Policy Analysis of Water Management for the Netherlands

Vol. I, Summary Report

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Rand

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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. In addition to the present report, the series contains the following volumes:

- 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 PAWN final 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 mid-1983, 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 this summary report, which contains most of the contextual and evaluative material.

This report summarizes the PAWN project. It describes the methodology and results presented at the PAWN final briefing in December 1979, but with many additional details. In a few instances, explicitly noted, changes have been made. It should be emphasized that this volume does not merely summarize the other PAWN volumes, for it contains considerable material that appears nowhere else.

This report is intended to perform several functions for multiple audiences. The obvious one, of course, is to provide a more comprehensive description of the PAWN results and methodology than has been previously available for those interested in Dutch water management. But there are less obvious audiences, not only in the Netherlands but in the United States and other countries.

The report provides a thoroughly documented case study for government officials, engineers, regional planners, and others in fields outside water resource and environmental analysis who wish to learn how a policy analysis of complex natural resource and environmental questions can be carried out. Moreover, for specialists in these fields, it introduces an operational methodology that is more comprehensive than others and that employs several useful new techniques.

Finally, for those concerned generally with the analysis of public policy decisions, either as producers or consumers, the report offers a complete description of the approach and results of a study that contributed directly and substantially to the making of a major public policy decision.

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

S.1. INTRODUCTION

This study examines the consequences of alternative policies for managing the water resources of the Netherlands. On one level, the analysis addresses the specific problem of estimating the effects of different policies on the various water users and uses; on another, it demonstrates an approach to a general policy problem--assessing the complex effects of public policies on the environment, on regional and national economies, and on individuals.

Although the historical Dutch water management problem has been too much water, in recent years the Dutch have had to turn their attention to the new problems of too little water and too much pollution. Like other developed countries, the Netherlands faces water shortages, water quality problems, and environmental and distribution problems because of increased population and industrialization and higher standards of living. Competition among water users has grown. These problems are intensified in the Netherlands because of the dense population, because so much of the country lies below sea level, and because the major source of surface water is the polluted Rijn River.

The severe drought of 1976 brought these concerns sharply into focus. The drought caused extensive damage. Agricultural losses exceeded 5000 million Dutch guilders, about $2000 million. Low river levels caused serious shipping delays and costs because ships could not navigate the waterways with full loads. And the water shortage worsened water quality problems. These events, coupled with Dutch awareness that the modern water management problem is no longer local in scope, stimulated the government to commission an analysis that could be used as the basis of a new national water management policy. The resulting project, Policy Analysis for the Water Management of the Netherlands (PAWN), was conducted jointly by The Rand Corporation and two Dutch institutions: the Rijkswaterstaat (the government agency responsible for water control and public works) and the Delft Hydraulics Laboratory. Analysts from both countries cooperated closely in all stages of the study.

The PAWN project was a major undertaking. It directly involved about 125 man-years of effort, created several dozen computer programs, consumed over 600,000 guilders ($250,000) of computer time, and gathered and structured an enormous amount of data (for example, the computerized database representing agriculture contains over 12,000 elements). Additional resources were provided indirectly as various institutes and agencies responded to requests. During the peak period of the study, there were about 15 researchers at Rand, six at the Rijkswaterstaat, and six at the Delft Hydraulics Laboratory working full-time on the analysis, plus numerous full-time and part-time data-gatherers and technical specialists.

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 for the Netherlands and to assess and compare their consequences.
3. Create a Dutch capability to conduct further analyses of this kind by training Dutch analysts and by documenting and transferring to the Netherlands methodology developed at Rand.

The Rijkswaterstaat combined results of the PAWN analysis with results from additional analyses of its own (performed with the PAWN methodology by Dutch analysts trained in PAWN) to draft its Nota Waterhuishouding, the new national policy document on water management.

S.2. WATER MANAGEMENT PROBLEMS OF THE NETHERLANDS

PAWN distinguished four classes of water management problems.

Shortage. The future (1985-1990) demand for fresh water is expected to exceed the supply in some dry years, and competition among users will increase. Water shortages cause agricultural losses and increase shipping costs and other users' costs.

Salinity. Salt water from the sea continually intrudes into the low part of the country, much of which is below sea level, through estuaries, harbors, and shipping locks, and by seepage through the subsoil. The country's major source of fresh water, the Rijn, is itself increasingly saline because of waste salt dumped in the river by nations upstream (particularly France, whose Alsatian potash mines dump a large quantity of waste salt).

Highly saline water can damage valuable crops and poses a threat to the environment and to personal health. Although fresh water is used to flush salt from the land and to keep back the influx of salt water, this use worsens the shortage problem.

Quality. PAWN applies the term "quality" to problems caused by pollutants other than salt and to other issues of environmental quality. By far the greater part of most pollutants is generated outside the Netherlands and imported by the Rijn and Maas rivers. Such imported pollution, including salt, can be dealt with through international treaties. But action on domestic pollution is also important, for pollution generated within the country can lead to high local concentrations and hence damage. Among the most troublesome water quality problems are eutrophication (heavy growths of algae because of high concentrations of phosphorus and other nutrients in the water) and thermal pollution (from the heat discharge associated with the cooling cycle necessary for electricity-generating plants). Like salinity problems, water quality problems are intensified by water shortage.

Flood. Although flood risk has been generally controlled in the Netherlands, it is still a critical issue around the IJssel lakes, the system of huge freshwater storage basins that supply the northern part of the nation. When we consider changing the policies that govern their water levels so as to store extra water to help alleviate shortages, we increase the flood risk to the surrounding land.

S.3. GENERAL APPROACH

A water management policy involves a mix of tactics, each of which is a single action to affect water management, such as building a particular canal or taxing a particular use.

We considered four kinds of tactics, the first two directly affecting the supply of water, and the last two the demand:

- Technical: additions or modifications to the current water distribution facilities (infrastructure).
- Managerial: changes in the rules by which a particular infrastructure, current or new, is operated.
- Pricing: imposition of a charge (tax) on water use or discharge.
- Regulation: administrative or legal restrictions on water use or discharge.

A strategy is a combination of tactics of the same kind. A policy is a particular combination of all four kinds of strategies, and may contain any number of tactics. A particular policy should be thought of as an overall water management policy for the Netherlands in much the same way as we would think of the Netherlands' foreign policy.

During the analysis, the chief objective of PAWN was to design a number of overall policies that address the water management problems, to assess their many diverse effects, and to present these effects in such a way that they are visible and comparable, thus enabling policymakers to choose between policies while knowing the consequences of the choice.

Figure S.1 schematizes our general approach, indicating the stages of analysis that take place after problem formulation.

Each kind of water management tactic offers many alternatives; for example, technical tactics could modify the current water distribution system--the infrastructure--in hundreds of different ways. Thus, it becomes impractical to evaluate the detailed consequences of all of them. We deal with this problem by performing the analysis in a series of stages. In the early stages we evaluate many possible alternatives

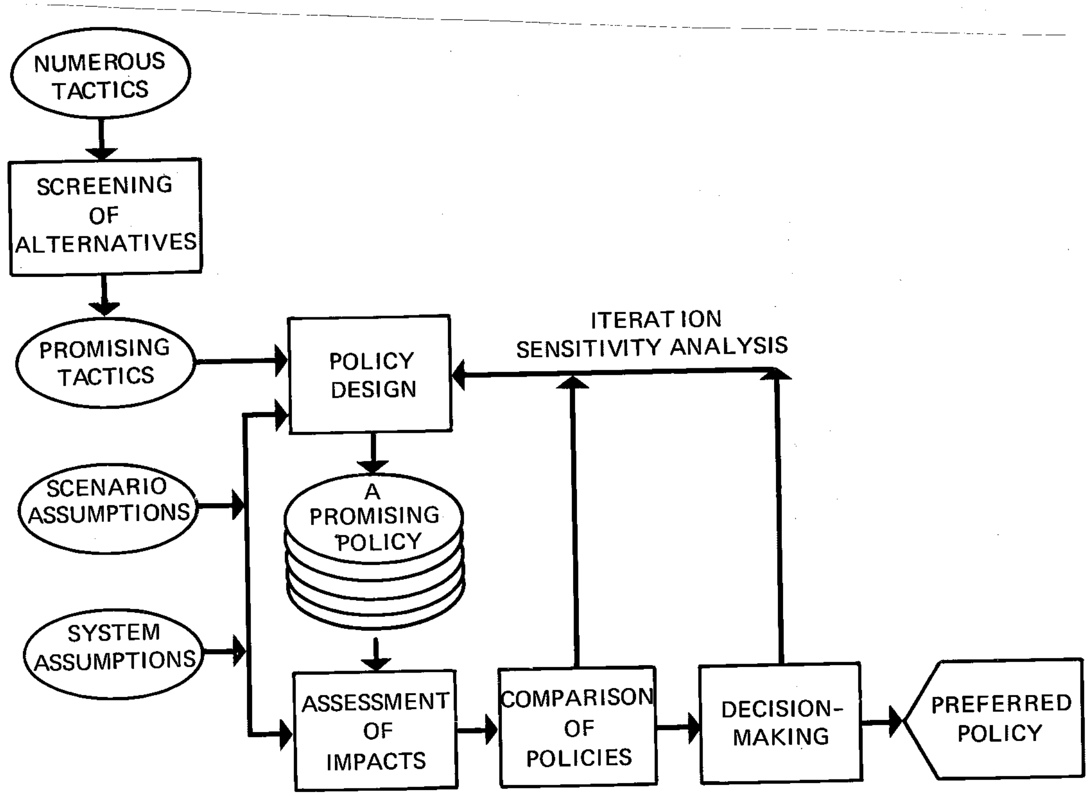

Fig. S.1--Stages of policy analysis

in terms of a few major effects, whereas in the final stages we evaluate relatively few promising alternatives in terms of the full set of potential effects. As the stages progress, we are learning how to design increasingly promising alternatives.

In the screening stage of the analysis, we reduced the number of tactics to be considered in detail--we identified the promising alternatives (and set aside the inferior ones). The criteria for screening included administrative feasibility, cost-effectiveness, and dominance. Under the dominance criterion, for example, when evaluating several cost-effective tactics for the same purpose, we would rule out those that provide lower benefits at the same cost or the same benefits but at higher cost.

In the policy design stage of the analysis, we combined various promising tactics in different ways into promising strategies, and then used these to derive sets of promising water management policies.

In the impact assessment stage of the analysis, we used various mathematical models to determine the effects--called _impacts_--of these policies on the water management system, the different users, the natural environment, and the nation as a whole. The policies were evaluated with a number of different scenario and system assumptions. Scenario assumptions include the external supply of water, the effect of future international treaties on the amount of pollution entering the Netherlands, and the socioeconomic context; system assumptions include the geographic distribution of current crops and sprinklers (irrigation systems), power plant efficiencies, etc.

The many impacts of the policies are presented to the decisionmakers who will compare the alternatives. It is common practice for analysts in studies of this kind to combine impacts into a single measure of performance, but such an approach usually loses information and may substitute the analyst's values for those of the decisionmakers. In our approach, the various impacts are displayed on a scorecard, a table that also shows, by color code, each alternative's ranking for a particular impact. To this factual knowledge, the decisionmakers can then add their value judgments about the relative importance of the different impacts, thereby weighing and trading off the impacts to select a preferred alternative--that is, to make "the decision."

From an initial comparison of policies, the analysts and decisionmakers (represented by an advisory group of senior Rijkswaterstaat managers) identified a number of sensitivity analyses to perform that involved a change in the policies, the scenario, or the system assumptions. This process would continue--iteratively--until the decision was made. For example, the impact assessment stage might be repeated with a stricter set of environmental standards; the change in the impacts would be the "cost" of the stricter standards.

S.4. METHODOLOGY

To analyze the intricate pattern of tactics, policies, and effects, we built a comprehensive methodology, which includes a toolkit of models. Figure S.2, the PAWN system diagram, gives a general impression of how we conceived the problem. Each "box" represents a different model or substudy and the lines show their interrelations. At the heart of the methodology is the water distribution model, which simulates the operation of the national and regional water distribution systems. We used this large model to calculate the state of the distribution system--river flows, lake levels, shipping depths, pollutant concentrations--and to determine the effects of all these variables on various parts of the problem (sectors) every ten-day period. Whenever possible, the models for the various sectors were linked to the water distribution model.

Consider an example of the interaction among sectors during one ten-day time-step: The external supply of water consists of the amount of net rain (precipitation minus evaporation) being received by agriculture and various other sectors and the amount of river water entering the country. On the basis of the rain received, the agriculture sector models determine how much irrigation water is needed to avoid damage to

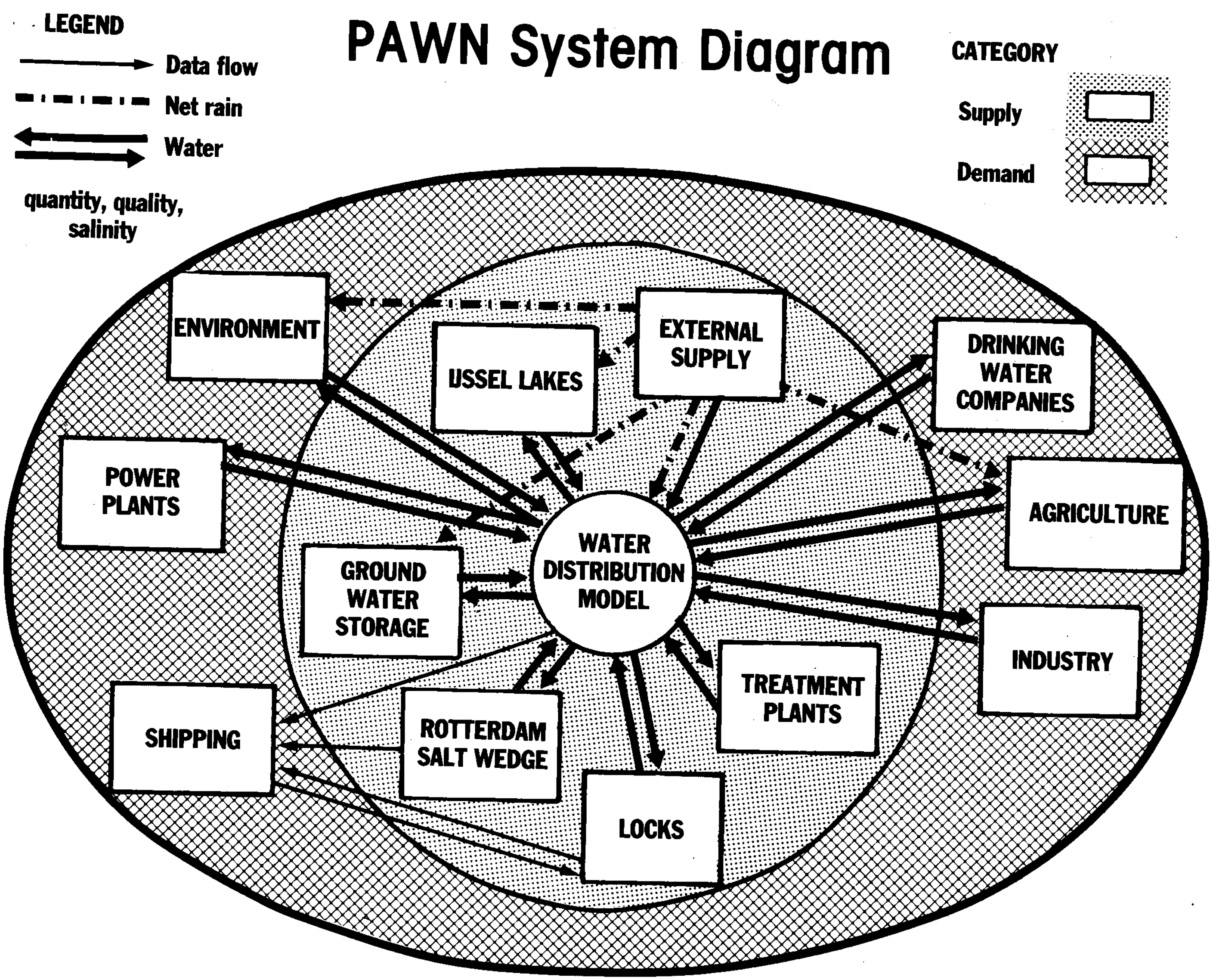

Fig. S.2--PAWN system diagram

irrigated crops, and demand this amount from the water distribution model. The water distribution model balances this demand with similar demands from the other sectors and, on the basis of the specified managerial strategy, decides how, and to what extent, to meet the demands. It may respond to demands by withdrawing water from storage and by using part or all of the external supply of river water in the time-step. It may also use some of this river water to replenish surface water storage in the IJssel lakes. If agriculture does not receive all the water it demands, it suffers losses to crops that have irrigation equipment as well as to those that do not; the agriculture sector models calculate these losses. Similarly, the reduced water levels in the rivers and canals caused by large extractions of water for agriculture lead to monetary losses by the shipping industry, which are calculated by appropriate models for that sector. When groundwater is extracted for irrigation, groundwater levels and the natural flows of groundwater into rivers and streams change. The agricultural models also calculate this change, and thus provide the linkage between groundwater and the surface water considered in the water distribution model.

The component models and other aspects of our methodology are discussed in Chaps. 3 through 20 of this report.

S.5. RESULTS

Some of the most important results of the PAWN analysis are as follows.

S.5.1. Dominance of Agriculture

The financial losses caused by damage in dry years and hence the potential benefits from an improved water management policy are far greater for agriculture than for any other sector. For example, we estimate that the monetary value of the agricultural losses due to drought and salinity damage in an extremely dry year is over 6000 million guilders, while the "next best" sector is shipping, with losses of about 70 million guilders. In a moderately dry year, agricultural losses are about 1700 million guilders, while electricity generating plants are in second place with losses of around 2 million guilders.

