implemented: Waterboards are Dutch local governmental entities that make all local water management decisions. (Actually, the entities making those decisions are not everywhere called waterboards, but this is unimportant for our purposes.) Many waterboards have proposed improvements to local water distribution systems that would increase the areas to be irrigated with SW. These proposals are called waterboard plans in PAWN. Some of the areas served by the plans might also be irrigated, albeit at higher cost, with GW. Thus, if the plans were implemented, we would expect to see less GW irrigation in the future than if the plans were not implemented.
- GW-sprinkler intensity: Certain areas are deemed eligible for GW irrigation, but only a relatively small fraction of these areas were actually irrigated (or sprinkled) in 1976. We have defined three GW-sprinkler intensities: a low intensity, where the fraction of eligible area sprinkled is as in 1976; a high intensity, where the fraction has been much

increased; and a medium intensity, intermediate between the other two. These are fully discussed in Vol. XIV. In the cases discussed in the present volume, the medium intensity does not appear.

- DW-pricing scheme: We considered that DW companies might sell their DW at a price based either on the average cost of production (which is current practice), or on the marginal cost of production. Economic theory states that marginal-cost pricing leads to a more efficient allocation of scarce resources, and the analysis in Vol. IV suggests that marginal-cost pricing leads to lower industry plus DW company total costs than does average-cost pricing. (The difference is only significant in cases with very low GW quotas.) In the cases examined here, we consider only marginal-cost pricing.
- DW demand (context): In the cases considered here, we considered demands for DW as projected by RID for the year 1990. In some cases reported in Vol. IV, we considered DW demands as they were in 1976.
- Industry production growth rates: To obtain the industrial demands for DW and GW, we started from the 1976 demands by type of industry and projected the growth of each industry type forward to 1990. We considered a range of growth rates from zero to "high" in Vol. IV (see Vol. VIII for sources of growth rates); in all cases considered here, the growth rates were "high."

In Table S.1, cases A-G represent PAWN's primary cases, and F, G, and the remaining four constitute the GW cases, so called because values of the GW variables--quota, use charge or tax, and extraction priority--are varied across these cases. (The terminology used here is the same as that used for the impact-assessment cases defined in Vol. I. Note that cases F and G appear among both the primary and GW cases.) Note that cases A-F contain distinctive features that have no effect on DW production or use, hence are grouped together as one case for this analysis. This in effect reduces the number of distinct cases to six.

Our principal tool for carrying out this impact assessment is a linear program called RESDM. It represents industries by means of a single composite industrial firm in each of the 78 PAWN districts, which are the water management areas into which we have partitioned the Netherlands for the PAWN analysis. It represents DW companies by means of one composite DW company in each pseudo-province. (Pseudo-provinces are aggregations of districts which approximate the actual provinces. Actual provinces cut across some districts, and hence are not so convenient to use in this analysis.) It selects the least costly long-run responses of DW companies and industry to long-run pricing and regulation strategies by minimizing the water-related costs of the two sectors. At the same time, it is constrained to extract no more GW or SW than is available, to meet precisely the demand for DW in every pseudo-province, and to give industry in every district at least the minimum GW it needs to function. By choosing those responses,

Table S.1

THE TEN PAWN CASES INVESTIGATED

Independent Variable	Variable "Value" by Case					
	A-F	G	L	M	P	Q
GW quota	1.0	.25	1.0	1.0	1.0	1.5
GW charge on industry and agric. (Dfl/m^3)	0	0	.20	.20	0	0
GW priority above current sprinklers	I/D	A	I/D	A	A	I/D
Waterboard plans implemented	No	No	No	Yes	Yes	Yes
GW-sprinkler intensity (a)	--	Low	--	High	High	--
DW-pricing scheme	MC	MC	MC	MC	MC	MC
DW demand (context)	1990	1990	1990	1990	1990	1990
Industrial-production growth rates	High	High	High	High	High	High

NOTE: GW quota represents the maximum amounts of GW that may be extracted in each district and province and is expressed as a fraction of RID's estimates of the GW-extractable amounts. I/D = industry and DW companies; A = agriculture; MC = marginal-cost basis. Volume I contains full explanations of these cases and how they were selected, as well as a glossary of terms.

(a) Applicable only when agriculture is given priority in extracting GW.

RESDM calculates the most efficient (optimal) allocation of GW (for particular sets of input conditions) both geographically and between the two sectors. It also calculates the amount and composition of DW produced in each province, which SW reservoirs need to be built or expanded and how much SW will be extracted from each one, the marginal value of GW and the marginal, average, and total costs of supplying DW, as well as the cost and revenue impacts on DW companies. Accordingly, we analyzed the six different GW cases on RESDM, carried out some sensitivity runs, and assessed the resulting impacts.

IMPACTS

We compared the cases in terms of a list of impacts chosen to highlight the most important effects of case differences on DW companies and their customers. The impacts selected were:

- The amounts of GW and SW used by DW companies and the amount of DW produced.

- The amounts of DW demanded by industry and by households and commercial entities. (Commercial entities include service and small business, public, agricultural, and recreational DW users, as well as leakage and unaccounted use.) Household and commercial-entity use by pseudo-province is an input to the model and is not changed during a model run. A nominal industrial demand for DW is also an input, but in the model, industry can respond to DW price changes or other factors by changing its DW consumption.
- The amount of DW shipped between DW companies, i.e., produced in one pseudo-province but consumed in another.
- The percentage of GW in DW, which we view as a proxy measure of DW quality. GW generally has higher quality and lower salinity than SW and hence is favored for reasons of public health as a source of DW. We realize that GW from different locations has different quality as does SW (e.g., Maas water is much less saline than Rijn water), and that our proxy measure of quality is therefore quite crude. However, to calculate more sophisticated measures would have required a separate, complex study.
- The number of SW facilities (e.g., reservoirs) that DW companies must build in order to meet the demand. These are called SW projects and are important because building them involves undesirable environmental impacts, as well as substantial financial costs.
- The average and marginal costs of supplying SW expressed as Dfl/m^3. The average cost is defined as the total cost divided by the number of cubic meters of DW supplied, while the marginal cost is the cost of supplying one additional cubic meter. These differ by pseudo-province, but can be combined into national averages. The marginal costs are shadow prices associated with certain of the constraints in RESDM and are calculated as a by-product of the standard linear programming algorithm (the Simplex method) used in RESDM. The average costs are calculated by assigning the cost of producing each cubic meter of DW to the DW company that ultimately supplies it to an end user and dividing the sum of these costs by the amount of water supplied. Note that these costs include the capital costs of any SW projects built, prorated to the water produced.
- The costs and revenues of DW companies. Costs are calculated as average cost per cubic meter of DW times the amount of DW produced, while revenues are calculated as marginal cost per cubic meter of DW (in the marginal-cost pricing cases) times the demand for DW. Costs and revenues can be calculated separately for industries and for households and commercial entities and can be distributed across pseudo-provinces.
- GW shadow prices. These measure the amount by which industries and DW companies could reduce their combined costs if the amount of GW available were increased in each district by 1 m^3. (There is one GW shadow price for each district; it is calculated as a by-product of the standard linear programming algorithm (the Simplex method) used by RESDM.)

FINDINGS

Our analysis produced a number of major findings, the first four of which focus on the comparison of the basic case (A-F in Table S.1) with others in the table:

1. Imposing a GW charge on industry and agriculture at a GW quota of 1.0 has virtually no effect on DW companies (comparison of case L with A-F). Although slightly more DW is produced in case L, other impacts are zero.

2. Giving agriculture priority over DW companies and industry in extracting GW, with high GW-sprinkler intensity and all waterboard plans implemented at a GW quota of 1.0, results in only small effects--some positive, some negative--on DW companies (comparison of cases M and P with A-F). Case M differs from case P only in a GW charge imposed on industry and agriculture, but the effect of that charge is lost by the change in GW priority of the two cases compared with the basic case. The principal impacts are:
   - 22-34 million cubic meters per year (mcm/yr) (2 percent) more DW is produced, but at an average reduction in the proportion of GW of 2-3 percent.
   - 30-43 mcm/yr more SW is extracted, requiring two more SW projects.
   - The marginal cost of supplying DW rises 4-8 percent to .53-.55 Dfl/m^3.
   - The average cost of supplying DW goes up by less than 0.01 Dfl per cubic meter, increasing total costs by 14-18 Dflm/yr (2-3 percent); however, this is more than offset by higher revenues of 53-78 Dflm/yr (7-11 percent), resulting in higher DW company surpluses of 39-58 Dflm/yr (35-52 percent).

3. Sharply reducing the GW quota to one-fourth of its basic level has serious and adverse consequences on DW companies (comparison of case G with A-F). The effect of reducing the quota to that extent swamps the much smaller effect produced by giving agriculture, with low GW-sprinkler intensity, GW-extraction priority over DW companies and industry. The major impacts are:
   - DW companies extract less than one-fourth of the GW they did in the basic case.
   - SW extractions nearly quadruple to make up the large deficit (bringing into play 12 additional SW projects for a total of 18), with the result that the proportion of GW contained in the DW drops to about one-fifth its value under the basic case, which is undesirable for public health.
   - Only 60 percent of the DW shipped to other DW companies under the basic case is shipped under case G, because much

of the DW contains large proportions of SW that raise its cost over that of SW from nearer sources.

- The marginal cost of supplying DW almost doubles to .94 Dfl/m^3, while average costs rise by only 70 percent to .71 Dfl/m^3.
- DW-company revenues thus increase more than total costs, leading to a tripling of their surplus (from 112 to 333 Dflm/yr).

4. Increasing the GW quota by 50 percent gives every province all the GW it needs except for the three westernmost provinces, which are still short (comparison of case Q with A-F). Compared to case G, the impacts are less severe and in the opposite direction. They are:
   - 138 mcm/yr (13 percent) more GW is extracted by DW companies, improving the quality of DW by 13 percent to 87 percent GW.
   - 142 mcm/yr less SW is required, and from three fewer SW projects.
   - Almost twice the amount of DW is shipped among DW companies, all of it GW.
   - The marginal cost of supplying DW goes down by 14 percent to .44 Dfl/m^3, and the average costs by almost 10 percent to .38 Dfl/m^3.
   - DW-company costs and revenues drop by 6 percent and 14 percent, respectively, so that the overall surplus drops by 42 percent to 65 Dflm/yr.

5. DW companies in three western lowlands provinces--Noord-Holland, Zuid-Holland, and Zeeland--face far more acute problems than do those in remaining provinces. Not only are their GW supplies woefully inadequate compared to the current DW demands they face, but the gap between available GW and demands for DW will widen more quickly there than elsewhere between now and 1990. However, adequate SW sources are planned for this region during that period so that DW companies there should still be able to meet the demands placed on them. The critical concern is whether they can keep the quality high enough.

6. DW companies, by building large enough SW reservoirs and infiltration plants in certain parts of the country, can cope with severe GW shortages. However, two inescapable side effects are that the resulting DW costs more and is of appreciably lower quality, as measured by the percentage of GW in DW.

7. Whenever DW companies use marginal-cost pricing and those marginal costs are greater than average costs in supplying DW, DW companies will show larger revenues than costs, i.e., a surplus. Such a surplus increases as the gap between GW availability and DW demands widens.

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We are grateful to the many people who contributed to the work reported in this volume. However, special thanks go to the Rijksinstituut voor Drinkwatervoorziening (the Netherlands' national institute for DW supply) for constructing and putting at our disposal RID's DW model (RIDDWM), which we used in constructing our RESDM model. We thank VEWIN (the Dutch union of DW companies) for providing many data and much advice. We would also like to thank P. J. A. Baan and J. van Gameren of the Delft Hydraulics Laboratory for assisting us in reducing the number of industry vectors from IRSM (PAWN's Industry Response Simulation Model) into RESDM, and for contributing greatly to our understanding of the various models involved. W. A. Dorsman deserves special mention for his active and valuable participation in the analysis and his close scrutiny of the manuscript.

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We remain responsible for any errors of omission or commission that may still have eluded us.

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Chapter 1

INTRODUCTION

The PAWN project is concerned with designing a set of policies for managing the Netherlands' water resources and assessing the diverse impacts of those policies. As a result, decisionmakers in the Netherlands can be given new and relevant information with which to develop a water-management policy of their own. Perhaps the greatest contribution of this project--which also fulfills its principal objective--is the tools and techniques developed both to generate the policies and to assess their impacts. Most of them are in the form of computer models, whose form and input data can be continually modified by Dutch analysts to refine existing, or create new, water-management policies for the future.

The stages of policy analysis are shown schematically in Fig. 1.1. The principal iterations with which the PAWN team are concerned involve delineating scenario and system assumptions, screening promising tactics, designing policies, assessing the impacts of promising policies on the major sectors of the Dutch economy as well as on the natural environment, comparing policies, and performing sensitivity analyses. The ultimate step of deciding on a preferred policy is properly left to the Dutch people and their elected representatives.

This volume presents the impacts on drinking-water companies (DW companies) and their customers of some of the water-management policies designed by PAWN. (Impact assessments were also carried out directly on industrial firms (Vol. VIII) and shipping (Vol. IX), and on agriculture and the environment, although there are no separate impact-assessment volumes for these last two sectors.) This study also explains why DW companies form an important sector of the economy and describes some of the problems they are experiencing. It presents a full description of the model used to perform the impact assessment, as well as how the assessment was done. Finally, it comments on what the results mean for DW companies and their customers.

Below, we describe briefly the objectives of this particular study and our approach to achieving them. The introduction ends with an outline of how the rest of the report is organized.

1.1. OBJECTIVES AND APPROACH OF STUDY

It is impossible to talk about the approach of this study without recognizing first its integral role in PAWN. Our approach is thus geared to the water-management policies designed by PAWN, and in particular to the following objective:

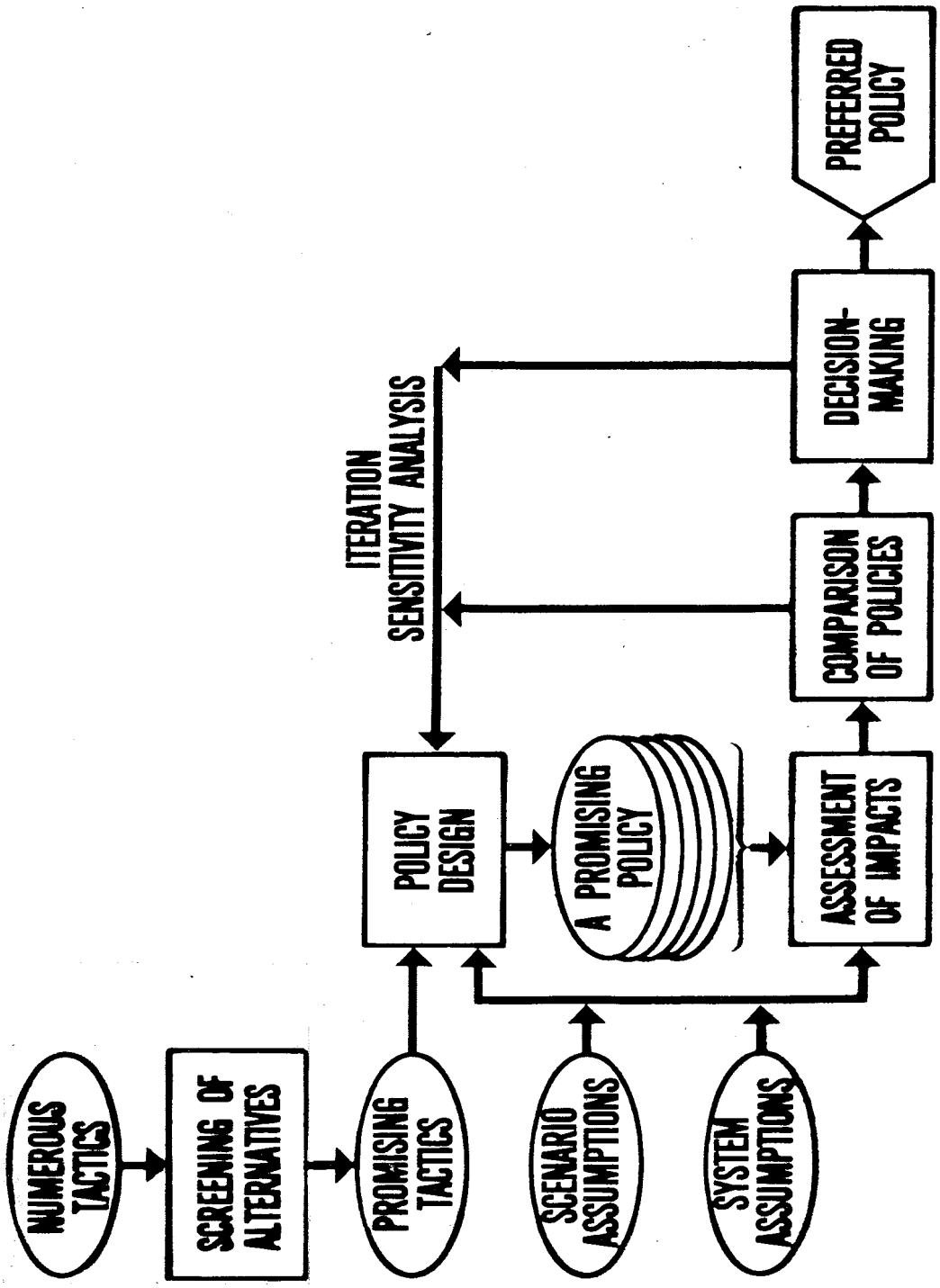

Fig. 1.1--Stages of policy analysis

To determine the impacts on DW companies and their customers of water-management policies designed by PAWN, especially its primary cases and GW cases.[1]

To achieve this objective, our analysis must show how DW companies are affected by variations in the availability of GW; by variations in charges imposed on industry alone, on industry and DW companies, or on industry and agriculture; by variations in DW demand; and by the method of setting DW prices. It must also show how sensitive the impacts are to the assumptions underlying some of the more uncertain data, in order to get an idea of how robust the impacts are.

We use a linear program called RESDM (Response Design Model) as our primary tool, choosing inputs for each run in a systematic way to yield the impacts of cases we wish to analyze. We show and discuss for each run made the inputs, results for the Netherlands as a whole, and impacts by province on DW companies and DW production. Finally, we perturb the values of certain variables estimated with a high degree of uncertainty to determine how sensitive the results are to the estimated values.

