A RAND NOTE

Policy Analysis of Water Management for the Netherlands

Vol. II, Screening of Technical and Managerial Tactics

W. E. Walker, M. A. Veen

November 1981

N-1500/2-NETH

Prepared for The Netherlands Rijkswaterstaat

Rand
SANTA MONICA, CA. 90406

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PREFACE

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

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

The primary tasks of the PAWN project were to:

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

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

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

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

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

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

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

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

The present volume, Vol. II in the PAWN series, describes one of the first steps in the evaluation of alternative policy options for water management--the screening of technical and managerial tactics. In this step, a large number of possibilities for changing the movement and storage of water throughout the Netherlands (tactics) were evaluated in terms of a small number of impact measures in order to screen out those that are clearly not attractive. The output from this step is a relatively small list of tactics that are sufficiently sensible and beneficial relative to their costs that they deserve a more thorough examination.

The benefits that would accrue from implementation of the various tactics were estimated using the Water Distribution Model, which is described in Vol. XI. The tactic costs that were used in the screening analysis are those presented in Vol. XVI.

This volume should be of interest to several different audiences. First, it should be useful to those who are interested in the Dutch water management system, its problems, and the merits of various solutions. More generally, it should be of interest to anyone who is involved in the analysis of water management problems. The volume should also be of interest to policy analysts in diverse application areas, since it presents new methodological approaches for analyzing large, complex systems in which many alternatives must be evaluated in terms of multiple impacts.

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

In a policy analysis study as large as PAWN, there are generally too many alternative policies to examine in detail given time and budget constraints. As a result, such a study often includes a step in which a large number of policy options (tactics) are evaluated in terms of a small number of impacts in order to screen out those tactics that are clearly not attractive. The output from this screening step is a relatively small list of tactics that are sufficiently sensible and beneficial relative to their costs that they deserve a more thorough evaluation. (We refer to such tactics as "promising.")

This volume describes the screening of tactics that would change the movement and storage of water in the rivers, canals, ditches, and lakes of the Netherlands. (Such tactics are referred to as "technical and managerial" tactics.) The tactics are primarily designed to alleviate problems caused by shortages of surface water (including low flows and levels in waterways) and/or by the salinity of the water.

For purposes of the analysis, the country was divided into eight regions. Tactics were evaluated for six of the regions. (A preliminary analysis of the benefits that might be derived from tactics indicated that there was little or no reason to consider tactics for two of the regions.) In addition, a number of tactics that involved changes to the national water distribution system and that affected more than one region were evaluated.

The screening process for each tactic involved obtaining an upper bound on the expected annual benefits from the tactic under various assumptions about future demands for surface water, and comparing this upper bound with a measure of the annual cost of the tactic--the tactic's annualized fixed cost. If the annualized fixed cost was less than the upper bound on the expected annual benefits, the tactic was considered promising, and was retained for further analysis. If not, the tactic was screened out.

The benefits considered in the screening analysis were (1) reductions in agriculture shortage losses, (2) reductions in agriculture salinity losses, and (3) reductions in shipping losses caused by low flows on the waterways. An upper bound on the expected annual benefits from a tactic was obtained by taking a weighted average of the estimated benefits in four years of varying dryness. The weights were based on the probabilities of occurrence of the various types of years.

In general, we found that, unless the demand for surface water increases significantly above current levels, there are relatively few tactics that are worth considering further. In the case of increased demand for surface water, we found a number of promising tactics. Most of them were small, inexpensive, regional tactics. Almost all of the large, expensive, national tactics (some of which have investment costs of over 200 Dflm and have been under discussion in the Netherlands for many years) were screened out.

Two categories of technical and managerial tactics were considered in the analysis:

1. Tactics associated with the major lakes and waterways of the country.
2. Tactics that would bring water from these lakes and waterways to farms that currently have no access to surface water for sprinkling.

The second category of tactics is specified for a region by its local waterboard (a government body that is responsible for local water management), not by the national government. We therefore called the tactics "waterboard plans." Sixty-five waterboard plans were analyzed, and 46 of them were found to be promising. The promising ones were incorporated into some of the demand scenarios used to analyze the first category of tactics.

In the analysis of the Category 1 tactics, six were found to be promising independent of the demand scenario used. They include two that are aimed at reducing agriculture salinity losses, one that will help reduce agriculture shortage losses, two that will reduce low water shipping losses, and one that is designed to reduce the chance of flooding. The total annualized fixed cost for all six tactics is only 7.5 Dflm.

There were few additional promising tactics for the various demand scenarios except for the one representing the highest expectation of future demands. For this scenario, in addition to the six tactics already mentioned, eight were found to be very attractive, and eleven more, although promising, are dominated by one of those eight (i.e., they attack the same problem, but have higher costs and/or lower benefits).

The study discusses several qualifications on the results caused by difficulties that were found in the data and models used in the analysis, most of which were discovered after the final PAWN briefing in December 1979. Generally, the qualifications suggest that the benefits may have been underestimated for certain of the tactics. This implies that some tactics that we found to be promising are likely to be even more worthwhile than we show. It also means that there may be other promising tactics that were not considered in our analysis or that we screened out.

ACKNOWLEDGMENTS

The analysis reported in this volume was carried out in close cooperation with various departments of the Rijkswaterstaat (RWS). Most of these departments were represented on a coordination committee that was set up to provide help and guidance to the screening analysis. This committee came to be known as the Netherlands Support Group (NSG). The NSG was composed of staff members from the Central Office of the Directie Waterhuishouding en Waterbeweging (WW) of the RWS, three of the districts of this directorate (Districts Southwest, Southeast, and North), and the Central Directorate of the RWS. In addition, we received information for the analysis and feedback on the results from various regional directorates of the RWS.

Three members of the NSG deserve thanks for their special efforts to help us in the data-gathering and analysis phases of the project. Harrie Groen, then with WW, served us in two ways. He did the ground work for the screening of waterboard plans and, more generally, was always available to help us in getting answers to the innumerable questions that arose during the data-gathering phase. Ton Sprong of the Central Directorate provided valuable assistance in defining the tactics and evaluating the preliminary results of the analysis. Hans Pulles of WW helped us in all phases of our work, both as a member of the NSG and as Dutch monitor of the PAWN project. In addition, he expended a considerable effort in reviewing an earlier draft of this volume, which led to many improvements in the text.

The screening analysis used the results of many other research activities of the PAWN project. Among the Rand staff members whose work contributed directly to our analysis are Allan Abrahamse, Joseph Bolten, David Jaquette, Norman Katz, and Robert Petruschell. Bruce Goeller, Project Leader of PAWN at Rand, provided broad guidance throughout the course of our work. We would especially like to thank Louis Wegner, who made our work possible by creating the principal instrument for our analysis--the Distribution Model. Working closely with us, he had the painstaking task of making numerous adjustments to the model in order to tailor it to our needs.

We are also grateful to Gene Fisher, head of the Management Sciences Department at Rand, for his review of an earlier draft of this volume. His comments have improved its substance and clarity considerably.

Our sincere thanks go to Eleanor Gernert, Managing Editor for the PAWN documentation, and her colleagues in Rand's Publications Department for their care in guiding the volume through the publications process; to Nancy Moll for her careful editing; to Loanne Batchelder and Doris Dong for preparing the many figures that appear in this volume; and to Marjorie Dobson for her diligence in typing the many drafts of the text.

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GLOSSARY

boezem	A system of drainage canals surrounding one or more polders, which allows for the flushing of and independent water level control in those polders.
BTW	Belasting over de toegevoegde waarde (value-added tax)
cm	Centimeter.
decade	Used by the Dutch to refer to one-third of a month. The first two decades in any month have 10 days, and the third decade has the number of days necessary to complete the month.
DEX	The extremely dry year used as an external supply scenario. Rainfall and river flows as low as those in DEX are likely to occur an average of no more than once every 50 years.
Dfl	Dutch florin (guilder).
Dflm	Millions of Dutch florins.
district	The basic hydrologic entity in PAWN. The Netherlands has been partitioned into 77 districts, each of which is small enough that internal details of surface water movement can be regarded as unimportant from a national water management standpoint.
DM	PAWN's water distribution model.
dw	Drinking water.
eligible area	Cultivated land that can be supplied with surface water for sprinkling crops.
gw	Groundwater.
ha	Hectare.
highlands	That part of the Netherlands where the ground elevation is more than 2 meters above mean sea level.
km	Kilometer.
km^2	Square kilometer.
lowlands	That part of the Netherlands where the ground elevation is less than 2 meters above mean sea level.

m	Meter.
m^2	Square meter.
m/s	Meters per second.
m^3/s	Cubic meters per second.
managerial tactic	A tactic that involves changing the way the water management infrastructure is managed (e.g., changing flushing rules).
MAXTACS	The set of nine dominant promising technical and managerial tactics presented at the final PAWN briefing held in the Netherlands, December 1979.
NAP	Normaal Amsterdams Peil, the reference level for measuring elevations in the Netherlands.
national distribution system	The major rivers, canals, and lakes in the Netherlands.
PAWN	Policy Analysis for the Water Management of the Netherlands.
polder	A land area surrounded by dikes, in which the water level in the ditches is controlled independently from neighboring areas.
ppm	Parts per million.
RALL	A future situation reflected in the demand scenarios in which the implementation of all promising waterboard plans have led to an eligible area larger than the current one.
region	The basic geographic unit used in the screening analysis. The Netherlands is divided into eight regions, each of which is a combination of contiguous districts.
RNONE	The situation in demand scenarios in which no promising waterboard plans have been implemented. This reflects the current situation with respect to eligible areas in the Netherlands.
RWS	Rijkswaterstaat, the Dutch national government agency responsible for water control and public works.
screening	The first stage in the PAWN study. In this stage a large number of potential tactics was reduced to a small number of promising tactics that were subsequently examined more extensively.

SPRHI	A future situation reflected in the demand scenarios in which farmers in eligible areas optimize their use of sprinklers.
SPRLO	A situation reflected in the demand scenarios in which the installed sprinkler equipment in the eligible area approximately corresponds to the current situation in the Netherlands. (SPRLO is referred to as SPRLOW in other PAWN volumes.)
sw	Surface water.
tactic	A change in the water management system that is designed to meet a particular objective.
technical tactic	A tactic that involves changing the water management infrastructure (e.g., building a pumping station).
waterboard	A governmental body that is responsible for water management within its boundaries. There are about 200 waterboards in the Netherlands.
waterboard plan	A plan developed by a waterboard for expanding or improving the water supply possibilities within its jurisdiction.
WW	Waterhuishouding en Waterbeweging, the directorate within the RWS for which the PAWN study was carried out.

Chapter 1

INTRODUCTION

1.1. OVERVIEW

The PAWN study is a policy analysis of water management in the Netherlands. Its purpose is to compare alternative water management policies in terms of their multiple impacts on the Netherlands in general, and on the various user groups in particular. Most policy analysis studies involve carrying out the same general series of steps, including problem definition, evaluation of alternatives in terms of their impacts, and recommendation of preferred policies. Figure 1.1 shows the specific steps carried out in the PAWN study.

In large policy analysis studies, the number of alternative policies is too great to consider each in detail. As a result, such studies often include a step in which a large number of options (tactics) are evaluated in terms of a small number of impacts in order to screen out those tactics that are clearly not attractive. The output of screening is a relatively small list of tactics that appear to be promising--i.e., are sufficiently sensible and beneficial that they merit a more thorough evaluation.