It is clear that losses to agriculture from water shortages and salinity are orders of magnitude greater than the losses to any other sector. As a result, most of the technical and managerial tactics considered were designed to increase the quantity or quality of water supplied to agriculture.

S.5.2. Expected Increases in Sprinkler Irrigation

Irrigation in the Netherlands is done almost entirely by sprinklers. In 1976 Dutch farmers sprinkled only about 13 percent of the land under cultivation. The high value of agricultural crops makes this sprinkling policy economically inefficient. The average annual cost of a sprinkler system ranges from 200 to 800 guilders per hectare, while average monetary yields from Dutch agriculture range from 2000 to over 10,000 guilders per hectare. Thus the most expensive sprinkler system costs less than half the value of the least valuable crop. Therefore, it would be economically efficient for farmers to greatly increase the amount of land they sprinkle. But sprinkling would then strain the water supply even more.

Only about half of the cultivated land of the Netherlands has access to ditches, canals, and other elements of the surface water distribution system, from which farmers can draw water for sprinkling if they own the necessary equipment. We call such land eligible for surface water sprinkling. Sprinklers currently exist on only about 20 percent of the eligible area. Therefore we say the intensity of surface water sprinklers is 20 percent. (By intensity we mean the percentage of an eligible area on which sprinklers are installed.)[1]

The number of sprinklers can increase in two ways: First, the intensity can increase as farmers purchase additional equipment for the currently eligible area. Second, the area eligible for surface water can increase as a result of expanding the infrastructure to bring surface water to areas where it is not currently available, and farmers might purchase equipment to tap this new source.

As sprinkler intensity increases, the benefits rise proportionately. The costs increase, too, but not in the same proportion. The optimal intensity is the intensity that maximizes the expected net benefits to farmers.[2] We used our agricultural models in a special procedure to compute optimal sprinkler intensities for each crop, on every type of soil, and in every hydrologic area in the Netherlands. One set of intensities was computed for surface water sprinkling and another set for groundwater sprinkling.[3] The optimal sprinkler intensity reflects an optimistic view of future developments. Under it, nearly half of the currently eligible area would have sprinklers, more than tripling the current sprinkler intensity.

S.5.3. Technical and Managerial Screening Results

Because of the number of tactics to be considered, and because the benefits to be derived from a tactic depended on the external supply of water, which varied statistically, we took care to make our research design for screening adaptive and systematic. First, to avoid the time and expense of determining the precise benefits of every tactic, we began with an initial screening step that compared a tactic's cost with an estimate of the maximum benefit that any tactic could produce when applied for the same purpose. Only the tactics whose costs were less than the maximum benefits survived to be evaluated in detail in the next step of screening.

Second, to deal with the fact that the benefits of a tactic varied statistically with the external supply of water, we wished to compare the average benefits over a number of years of differing dryness (i.e., the expected benefits) with the costs. Because it was prohibitively expensive to calculate the benefits for many years and then take the average, we developed an alternative approach: We selected five external supply scenarios (ranging from extremely wet to extremely dry) and assigned probabilities to them. We could then calculate upper and lower bounds on the expected benefits using appropriate weighted averages of the benefits computed for the five selected scenarios. The cost-effectiveness criterion we used throughout screening was that the annual cost of a tactic should be less than the upper bound on the annual benefits it was expected to produce.[4] Our estimates were necessarily uncertain, but we tried to ensure that no promising tactic was screened out.

Waterboard Plans. On the local level, we screened 65 plans developed by waterboards, the authorities responsible for water management of groups of polders.[5] These plans would increase the area eligible for surface water sprinkling by building local distribution facilities. In the initial screening step, we eliminated those plans whose costs were greater than the maximum benefits to be derived from reduced crop losses. We estimated the maximum benefits by using the optimal sprinkler intensities in our agricultural models (the plans produce only agricultural benefits)--under the optimistic assumption that plenty of surface water was available for sprinkling. The initial screening step eliminated 19 of the 65 proposed plans.

To determine if the 46 surviving plans would still be promising if water shortages made cutbacks in sprinkling necessary, we used the water distribution model to estimate the benefits from implementing the plans under two different assumptions about the surface water sprinkler intensity (current level and optimal intensity). The results show that with either sprinkler intensity, implementing the 46 promising waterboard plans would produce significant benefits for the country. The benefits increase as the sprinkler intensity increases. At the current sprinkler intensity, the expected annual benefits exceed the plan costs by an amount between a lower bound of 10.3 million guilders and an upper bound of 72 million guilders; at the optimal intensity, the amount is between 27 and 146.3 million guilders. Being clearly promising, the 46 waterboard plans were included in the screening of the remaining tactics.

National and Regional Tactics. The other tactics examined in the screening analysis involved changes to the national and regional water distribution systems. The initial screening step was to estimate the maximum benefits that could be obtained from implementing any tactic. (For each region in the nation, this was done by using the agricultural models to estimate the decrease in agricultural damage when the current infrastructure was expanded sufficiently that the surface water sprinkling demands could be fully met--again under the optimistic assumption that there was plenty of surface water available for sprinkling.) This was done for four demand scenarios, each a different combination of sprinkler intensity (current and optimal) and decisions about the 46 promising waterboard plans (implement or not). If a tactic's cost was greater than the maximum benefits for the affected region (or regions or the entire nation) for a particular demand scenario, then the tactic was eliminated from further consideration for that scenario. For regions where the maximum benefits were large, we enriched our list of applicable tactics by consulting with Dutch experts and subjected these additional tactics to screening also.

To consider what would happen if water shortages made cutbacks in sprinkling necessary, we used the water distribution model to estimate the benefits of the tactics that had survived initial screening in each surface water demand scenario. For each scenario, we rejected tactics that were not promising (i.e., cost-effective) or were dominated by other promising tactics. We found eight tactics that were dominant and promising under all four demand scenarios, and six more under the highest demand scenario (optimal intensity with waterboard plans).

Among the 57 regional and national tactics considered in screening were several large, very costly construction projects, some of which had total investment costs of well over 200 million guilders. We found only one such tactic to be dominant and promising (a water supply pipeline from the Maas to Delfland). All other dominant, promising tactics had investment costs of less than 80 million guilders, and most were considerably lower than that. Except for a few very inexpensive national tactics, most of the promising tactics affect a single region.

New Policy for Flushing the Markermeer. We devised one managerial tactic that produced substantial benefits and could be implemented at essentially no cost. This tactic entailed reducing the amount of fresh water used to flush the Markermeer (the second largest of the IJssel lakes) to reduce its salinity. The new flushing policy would substantially reduce agricultural losses due to water shortage and only slightly increase the losses due to increased salinity of the water. The expected annual benefits from the new policy ranged from an upper bound of 2.5 million guilders to a lower bound of 0.7 million guilders. Because this managerial tactic would be so cost-effective, we assumed it would be implemented by the Rijkswaterstaat (RWS). (And it was.) We therefore introduced this one modification into the current rules that the Dutch use to manage their infrastructure, and called the result the RWS managerial strategy. We used the RWS strategy in all of our screening and throughout the rest of the analysis.

S.5.4. Pricing and Regulation Screening Results

Although it uses the same general criteria, the screening of pricing and regulation tactics differs in both kind and degree from that for technical and managerial tactics. Where the latter develops detailed estimates of costs and benefits for a large (but limited) number of potential tactics, the former takes a broad approach to a virtually limitless set of possible tactics. (Limitless because, for example, the tax on a particular user may, in principle, be set at any level.) In pricing and regulation screening we used qualitative assessments (e.g., whether a tactic will be hard to administer) in combination with rough estimates of a tactic's potential effects (e.g., whether it will save a great deal of water). Furthermore, we generally used existing information and did not develop our own estimates of costs and benefits until later stages of the analysis, when the number of tactics to be considered had been greatly reduced.

We adopted a three-tiered screening procedure. First, we screened user groups, that is, we determined where a pricing or regulation tactic of any type might be useful. Then we screened control points, that is, we determined where the actions of those selected users might best be controlled. Finally, we screened policy instruments, that is, we attempted to determine what particular form of tax or quota would be most appropriate for each surviving user-and-control combination.

Our screening analysis identified six combinations of user groups and water types as promising for control by pricing and regulation tactics: surface water use by agriculture and drinking-water companies (companies that produce drinking water); groundwater use by agriculture, drinking-water companies; and industrial firms, and drinking water use by industrial firms. Considering the control points for each of these groups, we reached several additional conclusions. For industrial firms and drinking-water companies, withdrawal tactics that monitor and control the amount of water withdrawn by individual users are appropriate. For farmers, long-run controls to limit the ownership of equipment (e.g., pumps and sprinklers) for surface water and groundwater sprinkling, and short-run controls to limit who has access to surface water, are appropriate. Short-run tactics operate over periods of days or a few weeks. Long-run tactics operate continuously over much longer time periods. Withdrawal tactics are long-run tactics.

We did not recommend specific policy instruments for particular applications. However, we did consider specific mixes of instruments in the policy design and impact assessment stages of our analysis. For methodological reasons, the short-run access tactics for agriculture were implemented in the water distribution model as managerial rules that determine the degree of cutback, if any, in the amount of surface water sprinklers, and hence are considered part of the managerial strategy.

S.5.5. Design of Long-Run Pricing and Regulation Strategies

We designed long-run pricing and regulation strategies for those combinations of user groups and water types that our screening analysis found promising. These strategies were intended to simultaneously control groundwater withdrawals by industry, drinking-water companies, and agriculture--preserving future groundwater supplies and protecting agriculture and nature areas from damage by a drop in groundwater levels--and the interrelated withdrawals of surface water by drinking-water companies and drinking water by industry. The two primary tactics we considered were the imposition of a charge on groundwater extractions and the imposition of a quota to limit the amount of groundwater extractions. In most cases we set the charge at zero, which reflects the current situation, but sometimes we used a charge of 0.20 guilders per cubic meter, the maximum charge being considered by the Dutch Parliament at the time of the study. The quota we usually used was based upon "extractable amounts" of groundwater that the Netherlands Institute for Drinking Water Supply (RID) established to indicate how much groundwater can be extracted in each province during an average year without risking serious consequences from the accompanying drop in groundwater levels. This quota is essentially a proxy for the current policy. For parts of the analysis, we reduced or increased this quota.

We investigated a range of groundwater extraction quotas and charges that, applied to different users in various combinations, could be thought of as progressively "stressing" the system--putting more pressure on groundwater users by restricting supply, raising cost, or assuming a higher demand for groundwater or drinking water. For industry and drinking-water companies, our most important conclusions are:

- The largest amount of groundwater can be saved by imposing quotas to restrict withdrawals, but the costs increase substantially with the severity of the restriction, while the quality of the drinking water produced decreases. Nonetheless, it is clear that both industry and drinking-water companies can considerably reduce their groundwater consumption.
- Imposing charges on groundwater use by industry and drinking-water companies saves a little groundwater, but at considerable extra cost. When groundwater withdrawals are severely restricted, charges save essentially no groundwater at all, but the cost--in the form of the charge--is still incurred. The primary effect of this tactic is to reallocate some groundwater from the industrial sector to drinking-water companies where it is more cost-beneficial.

When we attempt to design strategies for agriculture, the problem becomes more difficult. There is a serious question of whether farmers could be made to respond to quotas or charges on the groundwater extractions they currently make for sprinkling. Because farmers, unlike industrial firms and drinking-water companies, extract groundwater from innumerable small wells scattered about the countryside, it is very difficult to monitor their extractions reliably, so as to enforce quotas or charges. It may be practical, however, to limit the number of new groundwater sprinkler systems, perhaps by requiring permits to dig new wells or buy additional sprinklers. We therefore consider the extent to which quotas would affect the number of <u>new</u> sprinklers that are permissible and how charges would affect the number that is economical. (Methodologically, we do this as part of our procedure for generating groundwater sprinkler intensities.)

Ideally, we wished to create a single model that combined groundwater-conserving pricing and regulation strategies for all three sectors--industry, drinking-water companies, and agriculture--because they all compete for the same groundwater and because some industry responses involve buying drinking water instead of extracting groundwater. However, including agriculture in the same model with the other two sectors would have made the model too complex. We therefore created the response design model to deal simultaneously with the industry and drinking-water company sectors (the conclusions above were derived with it), and we used the tactic of setting priorities to deal with the competition between these sectors and agriculture. That is, we specified the priority that one sector has over another for groundwater extractions. In most cases, we let industrial firms and drinking-water companies take as much groundwater as they wished, up to the quota, with the remainder available to agriculture, but in others we reversed the priorities. In our analysis of priorities, we used the response design model to determine a strategy's effects on industry and drinking-water companies, and we used PAWN's agricultural models to determine them for agriculture. Our primary conclusion about priorities is:

- From the standpoint of the nation, it is economically more beneficial to give priority for extracting groundwater to industry and drinking-water companies when their demands are significantly higher than they are currently and when agricultural demand for groundwater is also somewhat higher. In other circumstances, it is economically more beneficial to give priority to agriculture, although the resulting decrease in drinking water quality may be undesirable for public health.

S.5.6. Design of Managerial Strategies

PAWN investigated the problem of designing managerial strategies that had the goal of distributing surface water in the way most beneficial to all water users and uses. These strategies consist of managerial tactics that change the rules controlling day-to-day operation of the national system of rivers, canals, lakes, and reservoirs. For example, they might alter the flows in some rivers and canals or the levels in some lakes by changing the operation of pumping stations and weirs. We constructed a model (the managerial strategy design model, MSDM) that used mathematical programming techniques to find the mix of managerial tactics that minimized the direct economic losses to water users, plus the costs of the managerial tactics, while meeting standards for water quality and requirements for various water levels and flows.

We ran the managerial strategy design model for a wide variety of circumstances reflecting extremes for both surface water demand (different infrastructure and sprinkler intensities) and supply (different river flows, net rain, and accumulated water in storage at the start of the period), and found a different optimal strategy for each. However, examining the results led to two important conclusions:

1. Dilution is no solution to pollution. There is no national strategy to redistribute water that will markedly reduce the violation of pollution standards, although highly localized reductions might be achieved. This result argues for a regional approach to pollution problems.
2. Despite individual differences in the optimal strategies, we can describe them all generally in terms of the same priority list, with the priorities corresponding roughly to the relative economic values that water has in various uses. We call this priority list the MSDM strategy. The major difference between the MSDM strategy and the RWS managerial strategy lies in the tradeoff called for in the third-highest priority, although there are differences in lesser priorities as well. The MSDM strategy explicitly trades off shipping losses due to low water on the Waal and IJssel and salt damage to agriculture due to the Rotterdam salt wedge.[6] The tradeoff performed in the MSDM strategy can yield large savings over the RWS strategy during periods with very low Rijn flows.[7]

A simplified version of this strategy, the SIMPLE MSDM strategy, was implemented in the water distribution model in order to compare it with the RWS strategy, which was already implemented, in the impact assessment stage of our analysis. The SIMPLE MSDM strategy incorporates the shipping loss tradeoff discussed above, but not the changes in lesser priorities, because we lacked sufficient time to implement them. To test the degree, if any, to which the full MSDM strategy is truly superior to the RWS strategy will require further investigation outside the present study.

S.5.7. Eutrophication Control Strategies

Eutrophication--excessive growth of algae--is the most pressing and widespread water quality problem in the Netherlands. An algae bloom (a sudden very heavy growth of algae) is undesirable because it can have a toxic effect on domestic animals, may clog filters and intakes for water treatment, and can cause the water to taste and smell foul.

The PAWN analysis of this problem suggests three general conclusions:

1. By itself, the current Dutch eutrophication control strategy of phosphate reduction will be largely ineffective because the Dutch cannot control the large amounts of phosphate brought into the country by the Rijn and Maas rivers. In addition, the bottom sediments of eutrophic Dutch lakes are phosphate-rich, and their phosphate also supports algae blooms.
2. No single tactic is capable of solving the eutrophication problem in all lakes; strategies must be adapted to local circumstances.

3. A single tactic will probably not solve the problem in <u>any</u> lake. Combinations of tactics should be considered--for example, light dredging combined with reducing the phosphate loading.

The methodology used for this part of the PAWN analysis should be helpful in determining the combination of tactics appropriate for each lake. However, because of the large technical uncertainties in eutrophication control, we recommend that, for many of the tactics considered, field testing or demonstration projects should precede widespread implementation.

S.5.8. Impacts of the Primary Policies

We combined sets of water management strategies into policies and, in the impact assessment stage, considered their effects in a variety of cases, that is, under specific scenario assumptions. The screening analysis ruled out some tactics as unpromising. The remaining components to be combined into policies were:

- Technical tactics: whether or not to include the changes to the current infrastructure that screening had identified as promising.
- Managerial tactics: a choice of the RWS or MSDM strategy.
- Waterboard plans: whether or not to implement the promising plans.
- Sprinkler intensity: a choice of current, optimal, or intermediate levels for both groundwater and surface water sprinkling.
- Groundwater extraction: a choice of the current amount or reduced extraction.
- Groundwater extraction priority: a choice between industry/ drinking-water companies and agriculture.
- Charge on groundwater extraction: whether or not to impose the charge on industry or agriculture.

We combined the components into six primary policies. They were designed to provide a different mix of impacts, both in the aggregate and in their distribution among users and regions. Because we wanted to determine both the extreme effects of the policies and "average effects"--those that might be expected to occur--we used two different assumptions about water supply. For extreme effects, we used the external water supply scenario equivalent to an extremely dry year; for expected effects, we used the supply scenario for a year whose effects were shown to approximate the average over many years.