1.2. ORGANIZATION OF REPORT

In order to appreciate why we are interested in DW production, and why we chose the model we did to perform the impact assessments, we summarize briefly in Chap. 2 the major water-related problems facing DW companies in the Netherlands today, and show why we believe they will become more severe in the future. In Chap. 3, we describe our methodology in detail, beginning with an essentially nontechnical overview. We show how the first model we used--developed by RID (Rijksinstituut voor Drinkwatervoorziening, or State Institute for Drinking Water Supply)--captures the main elements of real-world DW companies and their problems, albeit in highly aggregated form. In PAWN, that model is called RIDDWM--RID's DW Model--and we describe its structure, assumptions, and input data in detail. Next, we show how we combine the DW company and industry sectors into our linear-programming model RESDM; although the DW sector portions of RIDDWM and RESDM are identical, we have used the latter model for this analysis because it conveniently includes the amounts of extra DW demanded by industry in its long-run responses. We also describe RESDM's inputs and outputs.

Chapter 4 presents the impacts and associated discussion of PAWN's primary and GW cases on DW production, and on DW companies and their customers. It begins with an explanation and list of the cases chosen to perform the analyses. Finally, in Chap. 5, we assess those impacts, draw some overall conclusions, and discuss the implications of those conclusions for the future supply and costs of DW in the Netherlands.

NOTE

1. The policies contained in PAWN's primary cases are constructed from a menu including all technical tactics that survived screening (MAXTACS) as well as key agricultural sprinkler policies. A full account of these policies is contained in Vol. I. The GW (groundwater) cases include a special set of policies that explore the effects of varying the extractable amounts or quotas of GW, the effects of charges imposed for GW use on industry and agriculture, and whether priority for extracting GW is given to agriculture or jointly to industry and DW companies.

Chapter 2

PROBLEMS FACING DRINKING-WATER COMPANIES

Drinking water is produced in the Netherlands exclusively by public water companies called DW companies. They are obliged under Dutch law, specifically the Waterleidingwet or DW law, to produce enough DW to satisfy whatever is demanded for reasons relating to public health, and to maintain the quality of the DW at or above the minimum health standards prescribed by the law. Compliance with the law is monitored and enforced by a team of regional inspectors. Of 103 DW companies in 1978, 70 were owned and operated by the towns or villages of which they were a part, 27 jointly by several communities and provinces, 5 by private parties, and 1 directly by the state. (The Waterleidingwet recommends that DW companies should reorganize, which means that more mergers will probably take place in the future.)

DW companies strive to use GW whenever possible in producing DW. With few exceptions, GW is clear, of constant quality, appropriately cool for DW purposes, and tastes pleasant. It is also the cheapest of all DW sources, requiring only aeration, single or double filtration, and (usually) softening, as well as pumping and distribution. The trouble is that in some places, there is not enough GW available to meet the DW demand, while in other places extractions are limited because of possible damage to agricultural crops and to the natural environment.

To make up the difference between the DW demanded and the GW available, DW companies turn to surface water (SW), which is much more expensive and less desirable than GW. Not only are SW sources often farther away from DW-company customers, thus entailing shipping (pipeline) costs, but the sources are often more polluted, thus requiring extensive treatment before SW can be used as DW. (Surface waters generally contain BOD (biochemical oxygen demand), inorganic salt, and toxic and nondegradable substances, as well as mineral oils. The Rijn and Maas rivers contain concentrations of some heavy metals that exceed Dutch basic water-quality standards.) Further, reliance on SW sources makes DW companies vulnerable to intense pollution episodes, such as sudden increases in toxic substances resulting from either a shipping accident or an inadvertent but excessive industrial discharge.

Because by law only DW companies may supply DW in the Netherlands, they constitute a monopoly service in the areas in which they operate. For that reason, they are regulated--in what they can charge for DW, in the quality of DW they produce, and in the location and capacity of the sources they can tap for their DW. A number of different units of government are involved in regulating DW companies:

- Licenses for extracting GW are issued by the Ministry of Public Health and the Environment (MPHE) after an assessment

by COGROWA (Government Advisory Committee on GW Extraction), one of whose principal functions is to recommend or advise against issuing a license. (GW extractions are presently regulated according to provisions in the Grondwaterwet Waterleidingbedrijven, and in the future, will be regulated by the proposed groundwater act, or GW law.)

- DW quality is monitored directly by MPHE which uses the minimum standards contained in an appendix to the Waterleidingwet as its quality criteria.
- The GW tables in different parts of the country are continuously monitored by TNO (Instituut voor Toegepast Natuurwetenschappelijk Onderzoek).
- DW prices are regulated directly by provincial and municipal governments (which hold more than 50 percent of the shares of most DW companies) and indirectly by the Ministry of Economic Affairs.
- By virtue of their majority ownership, provincial and municipal governments are also involved in many major decisions of DW companies, such as making capital investments, finding new DW sources, and dealing with claims by farmers for damages to their crops.

Producing enough DW is made more difficult for DW companies by the fact that the demand for DW is growing while restrictions are being placed on how much GW can be extracted. Below, we describe some of the difficulties that DW companies are experiencing in trying to meet their two main objectives--insuring adequate DW supplies and maintaining the highest quality possible above the minimum standard.

2.1. DIFFICULTIES IN EXTRACTING GROUNDWATER

DW companies in certain areas are having to face three kinds of problems related to their current extractions of GW. First, farmers claim that DW companies are directly responsible through GW extractions for lowering their crop yield, and thus they seek compensation for damages. Second, evidence is mounting that excessive GW extractions in nature areas can inflict irreparable harm to the environment. The third kind of problem concerns the need to obtain more GW by drilling new wells or by transporting GW via pipeline from sources farther afield.

2.1.1. Damage to Farmers

In certain areas, the extraction of a large volume of GW through a well draws down the level of water in the root zone and leads to significant crop damage (mainly grasslands). In some cases, farmers receive compensation from DW companies for such damage. According to a study conducted in Gelderland [2.1], a well producing one million cubic meters/year may cause a drop in the water table of 5 cm or more in an area of several square kilometers around the well; such a drop may affect farmers' revenues adversely.

So far, GW extractions by DW companies in East Gelderland, East Overijssel, and East N.-Brabant are directly responsible for such losses. Compensatory payments to some farmers were made in 1979 as a result of extractions from 8 wells or GW-pumping stations; in the case of 37 other wells, farmers have already submitted claims for damages. (In instances where the farmers and DW companies cannot agree as to fault or damages, the COGROWA acts as arbitrator.)

2.1.2. Damage to the Environment

Since nature areas of beauty and wilderness depend on a sufficiently high GW level below them, lowering that level or altering its pattern of fluctuation can have adverse--and often severe--effects on plant life and the character of these preserves. Extractions by DW companies and others, as well as various water-management measures and forest plantings, have affected the GW levels in several nature areas. For example:

- About 280 plant types have, since 1900, either disappeared or are endangered (one study shows that in the dune area of Meyendel, 57 types of plant were lost because of GW extractions there [2.2]).
- Wet dune areas, wet grasslands, and forest and humid weather areas have disappeared or lost characteristic plants.
- Brooks and ponds have run dry or suffer low water levels.

We have no systematic data about where and to what extent these impacts occur, nor do we know the extent to which withdrawals by DW companies are responsible, but various reports have mentioned the Utrecht hills, the Veluwe borders, East N.-Brabant, and the dunes as affected sites.

So far, there are no provisions for paying the government for damages that nature areas may experience, although the possibility of charging a fee or tax for extracting GW may be included in the proposed GW law. The difficulty of putting a price on such damages or even assessing the value of the GW extracted could be one plausible reason why such fees have not heretofore been charged. However, the problem seems to have been bypassed by limiting the GW extractions in those areas to certain thresholds in order to curtail damage. As the demand for GW increases, decisions about these thresholds will become more difficult, and the decisions may have to be reexamined, particularly with reference to the proposed GW law.

In PAWN, we have chosen thresholds based on a study of this problem by RID. The amounts of GW that RID estimates can be extracted annually in each province thus form the basis for our estimates of the extractable amounts of GW in each district.[1] RID believes that if GW extractions are limited to (or held below) these extractable amounts, natural recharge will be sufficient to maintain environmentally acceptable GW levels indefinitely. Larger extractions would result in the GW achieving steady-state levels too deep to be acceptable.

2.1.3. The Need for More Groundwater

Access to GW is obtained through a license either to open a new well or to expand the pumping rate of an existing well beyond the maximum rate permitted on the current license. (Licenses typically restrict the withdrawer to maximum annual, monthly, and daily amounts of GW.)

Another alternative open to a DW company that needs more GW is to pipe it in from wells further afield. Because many such pipes are already used for transporting GW within the distribution areas of DW companies (mainly to guarantee uninterrupted deliveries of DW in case of an emergency), the costs involved are relatively small--0.01 Dfl/m^3/km, and less if the quantity transported requires a larger-capacity pipe. (This figure does not include the cost of reservoirs to ensure a continuous DW supply in the event of transport failure.) As the search for GW becomes more urgent and licenses more difficult to obtain, this alternative will become more attractive, and it is likely that more GW and DW will be transported between DW companies.

2.2. PROBLEMS WITH EXTRACTING SURFACE WATER

So long as DW companies can produce DW using only GW, they can be virtually certain that the quality will more than meet the minimum standards set down by the Waterleidingwet.[2] But in certain parts of the country, most notably the western and southwestern lowlands provinces, the amounts of extractable GW are insufficient to meet the DW demands. As the demands there and elsewhere increase--without a corresponding increase in the amounts of GW available--DW companies will be forced to turn to SW in order to continue to fulfill their obligations to their customers. Because SW generally has lower quality than GW, the prospect of having to use increasing amounts of it raises the question of whether DW companies can maintain the quality of the resulting DW above the lawful level ("quality" here is concerned as much with taste as with the elimination of harmful pollutants from the water).

The principal sources of SW in the Netherlands are the Rijn and Maas rivers, their tributaries, and the IJsselmeer. The Rijn is by far the most plentiful source--about 3370 mcm/month in a dry month of a normal year--but is also the most polluted. In a dry year, much of the SW must come from the Rijn,[3] with these important implications for DW companies: their ability to maintain the high quality of the DW will be severely taxed; and the combined possibilities of shortages and excessive pollution (not to mention accidents) call for storage reservoirs and extensive treatment facilities that will burden DW companies.

Access to SW is controlled by RWS for state waters and by local waterboards or provincial authorities in other cases. Because SW extractions to date have been rather small, it has been the exception rather than the rule for a license application to be turned down.[4]

(Impacts tend to be local, and alternate SW sources are usually available at roughly the same cost.)

Of the three major SW sources, the two most used are the Rijn and the Maas (see Table 2.1). This is not surprising, because the shortage of GW is felt most acutely in the western and southern provinces. Whereas the Rijn is low on quality, the Maas is not nearly as full-flowing and, in dry years, runs dangerously low. Thus, DW companies that depend on the Maas directly or indirectly for additional SW may face severe problems in the future. The Biesbosch reservoir, which supplies SW to many DW companies in the southwest, draws its water from the Maas, currently at a rate of about 4-5 m^3/s. Future plans call for increasing the capacity of this reservoir from 160 to 500 mcm/yr, the latter figure implying an extraction rate of 15-20 m^3/s. But the discharge of the Maas in a dry year (downstream of the Roer) can be as low as 12 m^3/s. (The Maas can run low not only as a result of inadequate rainfall, but also from agricultural withdrawals upstream and adjustments to maintain the water levels of the Brabant and Limburg canals.)

Table 2.1

SW EXTRACTIONS FROM MAJOR SOURCES BY DW COMPANIES

Major SW Source	DW Companies' SW Extractions (mcm/yr) in 1976
Rijn (a)	130
Maas (a)	155
IJsselmeer	20
Other (b)	10
Total	315

SOURCE: VEWIN.

(a) Includes tributaries.

(b) Includes Waddenzee, Drentse Aa, and Isabella-wetering.

2.3. SAFEGUARDING WATER QUALITY

Because DW companies are compelled to use increasing quantities of relatively impure SW, safeguarding the quality of the resulting DW becomes crucial. A common method used is infiltration, where SW is transported and infiltrated into sandy soil (like the dunes) for a staying period that depends on the natural circumstances and production method (from about 40 days in Leiden to about 100 days in N.-Holland). A recent study found that a reservoir relying on Rijn water would need a staying period of about six months to reach a stable salinity level below 200 mg/l, a level presumably low enough for DW purposes. If the salinity of the Rijn could be reduced by 50 kg/s, the staying period would only have to be about four months long to achieve the same output quality. The two months saved would,

assuming the reservoir were used to its full capacity, lower the cost of producing DW by a few cents per cubic meter [2.3]. Another example provides an estimate of the additional costs that some DW companies face when having to turn to sources of rather impure SW. Because of the high salinity of water from the Rijn, the Rotterdam and The Hague DW companies have turned to the Maas for SW. The extra transport costs incurred are 0.10-0.15 Dfl/m^3 and 0.20 Dfl/m^3 for the two DW companies, respectively.

DW companies that use additional SW need to protect themselves from unforeseen accidents that might contaminate the SW sources they use. They have done this by building a number of reservoirs that serve not only as a buffer against low river flows but also as a contingency against sudden toxic spills or industrial discharges that give the water a foul taste or are unhealthful. They also improve water quality through natural processes and mixing. Such reservoirs are not legally required, yet DW companies feel obliged to take such steps if they are to fulfill their basic charter of providing high-quality DW to their customers. Reservoirs are designed with certain cover periods in mind depending on the estimated probability of a calamity occurring and its likely severity, the probability of a shortage, and the need for improving the water quality. (A cover period is the average length of time a drop of water stays in the reservoir before being used.) CVZO (Commissie Voorraadvorming en Zuivering Oppervlaktewater) suggests that in the case of calamities, cover periods of about a month are adequate for reservoirs that take in water directly from the Rijn or Maas, but much too short for water drawn from the IJsselmeer.

2.4. PROGNOSIS FOR THE FUTURE

Many of the problems facing DW companies that are outlined briefly above are not only expected to continue in the future, but to get worse. Three principal reasons underlie this prognosis.

First, RID has estimated that the demand for DW will rise steadily to the figures for 1990 shown in Table 4.1. It can be argued that such demands could be reduced substantially if users of DW decided to conserve water. But some rough calculations suggest that at most, given current technology, it would not be reasonable to expect more than a 10-percent reduction in the basic demand for DW.[5] Further, the largest demands for DW occur in the western-lowlands provinces, precisely those areas in which GW is most scarce.

Second, demands for GW from other users (such as industry and agriculture) are also expected to grow. This means less for DW companies (given the same amount available in the GW table) or, at the very least, expanded rounds of negotiations, agreements, and arbitrations with other users and licensing authorities. In addition, as nature preserves become scarcer and hence more precious, the availability of GW for DW companies will be further reduced.

Third, while DW companies may have access to much more SW than GW in producing DW, they will be constrained in how much they can use. For example, the Biesbosch reservoirs will ultimately have a capacity of about 500 mcm/yr, which implies an extraction rate of about 15-20 m^3/s from the Maas. This in turn may shortchange agriculture in Brabant and Limburg. Also, amounts of SW from the Lekkanaal, Twentekanaal, Lek, and possibly Zoommeer may not be extracted at will because of potentially adverse effects on shipping and agriculture, as well as on water needed for flushing purposes.

This state of affairs naturally raises questions about ways in which DW companies can cope in the future: whether they can continue to meet growing demands for DW in the face of increasing difficulties in obtaining more GW; whether they can or should hold their prices at their current levels; how conservation efforts or shortages of GW might affect the quality and costs of producing DW; and how the impacts on DW companies and on the DW produced varies from province to province.

The importance placed on DW by the Dutch people and their concerns about both its quality and sufficiency in the future are central to this part of the PAWN study.

NOTES

1. Throughout the PAWN study, we have based our analysis geographically on 78 specially defined areas called districts. This is convenient for many reasons relating to water management, although a major drawback is that districts are sometimes split among several provinces, so that data reported at provincial levels are difficult to distribute among districts.
2. Uncontrolled dumping of toxic materials has recently threatened the quality of GW. The Dutch authorities have decided that the problem can most effectively be handled by enacting and enforcing strict antidumping controls rather than through nationwide water management policies.
3. In a 95-percent dry year, the lowest monthly discharge of the Rijn is about 2270 mcm; of small rivers, about 50 mcm; and of the Maas, virtually zero (down from about 115 mcm in a dry month of a normal year). However, DW companies prefer Maas water to Rijn water because of its higher quality, and in 1976 roughly 50 percent of the SW in DW came from the Maas.
4. For example, the Rynkennermerland water company was denied permission to increase its extractions from the Amsterdam-Rijn canal beyond 7 m^3/s, but could instead take water from the IJsselmeer.
5. These calculations took into account, for example, the consumption of water by households' toilets, baths, showers, washing machines, and dishwashers. They also included the extent of possible savings in consumption if such household equipment were replaced in time by feasible new designs that used water more sparingly, i.e., used less of it to do the same job.

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2.3. RID, Optimale keuze van waterwinprojecten en leidingen, deel III, Toepassing van het model op regionaal niveau, January 1978.

Chapter 3

METHODOLOGY FOR ASSESSING THE IMPACTS ON DW COMPANIES

In this chapter, we discuss fully the tools, procedures, and data that we used to perform the impact assessment. The chapter begins with an essentially nontechnical overview of the methodology.

3.1. OVERVIEW

Our objective was to determine and assess the impacts on DW companies and their customers of PAWN's primary and GW cases. Our basic tool for doing so is the Response Design Model (RESDM). RESDM, which Vol. IV describes in detail, is a linear-programming model of the long-run options of DW companies to produce DW and of industries to alter their consumption of DW. It was created by combining RIDDWM (a version of RID's DW Model, also a linear program) and essential data, in greatly reduced form, from IRSM (PAWN's Industry Response Simulation Model). By "long-run," we mean that the model considers that enough time has passed for major construction to have taken place and for all parties to have reached an economic equilibrium state. As a rule of thumb, we assign the date of 1990 to our cases, although this is, if anything, too early for long-run (in our sense) adjustments to occur.