The essence of screening is (1) to construct a list of tactics that may or may not turn out to be promising, and (2) to produce a list of promising tactics by means of limited, broad-brush assessments based on a small number of selection criteria. In PAWN, our initial list came partly from prior studies and recommendations by Dutch experts, and partly from a needs assessment carried out by the PAWN team to identify problems with the existing water management system where new tactics might be useful. The selection criteria were related to a tactic's cost, the water management goals and objectives identified for the various regions of the country, and the overall goals and objectives of the system.

Screening is more an art than a science. Since a limited number of tactics is considered and a limited number of selection criteria is used, it is conceivable that a tactic worthy of serious consideration will not even be considered or will be screened out, and that a tactic carried over to the final list will later be found to be unattractive. The results from screening rest to a considerable degree on insight, judgment, and knowledge about the water management system.

The entire process can be compared to the steps most people follow in buying a new house. There are generally too many houses for sale in the chosen city to visit each individually. However, a few basic criteria such as purchase price, neighborhood, and number of rooms will normally reduce the number of alternatives significantly. Then

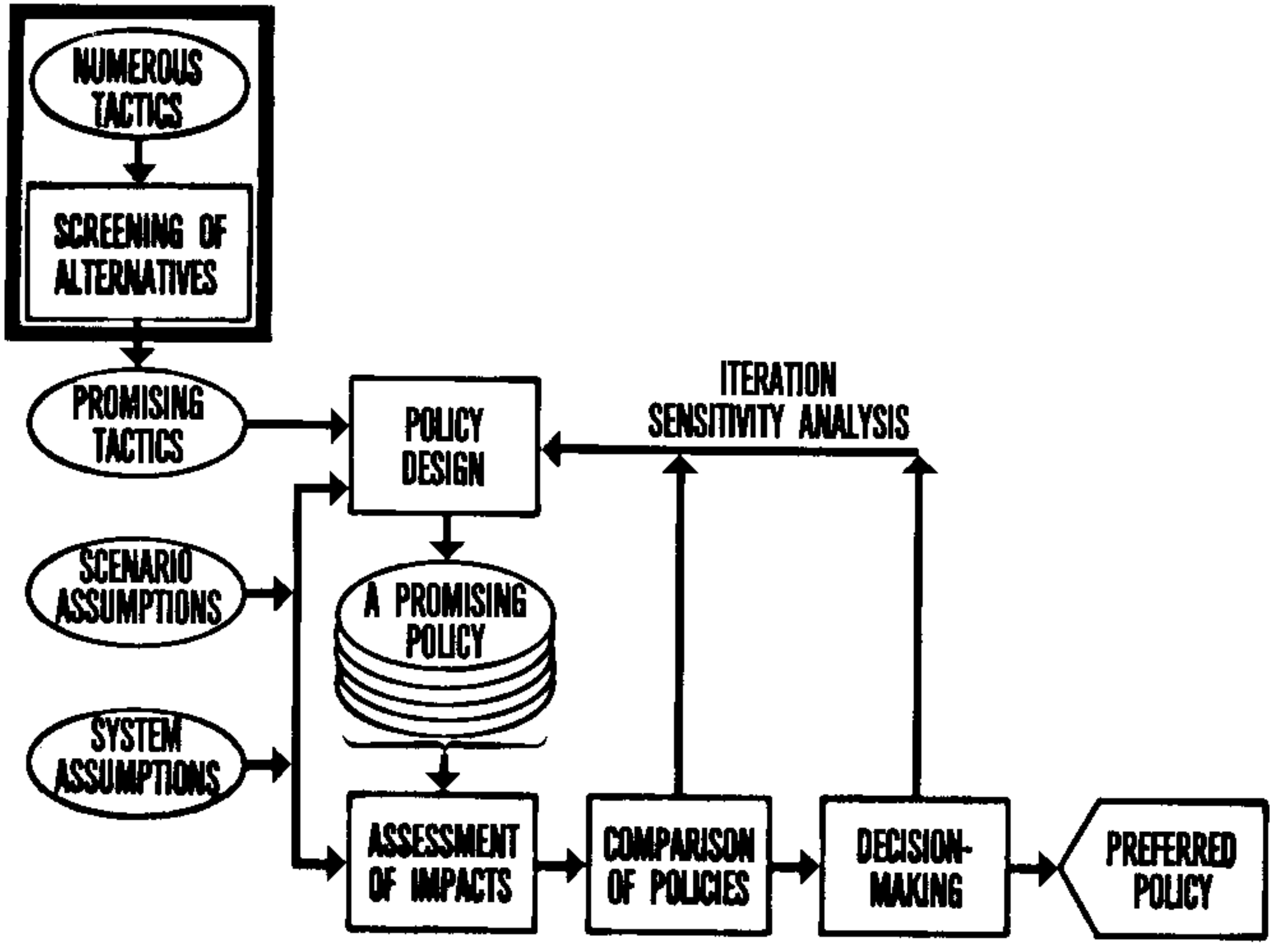

Fig. 1.1--Stages of policy analysis

more detailed criteria, such as the heating system, layout of rooms, etc., can be considered for the remaining houses. If one follows this strategy, it is possible that one's "dream house" will be screened out in the first stage (e.g., because the price is slightly too high); but the result is usually quite satisfactory.

A government's options for the management of its water resources include physical control of the movement and storage of water in rivers, canals, and lakes, and legal control, such as taxing its use, controlling prices, and prohibiting certain activities. In PAWN, we call such options, singly or in combination, water management tactics. In this volume we consider technical and managerial tactics, which relate to the physical control of the water. The screening of pricing and regulation tactics is described in Vol. IV.

An overview of the Netherlands' water management problems is given in Vol. I. We limit our discussion in this volume to tactics concerned with alleviating problems caused by shortages of surface water (including low flows and levels in waterways)[1] and water salinity (which refers to the concentration of chloride ions in the water).[2]

Water shortages occur when the amount of water available at a given time in a given place is less than the amount desired by users. Shortages also occur when levels in waterways become too low for some types of cargo ships or cause long delays at locks. Despite the fact that the Netherlands generally has enough water to supply current and future needs, widespread shortages have occurred in a few summers, and localized shortages occur in normal summers (e.g., in the higher areas of the country, which have limited supply capacities).

Salinity is a problem in the low-lying areas of the Netherlands. Salt enters the nation's surface waters through upward seepage of brackish water in the lowlands, intrusion of seawater into rivers and canals, and dumping of wastes into the Rijn at points along its route.

The screening analysis reported in Chaps. 5 through 12 was performed during a period of intense effort that lasted only about one month. Because of the limited time available, a number of tactics were examined less extensively than we would have liked. Furthermore, the screening analysis was designed to be an intermediate step in the project, in preparation for the more detailed impact assessment analysis; our analysis was never meant to generate the final results of the PAWN study. The reader should keep these two considerations in mind when reviewing our analysis and its conclusions. A number of qualifications on our conclusions are discussed in Sec. 12.2. The tactics that we found promising should be subjected to more extensive analysis, and should be evaluated on the basis of more impact categories than the ones considered here. Volume I of PAWN contains a first step in this direction--an impact assessment of some of the promising tactics. The Rijkswaterstaat is currently taking additional steps.

1.2. THE SCREENING PROCESS

As explained above, the purpose of the screening analysis is to prepare a list of promising technical and managerial tactics that will then be examined in detail in the remaining stages of the study. The screening process involves the following five steps:

1. Identification of tactics.
2. Estimation of the costs of the tactics.
3. Pre-screening of tactics.
4. Estimation of the benefits of the remaining tactics (singly and in groups) for different scenarios.
5. Comparison of costs and benefits; unpromising tactics are screened out and promising tactics passed on for further analysis.

Each of these steps is discussed below.

1.2.1. Identification of Tactics

A <u>tactic</u> is a change in the water management system that is designed to meet a particular objective. <u>Technical tactics</u> are those that add to or modify the existing water distribution infrastructure. They require the expansion of existing facilities or construction of new facilities, such as waterways, pumping stations, and dikes. In the surface water distribution system in the Netherlands, three different categories of waterways can be distinguished:

- Large rivers, canals, and lakes that comprise the <u>national system</u> (e.g., the Rijn River, the Amsterdam-Rijnkanaal, and the IJsselmeer).
- Smaller waterways that serve as the <u>regional distribution system</u> for water from the national system (e.g., the Zuid-Willemsvaart and the Overijsselsche Vecht).
- A system of ditches that carries the water from the regional system to individual farms. Technical tactics for expanding and improving this category of infrastructure are combined in <u>waterboard plans</u>, which are developed for any given region by its local waterboard, not by the national government.

<u>Managerial tactics</u> change the operation of the existing infrastructure. Weir control strategies, lake level management rules, and flushing rules for lakes and boezems are all examples of managerial tactics.

The analysis of waterboard plans is discussed in Chap. 4; the screening of regional tactics is covered in Chaps. 5 through 10; and national tactics are analyzed in Chap. 11. Chapter 12 summarizes the results of the screening analysis and presents some qualifications on the results that arise from difficulties that were found in the data and models used in the analysis.

Before the screening process was begun, an intense effort was made in PAWN to assess the major national and regional water management problems in the Netherlands. These efforts culminated in the description of the major problems (categorized under the general headings of shortage, excess, salinity, and pollution) contained in Vol. I. The first step in the process of screening technical and managerial tactics was then to compile a list of tactics that were aimed at resolving the major shortage and salinity problems.

This task required an extensive review of available information on proposed solutions to the various problems. Initial insights were obtained from several general RWS reports, such as the 1968 nota Water Management in the Netherlands [1.1]. We also consulted a large number of technical reports and documents dealing with tactics that were already being considered, such as a canal between Maarssen and Bodegraven [1.2] and waterboard plans [1.3].

Our most useful sources of suggestions were the discussions and meetings we had with Dutch water management experts. Early in the project a formal working group of such experts, called the Netherlands Support Group (NSG) was organized to provide information and guidance to the screening activities. It was composed of representatives of the various districts of the Water Management Directorate of the Rijkswaterstaat, and met on a regular basis. The NSG helped us to compile the list of tactics, supplied us with data needed to perform the analysis, and commented on our results as they were developed.

In a few cases our search for tactics to solve a specific problem did not reveal any candidates that had been previously proposed. In these cases we designed new tactics, and asked the NSG to comment on their feasibility and reasonableness, and to suggest changes that would make them more attractive.

This step of the screening process produced a list of 65 waterboard plans and 57 other tactics that were analyzed in succeeding steps. The lists are presented in Apps. A and B.

1.2.2. Estimation of Costs

The process of estimating costs for the tactics required a considerable amount of data gathering and analysis. For waterboard plans this process is described in App. B.

For the other tactics, separate estimates were made of investment costs (all of the one-time outlays needed to build the facilities required by the tactic and to make them operational), fixed annual operating costs (the costs to staff and maintain the facilities), and variable operating costs (the energy cost to operate the facility).

In order to place costs and benefits on a comparable basis, we annualized the costs. The annualized fixed cost (AFC) of a tactic was obtained by applying a capital recovery factor of 0.10 to the investment cost and adding the fixed annual operating cost. A capital recovery factor of 0.10 reflects a useful life of approximately 50 years and a discount rate of 10 percent.

Investment costs include a contingency of 15 percent but do not include value-added tax (BTW). The annual maintenance cost was estimated to be 1.0 percent of the total investment cost (excluding contingencies) for pumping stations and locks, and 0.5 percent for other facilities. All estimates of annualized fixed cost were standardized to 1976 guilders.

In comparing the costs and benefits of a tactic we generally used a tactic's annualized fixed cost and ignored its variable operating costs. We did this because the operating costs (mainly the cost of electricity to run the pumps) were almost always very small relative to the fixed costs (10 percent or less). In the few cases in which operating costs represented a large proportion of a tactic's expected annual costs, we included the operating costs in the analysis.