We describe briefly the results of the impact assessment for the primary policies in six basic categories:

* Agriculture
* Shipping
* Thermal pollution
* Water quality
* Dutch net benefits
* Other environmental concerns

Agricultural Impacts. Under either assumption about external supply, the sprinkling of grass, which supports milk and beef production, a major component of Dutch agriculture, accounts for 60 percent of the benefits to agriculture; and those benefits increase dramatically with the amount of sprinklers and the amount of surface water available through water distribution system expansions (waterboard plans and regional and national tactics). For example, in an extremely dry year, annual net benefits to agriculture (above the cost of sprinklers and waterboard plans, if any) of the primary policies increase from about 900 to 2200 million guilders. The average net benefits of the policies to agriculture show a similar trend, but are much smaller, increasing from about 150 to 370 million guilders per year.

Shipping. Under either assumption about external supply, shipping is not much affected by water management policies. Policies do not significantly influence shipping losses due to low-water-level or lock delays, dredging costs, or the size of the long-range shipping fleet.

Thermal Pollution: Imposing thermal pollution standards causes similar penalty costs under all primary policies. (These penalty costs are the extra costs to generate electric power when standards on thermal pollution discharges cause increased use of less efficient power plants.) The stricter standards increase these costs, but only slightly. The average penalties are about 18 million guilders per year, and the penalties in an extremely dry year are about 30 million guilders.

Water Quality. Under either assumption about external supply, all policies fail to improve water quality, which frequently violates the standards. They may, however, effect local improvements.

Dutch Net Benefits. This figure takes into account all the costs and benefits of implementing the policies. It is a summary figure that includes gross benefits and costs over all sectors, including agriculture, shipping, electric power generation (the thermal penalty) summarized above, and several other sectors (e.g., industry and drinking-water companies) whose benefits were negligible under nearly all the policies.

Because of the dominance of agriculture, Dutch net benefits increase strongly with the amount of surface water sprinklers and the amount of expansion to the infrastructure. In an extremely dry year, the Dutch net benefits increase from about 850 to 2100 million guilders per year. The average values show similar but smaller increases, from about 140 to 300 million guilders per year, except for one policy, discussed below.

Other Environmental Concerns. One of the primary policies was especially designed to reflect environmental concerns about the amount of groundwater extracted. It restricts groundwater sprinklers to the current number and imposes a quota to reduce groundwater extractions to only 25 percent of the current amount. This policy does reduce groundwater extractions by 1100 million cubic meters per year, but it has other, less desirable effects:

- It reduces average Dutch net benefits by more than 400 million guilders per year because of the increased costs that industrial firms and drinking-water companies incur in compensating for their lost groundwater. This overwhelms the agriculture benefits and turns the average Dutch net benefits into a more than 200 million guilders annual loss.
- It potentially jeopardizes public health by reducing the percentage of high-quality groundwater in drinking water from 77 percent to 16 percent, substituting treated surface water of lower quality.
- It entails a large negative environmental impact because it requires the construction of many more drinking water projects (e.g., reservoirs).

S.5.9. Sensitivity Analysis

In addition to assessing the effects of the primary cases on various users and regions, we conducted a number of sensitivity studies, including the effects of different managerial strategies, increasing surface water or groundwater sprinkling, and changing groundwater quotas, priorities, and charges. We describe briefly the results of two of these studies.

We considered the effect of a fivefold reduction in the amount of oxygen-consuming substances--measured in terms of BOD (biochemical oxygen demand)--in the Rijn to reflect the possible effect of German or French cleanup programs. Regardless of the external supply, violations of the BOD standard were reduced significantly in regional waters and spectacularly in national waters.

We investigated the effects of increasing the salt load in the Rijn; this increase can be interpreted as the failure to implement a treaty under which the French would agree to reduce the amount of salt they dump into the Rijn from their potash mines in Alsace by 60 kilograms per second by 1985. The higher salt load makes little difference in the frequency with which salt standards are violated in regional waters, but it increases violations significantly in the national waters, where the water supply is mostly from the Rijn itself.

The increased salt in the Rijn has economic consequences, especially for the farmers who use Rijn water to irrigate the high-value, salt-sensitive glasshouse (greenhouse) crops in the Midwest. In an extremely dry year, the lack of the treaty costs the Netherlands about 30 million guilders, essentially all of it net losses by agriculture. Expanding the water distribution system that supplies the water and increasing the sprinkler intensity has essentially no effect on the losses because the promising Maas-Delfland pipeline tactic cannot get Maas water, which is low in salinity. In less dry years, it can get Maas water, so expansion can have a large effect: The average losses due to the lack of the treaty are more than cut in half, from 14.7 to 7.1 million guilders per year, by the expansion of the water distribution system in combination with the increase in sprinkler intensity.

S.6. THE CONSEQUENCES OF PAWN

PAWN accomplished its tasks. First, it defined the scope of the problem, identified the key parameters, and developed a methodology for assessing the multiple effects of water management policies. Second, it applied the methodology to the design of alternative water management policies for the Netherlands, and assessed the effects of those policies. Third, it created a Dutch capability for further analysis by training Dutch analysts and by documenting and transferring the PAWN methodology.

PAWN contributed directly and indirectly to the formulation of the new Dutch national policy document on water management, the Nota Waterhuishouding. The RWS combined PAWN results with results of its own analysis in drafting the Nota. Indeed, most of the policy components adopted or recommended in the Nota arose from either the PAWN analysis or the additional RWS analysis done with the PAWN methodology.

In the Nota, several existing components of the national water management policy were changed, and several new ones were adopted:

- The decision not to build any new national water management infrastructure, with one exception. PAWN results showed that the upper bound on the expected benefits for such tactics, many of which require investments of several hundred million guilders, was generally less than their fixed costs. The decision to expand the Merwedekanaal, which is relatively inexpensive, was largely based on PAWN results.
- The new policy for flushing the Markermeer. This policy, developed in PAWN, will provide annual benefits of between 0.7 and 2.5 million guilders per year.
- A new policy for flushing the Zoommeer and a new rule for withdrawals at Tiel. Investigated in PAWN, the final form of these components is based on RWS analysis using PAWN methodology.

- A thermal standard of 3 degrees Celsius for canals. This decision was based largely upon PAWN's showing that the cost of this more stringent standard (the current standard is 7 degrees Celsius) was considerably less than had been feared, and that redistributing the generating load was sufficient to meet even the more stringent standard under future levels of power demand.

The Nota also recommends a number of policies. Among the PAWN components of their recommendations are the following:

- Serious consideration of the 46 waterboard plans identified as promising in PAWN's pre-screening analysis during the development of provincial water management plans.
- Serious consideration of a number of regional technical and managerial tactics identified as promising in PAWN's screening analysis during the development of provincial water management plans.
- Use of a regional approach to pollution problems.
- Use of a regional approach to eutrophication control. Complementary tactics would be added to the continuing national pollcy of phosphate control. The combination of tactics would be tailored to each lake, based on analysis with the PAWN methodology and experimental testing.

Besides the consequences mentioned above, PAWN produced models, techniques, and a case study example that have general utility in the field of policy analysis. Few, if any, studies have been undertaken of comparable breadth and complexity. Few studies have been as successful in terms of having their methodology institutionalized for national and regional planning and their substantive results incorporated in a new national policy. And, to our knowledge, no study of comparable complexity has been more carefully and thoroughly documented.

NOTES

1. In regions of the Netherlands where groundwater is fresh, groundwater sprinkling is not common, particularly where surface water is available for sprinkling, because groundwater sprinkling is more expensive and less flexible. Therefore, we assume that an area is <u>eligible for groundwater sprinkling</u> if and only if it is <u>not</u> eligible for surface water sprinkling. The current intensity of groundwater sprinklers is about 6 percent.

2. The expected net benefit to farmers is the average loss (over many years) that can be prevented by sprinkling minus the average cost to purchase and operate the sprinklers.

3. Both were created without regard to the extent that any area was eligible for each type of sprinkling, thereby permitting us to use them to evaluate plans for expanding, anywhere in the nation, the area eligible for surface water sprinkling.

4. Not only the benefits, but some costs vary with the external supply scenario; for example, energy costs for pumping or sprinkling will be higher in dry years when more water must be moved. Other costs, such as investment and maintenance costs, remain fixed at constant values regardless. Thus, the annual cost in this discussion is actually the annual fixed cost (the annualized investment cost plus the annual fixed operations and maintenance cost), while the annual benefits are actually the annual net benefits (the difference between the benefits and the costs that vary with external supply).

5. A polder is a land area surrounded by dikes, in which the water level in the ditches is controlled independently from neighboring areas.

6. The Rotterdamse Waterweg carries Rijn and Maas water into the North Sea. During periods of low Rijn discharges, tidal action forces the denser salt water of the North Sea under the lighter fresh water in the form of a salt wedge, which may penetrate tens of kilometers inland. When the salt wedge penetrates farther upstream, it mixes with the surrounding water, and water extracted at points in the Rijn Delta under the influence of the salt wedge will have an increased salt content. Damage to salt-sensitive crops begins at low levels of salinity--200 parts per million--so it is vital to keep high-salinity water away from the intake points for agriculture. The most important intake point threatened by the salt wedge is the inlet at Gouda on the Hollandsche IJssel. This inlet provides the water supply for the midwestern section of the country, an area that grows a high percentage of the valuable, and salt-sensitive, glasshouse (greenhouse) crops.

7. For Rijn flows below average, the RWS managerial strategy closes the weir at Driel almost completely, maximizing the depth of the IJssel and benefiting IJssel shipping. However, it minimizes the total flow to the west (Neder-Rijn plus Waal), which allows a maximum of salt damage to agriculture due to the Rotterdam salt wedge and leads to an unfavorable situation for Waal shipping.

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These researchers are therefore coauthors with B. F. Goeller, PAWN project leader at Rand, who wrote many of the chapters and organized and revised the entire report. In addition, M. E. Vaiana provided technical writing assistance to the project and drafted several chapters from raw materials provided by others.

Studies of this kind often involve the assistance of many individuals. In PAWN, a great deal of such help was needed--and, fortunately, was received--because of the diversity of the topics considered, the dependence on other organizations for essential information, the complexity of communication in two languages, and the widely separated geographic locations of the Dutch and American PAWN teams.

When so much help is received from so many sources, it is impossible to individually thank everyone who contributed in some way. We mention a few names here--and the remaining volumes of the series mention more--but there are others to whom we also owe a debt of gratitude. Of course, acknowledging various individuals and institutions does not imply that those who assisted us are responsible for, or necessarily agree with, our findings. The responsibility for any shortcomings rests solely with the authors.

Although not coauthors of this summary report, a number of our Dutch colleagues made substantial contributions to the underlying research. (Indeed, many of them are coauthors of other PAWN volumes.) Chief among these contributors was J. W. Pulles of the Rijkswaterstaat,[1] the government agency for water control and public works, who served as PAWN project leader in the Netherlands. In addition to managing the PAWN effort in the Netherlands, Pulles made important contributions in developing the overall research plan, coordinating its joint execution, and suggesting helpful revisions to drafts of all volumes.

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Four groups were formed in the Netherlands to provide essential data and expertise to support the analysis. In several instances, members of the groups became important participants in the analysis.

First, the Netherlands support group helped identify technical and managerial tactics to be considered, supplied necessary data, and commented on the results. The group was composed of representatives of the three districts of the Rijkswaterstaat Directorate of Water Management and Water Movement: N. W. Zuiderveen-Borgesius and H. J. Opdam of the Southeast District, P.W.N. Buisman and D. R. Querner of the North District, and A. W. van der Hoek and B.P.C. Steenkamp of the Southwest District.

Second, the pollution group helped formulate the approach for some of the pollution problems, and members F. J. Los, N. M. de Rooij, and J.G.C. Smits of the Delft Hydraulics Laboratory performed much of the analysis of the eutrophication problem. Additional members were S. Groot, R. Klomp, and J.A.v. Pagee of the Delft Hydraulics Laboratory, and S. H. Hospers of the State Institute for Wastewater Treatment.

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In addition to the above groups, which were concerned with performing the research, two advisory groups were formed in the Netherlands to provide guidance on the scope and emphasis of the research and to assist in resolving administrative difficulties. The Rijkswaterstaat guiding group included senior managers from the relevant Rijkswaterstaat services and directorates and was chaired by H. M. Oudshoorn, head of the Rijkswaterstaat Directorate of Water Management and Water Movement, the formal client organization for the study. His dedicated support of our nontraditional approach to this complex problem, which affects many organizations besides his own, was crucial to the project's success. The other members were K. P. Blumenthal and J. van Houte from the same directorate; W. H. Barentsen of the State Institute for Wastewater Treatment; S.I.E. Blok of the Rijkswaterstaat Information Processing Service; M. de Water and R. Filarski of the Rijkswaterstaat Headquarters Department for Shipping; L. Kock and J. Hendriksen of the

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NOTES

1. The organizational affiliations shown are those at the time the individuals worked on the study. Several individuals have since moved to others parts of the Rijkswaterstaat or other organizations.

2. A detailed review was also provided by the Rijkswaterstaat, incorporating suggestions from J. W. Pulles and M. A. Veen, among others.

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Chapter 1

INTRODUCTION

1.1. PERSPECTIVE

In this study we examine the possible consequences of alternative policies for managing the Netherlands water resources. On one level, we address a specific problem--estimating the many effects of diverse alternatives on the various water users and uses, and on the Netherlands as a whole. On another level, we demonstrate a specific approach to a general problem--assessing the complex ramifications of major public policies on the natural environment, on the national and regional economies, and on individual life-styles. A dominant aspect of this type of problem is that most of the consequences cannot be expressed naturally in the same units (e.g., money) and some cannot be quantified at all. Further, different groups perceive and value particular consequences differently.

Public policy evaluation of this kind is not easy. Uncertainties abound and useful data are limited. Simply identifying the key issues is a difficult task; and one does not have the luxury of ignoring certain topics because they are too messy or intractable. However, without analysis, important policy choices are based on hunches and guesses, sometimes with regrettable results. This type of study seeks to diminish the guesswork. It is impossible to eliminate conjecture entirely, because such studies cannot estimate complex consequences with the precision possible under more controlled conditions. But they can help--and not insignificantly. This study, we believe, has directly and substantially contributed to a major public policy decision--the selection of an overall water management policy for the Netherlands. And the methodological approach and tools it has developed and transferred to the Netherlands should greatly facilitate studies of similar or related problems.

1.2. GEOGRAPHY[1]

The Netherlands, which covers an area of about 37,000 square kilometers (km^2) (14,000 square miles), lies on the North Sea on the northwestern European plain. The country is the delta of three large rivers: the Rijn, the Maas, and the Schelde. Its geographical situation gives the Netherlands a temperate maritime climate, with temperatures ranging over the year from 2 to 20 degrees Celsius (centigrade) (deg C). Total yearly precipitation averages 700 millimeters (mm) of rain (28 inches). The rain is not seasonal, but ten-day periods without rain are not uncommon, and completely dry months do occur. In drought years, the difference between the amount of rain and evaporation becomes very large, and there is not enough water for irrigation. Even in average years, crop losses in areas without irrigation equipment cost the Dutch about 1,000 million guilders (Dfl)--about 400 million dollars.[2]

More than 70 percent of the Netherlands is cultivated land, of which nearly two-thirds is grassland used for feeding livestock. Arable farming--producing crops such as cereals, potatoes, and sugar beets--accounts for about 20 percent of the total land. Horticulture--the raising of vegetables, fruits, and flowers--accounts for about 4 percent. Some vegetables are raised in heated glasshouses (greenhouses); these crops require very little land but have an extremely high economic value.

Roughly half of the noncultivated land consists of woods, heath, and dunes of small economic importance but of great importance for nature conservation and recreation. The other half consists of buildings, roads, and surface water.

The Netherlands is one of the most densely populated countries in the world. Its population of 13.5 million results in an average density of approximately 400 persons per square kilometer. Despite the large fraction of its land devoted to agriculture, that sector of the economy engages only about 7 percent of the workforce. The largest percentage--40 percent--work in industry, primarily in metal manufacturing, food, chemicals, and textiles. Twenty-five percent of the workers are engaged in trade and transport. The rest are employed in service occupations, including the civil service, local government, and education.

The gross national product of the Netherlands--approximately 150,000 million Dfl (Dflm) in 1974--is the seventh largest in the world. The contributions of the individual economic sectors are roughly equivalent to the percentage of the workforce that they employ.

Because the Netherlands is physically the delta of three rivers and shares a long coastline with the North Sea, it has an unsettled relationship with its environment. More than a quarter of its total land area lies below mean sea level and is protected from flooding by an extensive system of dikes, many of them hundreds of years old. Without these dikes, nearly half the country would be permanently under water, or inundated by tides and high river discharges with such frequency as to be uninhabitable.

Water problems in the Netherlands differ among regions and are affected by land forms. Thus, before we describe the country's water problems, we will discuss three important areas of the country: the Highlands, the Lowlands, and the Delta, a section of the Lowlands with special characteristics.

1.2.1. Highlands and Lowlands

The Lowlands are that part of the Netherlands where the elevation of the ground surface is less than 2 meters (m) above mean sea level. The complement is called the Highlands. The distribution of these two regions is shown in Fig. 1.1. The Lowlands constitute about 60 percent of the total surface area of the country.