DW companies are represented one to a pseudo-province[1] and each has a menu of SW projects or sources from which to obtain DW if available GW is insufficient. Some of the SW projects have not yet been built, and some are expansions of existing reservoirs or infiltration plants. Likewise, industrial firms are represented by a composite firm in each PAWN district;[2] data about the options for industry to alter DW consumption were obtained through a process detailed in Vol. IV and based on data from Vol. XX. Given extractable amounts of GW in every district (i.e., maximum amounts of GW that all users together are permitted to extract), coupled with any policy that taxes the use of that GW, RESDM will choose industrial options in each district and DW-company options in each province that minimize the total combined-sector costs of those options. In addition, RESDM complies with several constraints, namely, that the GW and SW used by DW companies and industry do not exceed available supplies, that industry's minimum GW requirements in each district are met first,[3] and that every cubic meter (m^3) of DW demanded in a pseudo-province is supplied by its composite DW company.

The DW-company sector in RESDM is represented by RIDDWM. Each pseudo-province contains several DW companies, but for simplicity, a single composite company is assumed in each pseudo-province.[4] This composite DW company can extract GW from any of the PAWN districts in its pseudo-province, and we assume that the GW so extracted must be transported an average of 10 km. We assume that DW can be made from either GW, SW, or some combination of the two. Because of physical

space limitations and other considerations, only certain capital projects--such as reservoirs and infiltration plants--can be used for producing DW out of SW, and these are specified in the model.

RIDDWM contains a menu of SW projects--some existing, some that could be built or expanded--each with a specific maximum capacity and annualized cost per cubic meter withdrawn. The annualized cost is the sum of three components: the investment cost, prorated over the cubic meters withdrawn from the project during its lifetime; annual operating costs, such as energy costs for treatment and pumping, costs of chemicals for treatment, and labor costs; and adjustments for special circumstances. It does not include local distribution costs or administrative overhead. In the model, the DW companies choose the cheapest way of producing the required amount of DW in their respective provinces; their first choice is to use only GW in making DW, because that water is the least costly. If enough GW is not available, then, depending on costs, the deficit is made up with appropriately treated SW and/or DW transported from a neighboring province.

It should be noted that, because RIDDWM neglects certain costs mentioned above, the DW prices it calculates, based on marginal or average costs, are not fully comparable to real-world DW prices. As a result, the model gives better estimates of price changes than absolute prices.

Finally, RIDDWM requires that demands for DW be specified for each pseudo-province. These demands consist of the (projected) demand by households and commercial entities, plus a nominal demand by industry.

Besides RIDDWM, RESDM also contains a menu of responses available to industry in a district (pseudo-provinces contain anywhere from one to 14 districts). This representation of industry was developed from another model created for PAWN, IRSM. The responses comprise values of three variables:

- Amount of GW required (thousands of m^3/yr)
- Amount of extra DW bought (thousands of m^3/yr)
- Total water-related costs (thousands of Dfl/yr)

(Industrial firms use a lot of SW for a variety of purposes, but because practically all of it is returned to surface waters, the net effect on SW sources (except from the standpoint of pollution) is negligible. That is why our primary concern in this study centers on GW and DW and why we have excluded industrial use of SW from the RESDM data base.)

When we talk about "industry in a district," we really mean a composite industry. The original data are represented in IRSM by individual firms; for RESDM the firms were allocated to appropriate districts and combined, using weighted averages, into a single composite firm in each district. The responses thus represent the possible options that each composite firm has in responding to changes

in its GW supply. These range from the composite firm using only GW, through various combinations of GW and DW, to replacing all the GW with DW. The more that GW is replaced by DW, or the less GW that is used, the higher is industry's water-related cost.[5]

RIDDWM and IRSM are models that can be exercised independently. The beauty of RESDM, in operating them together, is that both industry and DW companies are made to draw their GW from the same sources. When and wherever GW is scarce, the model is able to allocate the GW efficiently--to arrive at the lowest financial cost. Such joint optimization is especially valuable when one recalls that when industry reduces its use of GW, it often compensates by increasing its use of DW--DW that contains a substantial proportion of GW.

An important theoretical consequence of this joint optimization is that industries behave as if they must purchase DW at its marginal cost of production. (Demand by households and commercial entities are fixed in the model, so theory has nothing to say about the price they seem to be paying.) But the marginal costs are far higher in most cases than the prices based on average historic costs that DW companies actually charge.

3.2. RID'S DRINKING-WATER MODEL (RIDDWM)

3.2.1. Background

RIDDWM was developed by RID in 1978 as a contributory study to the PAWN project. It was based on a more detailed region-based model which RID was using at that time. Its original purpose was to identify optimal choices of DW production projects and transportation routes based on data which RID had developed for planning purposes. At the PAWN team's request, RID used their model to determine the effects of 4 different scenarios on the supply of GW. The scenarios were: (1) values for the extractable amounts of GW in each province were based on RID's best estimates; DW companies were given lowest priority in extracting GW; they could take whatever was left after industry, agriculture, and "trenches" (excavations for construction projects) took what they needed; (2) values for the extractable amount of GW in each province were 50 percent of RID's estimates; DW companies still got lowest priority; (3) values for the extractable amount of GW in each province were 150 percent of RID's estimates; DW companies still got lowest priority; and (4) values for the extractable amounts were again as for scenario (1), but this time DW companies were given first priority in extracting GW. The model was based on estimates geared to 1990.

To use RID's study in PAWN, we had to modify it in certain respects: First, because we wanted to perform a joint analysis of DW companies and industry, we had to find a way of combining RIDDWM and IRSM, our industry model. What we did was to add industrial data to RIDDWM and call the resulting model RESDM. Second, to be consistent with other PAWN models, we treated the Zuid-IJsselmeerpolders as a separate "province" (the equally persuasive arguments for treating it

as part of Gelderland or Noord-Holland could not be resolved). Third, we transformed Dutch provinces into pseudo-provinces to avoid splitting up the many districts that straddled provincial boundaries (this transformation meant adjusting the data by province both for extractable amounts of GW and for DW demands, but not for unit production or transportation costs).

3.2.2. Structure

To model the world of the DW company, it became clear that a middle ground had to be steered between a prohibitively expensive and time-consuming detailed simulation on the one hand, and an aggregate model so coarse as to be useless on the other. PAWN asked RID to develop the model at the provincial level. That decision enabled the model to be greatly simplified (since PAWN is a nationwide study), yet to reveal important regional differences.

To be credible, the model also had to reflect the range of problems that DW companies experience, both now and in the future. These include potential shortages of GW and SW, curtailment of GW extractions in certain areas for fear of damaging crops or the natural environment, potential pollution of SW sources, possible lowering of DW quality, and future potentially high DW demands.

The model that RID developed does reflect most of the above problems. Because it takes the form of a linear program--to show what sorts of optimal decisions are possible at the provincial level--it cannot deal with problems such as a SW source suddenly becoming polluted, which would require a dynamic model. However, it includes longer-term responses that DW companies could adopt to bridge the gap between a limited supply of GW and a growing demand for DW. These responses include a menu of SW projects--reservoirs, infiltration plants--that are either expansions of existing SW sources or brand new projects, all of which could be dedicated to producing DW. Their costs reflect the capital investments, energy, and chemicals required to purify the water and protect it against sudden pollution episodes. The responses also include the possibility of transporting DW from one province to another. As a linear program, the model always satisfies the demand for DW from the least costly source, thus reflecting the true (higher) costs of obtaining more GW when its supply locally is either restricted or exhausted.

The basic network used in RIDDWM is shown in Fig. 3.1. The figure shows twelve composite DW companies--one to each pseudo-province--in which the whole province's demand for DW is assumed to be concentrated. Similarly, all the GW wells in each province have been collapsed into a single GW source, whose basic capacity is set equal to RID's estimate of the extractable amount of GW in that pseudo-province. The figure contains a menu of 20 SW projects, as well as 66 links or pipes for transporting water--38 connecting SW projects to DW companies, 12 supplying GW to DW companies, and 16 for transporting DW from one DW company to another (each of the last 16 links can accommodate flow

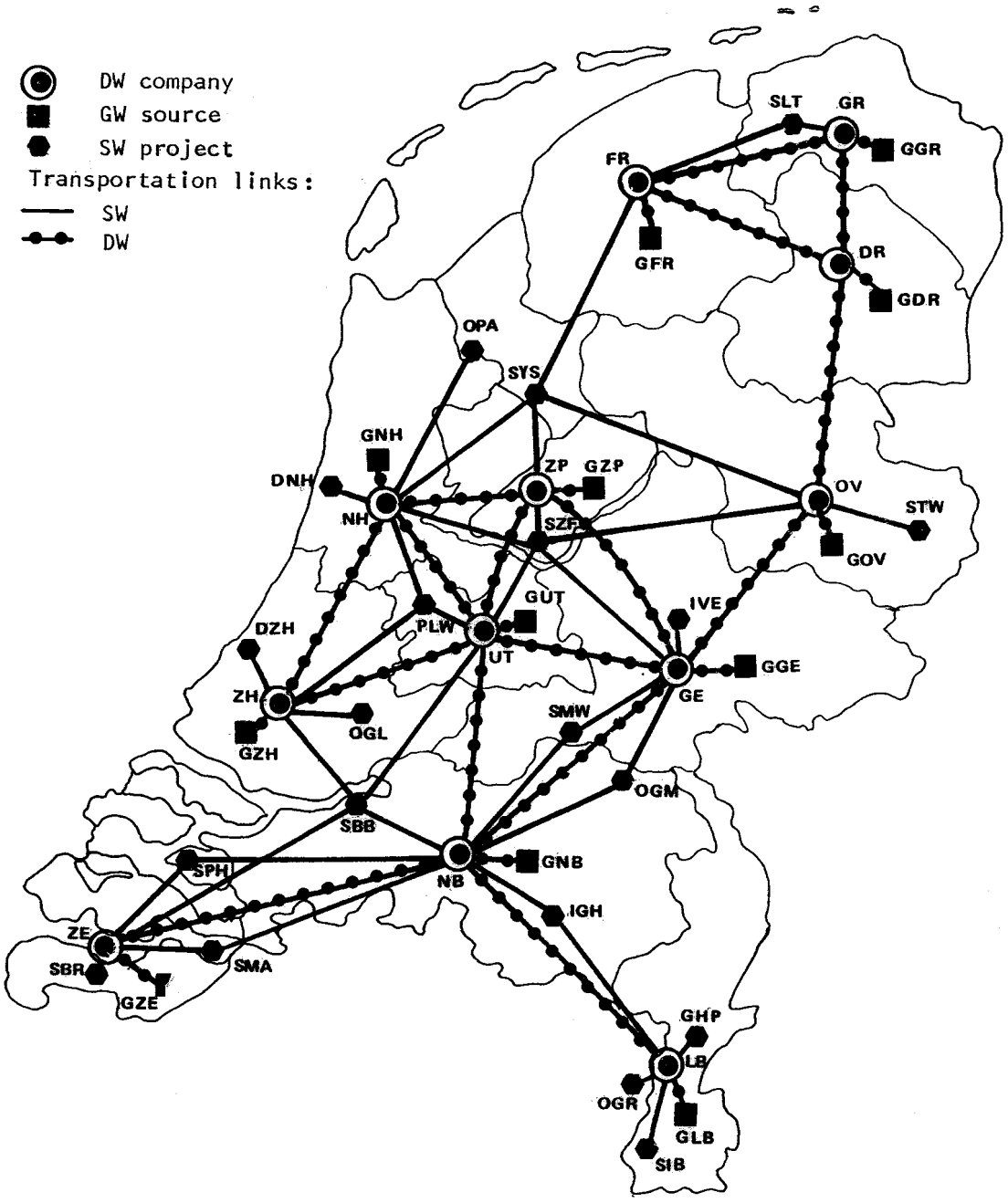


Fig. 3.1--RIDDWM network

in either direction). Note that each source of GW is connected to only one DW company. Thus, no DW company can obtain GW directly from another pseudo-province. Instead, it must buy DW, which may contain some GW, from another DW company.

It is important to note that no local DW distribution networks are included. This is in accord with the purpose of the model as a national planning tool, since changes in local distribution are not contemplated. However, since local distribution and fee collection contributes significantly to DW company costs, it must be kept in mind that the costs reported in this volume are far from total costs. Differences from one case to another, however, are unchanged by this omission.

3.2.3. Basic Data

The basic data used in RIDDWM (hence in RESDM too) are presented in Tables 3.1 through 3.3. Table 3.1 presents RID's estimates of the most likely extractable amounts of GW in the Netherlands, which PAWN has broken down by pseudo-province. (Appendix A in Vol. IV explains why we had to work in terms of pseudo-provinces, which districts belonged to each one, and how we adjusted our input data to conform

Table 3.1

GW EXTRACTABLE AMOUNTS,
BY PSEUDO-PROVINCE

Pseudo-Province		GW Extractable Amounts (mcm/year)
Groningen	GR	88
Friesland	FR	134
Drente	DR	157
Overijssel	OV	195
Gelderland	GE	463
Utrecht	UT	81
Z.-IJpolders	ZP	39
N.-Holland	NH	62(a)
Z.-Holland	ZH	123(b)
Zeeland	ZE	6(c)
N.-Brabant	NB	502
Limburg	LB	188
Netherlands		2038

SOURCE: RID for original data by real province, and Table 3.6 for breakdown by district to give above pseudo-province totals.

(a) Includes 33 mcm/yr from dunes.
(b) Includes 13 mcm/yr from dunes.
(c) Includes 6 mcm/yr from dunes.

Table 3.2

SW PROJECTS, MAXIMUM CAPACITIES, AND UNIT COSTS

Acronym	Name of SW Project	Maximum Capacity (mcm/yr)	Unit Cost (Dfl/m^3)
SLT	Spaarbekken Lettelbert	50	.70
STW	Spaarbekken Twente	57	.70
SMW	Spaarbekken Maas/Waal	100	.70
SYS	Spaarbekken Ysselmeer	500	.70
SZF	Spaarbekken Zuid-Flevoland	90	.70
SBB	Spaarbekken Biesbosch(a)	507	.60
SPH	Spaarbekken Philipsland	150	.70
SMA	Spaarbekken Markiezaat	200	.70
SBR	Spaarbekken Braakman	16	.70
SIB	Spaarbekken Itteren/Borgharen	60	.70
GHP	Grindgat Heel/Panheel	50	.60
DNH	Duininfiltratie Noord-Holland	150	.65
DZH	Duininfiltratie Zuid-Holland	110	.65
OGL	Oevergrondwater Lek	50	.35
OGM	Oeverinfiltratie Maas	50	.40
OGR	Oevergrondwater Roosteren	25	.35
PLW	Plassenwaterleiding Amsterdam	60	.65
IVE	Infiltratie Veluwe	500	.65
IGH	Infiltratie Groote Heide	20	.45
OPA	Oppervlaktewater Andijk	20	.70

SOURCE: RID.

NOTES: Unit costs are in 1977 guilders, and include capital replacement of the SW project, energy costs, and specific adjustments for particular SW projects; unit transport costs are not included. Acronyms for the SW projects are keyed to Fig. 3.1. Spaarbekken means "reservoir."

(a) Includes 7 mcm of Dordrecht reservoir capacity.

to them. However, because GW wells are strategically located and because their number does not vary with land area in the same way as does the general population, we had to use a special method to arrive at that breakdown: with RID's help, we estimated GW extractable amounts by district and then added them up to pseudo-province totals.) For RIDDWM, we used the figures shown in Table 3.1; for RESDM, which computes industrial GW demands by district, we used the breakdown by district shown in Table 3.6. (Note that the totals differ by 52 mcm/yr, an amount of GW obtained from the dunes and made available only to DW companies in the lowlands provinces of N.-Holland, Z.-Holland, and Zeeland.)

These extractable amounts form the "capacities" of the GW sources in the model; their extraction and treatment costs in every pseudo-province are assumed to be .25 Dfl/m^3. We were able to assume the same cost in each location because the GW in the Netherlands is

Table 3.3

TRANSPORTATION COSTS FOR LINKS IN RIDDWM NETWORK

Link	Cost Code	Transport Costs (Dfl/m^3)	Link	Cost Code	Transport Costs (Dfl/m^3)	Link	Cost Code	Transport Costs (Dfl/m^3)
GRFR	2	.45	ZENB	2	.56	SZFUT	1	.35
FRGR	2	.45	NBZE	2	.56	SZFNH	1	.37
GRDR	3	.16	NBLB	3	.41	SZFZP	1	.07
DRGR	3	.16	LBNB	3	.41	SBBUT	1	.52
FRDR	3	.33	GGRGR	3	.07	SBBZH	1	.29
DRFR	3	.33	GFRFR	3	.07	SBBZE	1	.86
DROV	3	.42	GDRDR	3	.07	SBBNB	1	.46
OVDR	3	.42	GOVOV	3	.07	SPHZE	1	.40
OVGE	2	.56	GGEGE	3	.07	SPHNB	2	.41
GEOV	2	.56	GUTUT	2	.09	SMAZE	1	.35
GEZP	1	.58	GZPZP	1	.07	SMANB	2	.36
ZPGE	1	.58	GNHNH	2	.09	SBRZE	2	.09
GEUT	3	.34	GZHZH	2	.09	GHPLB	3	.10
UTGE	3	.34	GZEZE	2	.09	SIBLB	3	.07
GENB	1	.77	GNBNB	3	.07	DNHNH	1	.26
NBGE	1	.77	GLBLB	3	.07	DZHZH	1	.17
UTZP	1	.35	SLTGR	2	.11	OGLZH	1	.32
ZPUT	1	.35	SLTFR	2	.34	OGMGE	1	.35
UTNH	1	.40	STWOV	3	.08	OGMNB	3	.13
NHUT	1	.40	SMWGE	1	.37	OGRLB	3	.10
UTZH	1	.49	SMWNB	2	.27	PLWUT	1	.29
ZHUT	1	.49	SYSFR	1	.69	PLWNH	1	.14
UTNB	1	.72	SYSOV	1	.95	PLWZH	1	.46
NBUT	1	.72	SYSZP	1	.40	IVEGE	3	.10
NHZP	1	.37	SYSNH	1	.55	IGHNB	3	.07
ZPNH	1	.37	SZFOV	1	.92	IGHLB	3	.30
NHZH	1	.43	SZFGE	1	.58	OPANH	1	.29
ZHNH	1	.43						

SOURCE: RID, except for links involving ZP which were estimated by RWS.