A list of the costs of all tactics is given in App. A. A complete description of how the costs were obtained is provided in Vol. XVI. Appendix A provides cross-references to the appropriate tables in Vol. XVI so that the interested reader can easily find the source of any cost figure.

1.2.3. Pre-Screening

The major analysis tool that we used in screening technical and managerial tactics was a detailed simulation model of the surface water system of the Netherlands. Since this model is a costly tool to use, we sought to limit the number of tactics and combinations of tactics that would have to be tested. As a result, two initial screening procedures were used to eliminate from further consideration those tactics for reducing agriculture shortage losses that were clearly unpromising--i.e., tactics having costs that were clearly greater than their benefits.

One procedure was to evaluate each of the 65 waterboard plans under consideration by the country's waterboards for expanding the cultivated area in their territory that can be supplied with surface water for irrigation. The evaluation compared the costs of implementing the plan (including the annualized investment cost of the plan and the farmers' costs of buying and using additional sprinkling equipment) with the expected benefits from increased sprinkling. We made optimistic assumptions about the benefits (e.g., that farmers would be able to receive all of the water they would like). The investment costs for the waterboard plans were taken from a survey conducted by the Union of Waterboards [1.3] and are likely to be underestimated. Thus, no truly promising plan was screened out. Nineteen of the 65 waterboard plans had negative expected net benefits and were set aside. The remaining 46 plans were retained for further analysis. The screening of waterboard plans is described in detail in Sec. 4.1 of this report.

The second procedure was to obtain upper bounds on the shortage losses to agriculture that could be prevented by implementation of tactics affecting the national and regional water distribution systems. If the annualized investment cost of a tactic to reduce shortage losses in a region were greater than the upper bound on the potential benefits (the preventable losses), then the tactic could be screened out without subjecting it to more detailed analysis. The results of this procedure showed that many tactics are cost-effective only under the assumption of significant growth in demand for surface water. The results are presented in more detail in Sec. 4.2.

1.2.4. Estimation of Benefits

The benefits and disbenefits from alternative water management policies accrue primarily to the direct users of water: farmers, shippers, industries, and drinking water companies. The policies also have more global impacts, such as on consumers, the environment, and other countries.

In screening, we focused attention on agriculture, since it is the largest consumer of water, and it suffers most from water shortages and salinity.[3] We also considered the impacts of the tactics on shipping, which is affected by low water levels on the nation's waterways. Impacts on other users and the more global impacts were investigated in other stages of the analysis. Table 1.1 shows the amounts of water consumed by the major users of surface water in 1976. (Shipping is not among them since it is not a consumer of water.)

Table 1.1

ESTIMATED SURFACE WATER USAGE, 1976
(Millions of cubic meters)

Agriculture		2728
Surface water sprinkling	473	
Control of levels in lakes and major waterways	962	
Control of boezem and ditch levels	1293	
Drinking water companies		308
Industries (consumptive use)		53

SOURCE: See Table 1.3.

NOTE: Water is also used to flush boezems and polders in order to reduce agriculture salinity losses. Water for this purpose (estimated to be 943 million m^3 in 1976) is not included in this table.

Agricultural uses of surface water include water for sprinkling of crops, water for maintaining the levels in the lakes, boezems, and ditches, and water for flushing the boezems to reduce their salinity. The table shows that the use of water by agriculture is about 9 times that of the drinking water companies and 50 times that of industries.

We have estimated the losses that agriculture and shipping suffer due to water shortages and salinity. Table 1.2 gives an indication of these losses. The first column presents estimates of the losses that were experienced in 1976, an extremely dry year. Losses in 1976, especially agriculture shortage losses, were considerably higher than those experienced in any other year in this century (even correcting for price levels).

Table 1.2

ESTIMATED AGRICULTURE AND SHIPPING LOSSES (Dflm)

	1976	Expected Loss	Average Year
Agriculture			
Shortage	6218	1424	532
Salinity	482	306	270
Shipping			
Low water	52	2	1
Lock delays	19	0	0

The estimated losses in a year with average rainfall and river flows are presented in the third column. Because of the skewed distribution of losses toward very dry years, the expected losses (averaged over all years) fall somewhere in between the losses in 1976 and the losses in a year with average dryness. From the table it is clear that losses to agriculture from water shortages and salinity are orders of magnitude greater than losses to shipping, and are considerable even in an average year. As a result, most of the tactics examined in screening were designed to increase the quantity or quality of the water supplied to agriculture.

The benefits from a tactic are defined as the difference between the losses to agriculture and shipping if the tactic is implemented, and the losses to those user categories without the tactic. The major categories of losses that were considered in our analyses are:

- Agriculture shortage losses. If a tactic increases the supply of water to an area, then, in years with low rainfall, a smaller proportion of the crops will die due to an insufficient amount of water. The benefits from increased supply are therefore measured in terms of reduced agriculture shortage losses.

- Agriculture salinity losses. If a tactic is able to reduce the salinity of water supplied to agriculture, then a smaller proportion of the crops will be damaged by salt. The benefits from reduced salinity are therefore measured in terms of reduced crop losses due to salinity damage.[4]
- Low water shipping losses. If the depths of the country's waterways are not sufficient, ships cannot carry their maximum loads, but must travel with less cargo to reduce their drafts. This means more trips and higher operating costs for transporting a given amount of goods. Tactics that change flows and water levels on certain waterways will affect shipping depths. The benefits from these tactics are measured in terms of a reduction in shipping losses.[5]

The benefits from a tactic vary from year to year depending on the rainfall and river flows. For example, tactics designed to reduce shortage losses will produce higher benefits in dry years than in wet years. Thus, since river flows and rainfall vary from year to year, the benefits of a tactic for any year are unpredictable. In order to compare a tactic's benefits with its costs, we need an estimate of its expected benefits (the average over a large number of years).

One possible approach to estimating the expected annual benefits of a tactic would have been to calculate its benefits for each of the more than fifty years for which we had data on rainfall and discharges of the large rivers. This approach was rejected as unpractical for many reasons, including considerations of time and cost.

Instead, we used a more efficient approach, which produced upper and lower bounds on the expected annual benefits based on the benefits produced in four different years. The bounds were obtained by taking weighted averages of the benefits in the four years. Here we illustrate the approach with an example based on the benefits in two years.

Suppose that we can estimate the maximum possible benefits from a tactic (i.e., the benefits in the "worst year") and the "10-percent benefits" (i.e., the benefits that would be exceeded only one year in 10). Then, it can be shown that the expected annual benefits (EAB) from the tactic must fall between two values:

$$\text{EAB} < 0.1 * \text{maximum benefits} + 0.9 * 10\% \text{ benefits} = \text{UB, and}$$
$$\text{EAB} > 0.1 * 10\% \text{ benefits} = \text{LB.}$$

The approach is described more completely in Sec. 2.1.1, where we develop similar formulas that use the estimated benefits from four years to obtain upper and lower bounds on expected annual benefits. In some cases the benefits considered will be reductions in agricultural shortage losses; in other cases, reductions in agricultural salinity losses, reductions in shipping losses, or combinations of all three.

Estimation of the benefits for each of the four years was carried out using the Distribution Model, which simulates the major components of the surface water system of the Netherlands.[6] Given information over time on how much water enters the country (from rivers, rainfall, and groundwater flows), and how much water is extracted by the various user groups, the model calculates the water flows in the major rivers and canals, the levels of the lakes, and the concentration of salt in these waters. Using this information, and the loss functions described in Vol. XII, it calculates the agricultural shortage and salinity losses, and losses to shipping from low water flows and lock delays.

1.2.5. Comparison of Costs and Benefits

The final step in the screening process is to compare the annualized fixed cost (AFC) of a tactic (which includes the annualized investment cost plus the associated annual maintenance cost) with the upper and lower bounds on the expected annual benefits (UB and LB). If AFC exceeds UB, the tactic is clearly not promising. We have chosen to consider a tactic promising if AFC is less than UB, recognizing that, unless AFC is less than LB, the expected annual benefits may in fact be less than the annualized fixed cost. If so, a decisionmaker who considers only the expected annual benefits of a tactic would like to reject the tactic. However, a decisionmaker who is risk averse (i.e., is willing to pay more than the expected annual benefits in order to avoid a large loss in a very dry year) might still want to accept the tactic. Thus, the list of promising tactics will include all tactics whose expected annual benefits exceed their annualized fixed cost, as well as some whose expected annual benefits are somewhat less than their annualized fixed cost.

1.3. DEFINITION OF REGIONS

The significance and manifestation of many of the shortage and salinity problems differ in different parts of the Netherlands, according to the location's elevation and its primary source of surface water. Two major landforms are distinguished in the country according to elevation: the lowlands (the shaded area on the map in Fig. 1.2) and the highlands (the white area on the map). The lowlands are defined as all land lying below NAP + 2 m (almost all of which is below sea level). Most of the lowlands consist of polders--flat land surrounded by dikes that is artificially drained. Because of the need for artificial drainage, the lowlands are interlaced with a dense network of man-made drainage ditches and drainage canals (called boezems). They cover approximately half of the country's land area, are inhabited by over 60 percent of the country's population, and account for most of the country's commerce and industry. They are protected against sea and river flooding by dunes and dikes.

The remainder of the country (all land lying above NAP + 2 m) is referred to as the highlands. Compared to most lowlands areas, the highlands have a low density of population, little major industry, and

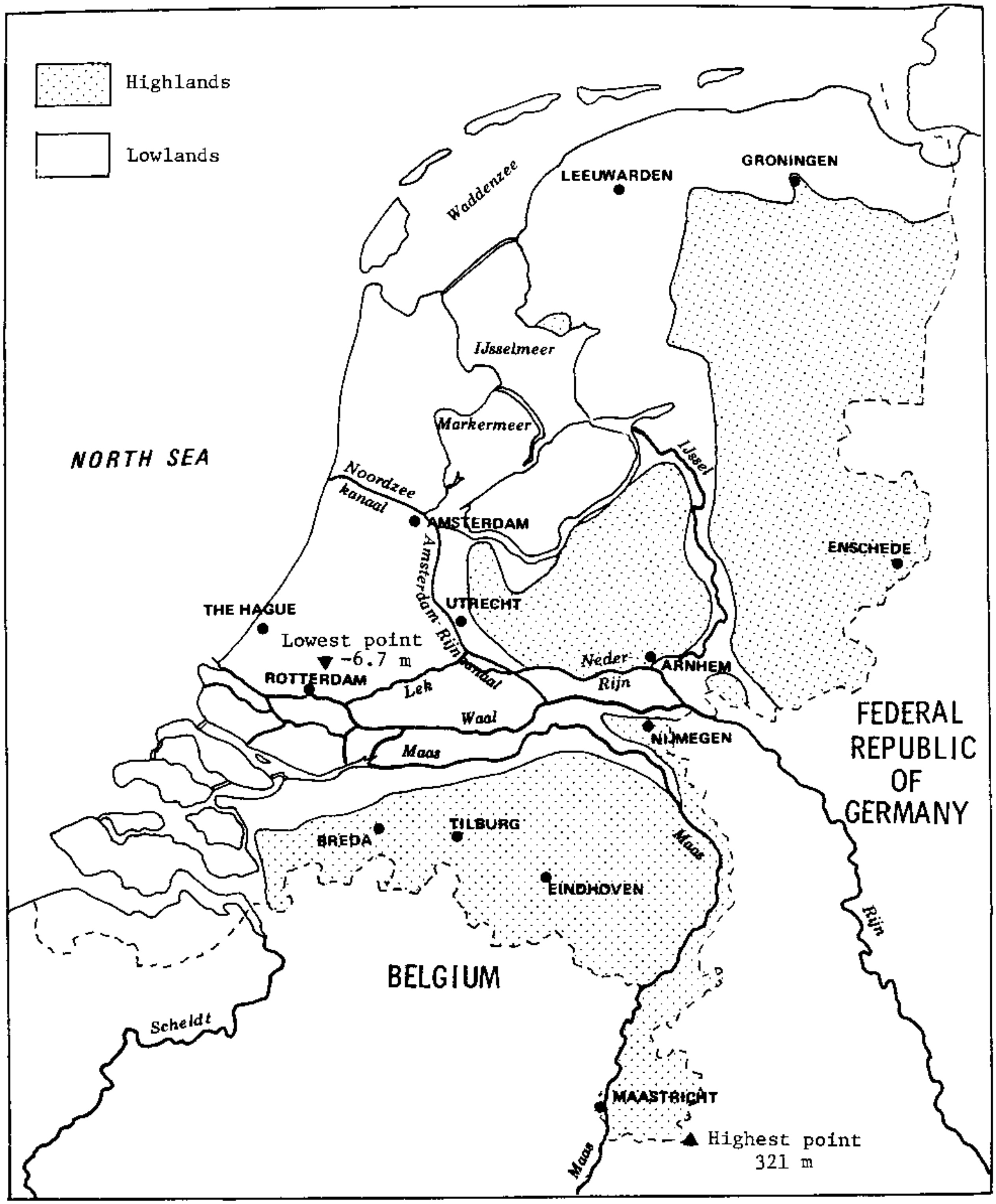

Fig. 1.2--Highlands and lowlands in the Netherlands

little need for an artificial drainage system. In general, shortage problems are worse in the highlands, and salinity problems are worse in the lowlands.