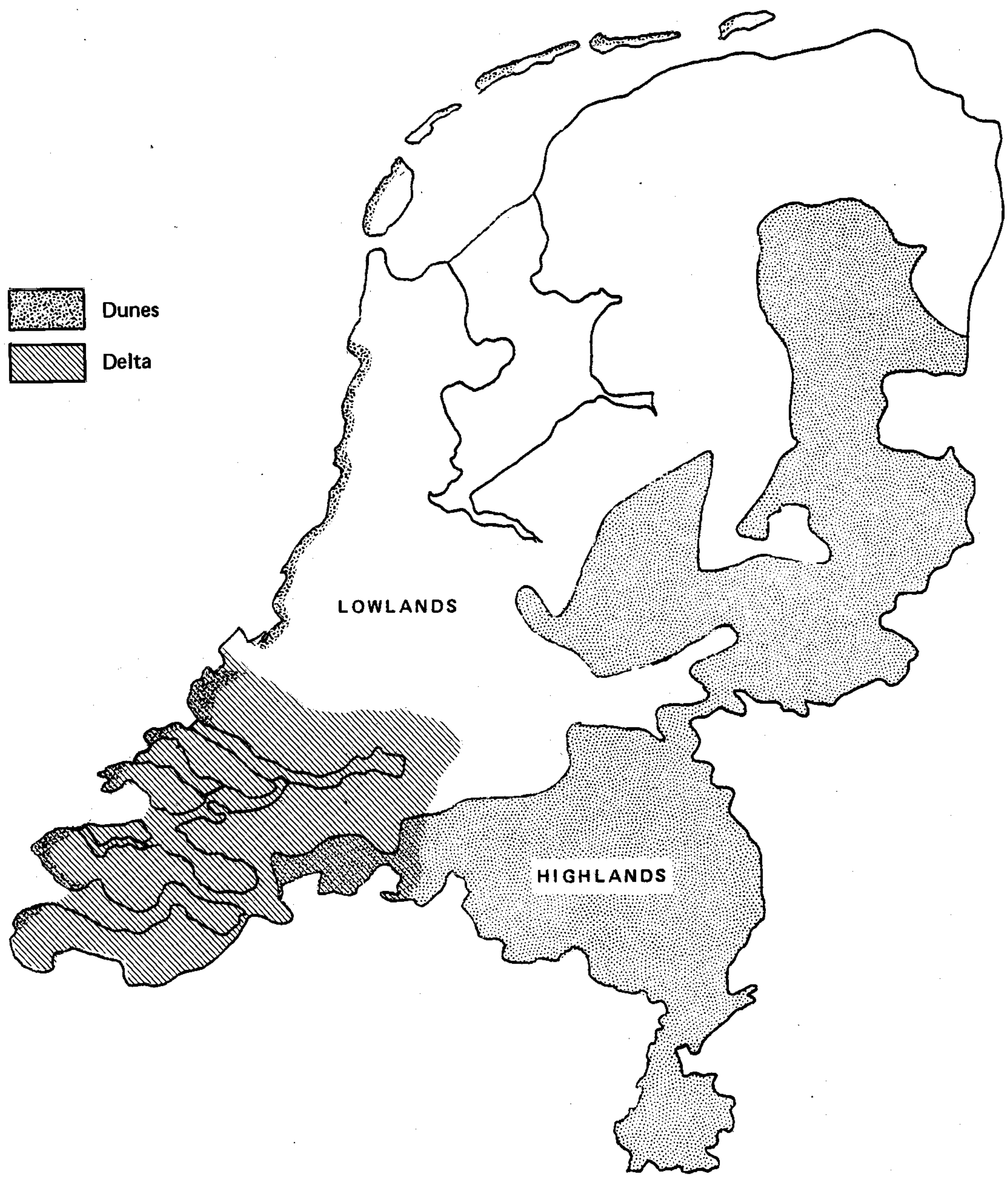

Fig. 1.1--Lowlands and Highlands of the Netherlands

The cross-section in Fig. 1.2 shows some of the major differences between these two landforms.

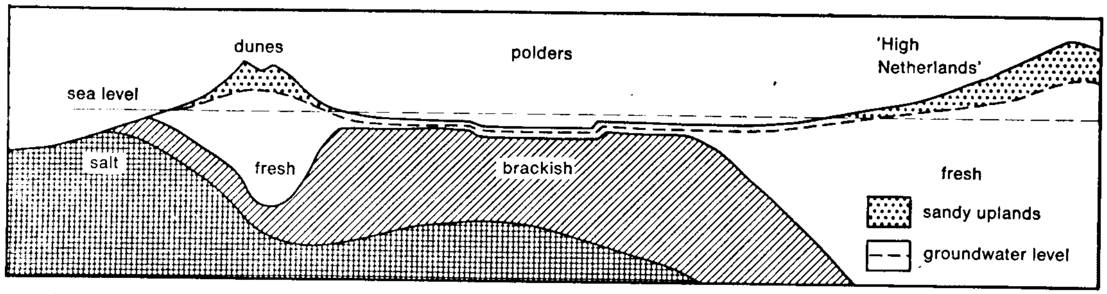

Fig. 1.2--W-E section across the western Netherlands; salinity of groundwater

(reproduced from "The Netherlands ± Water," *Land + Water International*, No. 42, 1980, p. 22)

The elevation of the Highlands ranges up to 40 m above sea level. In most places the land surface is slightly sloped. In the Highlands, as well as under the dunes along the North Sea, there is a large reserve of fresh groundwater. Most of the rainfall reaches the groundwater table, where gravitational forces cause it to flow to places with lower groundwater levels and eventually to brooks or small rivers. The Dutch have supplemented the natural drainage capacity of the Highlands with an extensive network of ditches to move water more quickly into the main distribution system.

The surface water supply system is much less developed in the Highlands than in the Lowlands, so groundwater is used more extensively for irrigation. Even though the demand for irrigation water has been relatively small, the supply routes from the major distribution system to the Highlands are inadequate during dry periods.

In the Lowlands, matters are quite different. This area was formerly an arm of the sea. Because much of it lies below sea level, excess water does not drain out naturally. This reclaimed land consists of polders--land surrounded by dikes and drained artificially.

Figure 1.3 shows a common system of water control in the Lowlands. The polder is enclosed by a dike and a belt canal or boezem. Inside the polder is a system of ditches and canals; the water level in these is maintained independent of neighboring polders. The belt canal functions as a storage basin and as a means of moving water between the polders and the rest of the surface water system. In most places, a large number of

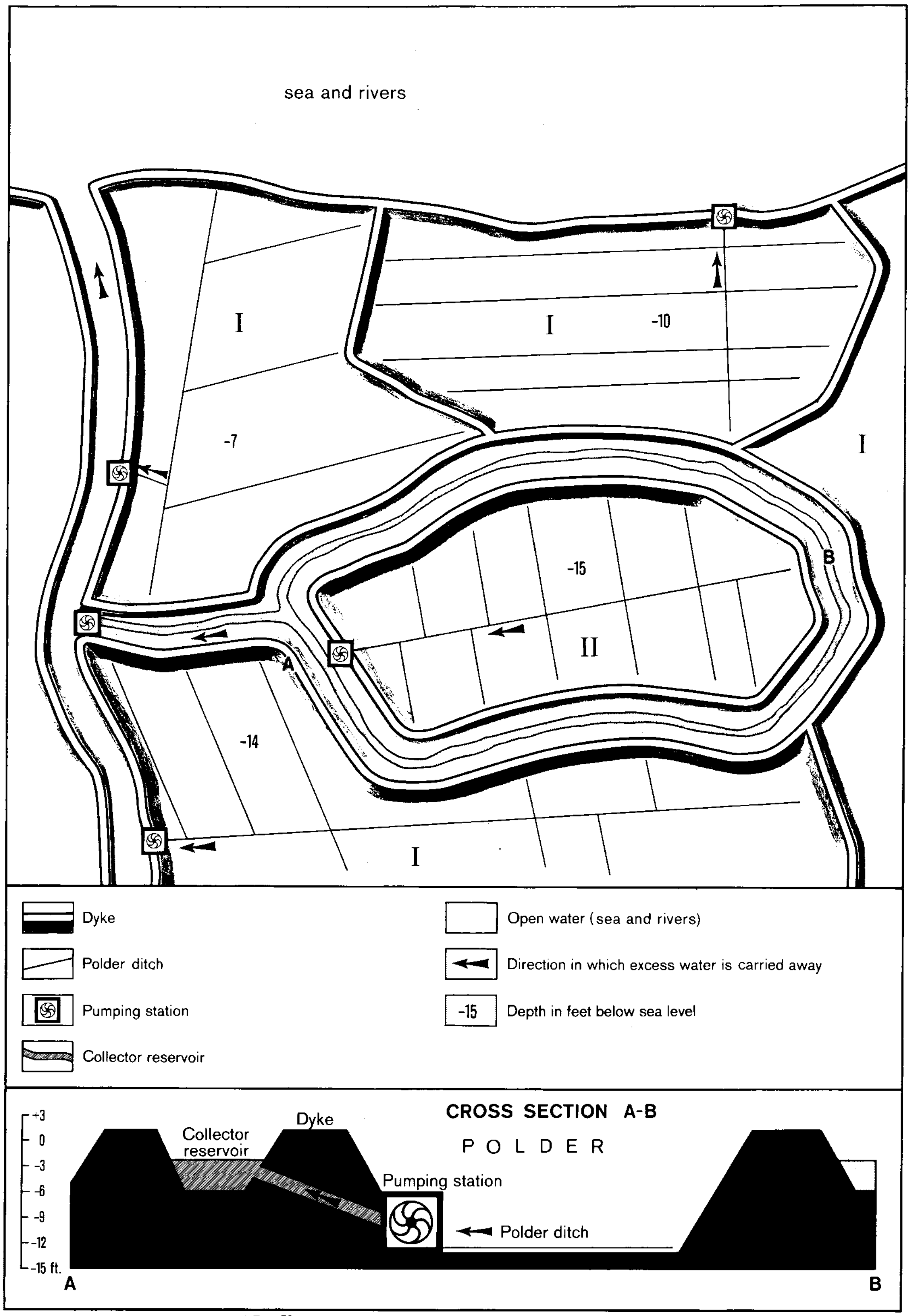

Fig. 1.3--Common system of water control in the Lowlands

polders are connected to the same boezem; its water level is usually much higher than that in the ditches of the connected polders. The ditches are the primary means of regulating the water in individual polders. Maintaining the desired level of water in the polder's ditches is called level control.

Level control requires careful balancing of the twin goals of eliminating excess water and maintaining moist soil. Each polder has a specified desired level of water in its ditches, usually determined by the polder's purpose. Whenever the water level in the ditches gets too high, pumps are turned on and the excess water is pumped into the boezem. From the boezem, the water either drains or is pumped into rivers, major canals, or open water. In dry periods, water from rivers or major canals can be pumped from the boezem into the ditches. Water in the ditches must be kept sufficiently high to prevent subsidence. (When the soil dries out, it shrinks and its surface sinks.)

Because much of the Lowlands is below sea level and because the fresh rainwater has to be continually pumped out to keep the polders dry, the groundwater in most of the Lowlands is saline or brackish. As a consequence, water for domestic use, industry, and agriculture has to come from surface water. However, salt can also be a problem with this water source. In polders lying below sea level, the considerable head difference between the ditches and the sea can cause a deep groundwater flow of saline water that penetrates the land and reaches the surface water. This phenomenon is called seepage. The rate of seepage and its salt content vary considerably from one area to another. Where the seepage is extremely saline, the ditches and boezems are flushed with fresh water to reduce the salinity and thus avoid crop damage.

The increasing salinity in the polders and boezems from soil seepage is diluted in wet periods by precipitation. But during dry periods, surface water is used to dilute and flush the saline water from the boezems. Flushing is the process of exchanging polluted or saline water in the polders for better quality water by letting water flow in at one end of the polder, then pumping it out at the other. Most of the surface water supply in the Lowlands is from the Rijn, and because the salinity of the Rijn itself has been steadily increasing, flushing is decreasingly effective.

1.2.2. The Delta

The third region of the Netherlands that must be distinguished from the perspective of water use is the Delta. (See Fig. 1.1.) The Delta is a 4000 km^2 area south and west of Rotterdam. The region consists mostly of estuaries, peninsulas, and islands formed by the repeated shifting of the outlets of the Rijn, Maas, and Schelde rivers. From north to south, the estuaries are: the Haringvliet, the Grevelingen (now a saltwater lake), the Oosterschelde, and the Westerschelde.

The Delta region is below sea level. The sea and the three rivers have changed the shoreline over the centuries, as have subsequent land reclamation efforts; former harbors now lie well inland, and former farmlands are under water. Future reclamation efforts are unlikely because in many parts of the Delta, estuarial waters are so deep that once drained, the area cannot be kept dry except by extraordinary measures.

In February 1953, a North Sea storm of unprecedented severity flooded much of the Delta region, inundating 130,000 hectares (ha) and killing several thousand people. In reaction to this disaster, the Dutch government embarked on a massive building program, the Delta Plan. This plan called for the construction of a system of dams and dikes to greatly increase the protection from flooding in all Delta estuaries. By the mid-1970s, this protective construction, called the Delta project, was nearly completed. The final component, the storm-surge barrier in the Oosterschelde, the largest estuary, will be completed in the mid-1980s.[3]

1.3. HYDROLOGY

We can view the hydrologic system of the Netherlands from many levels of detail from very general to highly disaggregated. For purposes of analysis, we have used the district as the basic hydrologic entity. A district is a region small enough that internal details of surface water movement may be considered unimportant for aggregate water management.

Each district consists of three parts: surface water, urban areas, and vegetation-covered areas.

- The surface water system includes canals, ditches, lakes, and other bodies of water open to the sky.
- Urban areas are those parts of a district that are essentially impervious to rain, for example, roads and buildings. Rainwater runs off these surfaces into the surface water system.
- Vegetation covers the major part of any district. It includes agricultural cash crops and "nature"--woods, fallow land, marshes, parks, etc. Areas covered by vegetation store water either in a relatively shallow top layer of soil (the root zone) or in the subsoil. The amount of moisture stored varies with the type of soil and increases with depth.

The hydrologic cycle is the interchange of water falling to earth in some form of precipitation, then eventually evaporating into the atmosphere. Figure 1.4 depicts the flows of water in the hydrologic cycle in any district.

Rain and Evaporation. Rain falls on the three basic areas of the district: surface water, urban areas, and vegetation-covered areas. Water also evaporates from each of these surfaces. Water is lost from vegetation-covered areas in a process called evapotranspiration. Water evaporates continually from surface water and, to some extent, from urban areas.

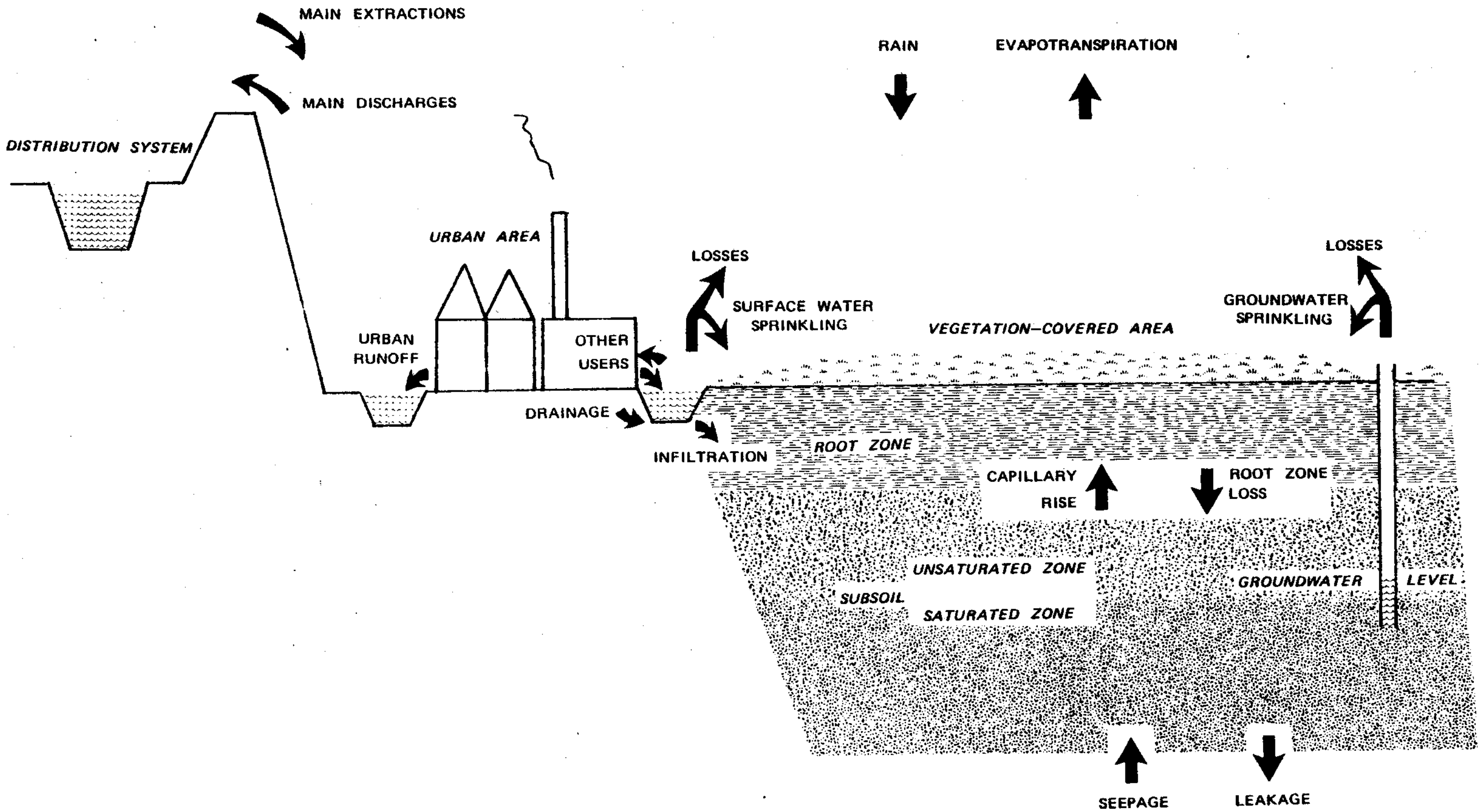

Fig. 1.4--Pathways for the flow of water

Sprinkling. Effective sprinkling is water that finds its way into the root zone, from which it may be evapotranspirated by crops. This water is drawn either from the surface water system or from groundwater. When crops are sprinkled, some of the water evaporates.