NOTES: Names of links include abbreviations of both their points of origin and destination; e.g., "GRFR" is from GR (Groningen) to FR (Friesland), GGRGR is from the groundwater source for Groningen to the Groningen DW company, and "SBBUT" is from SSB (Spaarbekken Biesbosch) to UT (Utrecht). Cost codes 1-3 represent estimates of high, medium, and low transport costs of .0115, .009, and .0065 Dfl/m^3/km, respectively (see also text). Transportation costs include capital and energy costs, and have been adjusted for length of link (distance).

hardly anywhere found at a great depth. At most, it is 100 m deep, in the southern part of Limburg, and in most places it is less than 10 m below the surface. Thus, the fixed costs of well construction and of buying pumps and pipes dominates the extraction costs. As these costs are nearly independent of well depth for the range of depths we consider, RID adopted the constant cost assumptions.

Table 3.2 lists the SW projects, explains their acronyms, and summarizes their estimated maximum capacities and per-cubic-meter water costs (how those unit costs are derived is explained later). Table 3.3 presents the per-cubic-meter transportation costs for each of the 66 transport links in the model (the name given to a link is composed of its origin and destination points in order; for example, IVEGE is the link from the SW project IVE to the composite DW company of GE).

As shown below, six of the SW projects presently exist, but may be expanded in the future. In much of the PAWN analysis, we considered costs of existing facilities to be "sunk," and did not estimate them, but here we have included the cost of some existing facilities. The reason for the difference is that here the facilities may be changed by adding capacity or by not replacing capacity as it wears out. In the case of Spaarbekken Biesbosch, SBB, we introduced a constraint that forbade RESDM to reduce its capacity below the present value. (Our reason for retaining SBB at its present capacity is that SBB provides water with very low salinity, since it obtains its water from the Maas. This is favorable for a number of industrial processes, as well as for public health.) We could just as well have included only those costs associated with increasing the capacity of SBB, since this would not have affected the optimal use of SBB that the model selected in each case. It would only have changed the total cost calculated by RIDDWM, but as the change would be by the same constant amount in every case, differences between cases would remain the same.

SW Project (Acronym)	1977 Capacity (a) (mcm/yr)	Max. Potential Capacity (mcm/yr)
SBB	160	507
SBR	11	16
DNH	104	150
DZH	70	110
PLW	30	60
OPA	20	20

(a) Data from VEWIN: Tienjarenplan 1978.

Capital costs for the transportation links are assumed to vary only with the type of subsoil supporting the pipes and the number of siphons used. The three categories of cost keyed to the "cost codes" in Table 3.3 are as follows:

Cost Code	Capital Cost of Transport Pipes (Dfl/m^3/km)	Comments
1	0.0115	For pipes on very weak subsoil and many or expensive siphons, e.g., for river crossings.
2	0.009	For pipes on very weak subsoil and few siphons, or on strong subsoil (sand) and many siphons.
3	0.0065	For pipes on strong subsoil (sand) and few siphons.

Energy costs (primarily pumping) for transporting the water are estimated at .0115 Dfl/m^3/km, and are added to the annualized capital costs of the pipe for each type shown above (prorated over the amount of water to be carried) to give per-kilometer transportation costs. The values given in Table 3.3 have taken into account the distances covered by each link to give transportation costs in Dfl/m^3 (the distance between the GW source and DW company in every province is assumed to be 10 km).

3.2.4. Assumptions Underlying SW-Project Costs

A number of assumptions underlie the calculation of these costs:

- SW projects--even those that are only planned--can only be built in segments of 10-30 mcm/yr capacity because of lack of space (as in the case of STW), or because purification units are limited (for example in the Biesbosch), or because they are built stage by stage in step with demand. This means that even if a large planned capacity is required, the calculations are based on the capacities of the smaller segments that comprise it (called segment capacity).
- When a SW project is built, it takes anywhere from 5-15 years before its full-capacity output is used. This period is called the fill-up time. We have assumed a linear increase in use during the fill-up time.
- In all calculations, the useful life of a SW project is assumed to be 40 years, the interest rate 9 percent, and the cover period (for reservoirs) 3 months.

Table 3.4 gives an idea of the kinds of SW project included in the model, their segment capacities, fill-up times, and other relevant information (Fig. 3.1 shows their approximate geographic locations).

The one-time capital costs and annual recurring costs for the SW projects are expressed in the form of unit capital costs in Dfl/m^3. They are calculated in a way that postpones part of the losses due to

Table 3.4

MORE DETAILS ABOUT INDIVIDUAL SW PROJECTS

SW Project (Acronym)	Type Code	Segment Capacity (mcm/yr)	Fill-Up Time (yr)	Source of SW
SLT	1	25	10-15	Hoendiep
STW	1	15	10	Twentekanaal
SMW	1	25-30	10-15	Maas, Waal
SYS	1	25-30	10-15	IJsselmeer, IJssel
SZF	1	25-30	10-15	IJsselmeer
SBB	1	50	10-15	Maas (Merwede)
SPH	1	25-30	10-15	N.-Brabant brooks (Volkerak)
SMA	1	25-30	10-15	N.-Brabant brooks (Rijn-Schelde connection)
SBR	1	20	10	ZE Boezems (Isabellawetering)
SIB	1	25-30	10-15	Maas
GHP	1	25-30	10-15	Maas
DNH	2	10-15	5-10	Amsterdam-Rijnkanaal, IJsslmeer
DZH	2	10-15	5-10	Maas, Z.-Holland Boezems (Rijn)
OGL	3	10-15	5-10	Lek
OGM	2	10-15	5-10	Maas
OGR	3	10-15	5-10	Maas
PLW	4	20-30	10-15	Amsterdam-Rijnkanaal
IVE	2	10-15	5-10	IJssel, IJsselmeer
IGH	2	10	5-10	Tongelreep
OPA	1	20	10	IJsselmeer

SOURCE: RID.

TYPE CODES: 1 Reservoir + treatment
2 Infiltration
3 Riverbank infiltration
4 Treatment only

NOTE: Segment capacities represent the sizes of units that comprise SW projects. Acronyms for SW projects are explained in Table 3.2. Fill-up time is the elapsed time in years before a segment is used at full capacity.

low-capacity utilization rates the project experiences in its early years. This enables the capital costs to be distributed uniformly to each cubic meter of water produced throughout the lifetime of the project.

3.2.5. RID's Method for Calculating SW-Project Unit Costs

Let UC = unit cost of SW from a project (Dfl/m^3),
UIC = unit investment cost of SW project (Dfl/m^3 of delivered water during the project's lifetime),
UEC = unit energy costs (Dfl/m^3),
ADJ = adjustment amount for special circumstances (Dfl/m^3).

Then

$$UC = UIC + UEC + ADJ. \tag{3.1}$$

Also,

$$UIC = I/(Q*F), \tag{3.2}$$

where I = total investment cost of SW-project segment (Dflm),
Q = segment capacity (mcm),
F = factor dependent on lifetime, interest rate, and fill-up time.

Now:

$$I = \left(\frac{P1}{1+r} + \frac{P2}{(1+r)^2} + \ldots \frac{Pn}{(1+r)^n}\right) * UIC, \tag{3.3}$$

where Pt = quantity produced in year t (mcm),
r = interest rate,
n = lifetime (yr).

Combining Eqs. 3.2 and 3.3 gives us the following expression for the F factor:

$$F = \frac{1}{Q} * \left(\frac{P1}{1+r} + \frac{P2}{(1+r)^2} + \ldots \frac{Pn}{(1+r)^n}\right). \tag{3.4}$$

Assuming that the quantity extracted per year increases linearly during the fill-up time from zero to the segment's capacity, we can write:

$$\begin{aligned} Pt &= \frac{t*Q}{FUT} \quad \text{for } 0 < t < FUT \\ Pt &= Q \quad \text{for } FUT < t < n \end{aligned} \tag{3.5}$$

where FUT = fill-up time (yr), the elapsed time before the segment is used at full capacity.

Combining Eqs. 3.4 and 3.5 gives:

$$F = \frac{1}{FUT*(1+r)} + \frac{2}{FUT*(1+r)**2} + \ldots \frac{FUT}{FUT*(1+r)**FUT} + \ldots \frac{1}{(1+r)**n} \quad (3.6)$$

Table 3.5 presents values for the F factor calculated from Eq. 3.6, for interest rates between 7 and 9 percent, fill-up times of up to 40 years, and n = 40; it shows how F varies with r and n.

Table 3.5

F VALUES FOR SW-PROJECT LIFETIME OF 40 YEARS

Interest Rate (%)	Factor F Values, by Fill-Up Time (yr)								
	1	5	10	15	20	25	30	35	40
7.0	13.33	11.58	9.78	8.33	7.14	6.17	5.37	4.70	4.14
8.0	11.92	10.20	8.48	7.13	6.05	5.19	4.49	3.92	3.45
9.0	10.76	9.07	7.42	6.15	5.17	4.40	3.79	3.30	2.90

SOURCE: Eq. 3.6.

Investment costs, I, are calculated as shown below in slightly different ways for the different types of SW project (all expressions include a factor of 1.1 to account for interest paid on the money used to finance construction).

For SW reservoirs with treatment facilities (SLT, STW, SMW, SYS, SZF, SBB, SPH, SMA, SBR, SIB, GHP, and OPA):

$$I = 1.1\ (5.22*Q**0.53 + 7.1*Q**0.73). \quad (3.7)$$

For SW-treatment facilities only (no reservoir) (PLW):

$$I = 1.1\ (7.1*Q**0.73). \quad (3.8)$$

For dune-infiltration plants (DNH, DZH, OGM, IVE, and IGH):

$$I = 1.1\ (7.0*Q**0.53 + 0.5*Q). \quad (3.9)$$

For riverbank-infiltration plants (OGL and OGR):

$$I = 1.1\ (7.0*Q**0.53). \qquad (3.10)$$

The calculation of unit costs for each SW project is fairly straightforward. Table 3.4 gives the type of each SW project along with its segment capacity and fill-up time (recall that we assume the minimum segment capacity when a range is given). The type is matched to one of Eqs. 3.7 - 3.10 to obtain I. Equation 3.6 gives F values for interest-rate/fill-up-time combinations (where a range is given for fill-up time, the interpolation is linear), and the appropriate F value is then used in Eq. 3.2 to give UIC. Therefore, UC may be calculated from Eq. 3.1 with the help of the following additional information:

- Energy unit costs (primarily for pumping) for all SW projects are estimated at 0.05 Dfl/m^3.
- The adjustment for special circumstances (ADJ) has values other than zero only for the following SW projects:

SW Project	ADJ (Dfl/m^3)	Explanation
STW	-.10	Existence of excavation holes
GHP	-.10	Existence of excavation holes
PLW	+.10	Inlet works, pretreatment costs
DNH	+.25	Inlet works (pipes to dunes)
DZH	+.25	Inlet works (pipes to dunes)
IVE	+.25	Inlet works (pipes to Veluwe)

Finally, values of UC have been rounded either downward or upward to the nearest .05 to yield the numbers in Table 3.2.

3.3. REPRESENTATION OF INDUSTRIES IN RESDM

In RESDM, the industrial-response data and analysis are by district. Table 3.6 presents GW extractable amounts by district; they serve as limits on the GW that can be extracted. Thus, while GW from the dunes in N.-Holland, Z.-Holland, and Zeeland, available only to DW companies, is included in provincial totals (see Table 3.1), it is excluded from the breakdown by district. In all other respects, the sum of the district amounts in Table 3.6 for a pseudo-province equals the respective pseudo-provincial totals in Table 3.1. (A map of the Netherlands divided into districts is shown in Vol. XII.)

Table 3.6
GW EXTRACTABLE AMOUNTS, BY DISTRICT

Pseudo-Prov.	Dist. No.	GW Extractable Amount (mcm/yr)
GRON	4	0
	5	5
	6	9
	7	35(a)
	9	39(a)
Total Groningen		88
FRIES	1	134
	2	0
	3	0
Total Friesland		134
DREN	8	34
	10	22
	11	34
	12	67
Total Drente		157
OVER	13	36
	14	0
	15	24
	16	36
	17	8
	18	29
	19	26
	20	23
	21	13
Total Overijssel		195
GELD	22	12
	23	34(b)
	24	34
	25	32
	26	25
	27	29
	28	107(b)
	29	55(b)
	55	45
	57	50
	58	25
	59	15
Total Gelderland		463
N-HOLL	31	0
	32	0
	33	0
	34	0
	35	1(c)
	36	0
	37	2(c)
	40	26
Total N.-Holland		29
Z-HOLL	38	10
	43	14
	45	15
	46	6
	47	0
	48	3
	49	0
	50	11
	52	18
	53	33
Total Z.-Holland		110
ZLAND	77	0
Total Zeeland		0
NBRAB	51	33
	54	28
	56	49
	61	25
	62	17
	63	83
	69	33
	70	33
	71	33
	72	31
	73	21
	74	71
	75	31
	76	14
Total N.-Brabant		502

Table 3.6 (continued)

Pseudo-Prov.	Dist. No.	GW Extractable Amount (mcm/yr)	Pseudo-Prov.	Dist. No.	GW Extractable Amount (mcm/yr)
UTREC	39	12	LIMB	60	14
	41	44		64	26
	42	11		65	15
	44	14		66	15
				67	90
Total Utrecht		81		68	28
ZIJP	30	39	Total Limburg		188
Total Z.-IJpolders		39	Total Netherlands		1986

SOURCE: Eelco van Beek (DHL), who assigned GW extractable amounts to PAWN districts from information supplied by RID.

NOTE: Totals for N.-Holland, Z.-Holland, and Zeeland do not include GW from dune areas, because such GW is available only to DW companies (see Table 3.1).

(a) District 7 includes 4 mcm/yr reassigned from district 9 to cover industrial extractions in district 7; the change is legitimate as GW for both districts comes from the same GW source. The change prevents RESDM from aborting the run.

(b) District 23 includes 9 mcm/yr--6 from district 28 and 3 from district 29--to cover industrial extractions in district 23; the change is legitimate as GW for all 3 districts comes from the same source. The change prevents RESDM from aborting the run.

(c) The original GW extractable amounts assigned to districts 35 and 37 were zero. However, we found that industries in those districts do extract GW, probably from the dune area. Thus, we have arbitrarily given districts 35 and 37 GW quotas of 1.0 and 2.0 mcm/yr respectively, with a proviso that these two quotas remain unchanged when GW quotas everywhere are reduced to 0.25 of RID's estimates. These precautionary measures prevent RESDM from aborting its runs.

The various firms in a district are collapsed into a composite firm representing that district's entire industry. The long-run responses enabling such composite firms to continue to function with much less GW and/or less DW are expressed as industry vectors, each of which details the amounts of GW and DW needed by the industry, and the water-related costs of that use-pattern. The development of the 2 to 10 vectors in each district is described in detail in Vol. IV. In general, the vectors range from all GW and no extra DW at one end of the spectrum to very little or no GW and all or mostly extra DW at the other. Vectors that save GW--whether or not extra DW is used as partial replacement--typically cost more.

During the time we were engaged in validating RESDM, we were reminded that in the Netherlands the Biesbosch was supplying DW companies in

Z.-Holland with about 100 mcm/yr of SW. Yet preliminary runs using RESDM gave results that showed other SW projects being used in preference to the Biesbosch, the latter apparently supplying the most expensive and hence least desirable SW. Since we had not overstated its costs, we were forced to conclude that the Biesbosch water was preferred in the real world for several reasons that RESDM could not account for, three of which are: (1) The Biesbosch was built when model alternatives such as SPH and SMA were not yet in the picture; (2) RESDM allows all available GW to be extracted first before other sources of water are brought into play from further afield (in the real world, DW companies leave some GW for future expansion, so in the southwest, lowlands need the water from the Biesbosch); and (3) the Biesbosch water is of a superior quality when compared with that available from most other SW projects, and hence may have been preferred for that reason. Accordingly, in an effort to represent the long-run world more closely, we set a lower bound on extractions from the Biesbosch of 160 mcm/yr (an amount equal to its 1977 capacity). We regard this as an attempt at taking into account two of the three differences with the real world noted above. Thus, in every run we made, at least 160 mcm/yr was extracted from the Biesbosch. (Most of the time that water went to Z.-Holland, but in cases where more than 160 mcm/yr was taken, some of it was also distributed to other nearby provinces.)

3.4. OPERATION OF RESDM

RESDM is a computer-based linear-programming model that combines in one model the long-run responses of DW companies, as in RIDDWM, with those of industries to a series of GW-conserving strategies. Since both sectors draw on the same sources of (limited) GW, the model can find the least costly way of allocating the GW between, as well as geographically within, the sectors. Briefly, it minimizes the combined water-related costs of both sectors subject to the following four constraints:

- The available GW in each district (for industry) or pseudo-province (for DW companies) must not be exceeded.
- The capacity of any SW project must not be exceeded.
- Minimum GW requirements of industry in each district must be met.
- Total DW demands in each pseudo-province must be satisfied.

RESDM works as follows: if enough GW is available in a pseudo-province for DW companies to make DW entirely from it, as well as for all of industry's needs, then, because GW is the least expensive type of water, RESDM allows those amounts of GW to be extracted in that pseudo-province.

However, if less GW happens to be available than the two sectors together would ideally require, the model chooses the least costly of the following three sets of possibilities:

1. Giving DW companies in a pseudo-province all the GW they require, but industry less than it would ideally like. Industry has options (in RESDM) of simply using less GW (by recirculating it), or of replacing some or all of the GW saved by DW (both at higher cost). Those options form part of the data base in RESDM, and for each composite industry include a range encompassing (a) all the GW it would like, and (b) the minimum GW it needs in order to continue operating.
2. Giving industry all the GW it can use, but DW companies less than they would ideally like. DW can be produced from a combination of GW and treated SW, or even from SW alone (these options are possible in RESDM; later, we discuss the implications for public health of using large amounts of SW). As for industry, using other sources of water increases costs, yet such options are feasible when GW is scarce.
3. Causing both DW companies and industry to choose responses that require less GW and in most cases more SW, at higher costs.

RESDM chooses the least costly set of options in each pseudo-province and district without violating any constraint. The last set of possibilities above is the one that RESDM most often chooses because, for many of the cases analyzed, there is not enough GW to go around. For details of the validation of RESDM, we refer the reader to Vol. IV.