The country obtains its surface water from three major sources: the Rijn River, the IJsselmeer and Markermeer (which receive their water from the Rijn via the IJssel River and can store it for later use), and the Maas River. (Rijn flows are normally over 8 times higher than Maas flows.)

Using source of surface water and natural boundaries, we divided the Netherlands into eight regions for purposes of carrying out our screening analysis:

1. North
2. Northeast Highlands
3. Flevoland and Veluwe
4. North Holland
5. Midwest and Utrecht
6. Large Rivers and Northern Delta
7. West Brabant and Southern Delta
8. Southeast Highlands

Each region is a combination of contiguous PAWN districts.[7] A map showing the PAWN regions and districts is given in Fig. 1.3. The major political subdivision in the Netherlands is the province. Figure 1.4 is a map of the country showing province boundaries. The following paragraphs provide a brief introduction to each of the regions. More detailed overviews of the regions for which technical and managerial tactics were examined are given at the beginnings of Chaps. 5 to 10.

Four of the regions are supplied primarily by water from the IJsselmeer and Markermeer: the North, Northeast Highlands, Flevoland and Veluwe, and North Holland. The North (Region 1) covers the provinces of Groningen and Friesland and parts of the provinces of Drenthe and Overijssel. The region consists mostly of lowlands; some highlands in Friesland and Drenthe are included. The surface water supply for the area in Overijssel comes directly from the IJsselmeer and the Zwartemeer. Surface water for the rest of the region is supplied from the IJsselmeer primarily through the Prinses Margrietkanaal and the Van Starkenborghkanaal (see Fig. 5.1).

Except for the Noordoostpolder, salinity is not much of a problem in Region 1. The crops planted in the region are not very salt sensitive (about 90 percent of the cultivated area of Friesland is grassland for cattle grazing), and salinity levels are generally low (the average salinity in the main boezem of Friesland is about 200 ppm). The main problem in this region is shortage of water for agriculture during very dry summers when the level of the IJsselmeer drops so low that cutbacks in extractions become unavoidable. In addition, water flowing to Groningen must pass through the Van Starkenborghkanaal, whose capacity is not sufficient to satisfy all demands in Groningen in dry summers.

Fig. 1.3--PAWN districts and analysis regions

Fig. 1.4--Province map of the Netherlan…

The Northeast Highlands (Region 2) includes most of the provinces of Drenthe and Overijssel and the portion of Gelderland east of the IJssel River. There are two important surface water supply routes for the region (see Fig. 6.1). One (primarily for Overijssel) extracts water from the IJssel River at Eefde and sends it through the Twenthekanaal; the other (primarily for Drenthe) extracts water from the Zwartemeer and sends it through the Meppelerdiep. Little brackish groundwater seepage occurs in this region, and salinity from river estuaries and seaward shipping locks does not reach it, so there is virtually no salinity problem. Only a small portion of the cultivated land in the region is currently sprinkled, although this fraction has been steadily increasing. Thus, the shortage damage that occurs in dry years is mostly not preventable by tactics, since it results solely from a shortage of rain and not a shortage of water for surface water sprinkling. As the prevalence of sprinkler equipment increases, tactics become more important; i.e., the capacity of the supply system will then have to be increased as well.

Flevoland and Veluwe (Region 3) is partly lowlands (the Flevoland polder) and partly highlands (the Veluwe, which is most of the province of Gelderland west of the IJssel River). Although there are some shortage (in Veluwe) and salinity (in Flevoland) problems in the region, our initial screening indicated that the problems were not of sufficient magnitude to make technical or managerial tactics worthwhile. However, Flevoland faces a problem with respect to potential flooding from the Markermeer. Technical tactics that deal with this problem are discussed in Sec. 11.3.

The region called North Holland (Region 4) is that part of the province of North Holland lying above the Noordzeekanaal. It is entirely lowlands. Surface water for the northern part of the region (primarily the Amstelmeer boezem and the areas dependent on it) is extracted from the IJsselmeer. Surface water for the southern part of the region (primarily the Schermerboezem and its dependent areas) is extracted from the Markermeer. Cultivation of flower bulbs and tubers, open-air vegetable growing, and grassland farming are the major agricultural activities of the region. These crops are not very salt sensitive. The major water management problem in the region is that the inlet capacity for the Schermerboezem may be insufficient to meet future demands.

There are two general problems facing all districts that extract water from the IJsselmeer or Markermeer for agriculture. One is the salinity of these lakes. Aside from the salt that is carried by the IJssel River (a branch of the Rijn), several of the surrounding polders (e.g., Flevoland, Wieringermeer, and Noordoost) discharge highly saline water into the lakes. Tactics for diverting these discharges have been investigated. The other problem is the fact that, as demand increases, the storage capacity of the lakes will become insufficient to satisfy all demands, which will force cutbacks in extractions in dry periods. Tactics for increasing the storage capacity of the lakes have been investigated.

The Rijn River is the direct source of water for two regions: Midwest and Utrecht, and Large Rivers and Northern Delta. Midwest and Utrecht (Region 5) covers the southern part of the province of Noord-Holland, the northern part of the province of Zuid-Holland, and the entire province of Utrecht. Only the eastern part of Utrecht is highlands. The remainder of the region is lowlands and includes the lowest point in the Netherlands--NAP - 6.7 m at a point northeast of Rotterdam. The country's largest cities are in this region: Amsterdam, Rotterdam, and The Hague. Surface water flows into the region in several ways. Most is extracted from the northern branch of the Rijn at IJsselmonde, flows through the Hollandsche IJssel River, and is pumped into the Gouwe River at Gouda (see Fig. 8.1). Most of the remainder is extracted from the Amsterdam-Rijnkanaal at Jutphaas and Utrecht. Of major economic importance in this region is the growing of vegetables (mainly tomatoes, cucumbers, and lettuce) and flowers (mainly roses, carnations, and chrysanthemums) in heated glass houses (greenhouses) in the Westland, south of The Hague. This region also contains the famous bulb fields located behind the dunes to the south of Haarlem. Water shortage is not the major problem in this region. Enough water is always available to meet the needs of the region, and the supply capacities are generally sufficient. However, agricultural yields are always lower than they otherwise would be as a result of high salinity levels. This is due partly to the salt carried in the water of the Rijn and partly to seepage in the polders and boezems. In addition, in dry periods salt water from the sea sometimes penetrates eastward beyond the entrance to the Hollandsche IJssel River, and flows up the river to the entrance of the midwestern boezem system. Since the water level in the boezem is not allowed to drop below its target level, this saline water is sometimes let in to keep the boezem at the target level. As a result, highly saline water is extracted from the boezem for sprinkling crops, which causes considerable salinity losses. We have examined several tactics designed to reduce the salinity losses in this region.

The region called Large Rivers and Northern Delta (Region 6) consists of the wedge of land between the northern branch of the Rijn (the Neder-Rijn and Lek) and the Maas, as well as the northern islands in the Delta area (including Voorne, Putten, Hoeksche-Waard, and the northern portions of Goeree and Overflakkee). Many orchards are found along the rivers, especially in the region known as the Betuwe. Our pre-screening indicated that the shortage and salinity problems of the region were not of sufficient magnitude to make technical and managerial tactics worthwhile.

The region called West Brabant and Southern Delta (Region 7) consists of the western part of Noord-Brabant and parts of Zeeland (Schouwen-Duiveland, Tholen, and parts of Goeree-Overflakkee and Zuid-Beveland) (see Fig. 9.1). It extracts its surface water from the Lower Maas (Bergsche Maas) and from the merged water of the Maas and the Rijn. The Maas (which is very low in salinity) and the Rijn (which is much higher) merge just beyond the Biesbosch reservoir and then become the Haringvliet. The Southern Delta does not currently have a source of fresh water since the Zoommeer and the Grevelingen are salt.

In the near future, the Zoommeer will be made fresh; it will then serve as a source of fresh water to most of the region. The benefits to agriculture from this change will be partly offset by losses caused by salinity of the water in the Zoommeer. In order to limit the salinity of this lake, it will be flushed with water from the Haringvliet. It is also possible that the Grevelingen will be turned into a freshwater lake, which would then provide water for agriculture on the island of Schouwen-Duiveland. A final water management issue in this region is related to the power plant located on the lower Maas (Amer). If too little water flows past the power plant, it cannot cool the plant's discharges sufficiently to meet the thermal pollution standards for the country's rivers.

The Maas River is the source of water for the Southeast Highlands (Region 8), which is composed of all of the highlands areas in the southern portion of the country (all of the province of Limburg and the central and eastern portions of North Brabant). It includes the highest point in the country (321 m above sea level). Salinity is not a problem in the region. As is true of the Northeast Highlands, only a small portion of the cultivated land in the region is currently sprinkled. However, its system of ditches and small waterways is considerably less developed than that of the Northeast Highlands. As a result, in some parts of the region (e.g., the Peel) there are large agricultural shortage losses even in average years. Complicating the supply situation in the Southeast Highlands is the fact that in dry years there is not always enough water in the upper Maas to meet all the demands. This problem will only get worse as farmers purchase more sprinkling equipment. We have examined tactics for increasing the supply capacity to the Southeast Highlands assuming both current and increased demands for surface water. Another important consideration in this region is the use of water to lock ships through the Julianakanaal (see Fig. 10.1). In dry years, low flows on the canal (which is supplied with water from the Maas) lead to shipping delays at the Maasbracht lock.

For purposes of comparison, the cultivated areas and water demands of all eight regions are presented in Table 1.3. Although we have emphasized the distinctive problems of each of the regions, because there are so few sources of fresh water for the country, all regions are closely interdependent. The Rijn is the source of 63 percent of the supply of surface water in the Netherlands in an average year; rain supplies 27 percent; the Maas, 7 percent; and other small rivers, 3 percent. In an average year rain supplies almost all of the demands of agriculture for water. However, in drier years, the Rijn becomes increasingly important as a source of water.