Urban Runoff. In urban areas, rainwater that does not evaporate flows into the surface water system, either directly via the sewage system or after going through some form of treatment.

Root Zone Loss and Capillary Rise. Root zone loss is the flow of water, forced by gravity, from the root zone into the subsoil. When the groundwater level is close enough to the surface, water rises into the root zone by a process known as capillary rise.

Seepage. Seepage is the movement of groundwater, under the forces of gravity, to places with lower groundwater levels. In the lower parts of the country, seepage may enter the surface water. In higher parts, water may leak from the subsoil for this reason. In some Lowlands areas, this seepage, driven by relatively high sea level, may be saline.

Drainage and Infiltration. Drainage is the movement of water, induced by gravity, from the subsoil into the surface water system. In polders, this water is pumped into ditches and canals. In the Highlands, the water moves naturally into streams and rivers, a phenomenon called basic drainage. Water can flow the other way--from ditches, canals, and rivers into the subsoil. This process is called infiltration (leakage).

Other Users of Water. Industries and drinking-water companies are typical of other users, whose extractions and discharges of water are beyond the direct control of the water management system.

Main Extractions and Discharges. The main discharge is the discharge of water from the surface water system of a district into the national water distribution system; the main extraction is the extraction from that place. These discharges/extractions are usually the result of managerial decisions made to control the water level in the canals and ditches of a district, to reduce the amount of salt, to provide water for sprinkling, etc. Note that the discharges from a district contain whatever pollution may have entered the district surface water as runoff from agricultural or urban areas, or as discharges from industrial firms and treatment plants.

1.4. MAIN FEATURES OF THE DUTCH WATER MANAGEMENT SYSTEM

Figure 1.5 shows a slightly stylized map of the Netherlands, giving the principal elements of its surface water supply and national management system. Rivers supply almost three-quarters of the country's surface water, and along with certain canals, they also function as the shipping lanes for the inland shipping fleet of Western Europe on its way to Rotterdam Harbor, the world's busiest port.

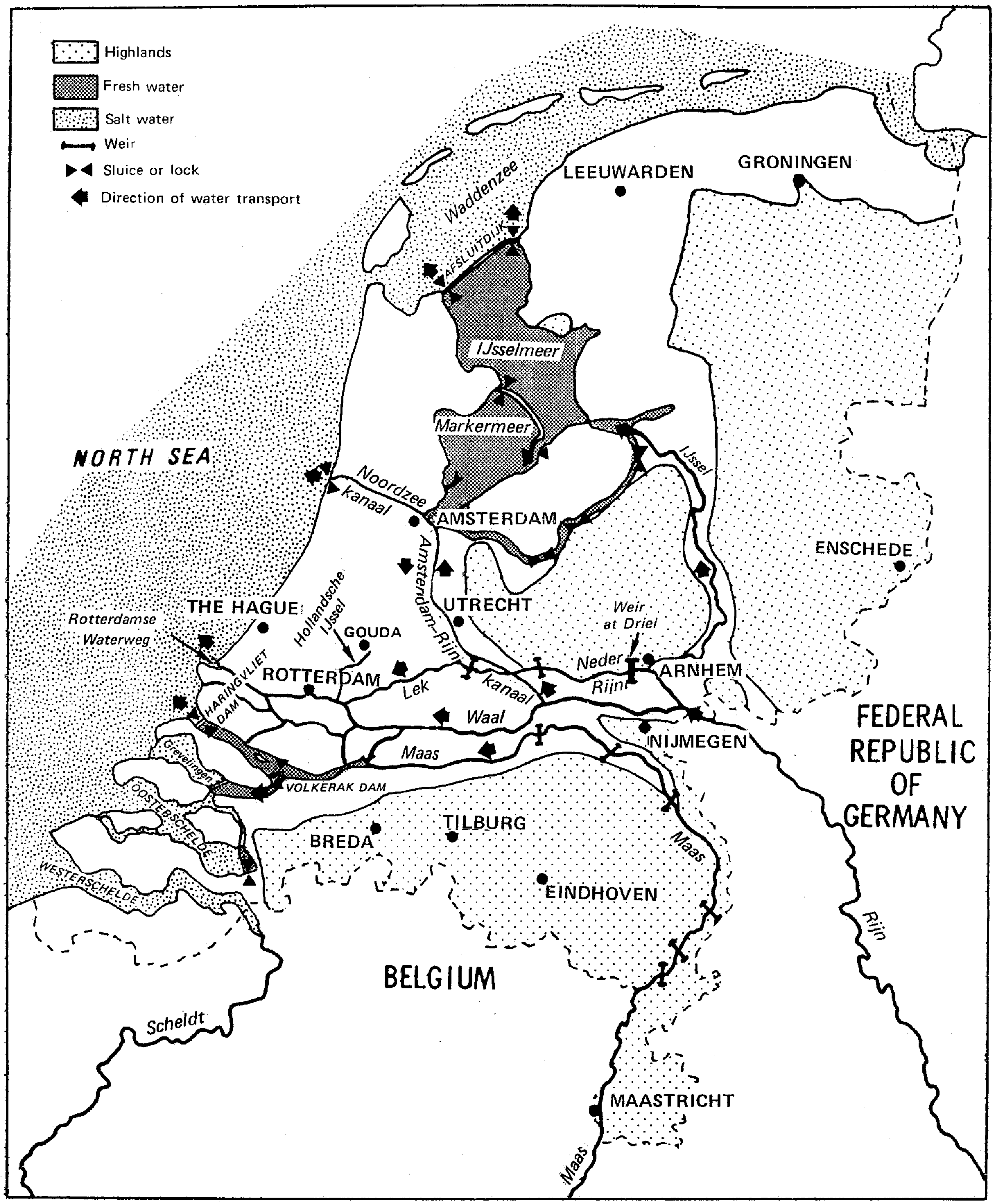

Fig. 1.5--Water system in the Netherlands: major features

The major source of surface water for the Netherlands is the river Rijn, which enters the country from Germany, i.e., from the southeast. In an average year, it brings 69,000 million cubic meters (m^3) of water into the country--about 63 percent of the entire supply of fresh surface water.

The Rijn is the major shipping artery for Western Europe. It is also known as the "sewer of Western Europe." Mines and industries along the river contribute many different kinds of pollution. Most damaging for the Netherlands is the river's increasing salinity. When the Rijn flow is high, the quality is better; but in dry periods, salinity exceeds the limits for municipal water supply and for high-quality agricultural production.

Shortly after crossing the border from West Germany, the Rijn divides into three branches: the Waal, the Neder-Rijn, and the IJssel. The Waal and the Neder-Rijn continue westward and flow into the Delta near Rotterdam. (On its way west, the Neder-Rijn becomes the Lek.) Along with the Maas River, the Waal and the Neder-Rijn provide the principal water supply for the southern part of the country.

The IJssel River flows north, discharging finally into the IJssel lakes, the former Zuiderzee. (The Zuiderzee was a salty estuary until the Afsluitdijk (barrier dam) was built in 1932, cutting it off from the North Sea.) There are two large lakes, the IJsselmeer and the Markermeer, plus several smaller border lakes. Nearly half of the former Zuiderzee is now reclaimed land, but the rest of the area is a huge storage basin, from which the northern part of the country is supplied with fresh water.

The Maas River enters the country from Belgium, i.e., from the south, then bends to the west and joins the Delta. The Maas is the main source of surface water for the southeastern section of the country, including that part of the Highlands. It supplies only 8 percent of the total surface water, but the quality is good. It is a navigation route and has been canalized to allow navigation even in the summer and fall when the flow drops almost to zero.

Between them, the Rijn and the Maas provide almost three-quarters of the country's surface water. Another 27 percent comes from precipitation. About 2 percent comes from small rivers (the Overijsselsche Vecht, Roer, Niers, and Swalm) and streams.

A regional system of small rivers, drainage canals, and lakes carries water between the national system and the rest of the country.

1.4.1. Important Components of the Water Management System

The Dutch distribute and manage the flow of these waters in a variety of ways. A network of weirs (barriers), dams, canals, and pumps controls the movement of the surface water. We discuss some of the most important of these features below.

The Weir at Driel. A large movable weir in the Neder-Rijn, about 10 km downstream from the point where the Neder-Rijn and the IJssel separate, controls the amount of water flowing among the Neder-Rijn, the IJssel, and the Waal. When the gate is lowered, flows increase in the IJssel and the Waal. (Increases in the Waal are relatively small, less than in the IJssel.) These increased flows improve shipping conditions in both rivers; and they also fill the IJsselmeer more quickly if that is desired. However, sending more water north is done at the expense of decreased supply to the southern and midwestern sections of the country. An important effect is an increased penetration of the Rotterdam salt wedge, with a resultant increased threat to the salt-sensitive glasshouse crops in the midwestern section of the country.

The Amsterdam-Rijnkanaal. Farther west at Tiel on the Waal is the Amsterdam-Rijnkanaal. It is used primarily for navigation, but it is also used to regulate the flows on the Waal and the Neder-Rijn. Water can be withdrawn from the Waal and sent north along the canal to augment the flows of the Neder-Rijn. Or water may be sent along the canal to Amsterdam, then west in the Noordzeekanaal into the North Sea.

The Afsluitdijk Sluices. The Afsluitdijk is the dam built between the IJsselmeer and the North Sea. The Dutch use the sluice gates in the dam to manipulate the water levels in the IJsselmeer. The target level is the level desirable for storage yet sufficiently low to provide adequate flood protection. At the emergency level, extractions are cut back in anticipation of supply problems. Water is always kept above a minimum level to protect the environment, maintain shipping, and make extractions for irrigation possible.

Flushing of the Markermeer. Typically, the IJsselmeer is less saline than the Markermeer, and the Markermeer is less saline than the Noordzeekanaal (a canal that flows from Amsterdam to the sea). Since a number of districts extract irrigation water from the Markermeer, the Dutch attempt to reduce its salinity by flushing it with large amounts of IJsselmeer water. Water from the Markermeer then passes through the IJsselmeer and the Noordzeekanaal to the sea, thus reducing salinity all along the discharge route. The flow also provides water for flushing the canals in Amsterdam and cooling water for several power plants.

The Volkerakdam. The Volkerakdam, built as part of the Delta Plan, separates the northern part of the Delta from the southern part. It prevents almost all of the flow from the Waal from reaching the southern Delta, discharging it through the northern part. That flow is itself regulated by another dam in the Haringvliet.

Rotterdamse Waterweg. The Rotterdamse Waterweg carries Rijn and Maas water into the North Sea. During periods of low Rijn discharges, tidal action forces the denser salt water of the North Sea under the lighter fresh water in the form of a salt wedge, which may penetrate tens of kilometers inland. When the salt wedge penetrates farther upstream, it mixes with the surrounding water, and water extracted at points in the Rijn Delta under influence of the salt wedge will have an increased salt content. Damage to salt-sensitive crops begins at low levels of salinity--200 parts per million (ppm)--so it is vital to keep high salinity water away from the intake points for agriculture. The most important intake point threatened by the salt wedge is the inlet at Gouda on the Hollandsche IJssel. This inlet provides the water supply for the midwestern section of the country, an area that grows a high percentage of the valuable, and salt-sensitive, glasshouse crops.

To be effective in fighting the salt wedge, the flow past Rotterdam has to be more than 600 cubic meters per second (m^3/s), roughly a third of the average Rijn flow. However, a flow of this magnitude cannot always be guaranteed; in a dry summer and fall it could constitute almost the entire supply to the country.

The Haringvliet Sluices. In the Haringvliet, a large estuary just south of Rotterdam, the Dutch have built a kilometer-long dam--the world's largest containing sluice gates. These sluices and the Rotterdamse Waterweg are the only escape routes for water from the Waal. When water is abundant, the sluices are left open and water flows through both routes. When the river is low, the Dutch ensure a sufficient flow to keep back the Rotterdam salt wedge by closing the sluices at Haringvliet completely, forcing all the water in the Waal to flow past Rotterdam.

Cutbacks. In addition to manipulating the supply of surface water, when necessary the Dutch also manipulate the demand for water. In dry years, during the growing season (March to October), water is pumped from the surface water system and sprinkled on crops. Under these circumstances, the sprinkling water demands can seriously reduce flows, making shipping more difficult and increasing salt intrusion. Reducing the amount of water used for sprinkling improves shipping and lessens the salt intrusion problem, but at the cost of crop losses.

Groundwater. Groundwater is another important element in the water management system. It is found everywhere, usually quite close to the surface of the land. In the Highlands, the quality of the groundwater is good, and it is an important source of drinking and irrigation water. In the Lowlands, the groundwater is usually saline or brackish. However, good quality groundwater can be found in the dunes along the North Sea, and drinking-water companies often pump surface water into the dunes to store it or to take advantage of the dunes' natural filtration characteristics.

Groundwater is recharged from rain, of which there is usually an adequate supply. Groundwater also flows into the Netherlands from its neighbors.

1.4.2. Water Management Agencies

Management of the large rivers, canals, and estuaries, as well as construction and maintenance of the related engineering works, is the responsibility of an agency of the national government, the Rijkswaterstaat, part of the Ministry of Transportation and Public Works. The Netherlands is divided into eleven provinces.[4] Each of these has tasks regarding water management and works, comparable to those of the central government, which they perform with some supervision from the Rijkswaterstaat. These kinds of management units are similar to those used in many other countries. Unique to the Dutch water management system are the "waterschappen" or polder boards. We refer to them as waterboards because of their similarity in structure to American school boards.

The purpose of the waterboards is to manage one or more polders. They construct and maintain the dikes, oversee the quantity and (in some instances) quality of the water used, coordinate land and water communications, and occasionally concern themselves with recreation and nature conservation issues. The money for carrying out these tasks is obtained from a tax levied on landowners or owners of real estate, supplemented, when necessary, by subsidies from the central or provincial government.

The waterboards fall under the legislative responsibilities of the relevant province, which may establish and abolish them. Concentration has taken place over the last fifteen years, and the number of boards has fallen from 2,500 to about 600. Each waterboard has its own regulations that prescribe its tasks and powers, but these must be approved by the central government. The directors of the waterboards are elected by the owners of land in the polders. In the case of waterboards that are responsible for defenses against the sea, the IJssel lakes, or the big rivers, the executive boards are appointed by the Crown.

The central government, the provinces, and the waterboards share the critical tasks of ensuring safety against flood and managing the distribution of water, but the waterboard is really the keystone of the system. The waterboards have been such a successful water management tool because they "unite in a harmonious way private and public interests" [1.1].

1.5. GENERAL WATER MANAGEMENT PROBLEMS OF THE NETHERLANDS

1.5.1. The Original Problem: Too Much Water

Historically, the Dutch water management problem has been one of too much water. In an average year, the amount of rainfall exceeds the amount of water that evaporates by about 250 mm. The annual inflow from the Rijn, if it could be retained and spread uniformly over the land, would cover the Netherlands to a depth of nearly 2 m. In the Lowlands, where much of the land lies below sea level, as much as 200 mm of water seeps up from below due to pressure from the sea.

Over the years, the Dutch have built an extensive and complicated system to protect themselves from an excess of water. The land, especially in the lower parts, contains a dense network of ditches and drainage canals to remove excess rain and seepage water. Dikes, weirs, and locks control the rivers. With the completion of the Delta project, in the mid-1980s, a system of dams and dikes will protect the land against such severe North Sea storms that flooding is to be expected only once in 4,000 years.

While the Dutch will never "solve" the problem of too much water, the problem is essentially "under control." In recent years, they have turned their attention to several new ones: too little water and too much pollution.

1.5.2. The Modern Problem: Too Little Water and Too Much Pollution

The Netherlands has been called "a wet country short of water" [1.1]. In 1976, for example, a severe drought occurred in Western Europe. The summer was very hot, many days passed between meager rainfalls, and rivers set record low discharges. The drought caused serious problems in the Netherlands:

- Farmers who lacked irrigation equipment or access to water lost much of their crops because of drought damage.
- Low river discharges allowed increased saltwater intrusion from the North Sea and resulted in higher salt concentrations in the surface water system. Farmers who used this water for irrigation lost some of their crops to salt damage. The agricultural losses from drought and salt damage together exceeded 5,000 Dflm (2,000 million dollars).
- Low river levels caused serious shipping delays because ships could not navigate the rivers with full loads.
- The shortage of water and the hot, dry weather aggravated existing water quality problems. For example, less water was available to dilute pollutants in the waterways.

The drought of 1976 was not the first time the Dutch had experienced problems like these: Such problems occur frequently, though usually to a much lesser degree. In common with other developed countries, the Netherlands faces shortages of water, water quality problems, environmental problems, and distribution problems--all stemming in part from increased population, industrialization, and standards of living. As elsewhere, the Dutch have experienced growing competition among various users of water: agriculture, shipping, electricity generation, industrial and commercial firms, companies that supply drinking water, households, and the natural environment (e.g., nature preserves). These problems are intensified in the Netherlands because of the dense population, because so much of the country lies below sea level, and because the major source of surface water is the polluted Rijn.