3.5. RESDM INPUTS AND OUTPUTS

In this section, we summarize the inputs required by, and the outputs obtained from, RESDM. The program listing and inputs are presented and described in detail in App. B of Vol. IV, and the output listing is presented and fully described in App. C, also of Vol. IV. In both appendixes, the listings presented and described are for the basic case, run 1 (which we discuss in Sec. 4.1.1 of this volume).

The input to RESDM can be thought of as being in two parts--(1) a basic set of data that usually does not change from run to run, and that includes all the capacity and cost data for GW sources, the SW projects, and the transportation links, as well as all the industry vectors; and (2) the "case" data set which is tailored to each run, and includes the DW demands, GW extractable amounts, GW charges, and the industrial-production growth rates. Table 3.7 summarizes the inputs required for a RESDM run.

The outputs can also be thought of as being in two parts--First, there is the standard output from the linear program. This consists of the final value of the objective function, a tabulation of the responses of industries (by district) and DW companies (by pseudo-province) to

Table 3.7

SUMMARY OF RESDM INPUTS

RIDDWM Portion (by Pseudo-Province)	IRSM Portion (by District)
"Basic" Input Data	
• GW-extraction costs • SW-project capacities • SW-extraction and -transportation costs • DW-transportation costs	• 260 industry vectors: - 2-10 for each district - Only 59 of 77 districts contain firms that are appreciable users of GW - Districts mapped into pseudo-provinces
"Case" Input Data	
• "Basic" DW demand • GW extractable amounts by pseudo-province (includes GW from dunes)	• GW extractable amounts for districts in model • Industrial-production growth rates, appropriate for context • GW charges, imposed on appropriate sector

NOTE: GW extractable amounts entered by district act as constraints on industry in those districts, while the extractable amounts by pseudo-province--which include GW from the dunes in N.-Holland, Z.-Holland, and Zeeland--act as constraints on DW companies.

whatever quotas or taxes were imposed on GW extractions, and a "shadow price," calculated for each constraint in the model, which tells the amount by which the objective function value would be reduced if that constraint were relaxed by one unit (e.g., by 1 m^3 if the constraint limited the amount of GW that could be extracted). The second part of the output consists of a number of tables that summarize the standard output just described. The supplementary tables are:

DW Balance: Shows for each pseudo-province that the DW supply equals the DW demanded.
Supply--shows the amounts of GW, SW, and DW that make up the supply;
Demand--shows the "basic" DW demand, the extra DW demanded by industry, and the DW shipped to other pseudo-provinces.

DW-Supply Costs: Shows for each pseudo-province the average unit costs for each type of water used in making DW, as well as average and marginal costs of supplying DW.

GW Balance: Shows how the available GW in each pseudo-province is allocated: how much is extracted by industry, how much by DW companies, and how much remains for agricultural and other uses. Also gives the GW shadow price in each pseudo-province.

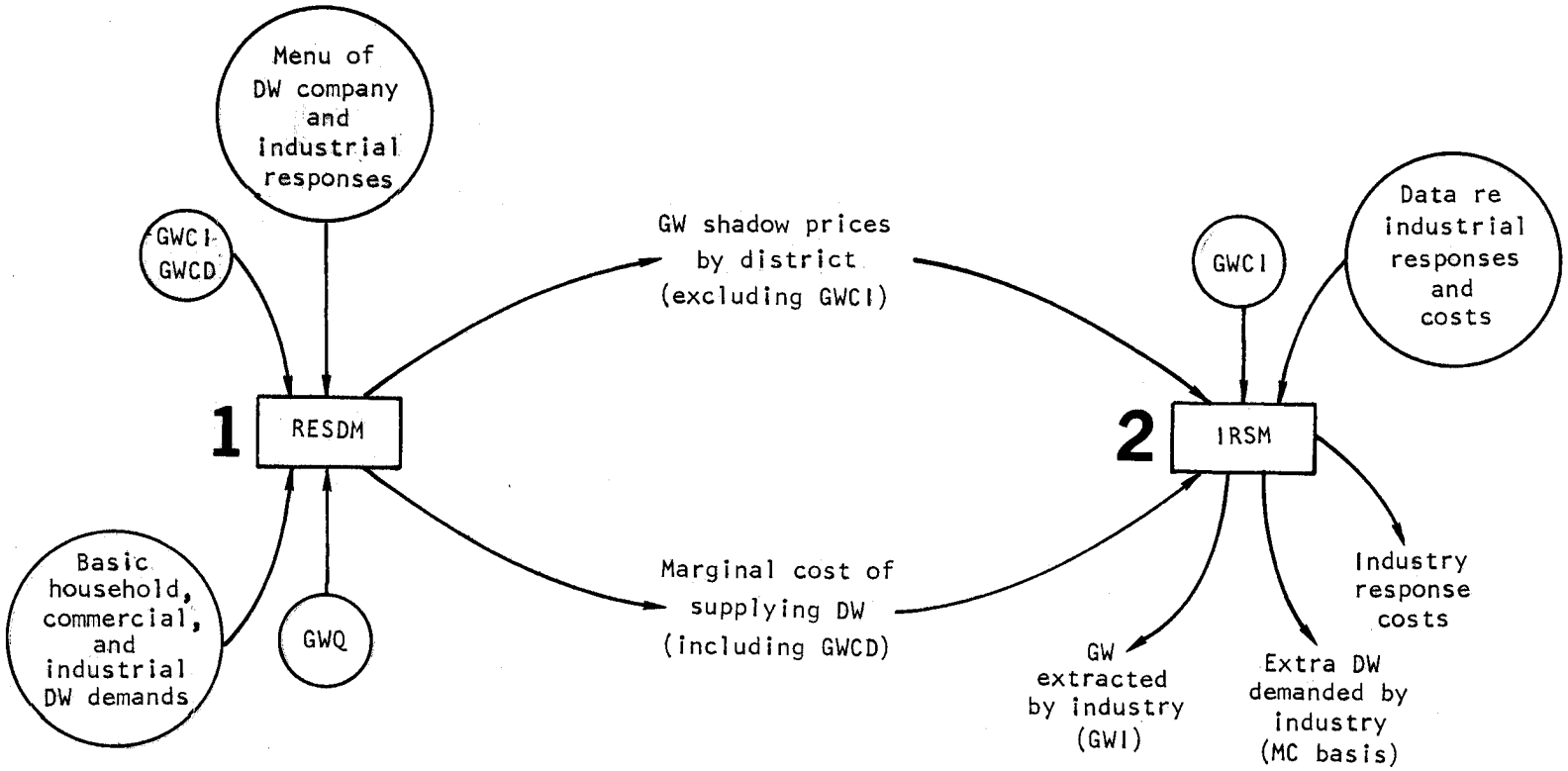
SW Extractions: Shows SW extracted from SW projects by node and by district in units of cubic meters/second (for use by the Distribution Model, see Vol. XI).

3.6. ANALYSIS PROCEDURE

Figure 3.2 illustrates the manner in which we used the models described above to carry out our analysis. For each case we first ran RESDM with the inputs appropriate to that case. We could have stopped there, since RESDM combines our other two models, IRSM and RIDDWM, and so estimates of all impacts can be obtained from RESDM. However, RESDM only approximates the impacts on industry as predicted by IRSM, so we ran IRSM as a second step. The inputs to IRSM were the marginal cost of supplying DW by pseudo-province, and the GW shadow prices by district, both of which are outputs from RESDM. The outputs from IRSM were revised estimates of response costs to industry, and GW and DW used by industry. Not only were these outputs slightly different from the analogous outputs from RESDM, they were presented for each industrial firm, rather than only on a district-by-district basis. Detailed impacts on industries are reported in Vol. VIII.

There was one rather tricky point involved in following a RESDM run by an appropriate IRSM run. The data on which IRSM was based did not separate DW use or cost by individual firms, so we could not simply replace the (nonexistent) DW prices in the calibration data with DW marginal production costs from RESDM. Instead, as explained in Vol. IV, we found estimates of actual DW production costs in 1977 (which should be close to those in 1976, the calibration year), and entered IRSM with differences between these and marginal production costs by pseudo-province from RESDM. This assumed that other components of DW prices, such as administrative costs and costs of local distribution, would not change.

We would have followed the run of IRSM by a run of RIDDWM. However, RIDDWM is entirely contained in RESDM, and the only reason there would be a different result from the original RESDM run would be the changes in the industrial GW and DW use effected by the IRSM run. Since these changes were trivial, when aggregated to pseudo-provinces, we omitted this step.



Notes: Numbers refer to order in which models are run.
Rectangles represent models.
Items circled represent model inputs (that do not come from other models).
Arrows denote information flow.
GWCI = groundwater charge to industry.
GWCD = groundwater charge to DW companies.
GWQ = groundwater quota.

Fig. 3.2--Procedure for using RESDM and IRSM in impact-assessment analyses

NOTES

1. Appendix A of Vol. IV explains the relationship between real and pseudo-provinces. Basically, the latter were created to avoid splitting up the PAWN districts that belonged in more than one province. Thus, although pseudo-provinces differ from real provinces in size--some are larger, some smaller--the impacts on the two are broadly equivalent. For example, if DW companies in the pseudo-province of Zuid-Holland need more GW than they can get, and must make it up by taking in SW from the Biesbosch and other sources, the same applies to the real province, except the absolute amounts may differ somewhat.
2. For analytical convenience during the PAWN study, the Netherlands was divided into 77 districts of various sizes. We define a district as an area small enough so that internal SW movements within it are unimportant from a water-management standpoint. (See also Vol. XII for a more detailed discussion.)
3. Among the options available to each composite industrial firm is one that gives the minimum amount of GW necessary to keep that composite industry at full production; any lesser amount would mean that one or more firms in the district would have to cut production. Our analysis is based on the assumption that no industrial production is to be cut due to a GW shortage; hence the model is constrained to give industrial firms at least their minimum GW requirements. (In practical terms, RESDM will not operate if the amount of GW available in a district is less than the amount specified in any option--another way of stating the above assumption.)
4. RID's version of RIDDWM operates with real provinces. We modified it for PAWN to operate with pseudo-provinces.
5. The DW included among the industrial responses is only the extra amount demanded to replace some or all of the GW saved. The DW ordinarily bought by industry as a matter of course, and included under the "basic DW demand," is not affected.

Chapter 4

IMPACT ASSESSMENT: CASES AND RESULTS

This chapter describes how we selected the cases to be analyzed and presents the results or impacts we obtained, together with our assessment of them.

4.1. SELECTION OF CASES

For purposes of impact assessment, we defined ten cases, which were given letter designations A, C, D, E, F, G, L, M, P, and Q. Although cases A-F differed in many ways, which are explained in Vol. I, they were identical as far as DW companies and their customers are concerned. Thus, for the purpose of this volume, the ten impact-assessment cases collapse into six distinct RESDM runs, which are numbered 1 through 6 in this volume. (In Vol. I, cases A-G are referred to as primary cases, while F, G, L, M, P, and Q form a series of GW cases, specifically designed to investigate the impacts of tactics to limit GW extraction on all parties--not just DW companies and their customers.) The correspondence between impact-assessment cases and RESDM runs is as follows:

Unique cases	A-F	G	L	M	P	Q
Run No.	1	2	3	4	5	6

In impact assessment, which is reported in Vol. I, case A is singled out as the base case, to which all others are referenced. There, most impacts of the other cases are expressed as differences from the base case. In the present volume, however, we have not differenced the impacts from case A (= run 1), and hence we have no real need to single it out as a base case.

The six runs all assume a 1990 context, with nominal DW demands as shown in Table 4.1. In this table, industry is assumed to have grown at the maximum rate projected by RID (see Vol. IV). For those seeking a correspondence between the runs in this volume and the runs in Vol. IV, run 1 is the same in each volume while run 6 in the present volume is the same as run 19 in Vol. IV. No other runs correspond.

In addition, all six runs jointly optimize over DW companies and industry. For theoretical reasons, this implies that industry behaves as though it must buy DW at a price equal to the marginal cost of DW production. (The marginal cost is the cost of producing one additional m^3 of DW.) Since households and commercial entities have constant demands in the model, theory says nothing about what price they may pay for DW, but we have assumed--and made financial calculations based upon the assumption--that all consumers of DW in all six runs pay a price based on the marginal production cost.

Table 4.1

1990 DW DEMANDS BY CONSUMER SECTOR

Pseudo-Province	Estimated 1990 DW Demand (mcm/yr), by Consumer Sector: Households and Commercial Entities	Industry	Total
Groningen	41.8	6.8	48.6
Friesland	51.6	15.3	66.9
Drente	32.7	5.9	38.6
Overijssel	83.9	14.4	98.3
Gelderland	153.1	29.7	182.8
Utrecht	65.2	7.1	72.3
Z.-IJpolders	20.0	--	20.0
N.-Holland	146.1	16.1	162.2
Z.-Holland	273.7	75.9	349.6
Zeeland	31.2	17.8	49.0(a)
N.-Brabant	191.8	32.6	224.4(a)
Limburg	96.8	17.5	114.3
Total	1187.9	239.1	1427.0

SOURCE: RID (average of high and low estimates for 1990 for real provinces).

NOTE: Data were adjusted for pseudo-provinces using Table A.1 of Vol. IV. Commercial entities include service and small business, public, agricultural, and recreational DW users, as well as leakage and unaccounted use. Figures may not add up exactly due to rounding.

(a) PAWN estimates the DW demand in Zeeland and N.-Brabant to be 15 and 10 mcm/yr higher, respectively, than RID's estimates. PAWN's estimates refer to semitreated water that industries in those provinces will need from the Biesbosch; RID's estimates had included only purified water.

(The price should be increased to cover the costs of distribution and overhead, which are not included in RESDM.) The marginal production cost will prove to be significantly higher than the average production cost, on which the price is currently based.

The six runs differ in three ways. First, different runs have different GW quotas. A GW quota of 1.0 corresponds to the RID estimates of extractable amounts, allotted among districts as shown in Table 3.6. A GW quota of 1.5 corresponds to extractable amounts 1.5 times those in Table 3.6, while a GW quota of 0.25 corresponds to extractable amounts one-fourth as large. Second, in some runs all parties could extract GW at the actual cost of digging wells, pumping, etc., while in other runs an additional tax or charge of 0.20 Dfl/m^3

was imposed on extractions by industry and agriculture. In no run was an additional charge imposed on DW-company extractions of GW. Third, the runs differed according to which group was given priority to extract GW. In runs where industry and DW companies have priority, they would extract all the GW they wished, up to the quota for that run, with the remainder available for agricultural extraction. In runs where agriculture had priority, it was allowed to extract the average amount of GW it would need, up to the quota for that run, and industry and DW companies were limited to extracting no more than was left. (We permit one exception to the priority scheme: currently installed GW sprinklers continue to operate, even if their extractions cause the quota to be violated. This rarely happens, and when it does, the quota is not violated by much.)

In order to extract more GW, agriculture must install more wells, for farmers have no economical means to transport water long distances from well to field for irrigation. We considered a number of agricultural scenarios involving different expansions of GW irrigation. Each scenario was defined by two factors: how much area was eligible for GW irrigation; and what fraction of the eligible area was equipped with irrigation systems (the GW-sprinkler intensity). The only way in which we altered the GW eligible area was to implement the so-called waterboard plans, which were plans to improve the distribution of SW so that new areas could be brought under SW irrigation. This affected the GW eligible area indirectly, because some of the farms newly supplied with SW were previously GW eligible; and to the extent that these farmers installed SW sprinklers, they had to be removed from the GW eligible area. The GW-sprinkler intensity, however, had to be adjusted so that agriculture would not extract more GW in the average year than was available to it in each district. How this adjustment was made is described in Vol. XIV. Later, Table 4.4 will show (for each run) the amounts of GW available to industry and DW companies in each pseudo-province. Table 4.2 summarizes the inputs for the six runs.

If the reader questions the many assumptions embedded in the RESDM model and wishes to see the additional runs comparing RESDM results to reality, or to investigate the sensitivity of results to assumptions, we direct his attention to Vol. IV. The runs in the present volume are devoted entirely to impact assessment.

4.2. IMPACTS

4.2.1. Impact Definitions

We compared the cases in terms of a list of impacts chosen to highlight the most important effects of case differences on DW companies and their customers. The impacts selected were:

- The amounts of GW and SW used by DW companies, and the amount of DW produced.

Table 4.2

SUMMARY OF PAWN'S SIX GW CASES

Independent Variable	Variable "Value" by Case and Run: A-F 1	G 2	L 3	M 4	P 5	Q 6
GW quota	1.0	.25	1.0	1.0	1.0	1.5
GW extractable amounts (mcm/yr)	2038	510	2038	2038	2038	3057
GW charge on industry & agric. (Dfl/m^3)	0	0	.20	.20	0	0
GW priority	I/D	A	I/D	A	A	I/D
Waterboard plans	No	No	No	Yes	Yes	Yes
GW sprinklers	--	Low	--	High	High	--
DW-pricing scheme	MC	MC	MC	MC	MC	MC
DW demand (context)	1990	1990	1990	1990	1990	1990
Industrial-production growth rates	High	High	High	High	High	High

NOTE: Cases A-G are primary cases; case F and all cases in other columns are GW cases. Blanks in table denote the current number of GW sprinklers already in use; MC = marginal cost.

- The amounts of DW demanded by industry and by households and commercial entities. (Commercial entities include service and small business, public, agricultural, and recreational DW users, as well as leakage and unaccounted use.) Household and commercial-entity use by pseudo-province is an input to the model and is not changed during a model run. A nominal industrial demand for DW is also an input, but in the model, industry can respond to DW price changes or other factors by changing its DW consumption.
- The amounts of DW shipped between DW companies, i.e., produced in one pseudo-province but consumed in another.
- The percentage of GW in DW, which we view as a proxy measure of DW quality. GW generally has higher quality and lower salinity than SW, and hence is favored for reasons of public health as a source of DW. We realize that GW from different locations has different quality, as does SW (e.g., Maas water is much less saline than Rijn water), and that our proxy measure of quality is therefore quite crude. However, to calculate more sophisticated measures would have required a separate, complex study.
- The number of SW facilities (e.g., reservoirs) that DW companies must build in order to meet the demand. These are called SW projects and are important because building them involves undesirable environmental impacts, as well as substantial financial costs.