Table 1.3

CULTIVATED AREA AND 1976 DEMAND FOR WATER BY PAWN REGION

			1976 Demands for Water (millions of m^3/yr)							
		Cultivated	DW Cos.		Industry		Agriculture			
		Area	SW	GW	SW	GW	Total	Level	SW	GW
No.	Name	(ha x 1000)				(a)	(b)	Control(c)	Spr	Spr
1	North	557	22	92		55	909	798	101	10
2	Northeast Highlands	385	6	105		52	135	47	22	66
3	Flevoland and Veluwe	147		73		62	197	130	54	13
4	North Holland	116		3		1	489	407	79	3
5	Midwest and Utrecht	154	117	102	35	21	458	347	51	60
6	Large Rivers and Northern Delta	127	8	57		15	375	290	69	16
7	W. Brabant and Southern Delta	168		74		20	311	113	69	129
8	Southeast Highlands	328	155	188	18	110	183	123	28	32
	Total	1982	308	693	53	336	3057	2255	473	329

SOURCES: Data for surface water demands by industry and drinking water companies come from MR-272 (unpublished PAWN memorandum), "Procedure for Developing Scenarios for Surface Water and Groundwater Extractions by Industry and by Drinking Water Companies," April 1979.

Data for groundwater demands by industry and drinking water companies come from the Rijksinstituut voor Drinkwatervoorziening (the Netherlands Institute for Drinking Water Supply).

Data for agriculture demands come from a Distribution Model run that simulated the actual 1976 situation.

(a) Total extractions by industry. Approximately 13 percent of these extractions is used consumptively. The remainder is subsequently discharged into the surface water system.

(b) Excludes flushing.

(c) Includes infiltration.

NOTES

1. The analysis of tactics relating to groundwater is described in Vol. VII.
2. Problems caused by other pollutants in the water are discussed in Vol. I.
3. For a more complete discussion of agriculture and its water-related problems, see Vol. XII.
4. The calculation of agricultural shortage and salinity losses is described in Vol. XII.
5. The calculation of low water shipping losses is described in Vol. IX. The loss functions used in our analysis consider only the short-run costs to shipping from implementation of the tactics,

not the long-run costs that would result from the need for changes in the shipping fleet. A supplementary analysis of this assumption indicated that the losses with and without the long-run costs are approximately the same.

6. The Distribution Model is described in detail in Vol. XI.
7. See Vol. XII for a description of agricultural districts.

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1.3. Unpublished report containing the results of a waterboard survey of water supply conducted by the Union of Waterboards, February 1978 (PAWN file DW-470).

Chapter 2

SCENARIOS

In order to assess the benefits to be derived from a tactic, it is necessary to specify the environment in which it will be operating. There may be different worthwhile tactics and different benefits to be gained if farmers significantly increase the amount of sprinkler equipment they own than if the amount of sprinkler equipment remains unchanged. Similarly, there may be differences in tactics and benefits if the amount of salt dumped into the Rijn River continues to increase compared with a situation in which the treaty to clean up the Rijn is implemented and the salt dumping is decreased.

Since we do not know for certain what the future environment will be, we examined the implications of a number of different possibilities called scenarios. Each scenario deals with factors (called scenario variables) that are outside the system, but which affect the system. Quade [2.1] divides uncertainties about the environment into two categories: stochastic uncertainties and real uncertainties. Stochastic uncertainties are due to random events whose probabilities of occurrence can be given a relative frequency interpretation. To the extent that the uncertainties in our study are stochastic, probability statements can be made about the benefits of implementing the various tactics. Fortunately for our analysis, the two most important determinants of surface water supply--river flows and rainfall--are stochastic uncertainties.

Uncertainties, such as agreement on a treaty with Belgium regarding the Maas River, whose probabilities of occurrence cannot be given a relative frequency interpretation, are called real uncertainties. We treated these scenario variables in one of two ways. For some, we considered several possibilities. For others, we chose one condition for the variable--usually the best prediction of the future environment (i.e., the expectation for 1985 or 1990)--and performed most or all of our analysis under that condition.

We have divided the scenario variables into three groups: those that affect the supply of surface water; those that affect the demand for surface water; and those that affect neither. Among the scenario variables affecting the supply of surface water are the time series of rainfall and flows in rivers, and the amount of salt that is dumped into the Rijn outside of the Netherlands. Among the scenario variables affecting the demand for surface water are the percentage of cultivated area farmers with access to surface water choose to irrigate, and the expansion of the area with access to surface water. Among the scenario variables affecting neither supply and demand directly are the prices farmers receive for their crops, and the construction of a second Oostvaardersdijk.

2.1. SUPPLY SCENARIOS

We considered the following scenario variables that affect the quantity and quality of surface water available to users in the Netherlands:

- Discharges of the Rijn, the Maas, the Overijsselsche Vecht, and several other small rivers.
- Rainfall and evaporation at 14 locations throughout the country.
- The quantity of salt dumped into the Rijn by industries outside of the Netherlands.
- Measures that Belgium might take that would affect the quantity of water entering the Netherlands.
- The effect of extractions of water from the Waal at Tiel on the depth of the river.

2.1.1. River Flows, Rainfall, and Evaporation

As pointed out in Sec. 1.2.4, the benefits from implementing a tactic will be different every year, depending primarily on the flows in the rivers over the year, and on the spatial and temporal pattern of rainfall. Just because a tactic produces large net benefits in an extremely dry year does not mean that the tactic is worthwhile. For example, suppose that the tactic provides benefits only in the extremely dry year (which is true of many of the tactics considered), and such a year can be expected to occur once every fifty years. Then the expected benefits from the tactic (the average over a large number of years) would be 1/50, or 2 percent, of the benefits in the extremely dry year.

Instead of estimating the expected benefits from a tactic by calculating the benefits in a large number of years and taking the average, we chose to obtain upper and lower bounds on the expected benefits by taking a weighted average of the benefits in four very different years in terms of their dryness: extremely dry, very dry, moderately dry, and average. We did not need a year wetter than average, since almost all of the problems we were trying to solve with tactics were related to low rainfall and river flows, so there would be few benefits from most of the tactics in wet years.

The supply scenario for each of the years selected consisted of:

- The average rainfall and evaporation at 14 locations (weather stations) for each of the 36 decades of the year.[1]
- The average discharges of the Rijn, the Maas, the Overijsselsche Vecht, and several other small rivers for each of the 36 decades of the year.

In principle, scenarios for rainfall, evaporation, and river flows could have been generated synthetically by a Monte Carlo procedure, using probabilistic descriptions of rainfall, evaporation, and river flows based on historical data. In practice, this would have been a complex, costly process involving the statistical analysis of multiple time series of data, using multiple measures of dryness. We, therefore, chose to use historical data for our external supply scenarios. (In addition to being easy to put together, the historical scenarios have the advantage of being familiar to the client and hence facilitate the understanding and interpretation of results.)

The four supply scenarios that we chose to use were selected on the basis of three measures of dryness. Historical data (by decade) for the years 1930 through 1976 were used to obtain the dryness measures. The 47 years were then ranked with respect to each measure, and the vectors of rankings were examined in order to choose (subjectively) the four years to be used.

The three dryness measures used were:

- Average Rijn discharge at Lobith (just west of the German border).
- Average Maas discharge at Borgharen (just north of the Belgian border).
- Maximum cumulative net deficit at De Bilt.[2]

For each year, values of the measures were calculated for each of three time intervals:

- Whole year (January-December)
- Entire growing season (March-September)
- Peak of growing season (May-August)

The last two intervals were chosen because the biggest economic impact of dryness is on agriculture.

The combination of the three dryness measures with the three time intervals produces nine dryness criteria. A tenth criterion was also considered--the critical capacity over the entire growing season. Critical capacity is similar to maximum net deficit, but takes into account the fact that water is stored in the root zone from one decade to the next, and is therefore a better indicator of crop damage. The critical capacity is the least amount of storage capacity that would be needed to compensate for a net deficit in any decade. (That is, it assumes that the difference between rainfall and potential evapotranspiration is made up by reducing the amount of stored water.)

Table 2.1 shows the rankings according to these ten criteria for the 14 years that ranked fifth or drier by at least one of the ten criteria.

The numbers in the columns represent the rankings (1 = driest, 2 = next driest, etc.). The ordering of the rows is somewhat subjective, and highlights the difficulties involved in determining the dryness of any given year. The rankings differ considerably depending on the criterion used. For example, 1964 ranks 2nd on Maas flow during the entire growing season, and 43d on critical capacity. The differences in rankings are due to the fact that dryness is a multifaceted concept. A year that has a lot of rain can have low river flows (e.g., 1964); a year that has little rain can have high river flows (e.g., 1941); a year can have high river flows over the entire growing season but low flows during the peak of the growing season (e.g., 1947); etc.

Table 2.1

RANKINGS OF SELECTED YEARS ACCORDING TO TEN DRYNESS CRITERIA

	Time Interval									
	Whole Year			March-September				May-August		
Year	R	M	D	R	M	D	C	R	M	D
1976	3	1	4	1	1	1	3	1	1	3
1959	9	10	1	6	10	2	1	8	9	1
1949	1	6	3	2	11	4	4	3	14	4
1947	8	11	2	16	33	3	2	4	6	2
1934	2	4	10	3	8	15	11	2	4	9
1964	4	3	17	5	2	33	43	5	3	33
1943	5	14	12	4	9	7	10	6	18	13
1971	6	2	8	8	3	8	8	12	11	22
1974	23	26	18	10	4	28	27	10	2	40
1973	12	5	32	15	6	18	39	21	13	18
1941	41	35	5	40	40	6	5	37	38	5
1944	29	34	7	12	7	5	6	11	5	7
1972	7	8	27	7	13	41	45	13	24	45
1938	14	15	21	11	5	14	25	17	7	20

R: Average discharge of Rijn at Lobith.
M: Average discharge of Maas at Borgharen.
D: Maximum cumulative net deficit at De Bilt.
C: Critical capacity at De Bilt.

Tables like Table 2.1 gave us a great deal of insight into the stochastic behavior of river flows, rainfall, and evaporation and enabled us to select the four years that we subsequently used in the analysis. Since our primary interest was agricultural losses, we gave greatest weight to criteria related to rainfall and evaporation over the growing season.

1976 is considered a particularly dry year by Dutch water management experts. They estimate its probability of occurrence at about 2 percent. Our rankings also show 1976 to be an extremely dry year. The Rijn discharge was particularly low in the spring (March-May) and during most of July. In fact, during the first two decades of July, the flow on the Rijn was the lowest in recorded history. A substantial increase in Rijn discharges in late July, which continued through August and September, kept the drought problems from becoming more critical--in the area around the IJsselmeer in particular. In search of an extremely dry year to use as a worst case scenario for evaluating tactics, we reduced some of the 1976 Rijn discharges by using, for each decade, the minimum of the discharges for that decade in 1934, 1949, and 1976. (These were the top-ranked years on the three Rijn discharge measures presented in Table 2.1.) We assigned the name DEX (for "extremely dry") to the supply scenario having these worst case Rijn flows (which are presented in Table 2.2), 1976 flows of the Maas and minor rivers, and 1976 rainfall and evaporation.

1959 was chosen as the "very dry" year. It ranked first on three of the criteria in Table 2.1, and was always among the top ten. 1943 was chosen as the "moderately dry" year, since it seemed the most appropriate among the many candidates for this type of year. We chose 1967 as the "average" year. Its Rijn and Maas flows were about average, and it ranked 18th out of the 47 years on critical capacity.