It is useful to distinguish four classes of water management problems: water shortage, salinity, quality, and flood.

Shortage. The future demand for fresh water is expected to exceed the supply in some dry years. 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. In most places the supply of surface water is sufficient except for limited periods during dry years, when there is competition not only among such users as agriculture, power plants, and shipping, but also among different regions. In a few places, localized shortages of surface water occur in normal summers (e.g., in the higher areas of the country, which have limited routes by which water can be supplied).

A water shortage may cause a user to experience damage or to incur extra costs to avoid damage. For example, when there is a shortage of rain, farmers may spend extra money irrigating their crops to avoid reducing the size or quality of the yield; if there is insufficient irrigation water or equipment, the crops will be damaged and the farmer will suffer economic losses. Low water levels in the rivers and canals will cause increases in shipping costs because the vessels cannot travel fully laden.

Salinity. Salinity is a long-standing and serious problem in the Netherlands, one that is particularly acute in times of water shortage. There is saltwater intrusion from the sea into the low-lying part of the Netherlands through estuaries, harbors, and shipping locks, and also, driven by hydraulic pressure, by seepage through the subsoil. The water and salt budgets in these low-lying areas must be carefully controlled lest the salt concentration in the ditches and canals become too high to permit irrigation. This is especially a problem during rainless periods, and when fresh river water is not available. Low-salinity river water has become less and less available as the Rijn has become more and more polluted. The salt load measured in the Rijn at Lobith, where it crosses the border, has risen from an annual average of 125 kilograms per second (kg/s) chloride in 1930 to about 300 kg/s chloride in 1976.

The salinity of the Rijn is aggravated during periods of low flow. In 1976, the average Rijn flow was only 1350 m^3/s, with an average chloride concentration of over 200 ppm (a widely accepted standard) and with periods when the concentration exceeded 400 ppm. By contrast, in 1977 the chloride load was about 50 kg/s higher, but because the average flow was also higher (2200 m^3/s), the average chloride concentration was lower (160 ppm) [1.5, 1.6].

High salinity can damage the quantity or quality of agricultural crops. For example, lettuce grown in Dutch glasshouses may have small brown edges on some of the leaves, rendering a valuable product almost worthless. Although high salinity probably has been most costly to agriculture, it also has corrosive effects on household and industrial equipment and fixtures, it can damage existing freshwater flora and fauna, and, at high concentrations, it can cause drinking water to become unpalatable or to have adverse health effects (e.g., contributing to high blood pressure).

Quality. We usually use the term "quality" to refer to pollutants other than salt and to other issues of environmental quality. (In later chapters we may for convenience occasionally include salinity problems within quality problems. When we do, it is generally clear from the context.)

The quality of water in a lake or stream is one of the most important factors in determining what species of plant and animal life can thrive there. In the terrestrial environment, the quantity and quality of water supplied to an area of land directly influence the composition of the plant community growing there, and the influence extends indirectly to animals, who ultimately depend on the plants for food and shelter.

Water quality also affects the uses that man may make of water. Drinking water, for example, must be free of toxic substances and must meet certain standards of odor and taste. Some industrial processes also require that water meet rigorous quality standards. Aquatic recreation is discouraged where the water is turbid or choked with weeds. If the water is sufficiently polluted, it may become a hazard to human health.

The ongoing Dutch surface water control program, which is building many new treatment plants for household and industrial waste, should by 1985 greatly improve water quality as measured by the level of the most common pollutants. However, several problems will remain.

By far the greater part of the offending pollutants are not generated domestically but are imported from outside the Netherlands, virtually all by the Rijn and Maas. In principle, this imported pollution can be dealt with by international initiatives such as the recent treaties with France, Germany, and Belgium, or by river management (e.g., concentrating the Rijn flow on a single path to the sea when quality is very poor). But action on domestic pollution is still important because it can lead to very high local concentrations and hence cause greater damage.

Heavy growths of algae--often referred to as eutrophication--are a particularly troublesome water quality problem in many Dutch lakes and reservoirs because the water contains sufficiently high concentrations of the nutrients algae require, such as phosphorus.

Thermal pollution is another important water quality problem in the Netherlands. This problem arises primarily when electrical generating plants extract large amounts of cooling water from rivers and canals and then discharge large amounts of heat as they return the water.

Like salinity, other water quality problems are aggravated by water shortage, for there is less water to dilute the polluting substances. Furthermore, eutrophication is particularly troublesome in a hot, dry summer like that in 1976 because it provides the algae not only with a higher concentration of nutrients but also with a greater amount of sunlight.

Flood. Although the problem of excess water is generally under control in the Netherlands, as noted earlier, there is one remaining aspect of particular importance--flood risk around the IJssel lakes. When we consider changing the policies that govern the water level in the IJssel lakes so as to store extra water to help alleviate shortages, we may increase the risk that the dikes protecting the surrounding land will fail. Furthermore, higher levels in the IJssel lakes might make it much more difficult for existing pumps to drain the surrounding polders; these additional drainage problems might lead to some direct damage.

1.5.3. Location of the Four Problems

In a general but oversimplified way, the four problems identified above can be associated with different regions (landforms) in the Netherlands. The Highlands has a particular problem with shortages, the Lowlands with salinity, the Delta with both, and the area around the IJssel lakes with flood. Quality is a problem, to a greater or lesser extent, everywhere.

1.5.4. The Need for a National Focus

The Dutch battle against their original problem of too much water was historically a local affair. In the largely agricultural era of many years ago, when population was sparse, the waterboards did a good job of solving problems associated with too much water. But in the modern industrial era, with dense populations, a local approach to problems of scarcity and quality is not sufficient. Upstream users take water away from downstream users and dump pollutants; the damage caused downstream by water shortage and poor quality may be greater than the benefits achieved upstream by using the water and dumping the pollutants. And the interests of some national water users such as the shipping industry cannot be adequately represented by the locally controlled waterboards. Thus, the modern water management problem is national in scope, not just because the problem is ubiquitous, but more important, because all its aspects are highly interrelated--a local solution to one part of the problem may make another part worse somewhere else.

The modern problem requires a shift from local solutions to regional and national ones. The need to treat the whole problem, nationally and in all its parts, led to the PAWN project.[5]

1.6. THE PAWN PROJECT

Facing the water management problems described above, 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. The Rijkswaterstaat established the agency Policy Analysis for the Water Management of the Netherlands (PAWN) Project in April 1977 as a joint research project of The Rand Corporation,[6] the Rijkswaterstaat (RWS),[7] and the Delft Hydraulics Laboratory (DHL), a leading Dutch research organization.[8] The research and analysis phase of the project, which had been preceded by a 9-month feasibility study, lasted from April 1977 to December 1979, and was followed by several years of reporting.

The PAWN project was a major undertaking. It directly involved about 125 man-years of effort, created several dozen computer programs, consumed over 600,000 Dfl ($250,000) of computer time, and gathered and structured an enormous amount of data (for example, the computerized database representing agriculture contained over 12,000 elements). Additional resources were provided indirectly as various institutes and agencies responded to requests. During the peak period of the study, there were about 15 researchers at Rand, six at the RWS, and six at the DHL working full-time on the analysis, plus numerous data-gatherers and technical specialists contributing full- and part-time.

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 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.

Accomplishing these tasks required close cooperation among the research teams. Rand had extensive experience performing policy analysis studies and developing methodology for the purpose but had limited knowledge of the Netherlands' water resource problems and institutions. The opposite was true of the Dutch, for although the RWS and DHL were experts on water resource problems and the Netherlands, they had little experience with policy analysis. The overall research plan was designed to capitalize on this complementarity. The problem was divided into major areas, and a Rand researcher and a Dutch counterpart were designated for each area. The Dutch counterpart helped to develop the methodology and perform the analysis, generally working at Rand for a number of weeks as well as in the Netherlands; this participation, as intended, provided thorough training for the Dutch analysts and greatly facilitated the documentation and transfer of the methodology to the Netherlands. The Dutch counterpart was generally also responsible for coordinating PAWN data-gathering and research in the Netherlands and for providing liaison with other organizations. One member of the RWS staff was at Rand throughout the analysis and for much of the documentation period.[9] A senior member of the DHL staff was at Rand for most of the research, and another member for the latter half.

Because the analysis was physically performed at Rand, the Rand counterpart was responsible for developing the methodology and performing the analysis in most of the major areas, and for helping the Rand project leader maintain coordination among the different areas of the project. The counterpart generally visited the Netherlands four times each year while the research was under way. The senior economist on the Rand team spent nearly the whole research period in residence in the Netherlands.

Besides the frequent exchange of visits, several other techniques were used to facilitate communication and coordination among the researchers. First, the project members wrote and circulated among themselves about 600 informal memoranda, describing the current status of their work--including progress or difficulties in problem formulation--and their needs from the other parts of the project. To encourage the free exchange of ideas by allowing the author to "think out loud," the memoranda received little circulation outside the project team.

Second, while the research was under way, the project regularly prepared and presented quarterly progress reports to the PAWN guiding group, which included senior managers from the relevant RWS services and directorates and was chaired by the head of the organization that was our formal client, the RWS Directie Waterhuishouding en Waterbeweging (Directorate of Water Management and Water Movement). These oral progress reports (briefings with overhead projector slides) covered the status of each part of the project, emphasizing the approach being taken and the difficulties encountered (e.g., shortage or delay of needed data). The guiding group identified issues that they felt needed attention, or ways that a shift in research emphasis could make the study results more useful. They also offered advice or assistance to help resolve difficulties. After each report, a booklet documenting the presentation and summarizing the discussion was distributed to the project team, the guiding group, and certain additional advisers. The process of preparing, discussing, and circulating progress reports regularly each quarter thus helped improve both the coordination of the research and the eventual utility of its results.

After more than two and a half years of research, the PAWN final briefing was presented at Delft on December 11 and 12, 1979. The briefing described the PAWN methodology and results and provided for questions and discussion by the audience. The audience consisted of several hundred representatives of governmental and private organizations concerned with water resources, environmental quality, and the economy. These organizations are listed in App. A.[10]

For Rand, the final briefing marked the end of the analysis phase of the project and the beginning of the documentation phase. The documentation phase continued for several years because the RWS wanted unusually thorough and extensive documentation of the methodology and results. Their intention was not only to produce a complete explanation of the PAWN analysis to support any conclusions or actions they might base on PAWN, but also to provide a case study that could be used as an example for training new analysts and for performing new studies.

The methodology and results of the PAWN project are described in a series of Rand publications entitled Policy Analysis of Water Management for the Netherlands. The series contains 21 volumes, whose titles are listed in the Preface. Although published by Rand, this series represents a joint Rand/RWS/DHL research effort. Many of the other volumes have Dutch coauthors, and all have Dutch contributors.

Rand and the RWS considered the PAWN results to be tentative because some of the methodology was not available until late in the analysis phase, and because the RWS planned to do additional analysis. Indeed, the PAWN methodology was successfully transferred to the Netherlands several months after the final briefing and considerable additional analysis was done with it in the Netherlands by Dutch analysts trained in PAWN.

The RWS combined some of the PAWN results from the December 1979 final briefing with the results of this additional analysis to draft its Nota Waterhuishouding, the new national policy document on water management. This policy document--scheduled for publication in late 1982, after extensive review and consultation with other government ministries, the provinces, and local waterboards--provides a new national water management policy for the Netherlands.

Because the understanding gained in the original PAWN 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. Thus, the PAWN volumes put primary emphasis on documenting the methodology rather than on describing the policy results.

Besides its contribution to a national water management policy, the PAWN methodology and results had several other intended uses: for example, contributing to the preparation of the first national water management law, helping the regions develop detailed water management plans, and providing input to international negotiations on water. Finally, the transferred methodology and the Dutch analysts trained in PAWN were intended to provide the Netherlands with a capability for developing solutions to similar or related water resource problems.

1.7. SCOPE AND PURPOSE OF THIS REPORT

This report describes the methodology and results presented at the PAWN final briefing in December 1979, which, for Rand, marked the end of the analysis phase of the project. Thus, whenever we refer to "current" policies, facilities, or conditions, the reader should understand that we mean those existing during the analysis rather than those that may exist now. In many instances additional details are given in this report that were not in the final briefing. And in a few instances, explicitly noted, changes have been made. It should be emphasized that this report summarizes the project rather than merely the other PAWN volumes, for it contains considerable material that appears nowhere else. Because the organization of the report is determined by our general approach, we first present an overview of the approach in the next chapter, before explaining the report organization.

This report is intended to perform several functions for multiple audiences. The obvious one is to provide a comprehensive description of the PAWN results and methodology. In addition, the report provides a thoroughly documented case study for government officials, engineers, regional planners, and others in fields outside water resource and environmental analysis who wish to learn how a policy analysis of complex natural resource and environmental questions can be carried out. Moreover, for specialists in these fields, it introduces an operational methodology that is more comprehensive than others and that employs several useful new techniques.

Finally, for those concerned generally with the analysis of public policy decisions, either as producers or consumers, the report offers a comprehensive description of the approach and results of a study that contributed in a direct way to the making of a major and highly controversial public policy decision. Most of the components of the new national water management policy for the Netherlands presented in the Nota Waterhuishouding arose from the PAWN analysis or the additional RWS analysis done with the PAWN methodology. The concluding chapter of this report identifies these components and relates them to PAWN results.

NOTES

1. This background section is written primarily for American readers. Our references to "the Netherlands" and "Holland" conform to Dutch usage, not to the common American and English practice of assuming the two terms are interchangeable. Thus, "the Netherlands" refers to the country and "Holland" to its populous central western part. In our discussion of Dutch geography and the water management system, we have drawn heavily on the Dutch publications shown in Refs. 1.1, 1.2, and 1.3.

2. The guilder is the official monetary unit of the Netherlands. The "fl" in the abbreviation comes from "florin," the historical unit. A conversion factor of 2.5 Dfl per U.S. dollar roughly approximates the fluctuating conversion rate. Throughout the report, the following notational conventions are used:

   - deg C for degrees Centigrade.
   - Dfl for Dutch guilders.
   - Dflm for millions of Dutch guilders.
   - m for meters.
   - m^2 for square meters (comparable to sq yd for square yards).
   - m^3 for cubic meters.
   - m^3/s for cubic meters per second.
   - mcm for million cubic meters.
   - cm for centimeters.

- cm^3 for cubic centimeters.
- km for kilometers.
- km^2 for square kilometers.
- ha for hectares (a unit of area analogous to the acre).
- g for grams.
- kg for kilograms.
- kg/s for kilograms per second.
- mg for milligrams.
- µg for micrograms.
- l for liter.
- ml for milliliter.
- ppm for parts per million.

3. For a discussion of the decision to construct a storm-surge barrier in the Oosterschelde, see Ref. 1.4.

4. Provinces are further divided into municipalities, but these have little direct responsibility for water management or policy.

5. It has also led to legislative action on water problems. An Anti-Water-Pollution Act is in effect and has already begun to improve surface water quality. One of its basic principles is decentralization of tasks among the different levels of government. The central government is responsible for the state waters described above, whereas the provinces or waterboards are responsible for the remainder. The first and second of the Five Year Plans required by the act have been approved by Parliament, covering the 1975-1979 and 1980-1984 periods, respectively. Each is called the IMP (Indicatief Meerjaarenprogramma--Prospective Multiyear Surface Water Control Program). The second plan was in preparation during our analysis.

   A Groundwater Act was recently passed by Parliament after several years of consideration. It will enhance control of groundwater quantity by means of a system of permits for groundwater extraction, based on national and regional groundwater policies. A companion Soil Protection Act is being prepared that includes the objective of protecting the quality of groundwater.

   Finally, the first national water management law emphasizing water quantity but linking all elements of water management together [1.1] was in preparation when PAWN began and has recently been sent to Parliament.

6. Rand had had extensive experience with similar kinds of analysis, had been working with the Rijkswaterstaat for several years on other problems, and had collaborated successfully with the Rijkswaterstaat on another major policy study (see Ref. 1.4).

7. 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.

8. Delft Hydraulics Laboratory research was performed under project number R1230, sponsored by the Netherlands Rijkswaterstaat.

9. A member of the Rand Graduate Institute doctoral program in policy analysis, he integrated his coursework with on-the-job training on the PAWN project, and has based his doctoral dissertation on an extension of his PAWN research.

10. A major public progress report was presented before a similar audience in April 1978, after one year of research and analysis. Its purpose was to inform the various organizations of PAWN's specific concerns and approach and to solicit their suggestions and assistance.

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Chapter 2

OVERVIEW OF APPROACH

2.1. INTRODUCTION

This chapter presents an overview of PAWN's approach. It begins by describing features of policy analysis. Then it discusses formulation of the PAWN problem, defines what we mean by a water management policy and the kinds of components that make up such a policy, and indicates the consequences (impacts) considered in our analysis of policies. Next it presents our analytical approach, discussing the different stages of analysis. Finally, in terms of these stages, it describes the organization of the remainder of the report.

2.2. FEATURES OF POLICY ANALYSIS

Policy analysis is a systematic approach to making complex choices. However, it is not a single method or technique, or even a fixed set of techniques. Indeed, because policy analyses take their characteristics largely from the problems they address, the analyses of different problems often show little resemblance. Thus, it is difficult to give a short definition of policy analysis that captures its essence. One such definition, on which we shall elaborate, is the following:

> Policy analysis is an inquiry whose purpose is to assist decisionmakers in choosing a preferred course of action from among complex alternatives under uncertain conditions.

Three key words in the above definition deserve special comment. The word assist emphasizes that policy analysis does not replace the judgment of the decisionmakers (any more than an X-ray or a blood test replaces the judgment of medical doctors). Rather, it aids the exercise of that judgment by clarifying the problem, outlining the alternatives, and comparing their consequences.