- Average and marginal costs of supplying SW expressed as Dfl/m^3. The average cost is defined as the total cost divided by the number of cubic meters of DW supplied, while the marginal cost is the cost of supplying one additional cubic meter. These differ by pseudo-province, but can be combined into national averages. The marginal costs are shadow prices associated with certain of the constraints in RESDM and are calculated as a by-product of the standard linear-programming algorithm (the Simplex method) used in RESDM. The average costs are calculated by assigning the cost of producing each cubic meter of DW to the DW company that ultimately supplies it to an end user, and dividing the sum of these costs by the amount of water supplied. Note that these costs include the capital costs of any SW projects built, prorated to the water produced.
- Costs and revenues of DW companies. Costs are calculated as average cost per cubic meter of DW times the amount of DW produced, while revenues are calculated as marginal cost per cubic meter of DW (in the marginal-cost pricing cases) times the demand for DW. Costs and revenues can be calculated separately for industries and for households and commercial entities, and can be distributed across pseudo-provinces.
- GW shadow prices. These prices measure the amount by which industries and DW companies could reduce their combined costs if the amount of GW available were increased in each district by 1 m^3. There is one GW shadow price for each district; it is calculated as a by-product of the standard linear-programming algorithm (the Simplex method) used by RESDM.

4.2.2. Impacts on DW Production

If any of PAWN's primary or GW cases were ever actually realized, i.e., if any of those policies were implemented and their accompanying system and scenario assumptions were to hold, then many impacts would be felt throughout the various sectors of the Dutch economy. For example, realizing a case would affect the extractable amounts of GW, and hence DW companies' decisions as to how best to meet the demands for DW in various parts of the country. Those decisions would in turn affect the quality of DW they might produce and how much it might cost to produce it.

For the primary and GW cases, the major impacts aggregated for the country as a whole are given in Table 4.3. (The major policy variables for each run are given in Table 4.2.)

In Table 4.3, DW companies in the basic case are allocated just over 70 percent of the available GW. Their highest share (percentage of total GW extractions by industry, DW companies, and agriculture), around 80 percent, occurs in cases L and M at the same GW quota, when both industry and agriculture are charged .20 Dfl/m^3 for GW, causing them to cut down on their GW extractions, thus making more GW available for DW company use.

Table 4.3

IMPACTS OF PRIMARY AND GW CASES ON NATIONAL DW PRODUCTION

Impact	Impact Values by Case and Run					
	A-F	G	L	M	P	Q
	1	2	3	4	5	6
Total GW extracted by DW companies (mcm/yr)	1102	250	1128	1106	1081	1240
Total SW extracted by DW companies (mcm/yr)	330	1278	330	360	373	188
Total DW produced (mcm/yr)	1432	1528	1458	1466	1454	1428
Composition of DW (% GW)	77	16	77	75	74	87
DW companies' share of combined GW extractions (%)	71	60	80	81	74	72
No. of SW projects used	6	18	6	8	8	3
DW shipped among DW companies (mcm/yr)	50	31	50	46	52	96
GW shadow price (Dfl/m^3)	.06	.72	.06	.09	.11	.03
Marginal cost of supplying DW (Dfl/m^3) (a)	.51	.94	.50	.53	.55	.44
Average cost of supplying DW (Dfl/m^3) (a)	.42	.70	.41	.42	.42	.38

NOTE: The GW shadow price in a pseudo-province is the amount by which the objective function value in RESDM (total water-related costs for both sectors) would decrease if one more cubic meter of GW could be extracted in that district. The marginal cost of supplying DW is what it would cost to supply one more cubic meter of DW to, say, a pseudo-province. The average cost of supplying DW is the total production and transportation costs of the component GW, SW, and imported DW that go to make up the DW demanded in a particular jurisdiction (here, nationwide), divided by the amount of DW demanded. Cases A-G are primary cases; case F and all cases in other columns are GW cases. The last three impacts are weighted averages of all pseudo-province values, with weights taken to be the amounts of GW extraction (for the GW shadow price) or the amounts of DW supplied (for marginal and average cost) in each pseudo-province. Strictly speaking, only for the average cost does this weight make sense, but the procedure does yield representative values in the other cases. For consistency, costs have been adjusted to constant 1976 guilders.

(a) Excludes costs of distribution from DW company to end user.

Now, the pairs L and M, and A-F and P, each have GW-extraction priority given once to industry and DW companies and once to agriculture; but the former pair has GW charges imposed while the latter does not. Examining each pair shows that giving agriculture priority forces the GW extractions of DW companies to be reduced by about 20 mcm/yr (less than 2 percent); but imposing a GW charge to industry and agriculture (and not to DW companies) gives DW companies over 80 percent, as opposed to 71-74 percent, of the combined-sector GW extractions.

Comparing case Q with A-F shows that DW companies receive about 11 percent more GW in absolute terms, though roughly the same proportion of the combined-sector extractions as before. But when the GW quota is reduced to 0.25 (case G), both the absolute extractions and share of combined-sector extractions go down. DW companies' share goes down because RESDM must fulfill the constraint of meeting industry's minimum GW requirements before allocating any GW to DW companies. When GW is scarce, this requirement consumes a significant fraction of the extractable amount in many districts.

Table 4.4 shows, for each pseudo-province, the GW extractable amounts available to DW companies and industry, the GW extracted by DW companies, and their extractions as a percentage of the GW available. Several points need to be made here:

- Z.-IJpolders and Zeeland have no industry with any GW needs in the model, hence all their quota goes to DW-company use.
- In cases A-F and L, M, and P (GW quota of 1.5), the DW companies in Utrecht, N.-Holland, and Z.-Holland are allocated virtually all the GW available. Evidently RESDM has determined that it is less costly, in the face of very high DW demands in those provinces, to allocate most of the GW to DW companies.
- In case G (GW quota of 0.25 and priority for agriculture), the DW companies in Drente and Friesland are allocated a higher proportion of their pseudo-province's quota because of a dearth of SW projects nearby. By contrast, DW companies' shares drop sharply in the more industrialized provinces of Utrecht, N.-Holland, Z.-Holland, N.-Brabant, and Limburg, simply because DW companies have the option of obtaining more DW from nearby SW projects. The fact that no GW is available to DW companies in Limburg is due largely to prior agricultural extractions there, together with the low GW extractable amounts available.
- In case Q (GW quota of 1.5), the GW extractions of DW companies remain the same as they were in the basic case with the exception of the GW-short provinces of Utrecht, N.-Holland, Z.-Holland, and Zeeland, all of which extract more when it is available.

In general, therefore, DW companies' share of the extractable GW relative to industry's share goes up when the GW available to these two sectors is reduced. Note that the GW available to industry and DW companies can be reduced either by a reduction in GW quota, which reduces extractions by all sectors (DW companies, industry, and agriculture), or by giving agriculture priority over the others for GW extractions.

Table 4.4

IMPACTS OF PRIMARY AND GW CASES ON GW AVAILABLE TO DW COMPANIES AND GW EXTRACTIONS BY DW COMPANIES, BY PSEUDO-PROVINCE

Pseudo-Province	GW Avail (mcm/yr)	GW Extd by DWCos (mcm/yr)	% Extd	GW Avail (mcm/yr)	GW Extd by DWCos (mcm/yr)	% Extd	GW Avail (mcm/yr)	GW Extd by DWCos (mcm/yr)	% Extd
	Case A-F (Run 1)			Case G (Run 2)			Case L (Run 3)		
Groningen	88	49	55	22	13	58	88	49	55
Friesland	134	67	50	33	30	90	134	67	50
Drente	157	39	25	36	27	75	157	39	25
Overijssel	195	98	50	42	28	67	195	99	51
Gelderland	463	187	40	94	55	59	392	194	50
Utrecht	81	76	94	19	15	78	81	77	95
Z.-IJpolders	39	39	100	9	9	100	39	39	100
N.-Holland	62	59	95	15	12	79	62	59	96
Z.-Holland	123	116	95	31	24	79	123	119	97
Zeeland	6	6	100	2	2	100	6	6	100
N.-Brabant	502	252	50	84	36	43	502	272	54
Limburg	188	114	61	30	0	0	188	114	61
Netherlands	2038	1102	54	417	250	60	2038	1128	55
	Case M (Run 4)			Case P (Run 5)			Case Q (Run 6)		
Groningen	85	49	57	82	45	57	132	49	37
Friesland	124	67	54	112	67	60	201	67	33
Drente	150	39	26	126	42	34	236	39	16
Overijssel	154	99	65	133	105	79	293	98	34
Gelderland	392	194	50	362	200	55	695	183	26
Utrecht	77	72	95	76	72	95	122	106	88
Z.-IJpolders	39	39	100	39	39	100	59	59	100
N.-Holland	62	59	96	60	57	95	93	90	97
Z.-Holland	123	119	97	123	116	95	185	178	96
Zeeland	6	6	100	3	3	100	9	9	100
N.-Brabant	429	272	64	404	255	63	753	249	33
Limburg	133	91	69	121	80	66	282	114	41
Netherlands	1773	1106	62	1640	1081	66	3057	1240	41

SOURCE: GW extractable amounts for runs 1 and 3 from RID for real provinces (adjusted by PAWN for pseudo-provinces); for run 6 they have been multiplied by 1.5; for runs 4 and 5, prior agricultural extractions have been subtracted from them; and for run 2, they have been divided by 4 and had prior agricultural extractions subtracted from them. See Vol. XIV for details.

NOTE: All figures have been rounded to the nearest whole mcm/yr or percentage, so totals may not add up exactly. Cases A-G are primary cases, and case F and all cases in other columns are GW cases.

The demand for DW that DW companies face in the primary and GW cases is made up of two components, as shown in Table 4.5. First, there is the basic DW demand estimated for 1990 (from households, commercial entities, and industry), and second, the extra DW demanded by industry for its long-run responses to the tactics in each case. Industry demands extra DW typically when it is charged for using GW, or when its GW supplies are restricted, or when agriculture's prior use leaves it less than it would like. It demands the most extra DW in case G when the GW quota is one-quarter and agriculture has priority; even then, the increase in the total DW demanded is no more than 7 percent.

Table 4.5

DW DEMANDED IN RESPONSE TO PRIMARY AND GW CASES

	Impact Values by Case and Run					
	A-F	G	L	M	P	Q
Impact	1	2	3	4	5	6
1990 DW demand estimated by RID (mcm/yr), other than industry	1188	1188	1188	1188	1188	1188
DW demanded by industry's responses (mcm/yr)	244	340	269	278	267	240
Total DW demand (mcm/yr)	1432	1528	1457	1466	1455	1428

NOTE: Cases A-G are primary cases; case F and all cases in other columns are GW cases.

DW companies that face larger DW demands than they can supply with GW must make up the difference from some other source. Sometimes, excess GW can be shipped in (bought) from a neighboring province. When a shortfall still exists, then DW companies must use treated SW from one of the SW projects. Tables 3.2 and 3.4 present data about the SW projects that are available to DW companies in the long run, and Table 4.6 presents the extractions made from each SW project for the primary and GW cases. The huge shortfall in case G, caused not only by the severe restriction in the GW extractable amounts but also by the 7 percent increase in the demand for DW by industry, requires 1,278 mcm/yr of SW from 18 projects, fully 10 projects more than for any other case. In contrast, the larger amounts of GW available in case Q (1.5 GW quota) mean that only three SW projects are used (one of which is the Biesbosch, which we decided should always be used to its 1977 capacity in every RESDM run; see Vol. IV).

The quality of DW is an important issue for the Dutch people, so is taken seriously by both the DW companies themselves and by those in the government charged with monitoring it. However, RIDDWM (and thus RESDM) does not explicitly deal with the question of DW quality; it has no way of taking into account the attribute of taste or other health effects on the population at large, and to

Table 4.6

SW PROJECTS AND EXTRACTIONS REQUIRED IN RESPONSE TO PRIMARY AND GW CASES

SW Project	SW Extractions (mcm/yr) by Case and Run					
	A-F 1	G 2	L 3	M 4	P 5	Q 6
SLT Spaarbek. Lettelbert	--	50*	--	--	--	--
STW Spaarbek. Twente	--	57*	--	--	--	--
SMW Spaarbek. Maas/Waal	--	100*	--	--	--	--
SYS Spaarbek. Ysselmeer	--	44	--	--	--	--
SZF Spaarbek. Z.-Flevoland	--	69	--	--	--	--
SBB Spaarbek. Biesbosch	160+	200	160+	160+	160+	160+
SMA Spaarbek. Markiezaat	--	31	--	--	--	--
SBR Spaarbek. Braakman	16*	16*	16*	16*	16*	16*
SIB Spaarbek. Itteren/ Borgharen	--	51	--	--	--	--
GHP Grindgat Heel/Panheel	--	50*	--	0	12	--
DNH Duininfiltratie Noord-Holland	21	90	20	25	28	--
DZH Duininfiltratie Zuid-Holland	23	110*	23	23	23	--
OGL Oevergrondwater Lek	50*	50*	50*	50*	50*	12
OGM Oeverinfiltratie Maas	--	50*	--	--	--	--
OGR Oevergrond. Roosteren	--	25*	--	25*	25*	--
PLW Plassen. Amsterdam	60*	60*	60*	60*	60*	--
IVE Infiltratie Veluwe	--	205	--	--	--	--
IGH Infiltr. Groot Heide	--	20*	--	--	--	--
Total SW Extracted	330	1278	330	360	373	188
Total Number of SW Projects Required	6	18	6	8	8	3

NOTE: Cases A-G are primary cases; case F and all cases in other columns are GW cases. Only two SW projects are not required in response to primary and GW-case policies--SPH (Spaarbekken Philipsland) and OPA (Oppervlaktewater Andijk). (OPA has relatively high transportation costs in the model which accounts for its not being used, even though it is currently used in the real world.) Blanks in the table denote the SW project is not required for that particular case; entries are rounded to the nearest whole mcm/yr.

* Extraction equals maximum capacity of SW project.

\+ 160 mcm/yr represents forced extraction from the Biesbosch.

have included them would have required a separate and complex study. Yet we have accounted for quality in a small though admittedly crude way. Since DW can be composed of GW and SW, and since the overwhelming preference is for GW because of its purity and taste, we use "percent of GW contained in DW" or "composition" as a proxy

measure for DW quality. When that percentage is 100 percent, DW is composed entirely of GW.

In fact, the DW associations in the Netherlands--VEWIN, RID, and the Ministry of Public Health and Environment--argue that this measure of DW quality is too crude. They state that there are large differences in quality between different SW supplies--e.g., Rijn versus Maas--and even between different GW sources. In addition, they think the risk of service interruptions should be incorporated as a public health consideration. It is therefore unfortunate that time and resource limitations prevented further analyses of these issues in PAWN, forcing us into the use of only our crude water-quality proxy, the percent of GW in DW.

Of the six GW cases, case Q requires the least amount of SW (see Table 4.3), from which we infer that the average quality of the DW produced is highest. Following the same logic, the quality of the DW produced in case G is the least desirable because the supply of GW has been severely restricted in that case, and about 4 times the SW of cases A-F was needed to make up the shortfall. In the other cases, on average, the DW produced is composed of three parts of GW to one of SW.

Table 4.7 shows the composition of the DW produced in each pseudo-province for the six GW cases. In most provinces for most of the cases, the DW consists entirely of GW; the two exceptions are:

- When GW quota is 0.25 and agriculture has priority (case G), every province must supplement its GW with either SW or imported DW (itself containing much SW). Limburg particularly must produce DW made entirely from SW, and N.-Holland, Z.-Holland, and Zeeland also use SW predominantly.
- When GW quota is 1.0, three provinces--N.-Holland, Z.-Holland, and Zeeland--must use large proportions of SW in DW because their supplies of GW are naturally insufficient. In case Q, Z.-Holland and Zeeland must still use SW in their DW, the former principally because it is forced in the model to draw SW from the Biesbosch.

DW companies in the real world may, as we discussed earlier in Sec. 2.1.3, need to arrange transportation of GW from points farther afield if the productive capacity of current wells cannot be increased or if for any reason their output is suddenly restricted. In RIDDWM (and RESDM), shipping GW between provinces is not an option; rather, DW is shipped from those provinces able to produce more than they require to others who cannot meet their demands. The criterion for such transshipments, of course, is whether buying such "imported" DW is the least-costly alternative available to a province.

Table 4.7

IMPACTS OF PRIMARY AND GW CASES ON DW COMPOSITION, BY PSEUDO-PROVINCE

	DW Composition (% GW) by Case and Run					
Pseudo-Province	A-F 1	G 2	L 3	M 4	P 5	Q 6
Groningen	100	20	100	100	100	100
Friesland	100	40	100	100	100	100
Drente	100	75	100	100	100	100
Overijssel	100	31	100	100	100	100
Gelderland	100	21	100	100	100	100
Utrecht	100	20	100	100	100	100
Z.-IJpolders	100	46	100	100	100	100
N.-Holland	50	7	51	48	47	100
Z.-Holland	33	7	34	34	33	51
Zeeland	67	3	67	67	67	67
N.-Brabant	100	15	100	100	100	100
Limburg	100	0	100	100	100	100
Netherlands (average)	77	16	77	75	74	87

NOTE: Cases A-G are primary cases; case F and all cases in other columns are GW cases. Figures in this table are based only on DW produced in, rather than supplied to, each pseudo-province, and hence exclude the GW contained in DW transported between pseudo-provinces.

Table 4.8 presents more details about which provinces export and import DW for the primary and GW cases. Several points are worth noting:

- Case G is the only one where the DW shipped contains any SW, reflected also in higher production costs.
- In case G, note also that no DW is shipped to the south-lowlands provinces (N.-Holland, Z.-Holland, and Zeeland) which traditionally are short of GW and face high DW demands. The reason simply is that it is less expensive to use SW from nearby sources than to import DW. On the other hand, it is less expensive for Overijssel to import DW from Gelderland because SW projects are even farther away. In the model, Drente does not have direct access to any SW project and so has no choice other than to buy DW from its neighbors Groningen and Friesland in order to meet its DW demand.
- Zeeland buys DW from N.-Brabant in 5 cases. Even though the transportation cost is relatively high, its only alternative is water from the Biesbosch, which costs more to withdraw and to transport. N.-Brabant is blessed with an excess of GW compared to its DW demand in these five cases.