In order to determine upper and lower bounds on the expected annual benefits of a tactic (as described in Sec. 1.2.4), we planned to take a weighted average of the benefits obtained using these four supply scenarios. For this purpose we first had to assign probabilities to each of the four scenarios. Two sets of probabilities were assigned to the years: one based on agriculture shortage losses, and one based on agriculture salinity losses.[3] We estimated the probabilities using a simplified version of the Distribution Model to determine agriculture losses for the 47 years 1930 through 1976.

For estimating shortage losses, only the water distribution system in the northern half of the country was simulated in detail (all districts that extract and/or discharge water from the IJssel River or the IJsselmeer lakes). It was assumed that the entire cultivated area of each of these districts was planted with grass (over 67 percent of the cultivated area in these districts is actually grassland, and the hydrologic properties of grassland and land planted with other crops are virtually identical). A Distribution Model run was made to simulate the period 1930 through 1976. Then these 47 years were ranked according to the total agriculture shortage loss over the year. Figure 2.1 is a graph (on semilog paper) of the cumulative distribution function of crop losses over the 47 (ranked) years. It shows that DEX was a 2-percent year (its shortage losses were the worst of all 47 years--over 35 percent of the grass crop was lost); 1959 was a 7-percent year; 1943 was a 21-percent year; and 1967 was a 63-percent year (less than 5 percent of the grass crop was lost).

For estimating salinity losses in the Midwest and Utrecht, only the water distribution system in that region was simulated in detail (Region 5). The existing distribution of crops was assumed, but losses were calculated only for the glasshouse crops (vegetables and flowers) in Delfland. These are the most valuable and most

Table 2.2

RIJN DISCHARGES AT LOBITH FOR 1934,
1949, 1976, AND DEX

Decade	1934	1949	1976	DEX
1	885	1076	1627	885
2	1237	1111	2279	1111
3	2262	1695	2877	1695
4	1389	1147	1724	1147
5	1178	1150	1971	1150
6	1168	1154	1797	1154
7	1271	1340	1549	1271
8	2083	1628	1265	1265
9	1987	1995	1187	1187
10	1394	1339	1167	1167
11	1236	1661	1168	1168
12	1300	1434	1055	1055
13	1331	1486	1147	1147
14	1336	1395	1141	1141
15	1079	1580	1210	1079
16	994	1688	1389	994
17	971	2020	1333	971
18	992	1514	1092	992
19	1362	1138	855	855
20	1181	950	837	837
21	1294	951	1149	951
22	1362	856	1467	856
23	1702	819	1067	819
24	1440	775	913	775
25	1371	788	901	788
26	1641	777	990	777
27	1482	782	1172	782
28	1180	737	1081	737
29	1133	701	1094	701
30	1321	694	1032	694
31	1212	657	957	657
32	1349	746	1025	746
33	1110	843	1704	843
34	1098	1161	1763	1098
35	1421	1309	2281	1309
36	1502	1750	1427	1427

salt-sensitive crops grown in the Midwest. Over 21 percent of the cultivated area of Delfland is devoted to glasshouse crops (3600 ha), which have a market value of over 1 billion Dfl. The Distribution Model was run for 47 consecutive years, and salinity losses for the glasshouse crops of Delfland were computed for each year. Our implementation of the model, designed largely for estimating single-year impacts, carries forward salt left in the root zone at the

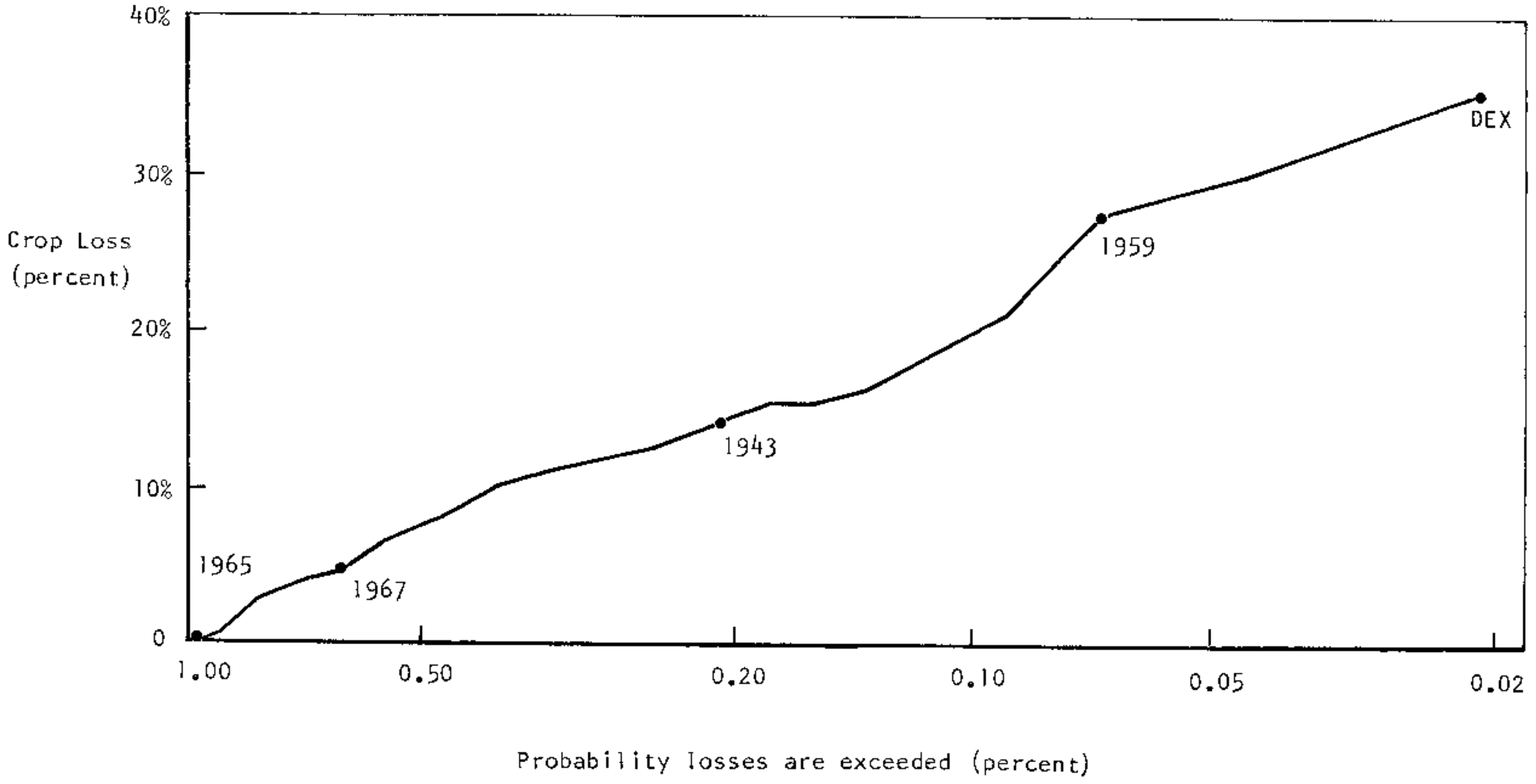

Fig. 2.1--Probability that agriculture shortage losses are exceeded (estimated for grass in northern half of country)

end of one growing season to the beginning of the next, and salinity losses indicated a considerable carry-over effect. Exceptionally wet years were followed by years with less-than-usual salinity losses (even if they were dry years); exceptionally dry years were followed by years with greater-than-usual salinity losses. Since we were interested in the probability distribution of salinity losses for independent years, we adjusted for this carry-over by regressing the annual salinity losses on the initial salt concentration, and then used the residual salinity loss as a measure of "current-year" loss. The 47 years were ranked according to their residual salinity losses. Figure 2.2 is a graph (on semilog paper) of the estimated salinity losses over the 47 (ranked) years. It shows that DEX was a 2-percent year (its salinity losses were the worst of all 47 years--over 11 percent of the glasshouse crops were lost because of salinity damage); 1959 was a 9-percent year; 1943 was a 13-percent year; and 1967 was a 57-percent year (only 3 percent of the glasshouse crops were lost).

The results described above are summarized in Table 2.3. Note that, although we have assigned a probability of .02 to DEX, this very likely overestimates the probability that such a dry year will occur (1976 is generally considered to be a 2-percent year, and DEX is drier than 1976). We, therefore, are likely to be overestimating the benefits to be derived from some of the tactics.

Table 2.3

PROBABILITIES OF ANNUAL LOSSES EXCEEDING
THOSE OF FOUR CHOSEN YEARS

	DEX	1959	1943	1967
Shortage losses	.02	.07	.21	.63
Salinity losses(a)	.02	.09	.13	.57

(a) These probabilities are used for estimating salinity losses in the Midwest and Utrecht region only.

To obtain the upper and lower bounds on expected annual benefits from a tactic, we assumed that the benefits that occur in DEX are the most the tactic can produce, and that benefits from a tactic are the additional losses that would occur if the tactic were not applied (i.e., the numbers in Table 2.3 indicate the probabilities that the benefits from the tactic would be obtained if the tactic were implemented).

To obtain the upper bound for expected annual benefits, we assumed that the benefits in DEX would be obtained in all years drier than 1959; the benefits in 1959 would be obtained in all years between 1959 and 1943 in dryness; etc. Calling a tactic promising if its annualized fixed cost is less than the upper bound on expected annual benefits is therefore a very conservative assumption. We are behaving in a risk-averse manner--as if we expect a year as bad as DEX to occur once

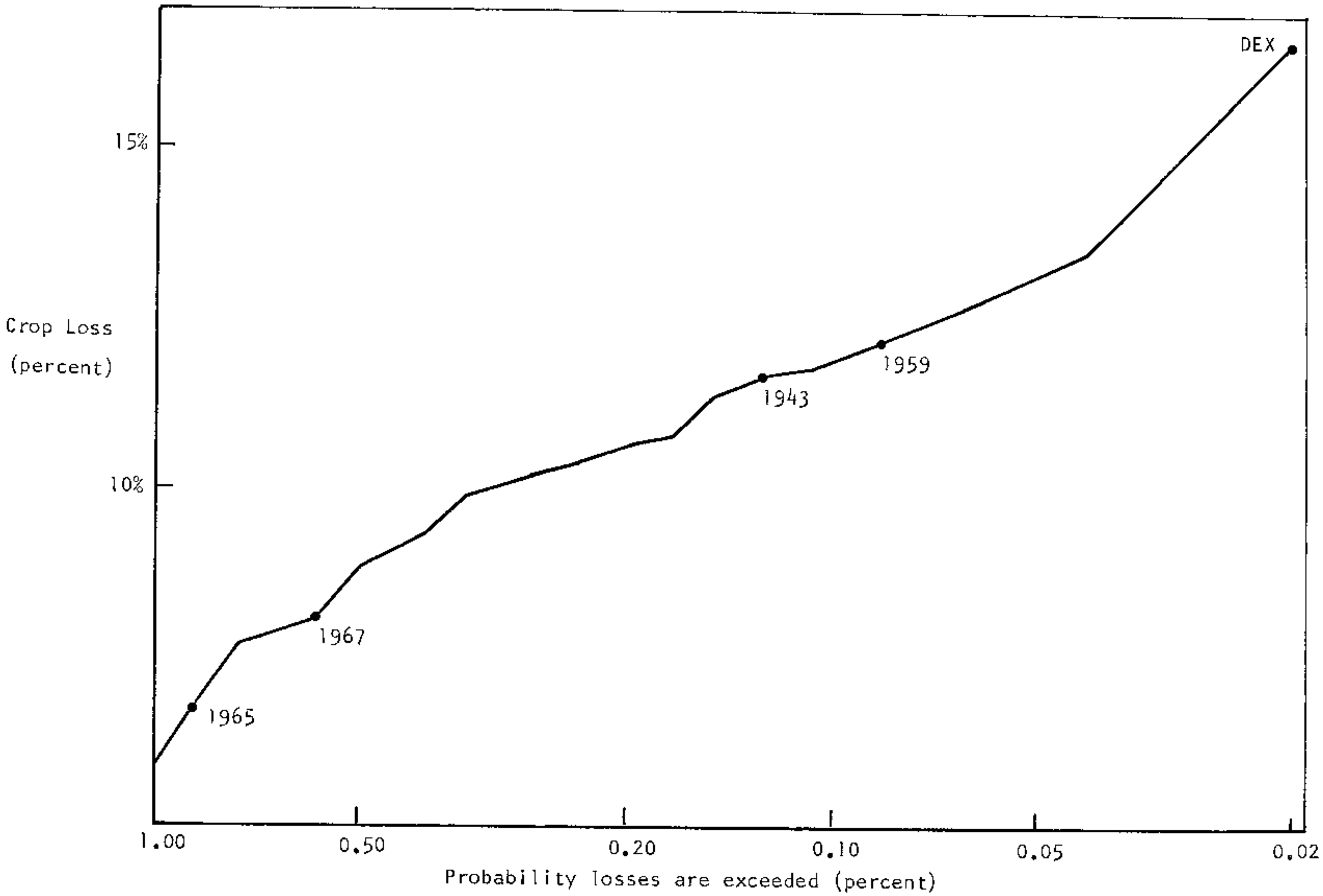

Fig. 2.2--Probability that agriculture salinity losses are exceeded (estimated for glasshouse crops in Delfland)