The word complex emphasizes that the alternatives are often numerous, involve mixtures of different technologies and management policies, and produce multiple consequences that are often far-reaching yet difficult to anticipate (let alone predict).

The word uncertain emphasizes that the decisionmaker must generally make choices on the basis of incomplete knowledge, among alternatives that do not yet physically exist, and whose predicted consequences will occur--if at all--only in an unknown future. Alternatives must be compared not only by their expected consequences but also by the risks of being wrong.

2.2.1. The Importance of Models

Policy analysis commonly uses mathematical models to predict the effects of different alternatives; there may be a single model or a series of models for a given problem, depending on its complexity. A model is an analog of reality; it is made up of factors relevant to a problem and the essential cause-and-effect relations among them. Depending on the kind of problem, the appropriate model may be a set of mathematical equations, a computer program, or even a map. The form of the model generally depends on the form of the question; if we are going sightseeing, the appropriate model is probably an ordinary street map; if we are going hiking, it is probably a topographic map.

For predicting the consequences of alternatives, PAWN needed the objective and systematic approach of models rather than an intuitive or ad hoc approach, for several reasons. First, the factors influencing the results were so numerous that their interrelations could not all be considered without the formal structure of a model; for example, the Netherlands' water management system included hundreds of waterways and junctions. Second, some alternatives had counterintuitive effects; for example, although increasing the irrigation in the Southeast Highlands by pumping more groundwater would help agriculture in dry periods, it would also tend to lower the water in the Maas, which would hurt shipping.

Finally, models simplified communication by introducing a precise terminology. More important, they increased objectivity by requiring assumptions to be explicit rather than hidden.

PAWN developed and used many models for analyzing the different impacts, including one to assess agricultural losses from water shortage and salinity and another to assess where water quality standards would be violated, and how often. These models are described later, in a series of chapters about the components of our methodology.

2.2.2. Focus on Problem Formulation

Problem formulation is concerned primarily with defining the objectives of and setting boundaries on the analysis. For a simple problem such as choosing your dessert in a restaurant, formulation is a trivial exercise; your analysis is limited by what is on the menu and your objectives are largely determined by whether you are dieting or not (that is, do you want the fewest calories or the best taste?). But for complex problems, formulation is a substantial--and crucial--fraction of the work. Choosing the wrong objectives, for example, means solving the wrong problem.

Even when the proper objectives have been identified, another difficult part of problem formulation remains: putting boundaries on the analysis. This involves deciding what factors to include and with how much detail; the neglect of important factors may cause the analysis to reach a misleading conclusion, yet the inclusion of irrelevant factors and unnecessary details may prevent it from reaching any timely or useful conclusions at all.

A later section will discuss problem formulation for PAWN.

2.2.3. The Explicit Treatment of Uncertainty

Because they involve the future, most important decision problems involve major uncertainties, and a policy analysis of such problems must explicitly treat uncertainty. This may be done in a variety of ways, two of which were particularly important for PAWN.

Scenario Construction. A scenario is a description of some hypothetical future state of the world. Scenario construction is like writing future history. However, where the usual history strives for completeness, the scenario tries to consider only the major factors, ones that might strongly affect the cost or performance of an alternative. Such factors might be advances in technology, scarcity of resources, attitudes of people, or politics and economics of nations.

In PAWN, scenarios consist of factors that are uncertain and whose values will be determined by outside processes (political or natural) beyond the control of water management decisionmakers. For example, each scenario considered would need to make explicit assumptions about the effect of future international treaties on the amount of pollution entering the Netherlands in the Rijn, the future economic situation (e.g., the level of activity in different industries), and the attitudes about public health and environmental preservation (e.g., how stringent a set of water quality standards society will want enforced).

To complement scenarios, which are assumptions about factors outside the system, PAWN also considers system assumptions--assumptions about factors inside the system that are beyond the decisionmakers' control. System assumptions usually reflect scientific uncertainties or modeling assumptions. Important system assumptions in PAWN included the geographic distribution of current crops and sprinklers, seepage rates, the efficiencies of electrical generating plants, and various economic data used in benefit calculations. Of these, the most important was probably the economic value of grass, because grass supports milk and beef production, the largest component of Dutch agriculture.

Sensitivity Analysis. In every policy analysis a few key parameters have quite uncertain values. Instead of using average values for these parameters, the analyst may successively use several values (say high, medium, and low) to see how sensitive the results (and the ranking of the alternatives) are to variations in the parameters.

If a certain alternative is superior in all of these sensitivity investigations, it is referred to as a dominant solution. Dominance is a characteristic that the analyst is always seeking, but its existence is rare in complex problems.

For the PAWN problem, several uncertainties have potentially major effects on the impacts and hence on the rankings. One is the amount of water entering the country during the year in rivers and in rain. This varies randomly and widely from year to year. Another uncertainty is how much additional irrigation equipment farmers will buy. Yet another concerns how much salt will be "dumped" into the Rijn by other countries. Still another is the economic value of grass.

2.3. PROBLEM FORMULATION PRELIMINARIES

To really understand a policy problem, the analysts must, in effect, put the decisionmaker "on the couch." That is, in the beginning policy analysis somewhat resembles psychiatry: The (policy) analyst holds lengthy discussions with the decisionmaker, who is often preoccupied with the symptoms of his problem, in an attempt to define the basic issues, identify the objectives, and set boundaries on the analysis.

To understand the range of alternatives that would be practical, the analyst must define the decisionmaker's span of control (e.g., which decisions are within his authority, which involve shared authority, and which are beyond his authority), and then clarify the political, institutional, and technological constraints on the decision. Identification of the time horizon for making the decision, for implementing the alternatives, and for tracing the impacts is also important.

At the beginning, and throughout the PAWN study, the PAWN analysts met frequently with the members of the guiding group, both collectively and individually, defining and refining the statement of the problem and its scope. We found the general water management issues (shortage, salinity, quality, and flood risk) to be those described in Chap. 1. We also found that the horizon and scope of the decision were largely determined by the requirements of the Nota Waterhuishouding, and that although we were to take a national perspective on the decision, we were to consider regional problems and issues to the maximum practical extent.

For the eventual definition of the policy alternatives, it was agreed that their implementation horizon could be either short-run (a few days or weeks) or long-run (i.e., they could take many years to build), that we should consider demands for water by different users as flexible (e.g., varying with price) rather than as fixed requirements to be met, and that we should consider both measures for improving the operation of the current infrastructure and for improving the infrastructure itself. These agreements are reflected in the concept of tactics, strategies, and policies presented in the next section.

Finally, it was agreed that we would attempt to trace the impacts of the alternatives to about 1985/1990; it did not appear sensible to try to estimate detailed impacts more than 10/15 years beyond the start of the study.

Note that a fundamental assumption of PAWN is that when we examine the impacts of a policy within a particular scenario, we assume that the policy has had time enough to be implemented and take effect. Thus, viewing a policy in a 1976 scenario is like assuming that the policy had taken effect instantaneously in a world that looked like the 1976 world described by the scenario--even though the policy did not actually exist in 1976.

To identify the objectives for the study and for the alternatives that would be considered, we attempted to determine the decisionmakers' primary goals, as well as any complementary or contradictory "bureaucratic" goals such as maintaining the organizational status quo, by means of in-depth discussions with the guiding group.

Then we identified, as best we could, all the different groups likely to be affected by the water management policies we would be considering. We talked with them and attempted to infer their goals and concerns. As part of this effort, members of the PAWN team talked with senior representatives of the Union of Waterboards; the Foundation for Nature and the Environment; the Ministry of Agriculture and Fisheries; the research institute for the Dutch electric power industry; the State Institute for Drinking Water, RID (Rijksinstituut voor Drinkwatervoorziening); the State Institute for Nature Management, RIN (Rijksinstituut voor Natuurbeheer); the Union of Environmental Defense; the Union of Dutch Business Concerns; and many other organizations, most of which are listed in App. B.

Furthermore, several members of the PAWN guiding group were members of the ICWA (Interdepartementale Coordinatie Commissie Waterhuishouding), the Interdepartmental Coordinating Committee for Water Management that included top-level representatives of all the government ministries concerned with water policy, or of the IWW (ICWA-Werkgroep Waterhuishouding), its working group for water management established specially for discussions about PAWN and the Nota Waterhuishouding. Through them we received considerable exposure to the concerns of other government ministries and agencies, and, since the IWW and ICWA were kept informed about PAWN's approach and progress, even received comments and suggestions specifically tailored to PAWN.

We found that there were multiple, conflicting objectives related to water management.

The direct water management objectives were to improve the efficiency of water management, both use of the water resources and use of the infrastructure; to provide water system flexibility, affording options for growth or for dealing with unexpected circumstances such as "spills" of toxic substances; to control the risk of water shortages or of water quality problems; and to control the risk of floods.

The relevant national objectives were to enhance navigation; to improve the economy, from the standpoint of both growth and efficiency; to promote social equity; to protect public health and the natural environment; and to support country planning (what the Dutch call "planology" and what in the United States might be called regional planning or land-use planning).

While investigating objectives and concerns, we also collected suggestions and information about many possible alternative measures for inclusion in a Dutch water management policy. These alternatives were so numerous and diverse that we needed the concept of tactics, strategies, and policies to organize them for analysis.

2.4. CONCEPT OF TACTICS, STRATEGIES, AND POLICIES

A water management policy involves a mix of tactics, each a single action to affect water management, such as building a particular canal or taxing a particular use.

We distinguish four kinds of tactics:

1. Technical Tactics--add to or modify the current water management infrastructure (facilities). These include digging a new canal, enlarging an old one, or constructing a new sluice or pumping station. In addition they also include applying various treatments to the water, which might be as simple as adding chemicals to the water or as complex as mechanically aerating the water.
2. Managerial Tactics--change the rules by which a particular infrastructure is operated. These tactics, which may alter the distribution of water among competing users or regions, include changing the operation of weirs, pumps, and sluices so as to affect the level in lakes and other bodies of water, or the flow in rivers and canals.
3. Pricing Tactics--impose a charge on water use or discharge. These tactics, which include surtaxes as well as various vicense or user fees, affect the quantity or quality of water extracted or discharged by the users to which they are applied.
4. Regulation Tactics--control water use or discharge with legal and administrative measures. These tactics, which may apply to either water quantity or quality, include quotas or permits that determine whether a particular user may extract or discharge water, and, if so, just how much.

The first two kinds of tactics directly affect the supply of water to particular users, whereas the last two directly affect users' demand for water.

A strategy is a combination of tactics of the same kind. For example, a technical strategy would consist of a particular set of technical tactics. Similarly, the regulation strategy would specify what, if any, restrictions had been applied to each user or user group.

A policy is a particular combination of all four kinds of strategies, and may contain any number of tactics. A particular policy should be thought of as an overall water management policy for the Netherlands in much the same way as we would think of the Netherlands' foreign policy or its economic policy. In PAWN, it is the consequences of alternative water management policies that we will be comparing. Although the policy that is eventually adopted may specify a number of actions, note that it may provide only guidelines for dealing with certain issues and may defer or delegate certain decisions entirely.

The actual tactics, strategies, and policies considered in PAWN, as well as their genesis, will be described in later chapters.

2.5. IDENTIFICATION OF IMPACTS

PAWN compares the consequences of policies, which we call "impacts." In choosing the impact measures, our primary criterion was that the set of impact measures be sufficient to span the full range of objectives--not just the general objectives listed above, but the more specific ones mentioned by the different interest groups. We wanted the measures to cover the objectives of all groups and to reflect both equity and efficiency considerations. Our intent was to choose a sufficiently comprehensive set of impact measures that each group would be able to see how a particular policy affected the attainment of its particular objectives.

For some of the objectives, finding appropriate measures was not always easy. We looked for good proxies to measure an objective's attainment, ones that were intuitive and easy to explain. We generally used natural physical units to express the impact measures, keeping the eventual presentation of results firmly in mind.

For the various policies considered, PAWN analyzed and compared many different impacts. Indeed, even the categories for these impacts are numerous.[1]

Impacts on the water management system include the investment and operating cost of technical and managerial tactics, and the flood risk in the IJssel lakes.

Direct impacts on users include the change in profit and expenditures for each user group such as agriculture, shipping, electrical power generation, industrial firms, and companies that supply drinking water. The environmental impacts include the violation of water quality standards, the damage to nature areas caused by the construction of new facilities, and the total amount of groundwater being extracted (which also has an impact on the risk of long-run shortages of groundwater).

Impacts on the entire nation include the net monetary benefits to the nation after transfer payments are removed; the total economic effects, both in terms of government revenues and in terms of changes in production, imports, and employment, that occur not only in industries directly involved in the construction of major new facilities but also indirectly in other, interrelated industries; and social/distributional impacts, which consider the uneven distribution of monetary benefits and costs among producers, consumers, and the government, as well as the uneven distribution of other impacts among different groups or locations.

The precise definitions and estimated magnitudes of the many impacts considered in PAWN appear in later chapters.

2.6. ANALYTICAL APPROACH: THE STAGES OF ANALYSIS

In a problem as complex as PAWN one risks being overwhelmed by the "curse of dimensionality." That is, there are so many possible alternatives, so many uncertainties, and so many potential impacts that no analysis can hope to consider all of them. One cannot truly optimize but only hope to "satisfice" efficiently (that is, search for "good" solutions).

In PAWN, and in a number of other complex analyses over the past 10 years, we have dealt effectively with the curse of dimensionality by performing the analysis in a series of stages. In the early stages we evaluate many possible alternatives in terms of relatively few major impacts, whereas in the final stages we evaluate relatively few promising alternatives in terms of the full set of potential impacts; as the stages progress, we examine fewer alternatives in greater detail. Since we are learning how to design increasingly promising alternatives as the stages progress, we are performing what might be called "explicit hierarchical design and evaluation of alternatives."

Figure 2.1 broadly portrays our analytical approach, indicating the stages of analysis. We briefly discuss some of its features below. Note that for simplicity the diagram assumes that the problem formulation preliminaries and the identification of impacts have already taken place; moreover, it omits certain subsequent stages in the policy process (implementation, evaluation, termination) because they exceed PAWN's scope.

2.6.1. The Screening of Alternatives

Each kind of water management tactic offers many possibilities; for example, technical tactics could modify the current infrastructure in hundreds of different ways, and, as another example, the number of pricing tactics is virtually limitless because the surtax on a particular user may, in principle, be set at any level. Thus, the possible alternatives are so numerous that it becomes impractical to evaluate the detailed impacts of all of them. One is thus compelled to identify a manageable number of the most promising alternatives for subsequent evaluation. Screening reduces the number of alternatives that merit further evaluation--that is, one identifies the promising alternatives (and sets aside the inferior ones). In PAWN the criteria

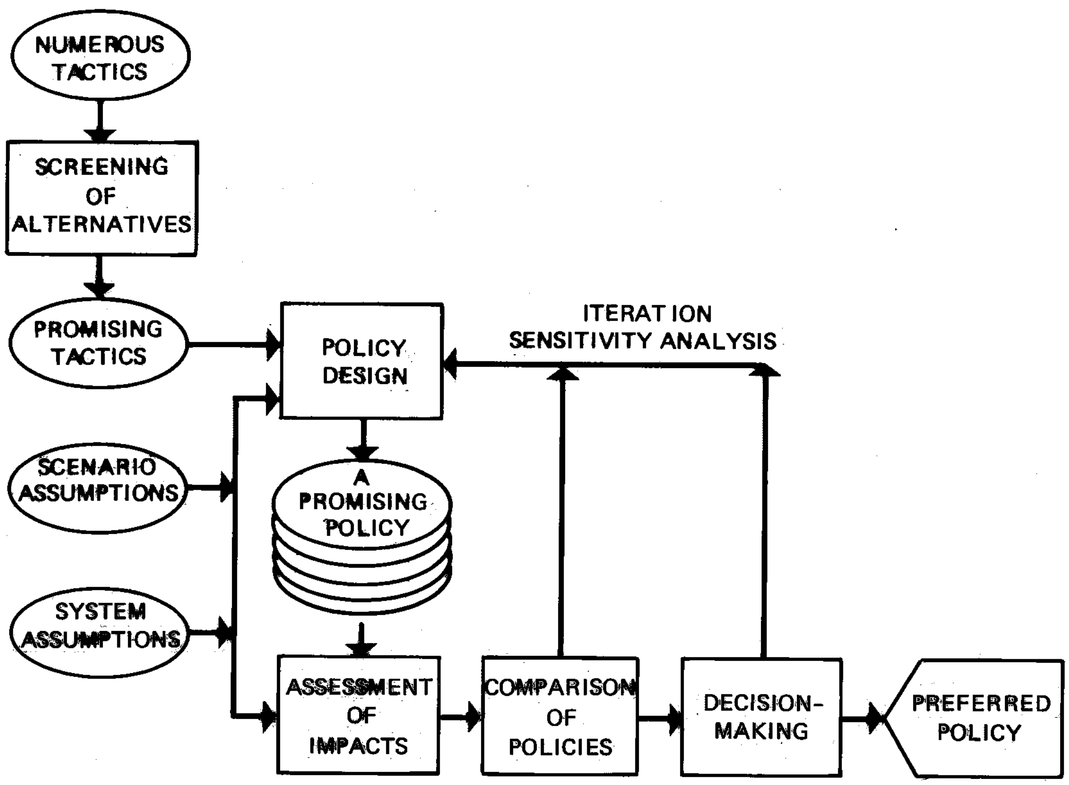

Fig. 2.1--Stages of policy analysis

for screening include administrative feasibility, cost-effectiveness, and dominance; for example, an alternative that would not clearly provide a benefit exceeding its cost or provided the same benefit with a higher cost than some other alternative would be ruled out.