- In case Q, N.-Holland and Zeeland both elect to buy DW rather than make up the demand deficit with SW, because the DW that is shipped is all GW, and much less expensive than SW from any nearby source. The same might be true for Z.-Holland if it weren't for the fact that we have constrained it to take in SW from the Biesbosch.

Table 4.8

INTERPROVINCIAL SHIPMENTS OF DW IN RESPONSE TO PRIMARY AND GW CASES

	Interprovincial Shipments of DW					
Case & Run	From	To	Quantity (mcm/yr)	Composition (% GW)	Prodn. Cost (Dfl/m^3)	Transp. Cost (Dfl/m^3)
A-F, 1	UT	NH	3.8	100	.32	.38
	ZP	NH	19.0	100	.30	.35
	NB	ZE	27.0	100	.30	.53
			49.8			
G, 2	GR	DR	8.4	20	.67	.15
	FR	DR	6.5	40	.90	.31
	GE	OV	16.4	21	.62	.53
			31.3			
L, 3	UT	NH	4.4	100	.32	.38
	ZP	NH	19.0	100	.30	.35
	NB	ZE	27.0	100	.30	.53
			50.4			
M, 4	UT	NH	0.03	100	.32	.38
	ZP	NH	18.5	100	.30	.35
	NB	ZE	27.0	100	.30	.53
			45.5			
P, 5	DR	GR	3.6	100	.30	.15
	GE	UT	0.3	100	.30	.32
	ZP	NH	18.5	100	.30	.35
	NB	ZE	29.7	100	.30	.53
			52.1			
Q, 6	UT	NH	34.0	100	.30	.38
	ZP	NH	38.5	100	.30	.35
	NB	ZE	24.0	100	.30	.53
			96.5			

NOTE: Cases A-G are primary cases; case F and all cases in other columns are GW cases. The production cost of DW that contains 100 percent GW is equal to the extraction cost of GW in those provinces. All costs have been adjusted to 1976 guilders using a 6.4 percent deflation factor. The DW composition figures in the table refer to DW produced, not DW supplied.

Averages of the GW shadow prices are shown in Table 4.3. Once one knows that a shadow price rises or falls more or less in proportion to how that particular commodity is valued by a user (and a needed resource that is scarce is valued very highly), then those average shadow prices for GW in Table 4.3 convey little additional information. The extreme shortage of GW in case G and its relative abundance in case Q result in the very high and low GW shadow prices, respectively. What is more interesting--and significant--is how GW is valued in different parts of the country for each of the cases. The GW shadow prices by pseudo-province are given in Table 4.9, and reveal a pattern also found in other tables that give a breakdown by pseudo-province: the impact of the six cases on the five lowlands provinces in the west and southwest is substantially different from virtually all other provinces.

Table 4.9

IMPACTS OF PRIMARY AND GW CASES ON GW SHADOW PRICES, BY PSEUDO-PROVINCE

	GW Shadow Price (Dfl/m^3) by Case and Run					
	A-F	G	L	M	P	Q
Pseudo-Province	1	2	3	4	5	6
Groningen	0	1.17	0	0	.15	0
Friesland	0	1.01	0	0	0	0
Drente	0	1.32	0	0	0	0
Overijssel	0	.93	0	0	.09	0
Gelderland	0	.40	0	0	0	0
Utrecht	.16	.67	.16	.16	.30	0
Z.-IJpolders	.21	.42	.21	.21	.21	.05
N.-Holland	.54	.54	.54	.54	.54	.38
Z.-Holland	.45	.52	.45	.45	.45	.31
Zeeland	.51	.67	.51	.51	.51	.51
N.-Brabant	0	.70	0	0	0	0
Limburg	0	.63	0	.36	.36	0
Netherlands (average)	.06	.72	.06	.09	.11	.03

NOTE: Cases A-G are primary cases; case F and all cases in other columns are GW cases. The GW shadow price in a pseudo-province is the amount by which the objective function value in RESDM (total water-related costs for both sectors) would be reduced if one more cubic meter of GW could be extracted in that pseudo-province. The GW shadow prices shown for each pseudo-province are averages of the district values and have been adjusted to 1976 guilders using a 6.4 percent deflation factor and rounded to the nearest cent.

GW shadow prices move from zero to a positive value just when more GW is required than is available, and the shadow price reflects the value placed on GW by the user who would benefit most from obtaining one more

cubic meter. In Table 4.9, there are two distinct situations where GW is short:

- In case G, where the extractable amounts are restricted, the shadow prices everywhere are higher than the basic case except in N.-Holland. The GW shadow prices in Groningen, Friesland, Drente, Overijssel, and N.-Brabant, are higher than in the three western provinces because alternatives to GW are more costly. This is due to the fact that the nearest SW projects are more distant, hence transportation costs are higher.
- In cases A-F, L, M, and P, five lowlands provinces in the west and southwest are short of GW: Utrecht, Z.-IJpolders, N.-Holland, Z.-Holland, and Zeeland. Even in case Q, where more GW is available, the latter four are still short. In Table 4.9, Limburg shows fairly high GW shadow prices for cases M and P where the GW left over for DW-company and industry use has been reduced by prior agricultural withdrawals. Agriculture's influence is very much felt in Limburg because farmers need more GW there, and the sensitivity to that demand is reflected in the higher GW shadow price. For Groningen and Overijssel in case P, the quotas are insufficient for DW companies, owing to the GW priority given agriculture and the lack of a GW charge on industry and agriculture; however, in case M the same GW quota is sufficient for DW companies even though agriculture still gets priority. The GW charge on both industry and agriculture and on industry alone makes the difference.

A similar pattern appears in Table 4.10, which shows the impacts of the primary and GW cases on the marginal cost of supplying DW in each pseudo-province. The marginal cost of supplying DW is highest for every province in case G, but particularly high for Drente, which has no direct access to any SW project and must transport very costly DW over long distances to help meet its DW demand. The low GW quota in case G has no apparent effect on the marginal cost of DW in N.-Holland because the last m^3 is produced expensively from SW in all cases. In cases other than G, the western and southwestern lowlands provinces again register marginal costs higher than other provinces do (the exceptions--Groningen and Overijssel in case P and Limburg in cases M and P--are explained again by the fact that GW is made more scarce due to prior withdrawals by agriculture in cases M and P). Note finally that when DW consists entirely of GW that is not imported, the marginal cost of producing DW is equal to the cost of extracting, treating, and transporting GW.

Because DW companies in the Netherlands in fact base their DW prices on historical costs, we show in Table 4.11 a breakdown by pseudo-province of average unit DW-supply costs for the six GW cases. Wherever sufficient GW can be obtained for a pseudo-province from within its own borders, the average unit cost equals that for GW, i.e., 0.30 Dfl/m^3 in

Table 4.10

IMPACTS OF PRIMARY AND GW CASES ON MARGINAL COSTS OF SUPPLYING DW, BY PSEUDO-PROVINCE

	Marginal Cost of Supplying DW (Dfl/m^3) by Case and Run					
	A-F	G	L	M	P	Q
Pseudo-Province	1	2	3	4	5	6
Groningen	.30	1.47	.30	.30	.45	.30
Friesland	.30	1.31	.30	.30	.30	.30
Drente	.30	1.62	.30	.30	.30	.30
Overijssel	.30	1.23	.30	.30	.39	.30
Gelderland	.30	.71	.30	.30	.30	.30
Utrecht	.48	.99	.48	.48	.62	.32
Z.-IJpolders	.51	.72	.51	.51	.51	.35
N.-Holland	.86	.86	.86	.86	.86	.70
Z.-Holland	.77	.84	.77	.77	.77	.63
Zeeland	.83	.99	.83	.83	.83	.83
N.-Brabant	.30	1.00	.30	.30	.30	.30
Limburg	.30	.72	.30	.66	.66	.30
Netherlands (average)	.51	.94	.50	.53	.55	.44

NOTE: Cases A-G are primary cases; case F and all cases in other columns are GW cases. Figures in this table have been adjusted to 1976 guilders using a 6.4 percent deflation factor and have been rounded to the nearest cent. The marginal cost of supplying DW in a pseudo-province is what it would cost if one more cubic meter of DW were supplied to that pseudo-province.

1976 guilders (0.32 Dfl/m^3 in Utrecht, N.-Holland, Z.-Holland, and Zeeland). (Differences among provinces are due to differing transport costs. See Table 3.3.) For all six cases, the average unit cost for DW rises above that for GW in N.-Holland, Z.-Holland, and Zeeland, accounting for the SW and sometimes the imported DW included in the mix. For the GW-restricted case G, the unit costs are also higher, by now a familiar pattern. Later, we shall see that the difference between these average unit costs of supplying DW and the higher marginal costs at which the DW is sold to consumers in RESDM accounts for the positive monetary surpluses that accrue to DW companies. Such surpluses are inevitable when revenues are based on the higher marginal costs necessitated by an optimal allocation program.

Table 4.11

IMPACTS OF PRIMARY AND GW CASES ON AVERAGE COSTS OF SUPPLYING DW, BY PSEUDO-PROVINCE

	Average Cost of Supplying DW (Dfl/m^3) by Case and Run					
	A-F	G	L	M	P	Q
Pseudo-Province	1	2	3	4	5	6
Groningen	.30	.67	.30	.30	.31	.30
Friesland	.30	.90	.30	.30	.30	.30
Drente	.30	.55	.30	.30	.30	.30
Overijssel	.30	.68	.30	.30	.30	.30
Gelderland	.30	.62	.30	.30	.30	.30
Utrecht	.32	.85	.32	.32	.32	.32
Z.-IJpolders	.30	.53	.30	.30	.30	.30
N.-Holland	.59	.77	.59	.60	.60	.48
Z.-Holland	.63	.75	.63	.63	.63	.56
Zeeland	.74	.88	.74	.74	.77	.71
N.-Brabant	.30	.71	.30	.30	.30	.30
Limburg	.30	.64	.30	.33	.36	.30
Netherlands (average)	.42	.71	.41	.42	.42	.38

NOTE: Cases A-G are primary cases; case F and all cases in other columns are GW cases. Figures in this table have been adjusted to 1976 guilders using a 6.4 percent deflation factor and have been rounded to the nearest cent. The average cost of supplying DW in a pseudo-province is the weighted average of the total production and transportation costs of the component GW, SW, and imported DW that go to make up the DW supplied in that pseudo-province (distribution costs to the final user are excluded).

4.2.3. Gross Financial Impacts on DW Companies

In this section, we explore the financial impacts of the primary and GW cases on DW companies. Table 4.12 presents, for each case and for the Netherlands as a whole, DW companies' costs for supplying DW and their revenues from selling it. The cost of supplying DW is calculated as the average cost (Table 4.11) for the entire Netherlands, multiplied by the amount supplied (Table 4.3 or 4.5). The revenues are calculated as the product of the marginal cost (Table 4.10), averaged for the entire Netherlands, and the amounts of DW consumed by industry and by others (Table 4.6). The net surplus is the revenue minus the cost.

Revenues from industry are identified separately in Table 4.12 because the DW demanded by industry differs in each case, whereas household and commercial demand is constant. Overall, revenues from industry account for between 17 and 22 percent of all DW company revenues; the adjustments industry makes in coping with less GW has very little financial impact on DW companies.

Table 4.12

GROSS FINANCIAL IMPACTS OF PRIMARY AND GW CASES ON ALL DW COMPANIES

Impact	Impact Values (Dflm/yr) by Case and Run					
	A-F	G	L	M	P	Q
	1	2	3	4	5	6
Cost of supplying DW	616	1095	624	630	634	572
Revenues:						
from households and commercial entities	604	1108	602	634	657	531
from industry	124	320	135	147	147	106
Total revenues	728	1428	737	781	804	637
Net surplus to DW Cos.	112	333	113	151	170	65

NOTE: Cases A-G are primary cases; case F and all cases in other columns are GW cases. Both costs and revenues shown here have been adjusted to 1976 guilders using a 6.4 percent deflation factor, and have been rounded to the nearest Dflm/yr. Commercial entities are defined in note to Table 4.1. Costs do not include local distribution and overhead.

As anticipated, revenues at marginal-cost prices exceed costs of supplying DW in every case because sales are made at marginal-cost rates and marginal costs are higher than average costs in every case. The magnitude of the surplus is higher the scarcer the GW: it is highest for case G and lowest for case Q (.25 and 1.5 quota, respectively; see Table 4.2); and higher for cases M and P than for cases A-F and L because agriculture has been given priority in extracting GW, effectively diminishing the GW quota.

Table 4.13 shows how the DW-company surpluses for each case are distributed among the pseudo-provinces. Again, we find the same pattern of higher surpluses wherever a shortage of GW exists. The surpluses are larger here because the marginal costs of supplying DW--in effect the sales price of DW in the model--increases much faster than the average costs of supplying the DW.

In reporting large surpluses for DW companies in these cases, we wish to emphasize that we do not advocate either the adoption of pricing policies based on marginal costs, or the realization of net surpluses. The net surpluses are simply a natural consequence of these policies when DW prices are based on marginal costs. Such net surpluses could be put to a variety of uses; in Vol. X, for example, it is assumed that surpluses are passed on to the government and used to reduce taxes.

Table 4.13

NET SURPLUSES OF DW COMPANIES FOR PRIMARY AND GW CASES, BY PSEUDO-PROVINCE

	Net Surplus of DW Companies (Dflm/yr) by Case and Run					
Pseudo-	A-F	G	L	M	P	Q
Province	1	2	3	4	5	6
GRON	0	43.3	0	0	6.7	0
FRIES	0	27.2	0	0	0	0
DREN	0	44.6	0	0	0	0
OVER	0	56.0	0	0	9.0	0
GELD	0	21.1	0	0	0	0
UTREC	11.6	9.6	11.6	11.6	21.7	0
ZIJP	4.1	3.9	4.1	4.1	4.1	0.9
NHOLL	43.0	13.2	43.1	42.2	41.6	35.6
ZHOLL	49.0	30.3	50.0	50.0	49.0	22.1
ZLAND	4.4	4.9	4.4	4.4	3.1	5.9
NBRAB	0	68.5	0	0	0	0
LIMB	0	10.8	0	38.3	34.4	0
NEDERLD	112.0	333.4	113.3	150.7	169.6	64.6

NOTE: Cases A-G are primary cases; case F and all cases in other columns are GW cases. Net surpluses are total revenues (from sales of DW at prices based on marginal costs) minus total costs of supplying DW (based on average unit costs). Where the surplus is zero, marginal costs equal average costs of supplying DW. All figures have been adjusted to 1976 guilders using a 6.4 percent deflation factor.

4.3. SUMMARY OF IMPACTS

In this section, we summarize the impacts of PAWN's primary and GW cases on DW companies, specifically on their DW production and their overall costs, as computed by the model RESDM. In so doing, we will describe briefly the results of cases A-F first, then relate the impacts of the other cases to them. Then, we describe a consistent distributional effect we observed in every case we ran. Some implications of these results are discussed in Chap. 5.

4.3.1. National Impacts

Cases A-F assume a GW quota of 1.0, no charges imposed on GW use, priority for GW extraction given to industry and DW companies, no waterboard plans implemented, 1990 DW-demand estimates, high industrial-production growth rates, and DW prices based on marginal costs. We summarize the principal results below.

DW companies and industry together extract 70 percent of the GW available in the Netherlands, based on RID's estimates; of that amount, DW companies extract 71 percent (but a high 95-100 percent in five western lowlands provinces--Utrecht, N.-Holland, Z.-IJpolders, Z.-Holland, and Zeeland). The DW supplied contains 77 percent GW and 23 percent SW; the SW is drawn from six SW projects--three that existed in 1977 (the Biesbosch and the two dune-infiltration plants in N.-Holland and Z.-Holland), two that would have to be expanded (the reservoir at Braakman and the treatment facility near Amsterdam), and one that would need to be built (a riverbank infiltration plant at Lek). Only three provinces--N.-Holland, Z.-Holland, and Zeeland--produce DW that has any SW in it, and so use all the 330 mcm/yr of SW that is extracted.

We have interpreted the RESDM output as if DW were priced in each pseudo-province at its marginal cost of production. For cases A-F marginal costs exceed average costs only in the five western lowlands provinces, enough to create a .09 Dfl/m^3 difference in the national figure (.51 marginal to .42 average). Whenever the marginal-cost selling price exceeds the average-cost production price, the DW company will register a surplus. In cases A-F, the cost of supplying 1432 mcm/yr in 1990 is 616 Dflm/yr (in 1976 guilders), their revenues are 728 Dflm/yr, giving a surplus of 112 Dflm/yr. (We remind readers we are not concerned here with whether surpluses are appropriate or how the monies might be used or distributed.)

In the following summary, we compare the results of cases G, L, M, P, and Q with those of A-F.

A GW charge of .20 Dfl/m^3 imposed on industry and agriculture (case L) has virtually no impact at a GW quota of 1.0. Although slightly more DW is produced, its quality remains unchanged. Also unchanged are the GW shadow price, marginal and average costs of supplying DW, and the resulting monetary surplus accruing to DW companies selling at their marginal production costs.

Giving GW-extraction priority to agriculture--with high GW-sprinkler intensity and every waterboard plan implemented (cases M and P)--produces small differences compared with A-F. The principal impacts caused by the switch in priority are:

- 22-34 mcm/yr or 2 percent more DW is produced, but at an average reduction in the proportion of GW in it of 2-3 percent.
- 30-43 mcm/yr more SW is extracted, requiring an additional two SW projects to be built (at Heel/Panheel and Roosteren), while an existing one was again not used.
- The marginal cost of supplying DW increases 4-8 percent to .53-.55 Dfl/m^3.
- The cost of supplying DW increases by 2-3 percent (14-18 Dflm/yr).

- Revenues increase by 53-78 Dflm/yr (7-11 percent) and, because they exceed costs, result in higher monetary surpluses of 39-58 Dflm/yr (35-52 percent).