every 11 or 14 years instead of once every 50 years. For the lower bound we assumed that the DEX benefits would be obtained in all years drier than DEX; 1959 benefits would be obtained in a year between DEX and 1959 in dryness, etc.; we also assumed that there would be no benefits from the tactic in any year wetter than 1967.

Letting $B(y)$ be the benefits obtained in year y from implementing a tactic, then the formulas for upper and lower bounds on the expected annual benefits (EAB) are:

For shortage losses:

$$.02B(\text{DEX}) + .05B(1959) + .14B(1943) + .42B(1967) < \text{EAB} < .07B(\text{DEX}) + .14B(1959) + .42B(1943) + .37B(1967).$$

For salinity losses in Midwest and Utrecht:

$$.02B(\text{DEX}) + .07B(1959) + .04B(1943) + .44B(1967) < \text{EAB} < .09B(\text{DEX}) + .04B(1959) + .44B(1943) + .43B(1967).$$

2.1.2. Rijn Salt Dump

In 1876 the average salt concentration in the Rijn at Lobith was less than 20 mg/l. In 1976 the average was over 200 mg/l (an average salt load of 284 kg/s). These figures suggest that as much as 90 percent of the total salt load in the Rijn now comes from waste salt dumped into the river by industrial firms, and the size of this salt dump appears to be steadily increasing. In 1976 the governments of five nations (the Netherlands, France, West Germany, Switzerland, and Luxembourg) reached an agreement on cleaning up the Rijn. Among other things, it called for the amount of salt dumped into the Rijn by the Alsatian potash mines in France (the worst single polluter of the river) to be reduced by 60 kg/s (about half of the current discharge). Although the treaty was approved by four of the nations, France has refused to ratify it. In our analysis we assumed a salt load that was slightly higher than the 1976 load and that the treaty would not be ratified.

In order to choose an appropriate average annual salt dump, and to specify how the amount dumped should be varied decade-by-decade over the year, we analyzed historical data on salt concentrations of the Rijn at Lobith. Data from 1970 through 1977 were used in a regression model to obtain a relationship for estimating the salt load in a decade, given the year's average salt load, the year's average Rijn discharge, and the Rijn discharges in that decade and the previous decade.[4] The results indicated that the "natural" salinity of the Rijn is 25 mg/l, and that there is an important seasonal pattern in the salt load. (This pattern was subsequently incorporated into the Distribution Model.)

These results allowed the salt dumped in any year to be estimated from the total salt load observed in that year. We estimated the salt dump for the years 1930 through 1977 (the years for which we had data on salt concentrations), and found that the trend in the amount dumped was fit rather well by the straight line:

$$D = 40 + 5.9\ (\text{year} - 1930),$$

where D is the amount dumped, in kg/s. For example, the dump in 1976 would be estimated to be 40 + 5.9(46) = 311 kg/s. Using the average salt dump for 1976, the natural salinity of the Rijn, and the seasonal pattern of the salt dump, we were able to produce decade-by-decade salt loads for each of the four external supply scenarios.

2.1.3. Belgian Measures Affecting Maas Supply

The Maas has its source in France, and flows through Belgium before it reaches the Netherlands. Thus, the Belgians have control over the amount of Maas water that enters the Netherlands. The historical Maas flows that were mentioned in the river flow scenarios of Sec. 2.1.1 are the average decade flows at Monsin (a point in Belgium just south of the border between Belgium and the Netherlands). In order to develop Maas supply scenarios for use in the analysis, we considered a number of ways that these flows might be changed to reflect future developments.

Figure 2.3 is a schematization of the major waterways in the vicinity of the border between the Netherlands and Belgium. Note that the amount of Maas water that is available for use in the Netherlands (which we will call the net Maas inflow) is the sum of the flows on the Grensmaas, the Julianakanaal, and the Zuid-Willemsvaart north of Lozen. There are three developments that may cause this sum to be different from past patterns.

Maas Treaty. The Dutch and Belgians have been negotiating a treaty dealing with a number of water resource issues for many years. According to the provisions of the proposed treaty, the Netherlands would be assured of a net Maas inflow of 28 m^3/s by means of the construction of a number of large reservoirs in Belgium.[5] (For comparison, in the first decade of July 1976 the net Maas inflow was 7 m^3/s.) Since chances for concluding this treaty are small, we assumed the case of no treaty in our supply scenarios.

Net Extraction for Albertkanaal. It is expected that increased shipping traffic on the Albertkanaal will increase the net amount of water that Belgium extracts from the Maas to send down this canal. The current net extraction is 8 m^3/s (15 m^3/s is extracted just north of Monsin, but 7 m^3/s is eventually returned for use in the Netherlands). A future net extraction of 12 m^3/s is likely. We used an extraction of 12 m^3/s in all of our supply scenarios.

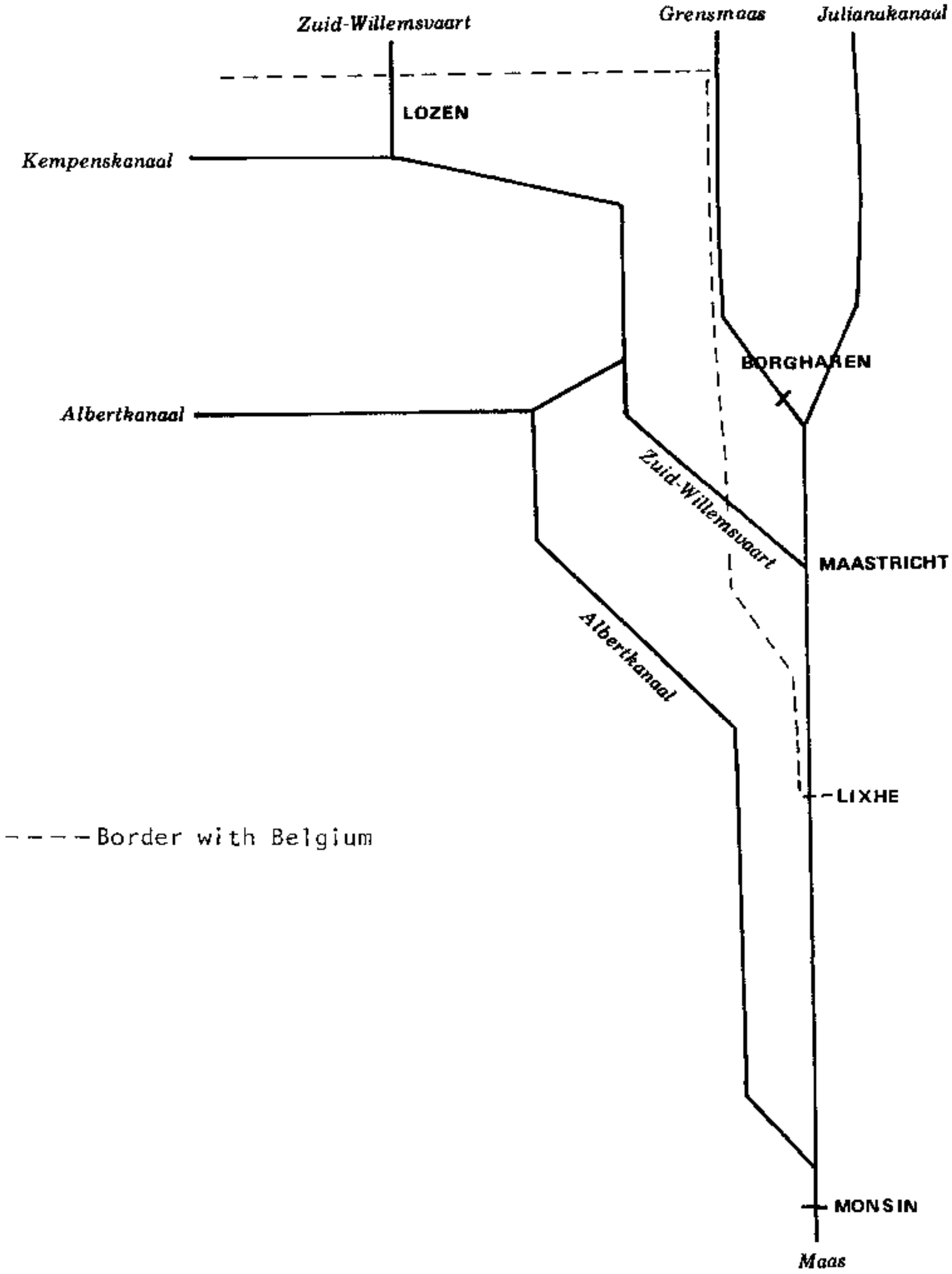

Fig. 2.3--Schematization of waterways around Belgian border

Weir at Lixhe. Belgium is constructing a hydroelectric power station and a weir on the Maas at Lixhe, just south of the Belgian-Dutch border. Water would be stored in an upstream reservoir and used for generating power. Excess water would be discharged through the weir into the Netherlands. The old weir at Lixhe was very leaky and let through 10 m^3/s when closed. It is estimated that the minimum flow on the Maas might be reduced to 5 m^3/s after completion of the Lixhe weir. However, this reduction in the minimum flow does not affect any of our scenarios, since, even in 1976, Belgium chose to discharge more than the 10 m^3/s minimum. (Most likely they discharge more than the minimum to avoid flooding. The volume of the upstream reservoir is quite small.)

2.1.4. Extractions at Tiel

The Waal River is the largest of the three branches of the Rijn in the Netherlands (the Waal, Neder-Rijn/Lek, and IJssel). In times of low water flows, it is sometimes desirable to send some Waal water north, for example, to increase the flow on the Lek River or to increase the flow on the Amsterdam-Rijnkanaal. At present, the way this is accomplished is by extracting the water at Tiel and sending it north along the Amsterdam-Rijnkanaal. (In 1976, Waal water was sent to the Markermeer by extracting it at Tiel and using a pump at Zeeburg to transfer it from the Amsterdam-Rijnkanaal to the Markermeer.)