The PAWN study does not attempt to evaluate or screen out tactics on the basis of their political feasibility, even though some of the tactics considered are controversial. (A few exceptions were made where the PAWN guiding group believed that implementing the tactics was politically impossible.) PAWN generally operates under the principle that the degree of public acceptance for each tactic should be assessed by Dutch policymakers and then considered, along with each tactic's costs and benefits, when they compare the different alternatives to select a preferred policy.

A different screening process is appropriate for technical and managerial tactics than for pricing and regulation tactics. We discuss the screening processes and results for the two groups of tactics in two later chapters.

2.6.2. The Design of Policies

Screening identifies promising tactics to use in designing policies. The policy design process requires considerable art because the combination of tactics (the policy) should be tailored to a particular scenario; for example, it should, if possible, satisfy the water demands and meet the water quality standards contained in the scenario. If many policies could match the scenario, then the one with the least net cost (or the largest net benefit) for the nation would be considered the promising one.

Different technical tactics would generally benefit different regions of the country and different groups of users. Thus, in designing policies, we would generally select a set of one or more promising technical tactics as the basis for a promising policy, and then determine the best combination of promising tactics of the other three kinds; for example, we would find the best combination of managerial tactics to go with the technical tactics selected. Then we would repeat the process for a different set of promising technical tactics, obtaining another promising policy; and so forth until we had a set of promising policies tailored to a particular scenario. Of course we would sometimes select some other kind of tactics than technical to start the design process. In this way we would obtain a set of promising policies, covering a range of promising tactics, where each policy would provide a different mix of impacts, both in aggregate and in their distribution among different regions and users.

2.6.3. Assessment of Impacts

Given a specification of the scenario and system assumptions, the many impacts of a policy are estimated with various models. Although it is easy to use models, it is difficult to build models that are good for policy analysis. Here we describe PAWN's modeling philosophy. (The models themselves are described in later chapters.)

When we began the PAWN analysis, some useful components for developing an overall methodology were already available, such as a shipping model for predicting the ship traffic between all origins and destinations on the waterways of Western Europe, or under development, such as a model for part of the eutrophication process. Other necessary components were not available. For example, there was neither a model to estimate the effect of a change in policy on groundwater extractions and levels nationwide, nor a model to estimate the corresponding effect on the concentration of salt and various pollutants throughout the water management system. When we attempted to develop the missing components, we were generally handicapped by a lack of both experimental data and scientific theory. Nevertheless, rather than omit these components, we have modeled them using whatever data were available in combination with the opinions of experts. Our decision to proceed reflects a widely held belief, perhaps best stated by Forrester:

> Much of the behavior of systems rests on relationships and interactions that are believed, and probably correctly so, to be important but that for a long time will evade quantitative measure. Unless we take our best estimates of these relationships and include them in a system model, we are in effect saying that they make no difference and can be omitted. It is far more serious to omit a relationship that is believed to be important than to include it at a low level of accuracy that fits the plausible range of uncertainty.
>
> If one believes a relationship to be important, he acts accordingly and makes the best use he can of the information available [2.1].

Because it is based on uncertain elements, our approach is challengeable on many grounds; but, given the state of knowledge, so is any other approach. If a wide range of impacts must be estimated--and we believe they must--then the choice is to estimate them either with models aided by expert judgment, or by expert judgment alone. We believe that the former approach has several advantages over the latter: Assumptions are more explicit; they address components of the problem rather than its entirety; effects of changes in assumptions may be tested by the models themselves; and computer programs for the models permit the examination of a large number of factors and interactions, some of them counterintuitive.

The methodology we have developed reflects PAWN's emphasis on policy analysis rather than on detailed engineering design or the search for scientific truth. It was created to assist in the evaluation of a large number of conceptual policies defined in fairly gross terms, emphasizing breadth of scope rather than depth of detail. Our policy models therefore attempt to include a broad range of factors, each with just enough detail to give adequately accurate results. (In contrast, most scientific and engineering models attempt to maximize accuracy by treating a narrower range of factors in greater depth of detail.)

All our models and methods were tailored to the needs of the PAWN project, but many are general enough to be adapted easily for use in similar studies in other regions. Because we wanted to examine many policies under different sets of assumptions, we selected the necessary inputs carefully and held them to a minimum to capture the most important characteristics of a variety of alternatives.

2.6.4. Comparison of Cases and Decisionmaking

In PAWN, the fundamental unit for analysis is the case. A <u>case</u> consists of a policy along with the system and scenario assumptions that affect its performance and impacts. We compare sets of cases. The cases that make up a set usually involve the same system and scenario assumptions but differ in policy. By comparing cases within a set, we can observe the effect of changing policy. And by comparing sets that include the same policies, we can observe the effect of assumptions on the policies' consequences.

The many impacts of the cases are estimated in the impact assessment stage of the analysis and then presented to the decisionmakers for the comparison of alternatives. The usual approach combines the different impacts into a single measure of performance, but this generally loses information and may substitute the analyst's values for those of the decisionmakers. In our approach, the various impacts are displayed on a scorecard, a table that also shows, by color code, each alternative's ranking for a particular impact. To this factual knowledge the decisionmakers can then add their value judgments about the relative importance of the different impacts, thereby weighing and trading off the impacts to select a preferred alternative--that is, to make "the decision." (A more complete discussion of the scorecard concept will be found below.) In PAWN, the decisionmakers were considered to be the RWS (Rijkswaterstaat). Ultimately, however, other government ministries were involved in the decisionmaking through the ICWA and, along with the provinces and the waterboards, through review and consultation on the Nota Waterhuishouding.

2.6.5. Iteration of the Analysis

From an initial comparison of cases, the analysts may identify as desirable a number of sensitivity analyses. Additional cases might then be designed that involve a change in the policies, the scenario, the system assumptions, or combinations of all three. Evaluation and comparison of these additional cases--or the expressed concerns of the decisionmakers in response--could yield yet another set of cases for evaluation. This process would continue--iteratively--until the decision was made.

In the early stages of the sensitivity analysis, the analysts generally select the additional cases to be considered. For example, in PAWN one might repeat the policy design process with a stricter set of environmental standards than had been used before as part of the scenario and see how the change in the scenario would change the policies or their impacts. The change in the impacts is the "cost" of the stricter standards.

In the later stages of the sensitivity analysis, analysts select cases in consultation with senior members of the decisionmakers' staff, who may be more sensitive to the decisionmakers' concerns or information needs. For PAWN this was done in part through regular interaction with the guiding group. But a major part of it was done in response to suggestions made by RWS senior decisionmakers and various experts during a week-long briefing and discussion of the project's preliminary results in early October 1979, two months before the final briefing. The RWS's comments on the preliminary results played a major role in shaping the final analysis by suggesting additional cases and sensitivity analyses to consider.

In the final stages of the sensitivity analysis, ideally, analysts would select additional cases to respond to the decisionmakers' explicit questions or concerns--after the results had been presented to the decisionmakers--as part of the actual decisionmaking process. Of course, the experienced policy analyst would be continually striving to anticipate the decisionmakers' concerns, problems, and information needs throughout the project; such anticipation, and frequent interaction with the decisionmakers or their senior staff, can help ensure that the completed policy analysis will be relevant to the decision at hand and will not merely have been an abstract academic exercise.

During PAWN, the analysts met with many of the decisionmakers. Furthermore, the additional analysis performed in the Netherlands, after the PAWN final briefing, received guidance from the decisionmakers and explicitly responded to questions arising from the final briefing.

2.7. DISPLAYING IMPACTS WITH SCORECARDS[2]

Once the impacts of the alternatives have been assessed, a major difficulty still remains: synthesizing the numerous and diverse impacts of each alternative and presenting them to the decisionmakers for comparison of alternatives. In an aggregate approach to synthesis, each impact is weighed by its relative importance and combined into some single, commensurate unit such as money, worth, or utility.[3] The decisionmakers use this aggregate measure to compare alternatives. Of the several aggregate techniques, perhaps the best known is cost-benefit analysis, which converts as many impacts as possible to monetary terms.

In our opinion, the aggregate approach has several major disadvantages for PAWN. First, the aggregation process loses considerable information: For example, it suppresses the fact that alternative A has environmental problems whereas alternative B has financial problems.

Second, any single measure of worth depends strongly on the weights given to the different impacts when they were combined and the assumptions used to get them into commensurate units. Unfortunately, these crucial weights and assumptions are often implicit or highly speculative. They may impose on the decisionmakers a value scheme bearing little relation to their concerns. For example, cost-benefit analysis implicitly assumes that a dollar's worth of one kind of benefit has the same value as a dollar's worth of another; yet in many public decisions, monetarily equivalent but otherwise dissimilar benefits would be valued differently by society. Also, in converting disparate impacts to monetary values, cost-benefit analysis must sometimes make speculative assumptions, such as: How much money is one red-necked grebe worth? Are a million grebes worth a million times one grebe?

Third, the aggregate techniques are intended to help an individual decisionmaker choose the preferred alternative, the one that best reflects his values (importance weights). Serious theoretical and practical problems arise when, as in PAWN, there are multiple decisionmakers: Whose values get used (the issue of interpersonal comparison of values), and what relative weight does the group give to the preferences of different individuals (the issue of equity)?

It has been proved that there is no rational procedure for combining individual rankings into a group ranking that does not explicitly include interpersonal comparison of preferences [2.9]. To make this comparison and to address the issue of equity, full consideration of the original impacts appears essential.

Finally, to be theoretically valid, the aggregate techniques (other than cost-benefit analysis) require that the importance (value) of each impact be independent of the size of all other impacts. But in the real world, this condition is not always satisfied. Each impact that violates this condition must be suppressed, either by eliminating it or by treating it at the next level of aggregation.

In PAWN, we have chosen to use a disaggregate approach that presents a column of impacts for each alternative, with each impact expressed in natural units. In comparing the alternatives, the decisionmaker can assign whatever weight he deems appropriate to each impact. Explicit consideration of weighting thus becomes central to the decision process itself, as we believe it should. Prior analysis can consider the full range of possible effects, using the most natural description for each effect. We therefore describe some effects in monetary terms and others in physical units; some are assessed with quantitative estimates (e.g., "100 jobs would be created"), others with qualitative comparisons ("recreation opportunities would increase slightly"), and still others with statements of nonordinal facts ("an attractive tourist site would be destroyed"). A disadvantage of this approach is that the amount of detail makes it difficult for the decisionmaker to see patterns or draw conclusions.

To aid the decisionmaker in recognizing patterns and trading off disparate impacts, in PAWN we have applied a useful display device called a scorecard.[4] Impact values are summarized (in natural units) in a table, each row representing one impact and each column representing an alternative. The scorecard is the table of impacts with color or shading added to indicate each alternative's ranking for a particular impact. A sample scorecard from a hypothetical comparison of transportation alternatives is shown in Table 2.1. We employed color to show rankings in the scorecards used in the PAWN final briefing--blue designating the best value, yellow the worst, and gray the intermediate--but we use shading instead for the scorecards in this report, to facilitate printing and subsequent photocopying. However, we shall discuss scorecard rankings by color for the rest of this section because descriptions of shadings could be confusing.

In a scorecard, an entire column shows all the impacts of a single alternative; an entire row shows each alternative's value for a single impact. Numbers or words appear in each cell of the scorecard to convey whatever is known about the size and direction of the impact in absolute terms--i.e., without comparison between cells. When colors are added to

Table 2.1

A SAMPLE SCORECARD(a)

Impact Categories	Alternative Ways of Traveling from Amsterdam to Vienna		
	Car	Train	Plane
Total travel time (hr)	7	9	3
Total travel cost ($)	11	21	33
Time under stress (difficult driving, carrying bags, fighting for taxi) (hr)	4	1	2
Degree of privacy possible	Much	Some	Little

Rankings: Best Intermediate Worst

(a)All numbers are hypothetical.

highlight differences in ranking among the alternatives, each impact must be considered separately. (That is, in each row impact values are ranked across columns, independent of all other rows. The ranking assignments do <u>not</u> involve comparisons between rows.) Sometimes a row will receive no color either because its impacts are comparable in size for all cases, or because they are highly correlated with some other, already colored, row. (When a scorecard presents the same impact in two forms--for example, absolute value and percentage--only one receives color.)

For PAWN, the scorecard has several advantages. It presents a wide range of impacts and permits a decisionmaker to give each impact whatever weight he deems appropriate. It helps him to see the comparative strengths and weaknesses of various alternatives, to consider impacts that cannot be expressed in numerical terms, and to change his subjective weighting and note the effect this would have on his final choice. When there are multiple decisionmakers, the scorecard has the additional advantage of not requiring explicit agreement on weights for different social values: It is generally much easier for a group of decisionmakers to agree on a preferred alternative (perhaps for different reasons) than on weights to assign to the various impacts.

The ranking assigned (color or shading) reflects certain assumptions about what is "best" or "worst" for each impact. To derive maximum benefit from scorecards, these assumptions must be made explicit, because different ones (and hence different rankings) might be appropriate in some circumstances and for some interest groups. For example, in times of a slack economy, an increase in employment would be a favorable impact. In that circumstance, the alternative with the largest stimulus to employment would be designated "best" and the one with the least stimulus would be designated "worst." When the economy is straining at full capacity, additional impetus to employment would only result in increased wage and price inflation and would have the opposite ranking.

As this example demonstrates, the assumptions underlying color assignments can be crucial. Generally, there is little doubt as to which assumptions should be adopted.[5] Sometimes, however, two different sets of assumptions are equally plausible; for example, the summer might be wet or dry. This quandary can be resolved by parallel but separate scorecards for each scenario. Although this technique is particularly useful for analyzing sensitivity to assumptions, it can also be used to show the impacts of policies through time; for example, by presenting scorecards showing the impact of a set of policies at, say, five-year intervals.

PAWN prepared separate scorecards to summarize the impacts of a number of sets of policies. These scorecards appear in later chapters presenting the results of the analysis.

Even apart from the ranking assumptions, scorecards can occasionally impose more of the analyst's values on the findings than appears at first glance. The analyst chooses the impacts to display, their order of presentation, and their units of expression. These choices can, of course, influence the impressions conveyed. To be effective, therefore, scorecards must be carefully designed and interpreted. Other techniques for synthesizing multiple impacts require similar caution but suffer from additional disadvantages, mentioned earlier.

2.8. ORGANIZATION OF THIS REPORT

The remainder of this report consists of parts that correspond to the stages of analysis. Part II discusses the methodology: It begins with a chapter presenting an overview of the methodology, continues with a series of chapters describing each of the components of the methodology, and concludes with a chapter summarizing scenarios.

Part III summarizes the results of screening: After a chapter presenting the general approach, it presents separate chapters discussing first the screening of technical and managerial tactics and then the screening of pricing and regulation tactics.

Part IV describes the design of policies, both the process and results. After a brief chapter on the general approach, subsequent chapters treat the design of long-run price and regulation strategies, of managerial strategies, and of eutrophication control strategies. Then the part concludes with a chapter identifying the primary policies and cases to be considered in impact assessment and discussing how they were selected.

Part V presents the results of impact assessment: An introductory chapter describes how the assessment was done and presents a flowchart showing the relations among all the major models, sets of data, and other components of the PAWN methodology. Then two chapters successively present extreme and average values for the impacts of the primary policies. Another chapter contains the results for many different sensitivity analyses.

Part VI, the final chapter in the report, discusses consequences of PAWN: how the PAWN methodology and results are reflected in the new national water management policy for the Netherlands contained in the Nota Waterhuishouding, and how its models, techniques, and approach can be useful for other locations and other policy problems.

Several appendixes support the main text. Appendix A lists the organizations represented at the PAWN final briefing. Appendix B lists organizations interviewed for PAWN. Appendix C presents the summary description and cost for the tactics affecting the national and regional distribution systems considered in the screening of technical and managerial tactics. Appendix D shows tables defining the cases considered in impact assessment. Appendix E gives a detailed analysis of the total economic impact of major infrastructure investments. Appendix F discusses the ultimate monetary effect of policies on households. (Appendixes E and F expand the discussion in Chap. 31.) Appendixes G through K provide details of some sensitivity analyses summarized in Chap. 32. Appendix L presents supplemental notes to the scorecards in Chaps. 30 and 31 that indicate where impact values have changed from those presented in the PAWN final briefing.

Hereafter, all monetary figures are given in Dutch currency (Dfl) at the 1976 price level, and all measurements are in metric units.[6]

NOTES

1. Within these categories, many possible impacts have been mentioned in many years of discussion on the Dutch water management problem; and still others, not previously articulated, are conceivable. PAWN has not tried to consider every conceivable impact; rather, it has sought to analyze all those that seem to have some practical significance.

2. This section presents a brief overview included primarily for readers who may not have ready access to remarks on scorecards in previous Rand reports or other sources. See particularly Ref. 2.2 (Sec. II); also Refs. 2.3 and 2.4. Note that scorecards can also be useful in screening.

3. See Refs. 2.4 through 2.8.

4. Scorecards were first applied in August 1971 as part of the STAR study conducted by Rand for the U.S. Department of Transportation. For discussion, see Ref. 2.2.

5. It is true that the colors will often have been assigned by an analyst. Because they represent rankings, the choices are usually clear-cut. Occasionally, when several alternatives have nearly the same value for a particular impact, the analyst must use judgment. However, since the actual impact values are clearly visible through the colors, the decisionmaker can detect color assignments that conflict with his judgment and change whatever colors he wishes.

6. The notational conventions used throughout the report are shown in note 2 of Chap. 1.

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