Restricting the GW extractable amounts to a quota of .25 and giving extraction priority to agriculture (case G) results in the least GW extracted by DW companies of any case and the highest proportion of SW used in producing DW. The principal impacts are:

- GW extractions by DW companies drop to less than one-fourth of those in cases A-F.
- SW extractions nearly quadruple to make up the large deficit, requiring 12 new SW projects to be built (plus two to be expanded--the Biesbosch and the dune-infiltration plant in Z.-Holland).
- The proportion of GW contained in DW drops to one-fifth of its value in cases A-F.
- Only 60 percent of the DW shipped among DW companies in cases A-F is shipped in case G.
- DW production costs rise by only 75 percent, yielding a monetary surplus that triples (from 112 to 333 Dflm/yr).
- The marginal cost of supplying DW almost doubles to .94 Dfl/m^3, virtually doubling DW-company revenues (assuming, as we have, that they sell DW at the marginal cost of production).

When, in case Q, we assume GW extractable amounts 50 percent larger than RID's estimates in the basic case, we obtain impacts which are less severe than--and in the opposite direction from--those produced by severely restricting the available GW (case G). Here, the principal impacts are:

- 138 mcm/yr (13 percent) more GW extracted by DW companies, improving the quality of DW (as indicated by the percentage of GW it contains) by 13 to 87 percent GW.
- 142 mcm/yr less SW required, and three fewer SW projects needed (of the three that are used, the Biesbosch exists, the reservoir at Braakman must be expanded, and the riverbank infiltration plant at Lek must be built; four of the SW projects in the cases A-F are not used, because more GW is available).
- DW-production costs drop by 6 percent, leading to a reduction in the monetary surplus of 42 percent to 65 Dflm/yr.
- The marginal cost of supplying DW drops by 14 percent to .44 Dfl/m^3, causing a matching reduction in revenues.

4.3.2. Distributional Effect

One rather significant distributional effect recurs time and again among the impacts of the six GW cases. DW companies in three western lowlands provinces--N.-Holland, Z.-Holland, and Zeeland--face far more severe problems than do those in the other provinces. (In case G, with its very low GW quota, problems in other provinces do begin to rival those in the western provinces.) Not only are their GW supplies woefully inadequate compared to the current DW demands they face, but the demands are estimated to grow more quickly there than elsewhere between now and 1990. How are these three provinces affected by the six cases?

In all cases with a 1.0 quota (A-F, L, M, and P), these three provinces account for virtually all the SW that is extracted, produce DW with the lowest percentage of GW in it, experience the highest GW shadow prices and marginal and average costs of supplying DW, and contribute 86 percent of the total surplus that DW companies everywhere register (55-64 percent when agriculture is given GW priority).

In case Q, where 50 percent more GW is available, Z.-Holland and Zeeland remain the only provinces to produce DW not made entirely from GW.[2] N.-Holland does not have enough GW, but imports DW from Utrecht and Z.-IJpolders. In the three western provinces, the marginal and average costs of supplying DW are substantially higher than elsewhere, and the DW companies there together contribute over 98 percent of the overall surplus registered by DW companies.

In the very restrictive case G, the proportion of GW in the DW produced by the three western provinces is 3-7 percent.[3] The marginal and average costs of supplying DW in the three provinces are among the lowest in this case. This is because alternative sources of water are more readily available there than in other parts of the Netherlands. As a result, DW companies there contribute less than 15 percent of the overall surplus registered by all DW companies.

The reason why we see a counterintuitive effect in these three provinces at a quota of .25 is that RIDDWM was never designed to be used at such a low quota. Remember, that quota was selected by PAWN to represent an extreme case, one that gave a very high priority to environmental preservation and hence allowed very little GW for the normal uses of DW by households, commerce, industry, and agriculture (see Vol. IV). RIDDWM made very few SW projects available near Groningen and Drente because those provinces were estimated to have adequate GW supplies at a quota of 1.0. Had more been planned in the north, the model's solution at the .25 quota would have been different: the marginal costs of northern provinces would have been lower, as would their contribution to overall surpluses, and those in the three lowlands provinces would have been slightly higher (along with miscellaneous other changes). The use of RIDDWM--and hence RESDM--at such a low quota seriously jeopardizes the results of the impact

assessment for case G. At the same time, it underscores the fact that RESDM is only an analytic tool, and like all such tools is vulnerable in the validity of its assumptions.

NOTES

1. The Netherlands Central Planning Bureau estimated each sector's production only until 1985, and between 1985 and 1990 estimated the total production only of all sectors combined. We thus used the average growth rate of all sectors after 1985. (Volume VIII contains full details of how these estimates were derived.)
2. It is worth recalling that we force 160 mcm/yr to be extracted from that reservoir in every case. Z.-Holland would still require some SW in this case, even though the amount may not come close to the 160 mcm/yr we force it to take.
3. Only the province Limburg has a worse result here with its DW composed entirely of SW, due mainly to its GW supplies being very sensitive to prior withdrawals by agriculture.

Chapter 5

CONCLUDING COMMENTS

It may be convenient, by way of introduction, to remind the reader that this volume has three purposes: (1) to assess the impacts of PAWN's primary and GW cases on DW companies and their customers; (2) to describe the methodology we used to carry out the impact assessment; and (3) to relate our analytic findings to the real world, exploring their implications for DW companies and their customers. We presented the results of the impact assessment in Sec. 4.2 and summarized them in Sec. 4.3; we explained the methodology in detail in Chap. 3 and in Sec. 4.1; and we recounted the major problems that real-world DW companies are experiencing in Chap. 2. In this chapter, we address the third objective.

Our concluding comments fall naturally into three parts. First, because RESDM is an optimizing model, and because we used it to produce the entire set of impacts on DW companies, we intentionally imposed on those companies the discipline of marginal-cost pricing for DW. Since in our view it is an important strategy for operating efficiently, we discuss briefly the pros and cons of marginal-cost pricing, and the resulting implications for the country. Secondly, our experience with RESDM has given us insights into how DW companies would ideally behave as the system becomes more highly stressed (by "stressed," we mean a widening of the gap between GW supply and DW demand by whatever means). We then discuss some potential long-term strategies for DW companies suggested by those insights. Finally, because we found ourselves using our analytic tools over ranges and circumstances for which they were not initially designed, we wish to comment on the degree to which our findings may have been jeopardized. In any case, how we applied these models suggests ways in which their initial formulation might have been improved.

5.1. MARGINAL-COST PRICING FOR DRINKING WATER

We have interpreted RESDM as basing its allocations of GW and DW as though DW companies sell DW at its marginal cost of production in each pseudo-province. In Vol. IV, we have explored how much difference this makes in allocations. When the GW quota is 1.0 or higher, it makes little difference, but at a GW quota of 0.25 it strongly affects the quantity of GW extracted, the quantity of DW produced, the distribution of that DW, and the long-run options selected by the DW companies in the model as they respond to changes in GW quotas or GW charges. These responses and distributions could be replicated among real-world DW companies, households, and industrial firms only by either mandating each detailed use and adaptation--a virtually impossible task--or by implementing marginal-cost pricing of DW and GW.

From a theoretical viewpoint, prices based on marginal cost are invaluable aids in distributing a scarce resource such as GW among a large number of potential users. They cause water to be allocated efficiently, i.e., to its most valued uses, without requiring administrative authorities to grant licenses or issue quotas. They insure the proper level of investment in DW production facilities by requiring that each unit of water supplied, including the last, be worth more than the cost of the resources needed to supply it. And they are fair to all users, charging each the same price (except possibly for differentials in distribution costs).

Dutch DW companies currently price DW according to the average, historical costs of production; each production facility is valued at its original construction costs, and all facilities in a pseudo-province are pooled to determine the average.[1] In a period of even mild inflation, such a procedure insures that DW will be underpriced and that too much of it will be produced. New facilities are not judged on their own merits but are lumped together with the costs of older, cheaper facilities. Users pay less than the production cost of the additional water, and so demand more than if the price were higher. Thus DW companies cannot accumulate sufficient revenue to finance the new facilities. Average-cost pricing encourages neither users to conserve water nor producers to search for less costly sources.[2] The most that can be said for average-cost pricing is that it provides low-priced water to users and generates sufficient revenues to cover costs as long as all construction costs can be deferred until the units are operational.

On the strength of both theory and the results reported in Vol. IV, we believe that the implementation of marginal-cost pricing for DW should be seriously considered by the Dutch authorities, in the event that GW extractions are limited to levels significantly below present extractions. The authorities should ascertain the political acceptability of such a system and should obtain cost estimates of implementation and administration. At this time we cannot predict the myriad local changes--both good and bad--that such a policy change would bring. But in light of the increasing stresses that the water system will have to bear in the future, serious thought should be given to implementing such a pricing scheme throughout the Netherlands. The western provinces of N.-Holland, Z.-Holland, and Zeeland might even consider it sooner, since for them fresh GW is already a scarce and costly resource.

5.2. LONG-RUN OPTIMAL BEHAVIOR OF DW COMPANIES

Determining the most economically efficient way of managing the Dutch water system is something PAWN was asked to do. In the case of DW companies, we determined the least costly way in which they could meet the demands for DW placed on them for a variety of cases by using a model that jointly optimized the use of scarce GW among the DW-company and industrial sectors. We used that model in this report to assess the impacts of PAWN's primary and GW cases on DW companies, assuming

that DW companies and industry behave in the way the model requires. RESDM also tells us generally what DW companies must do to achieve these impacts. RESDM does not provide a detailed plan of action, however; issues of implementation lie outside the scope of our charter.

The principal assumptions inherent in our model, RESDM, define both the world in which the impacts were computed and also offer a clue to the long-run strategies that, if followed, could produce these most economically efficient results. Consider the following three examples:

SW Projects: The model contains a menu of 20 SW projects dedicated to DW companies' use. These SW projects, strategically located throughout the country by RID (presumably to take into account both how they can be supplied by the Rijn or Maas as well as their proximity to highly populated areas with high DW demand), also form one part of a potential strategy for DW companies: Build those SW projects which have a high probability of being needed in response to conditions that themselves are highly likely to materialize in the future.

For example, the same six projects are used in all the cases with a 1.0 GW quota, with two more projects added when agriculture is given GW-extraction priority. Of these eight projects, five currently exist and three will have to be built; of the five existing, two will need enlarging. (RESDM never brought into use the project OPA that currently exists.)

SW Project	Capacity in 1977 (mcm/yr)	Max. Demand in RESDM(a) (mcm/yr)
SBB	160	160
SBR	11	16
DNH	104	28
DZH	70	23
PLW	30	60
OPA	20	--
GHP	--	12
OGL	--	50
OGR	--	25

(a) At 1.0 GW quota (cases A-F, L, M, P).

When the GW quota was lowered to .25 in case G, an additional ten SW projects were brought into play. However, we have already cautioned the reader that the model was never designed to operate at such a low quota. For one thing, had RID ever contemplated such a national restriction in the availability of GW, it would have planned more SW projects, certainly in the northern provinces, leading to very different results. Thus, although we examined case G as an extreme situation, we do not

believe such a condition will necessarily happen, so the additional SW projects may not all need to be built. The point is, the model will tell precisely which ones should be built given: (1) a particular water-management policy and attendant assumptions, and (2) a planned menu of SW projects from which choices can be made.

Centralized Planning: The DW-company model RIDDWM inherently assumes that all DW companies operate as if guided by a single hand. An alternative interpretation could be that they share the same cost-minimizing objectives and cooperate fully with one another to achieve them. In real terms, this argues strongly for national rather than provincial control of DW companies' operations. If GW is more scarce in certain parts of the country, but is considered a national resource, then it seems logical that the central government have the authority to allocate it to DW companies and other users in ways that are cost-effective for the country as a whole.

RESDM does more than assume perfect cooperation among DW companies--it includes industrial firms as well (by jointly optimizing the two sectors). Other analyses, reported in Vol. IV, show that such cooperation between the sectors yields tangible savings when GW is scarce (at a GW quota of .25, but not necessarily at 1.0). In real terms, this would mean central control of GW use for both sectors. Already, the hand of a central or provincial authority is at work granting licenses for extracting GW to various users--business firms, farmers, or DW companies. Because many complex factors have to be taken into account, among which are potential damage to the environment, access to alternative sources of water, and how many may benefit from the particular use, it makes sense for a central authority to make those decisions. (When talking about the two sectors, we believe that "full cooperation" between them is unrealistic, but that central control of their access to and use of GW--also implied by the joint-optimization of the model--is quite realistic. Another example of central control in evidence is parliament's current debate on whether to adopt a GW law that, among other provisions, calls for a charge on industry for GW use.)

Cost Minimization: Our analysis assumes that DW companies use the cheapest sources for the production of DW, regardless of quality or reliability considerations. Of course, all potential sources included in RIDDWM (and hence in RESDM) meet minimum standards of quality and reliability, or they would not have been considered. But there is evidence that DW companies' behavior is not perfectly described by a cost-minimizing principle; DW companies extract 160 mcm/yr from SBB (the Biesbosch reservoir) in spite of the existence of cheaper substitutes, probably because of the exceptionally high quality of water from this source. As explained in Vol. IV, we have imposed a requirement in all runs that at least 160 mcm be extracted from SBB.

We did not find other instances where DW companies' current behavior differs from cost minimization, but in the future, if new SW projects were constructed, new examples of such behavior might be found.

Insofar as the indicator we have used--"DW composition (percent GW in DW)"--is a valid proxy for DW quality, then DW managers and their customers alike should be greatly concerned about those cases where the DW contains large amounts of SW. In case G, as we would expect, the "quality" is very low: the national average composition is 16 percent GW, the three westernmost provinces register 7 percent or less, and Limburg produces DW made entirely out of SW. While those figures are unrealistic because the case is an extreme situation, the point is that the problem may arise more frequently in the future as GW becomes scarcer. And that problem will be difficult to solve.

Two theoretically possible solutions are to obtain more sources for GW and to improve the quality of the SW used. Given the GW extractable amounts in the model, then by definition no more GW can be obtained. In real terms, we come to much the same conclusion. For example, permission to extract more GW depends on two things: accurate estimates of GW-table levels locally throughout the country, and the method by which competing uses for GW are evaluated. We expect in the future a growing concern for the environment and a concurrent trend, which has already begun, toward conserving GW. Thus we anticipate stricter controls on GW use, leading to possibly lower levels of GW use in the future.

Many of the SW projects are fed by the Rijn, a highly polluted river [5.1], and substantially improving Rijn quality will take considerable time and resources. The long-run strategy for even attempting that belongs to the central government and not to individual or even provincial DW companies. Since the Rijn becomes so polluted from the dumping of salt and household and industrial wastes at several points upstream, and those points lie on foreign soil (Switzerland, France, and West Germany), the problem is appropriately tackled by the central government through diplomatic channels and national treaties, as has been done for several years now, albeit with limited success.

The remaining key difference between the model and the real world has already been discussed--the adoption of prices based on marginal cost for DW rather than those based on historical, average costs. Unless prices reflect marginal costs, the allocation efficiencies achieved in the model (or that could be achieved by the model given other conditions and water-management policies) will remain out of reach. Again, whether such a switch could be achieved in practice or whether it would even be politically desirable are questions that should be explored and discussed widely in the Netherlands. Certainly, no one wants to pay more than he has to for DW. But in the long run, if our prognosis that GW may become much scarcer is correct, then it may be in the country's interest as a whole that prices for DW rise both to reflect the higher cost of continuing to meet a rising DW demand and to begin to allocate GW to its most valued uses.

5.3. WAYS TO IMPROVE THE MODEL

During this study, we never did have sufficient time to develop the additional data that would have made our tools appropriate for the full range of our analysis. Clearly, any future refinement of this work will benefit substantially if such data were developed. By way of an epilogue, then, we offer the following suggestions for improving these tools, given the same purposes for the analysis:

1. For the lowest GW-quota level that planners estimate may be experienced in the future (somewhere between 1.0 and .25; RID's lower bound on its own estimates is .50), determine whether any additional SW projects may be required, and where they might be located. Develop cost and capacity data for them. (The menu of projects developed by RID in RIDDWM was not designed for a quota as low as .25.) Other options, such as waste-water reclamation, might also be explored.

2. Improve and enrich the representation of industry in RESDM. This is particularly desirable in cases with low GW quotas (like case G), where real-world industry responses are likely to involve major changes from present practice. Means for doing this are discussed in Vol. IV.

3. RESDM assumes a completely inelastic demand for DW; only industry, in responding to changes in GW quotas or GW charges, may increase its demand for DW to compensate for any GW saved. For all cases other than G, that may in fact be a realistic assumption. But we do not know how far GW use can be restricted, or the price of DW otherwise raised, before that demand pattern changes. Nor do we know how much DW consumers would be willing to save if they knew by so doing how much money they might save. Where DW prices are based on marginal costs, and in a world where GW is very scarce (resulting in high marginal costs), such monetary savings could be substantial if DW demand could be reduced.

NOTES

1. Typically, the per-cubic-meter costs of DW are based on an annualized average total cost consisting of: (1) the annualized capital cost of the production and distribution systems, and (2) the annual operating costs which include energy, chemicals for SW treatment, and employees' wages.

   Most DW companies' rate structures also distinguish between large and small users. Large users (who consume about 35 percent of all

DW produced in the Netherlands) pay a capacity charge, a fixed fee, and a variable charge per cubic meter based on their maximum hourly consumption of water. (To lower the impact of the variable charge, the purpose of which is to reduce the quantity of water demanded during daily peak hours, a user could install storage facilities and thus be able to spread peak demands for DW throughout the day.) Large users who pay a capacity charge are often given a much lower variable charge (approximately 80 percent of all DW companies impose capacity charges on large users). DW companies also offer a declining block rate to large users, enabling them to pay less per cubic meter of water than small users.

Finally, most users pay a one-time hook-up charge to be connected to the distribution system. This charge is usually a function of the capacity of the connection (m^3/hr), and sometimes depends on the distance to the nearest point in the existing distribution network. For residential users, however, the scheme is simple--one charge applies if the distance from the hook-up to the network is 50 m or less, and a higher charge if the distance is greater. Almost all of these details could be retained in a pricing system based on marginal costs.

2. Marginal-cost pricing will normally yield a surplus of revenues over costs to the DW companies. Such a surplus should not be considered a "profit" for the companies but both a reserve from which they can finance new projects (when justified) and a revenue fund for the provincial and state governments.

REFERENCE

5.1. Zoeteman, B. C. J., "The Potential Pollution Index as a Tool for River Water Quality Management," in Water for the Human Environment, Vol. III, Technical Sessions/Proceedings of the First World Congress on Water Resources (4 vols.), September 24-28, 1973.