However, extracting water at Tiel causes sand to settle to the river bottom below the withdrawal point, creating a sandbar that reduces the depth of the water at that point. If the sandbar is not removed, the decreased depth will lead to additional losses to shipping on the Waal. We assumed in most of our analysis that the sandbar could be removed by dredging (a relatively inexpensive solution). In case dredging were determined to be unacceptable, we evaluated (as tactics) two alternatives (see Sec. 11.6):

- Modify the groins in the Waal around Tiel or narrow its width.
- Add pumping capacity to the stretch of the Merwedekanaal between the Waal and the Lek, and use this canal instead of the Amsterdam-Rijnkanaal for northward transport of water.[6]

2.2. DEMAND SCENARIOS

Demands for surface water are generated by the various users of water. We developed demand scenarios for the following users:

- Agriculture (for sprinkling of crops).
- Industry and drinking water companies.

- The Zoommeer and Grevelingen (water for flushing).
- Shipping.

The demands of these users vary as their environment varies. In general, we performed our analysis with scenarios that best reflected estimated future demands for water--demands in 1985 or 1990.

2.2.1. Sprinkler Scenarios

As shown in Table 1.3, one of the largest uses of surface water is for the sprinkling of crops, and its use for this purpose has been growing steadily in recent years. Data from 1974 and 1975 indicate a countrywide growth rate in owned sprinkler equipment of about 12 percent per year. The 1976 drought accelerated this process. There was a 94-percent increase in owned sprinkler equipment in 1976, paced by a 324-percent increase in Friesland and a 197-percent increase in Groningen [2.4].

Increases in sprinkler capacity come about in two ways. First, farmers in areas that already have access to surface water purchase additional sprinkler equipment so that more hectares in these areas can be sprinkled. We call this an increase in sprinkler intensity (more sprinkler equipment per hectare of cultivated land). Second, changes in the infrastructure are made (by implementation of waterboard plans) that expand the area able to be supplied with surface water. We call this an increase in eligible area. In this case, farmers who previously had no reason to buy equipment for surface water sprinkling may now purchase such equipment.

We used four surface water sprinkler scenarios in our analysis.[7] Each scenario is defined by combining a definition of eligible area with a sprinkler intensity. Two situations were defined for each of these two scenario variables, one representing the current environment and one a projected future environment, thereby producing the four sprinkler scenarios. (Throughout the analysis we assumed that the groundwater sprinkler capacity was unchanged from the current situation.)

2.2.1.1. Eligible Area. The various regions differ considerably in the percentage of cultivated area that can currently be sprinkled. In the Northeast and Southeast Highlands (Regions 2 and 8), only 22 percent of the cultivated area currently has access to surface water. In the lowlands, practically all of the cultivated area has access. (See Table 2.4.)

The eligible area can be expanded through decisions by local waterboards to make improvements in the system of ditches that carries water from the regional distribution system to individual farms. In projecting future increases in the eligible area, we used information on the plans for such improvements that were under consideration in 1978, according to a survey of all local waterboards conducted in that year by the Union of Waterboards [2.5]. The survey produced a list of 65 individual waterboard plans. Our initial screening of these plans (which is described in Sec. 4.1 of this report) concluded that 19 of the plans had negative expected net benefits. In projecting the future situation, we assumed that all of the remaining 46 waterboard plans would be implemented.

Implementing the 46 waterboard plans would add over 264,000 ha to the area able to be supplied with surface water (an increase of 27 percent). The bulk of the increases would be in the highlands, although the percentage of the cultivated area that would be able to be supplied with surface water would still be under 50 percent in Regions 2 and 8. The area surrounding the Zoommeer would be able to obtain surface water for sprinkling when that lake is made fresh. This is reflected in a large increase in the eligible area of Region 7. Table 2.4 summarizes the information on eligible areas for the two values of the scenario variable. For ease in referring to the two conditions, we call the situation corresponding to the current eligible area <u>RNONE</u>, and the situation in which the 46 waterboard plans are implemented <u>RALL</u>.

Table 2.4

ELIGIBLE AREA FOR SPRINKLER SCENARIOS (ha)

		Currently Eligible (RNONE)		Eligible after Waterboard Plans (RALL)		Increase in Eligible Area
Region	Cultivated Area	Area	%	Area	%	%
1	556,588	350,387	63	400,143	72	14
2	385,261	84,651	22	124,837	32	45
3	147,049	59,984	41	74,847	51	24
4	115.900	100,853	87	100,853	87	--
5	153,609	146,943	96	149,320	97	1
6	126,522	120,632	95	123,269	97	2
7	168,126	53,428	32	129,646	77	141
8	328,085	72,538	22	150,849	46	109
Total	1,981,140	989,416	50	1,253,764	63	27

<u>2.2.1.2. Sprinkler Intensity</u>. The sprinkler intensity reflects the extent to which farmers in the eligible area purchase sprinkler equipment for use during dry periods. Sprinkler intensities were determined for two situations, high and low. The low sprinkler intensity (which, for convenience, we refer to as <u>SPRLO</u>) was designed to reflect 1976 levels. Combined with the current eligible area (RNONE), this intensity produces a sprinkler scenario that corresponds roughly to the sprinkler situation that actually existed in 1976. In the case of expanded eligible area (RALL), the same sprinkler intensities were extrapolated (crop-by-crop) to the areas that are currently not able to be supplied. An average of 22 percent of the eligible area is sprinkled under SPRLO.

The high sprinkler intensity (which we label SPRHI) reflects an optimistic view of future developments. It assumes that farmers in the eligible area will optimize their use of sprinklers--i.e., that they will purchase sprinkler equipment in such a way that it maximizes their expected net benefits.[8] An average of 55 percent of the eligible area is sprinkled under SPRHI.

Tables 2.5a and 2.5b provide some insight into the implications of the four resulting sprinkler scenarios. They present information by region on the areas that are sprinkled under each scenario. They show, for example, that nationwide less than 10 percent of the cultivated area is currently sprinkled. Under the SPRHI-RALL scenario, this figure rises to more than 30 percent. In the Northeast Highlands, where only 2.4 percent of the cultivated area is currently sprinkled, 22 percent would be sprinkled in the SPRHI-RALL situation.

Table 2.5a

CULTIVATED AREAS WITH SURFACE WATER SPRINKLING EQUIPMENT UNDER LOW SPRINKLER INTENSITY SCENARIO (ha)

Region	Cultivated Area	RNONE Area Sprinkled	%	RALL Area Sprinkled	%
1	556,588	56,355	10.1	66,427	11.9
2	385,261	9,334	2.4	16,617	4.3
3	147,049	6,914	4.7	8,194	5.6
4	115,900	33,648	29.0	33,648	29.0
5	153,609	28,272	18.4	28,275	18.4
6	126,522	26,004	20.6	26,568	21.0
7	168,126	9,950	5.9	20,394	12.1
8	328,085	22,849	7.0	39,518	12.0
Total	1,981,140	193,326	9.8	239,641	12.1

Table 2.5b

CULTIVATED AREAS WITH SURFACE WATER SPRINKLING EQUIPMENT UNDER HIGH SPRINKLER INTENSITY SCENARIO (ha)

Region	Cultivated Area	RNONE Area Sprinkled	%	RALL Area Sprinkled	%
1	556,588	164,065	29.5	187,620	33.7
2	385,261	57,425	14.9	84,688	22.0
3	147,049	19,847	13.5	24,694	16.8
4	115,900	52,311	45.1	52,311	45.1
5	153,609	57,318	37.3	59,239	38.6
6	126,522	46,346	36.6	47,830	37.8
7	168,126	24,001	14.3	59,910	35.6
8	328,085	45,315	13.8	98,943	30.2
Total	1,981,140	466,628	23.6	615,235	31.1

2.2.2. Demands by Industry and Drinking Water Companies

In our analysis we used projected net extractions of surface water by drinking water companies and industry for 1990.

2.2.2.1. Industry. About 90 percent of the industrial use of surface water is for cooling water and process water, which is generally discharged into the same waterways from which it is extracted without significant losses. As shown in Table 1.3, major industrial net extractions in 1976 were estimated to be 53 million m^3 (an average of 1.7 m^3/s over the year). These can be attributed to three sets of extractions that were large enough to be worthwhile taking into account in our models:

1. Industries in IJmuiden extracted 35 million m^3 from the Lekkanaal, which were discharged into the Noordzeekanaal and North Sea (and thus unavailable for further use within the country).
2. A large chemical company had a net extraction of about 12 million m^3 from the Julianakanaal.
3. Other industrial plants around Maastricht had net extractions from the Maas of about 6 million m^3.

The industrial surface water extraction scenario for 1990 that we used is presented in Table 2.6. (Two additional sets of extractions expected by 1990 were inadvertently omitted from the data file used as input to the Distribution Model.[9]) The scenario is based on the following assumptions:

- Industrial extractions from the Lekkanaal will be restricted in the future. We projected industrial extractions of only 10 million m^3 for 1990.
- Industrial extractions from the Julianakanaal and the Maas will grow by 2 percent per year.
- By 1990, 30 million m^3 of water will be delivered from the Biesbosch reservoir to industries in Zeeland and Noord-Brabant.

Table 2.6

SCENARIO FOR 1990 INDUSTRIAL SURFACE WATER EXTRACTIONS

Source of Water	PAWN Network Node	Quantity Extracted (million m^3/yr)
Maas	MASTRICT	10
Julianakanaal	BORN	15
Biesbosch	GERTRUID	30
Lekkanaal	JUTPHAAS	10

The 1990 scenario that we used implies that net extractions of surface water by industry will increase to 65 million m^3 by 1990 (an average of 2.1 m^3/s).

2.2.2.2. Drinking Water Companies. Table 1.3 shows that 308 million m^3 of surface water were extracted by drinking water companies in 1976 (an average of 9.8 m^3/s). We based our projections of 1990 demands on predictions by VEWIN (a trade association of the drinking water companies in the Netherlands). The 1990 scenario, which is shown in Table 2.7, projects drinking water company surface water extractions of 393 million m^3 (an average of 12.4 m^3/s).

Table 2.7

SCENARIO FOR 1990 SURFACE WATER EXTRACTIONS
BY DRINKING WATER COMPANIES

Project	Source of Water	PAWN Network Node (N) or District (D)	Quantity Extracted (million m^3/yr)
Infiltratie Z.-Holland	Andelse Maas	DENBOSCH (N)	59
Spaarbekken Biesbosch	Amer	GERTRUID (N)	140
Spaarbekken Andijk	IJsselmeer	IJSLMEER (N)	17
Infiltratie N.-Holland	IJsselmeer	IJSLMEER (N)	30
Infiltratie N.-Holland	Lekkanaal	JUTPHAAS (N)	70
Infiltratie Z.-Holland	Wassenaarse Wetering	RIJNLAND (D)	32
Loenderveense Plas	Amsterdam-Rijn-kanaal	GOOI (D)	45

2.2.3. Zoommeer and Grevelingen

In 1953 a major undertaking called the Delta Project was begun to protect the Delta area of the country from flooding by the North Sea. As the last phase of the project, in 1976 the Dutch Parliament adopted a plan for protecting the area surrounding the Oosterschelde, one of the estuaries in the area. According to the plan, the Oosterschelde is to be closed off from the North Sea by a storm-surge barrier. Furthermore, the current Oosterschelde will be divided into three basins separated by dams containing ship locks: a Western Basin, beginning at the storm-surge barrier and extending eastward; an Eastern Basin, located at the eastern end of the Oosterschelde and southern end of the Schelde-Rijn Connection; and a Northern Basin, located in the Krammer/Volkerak, at the northern end of the Schelde-Rijn Connection. (See Fig. 2.4.) Of these basins, the Western would remain salt water, while the Eastern and Northern (which together would be called the Zoommeer) would become fresh water.

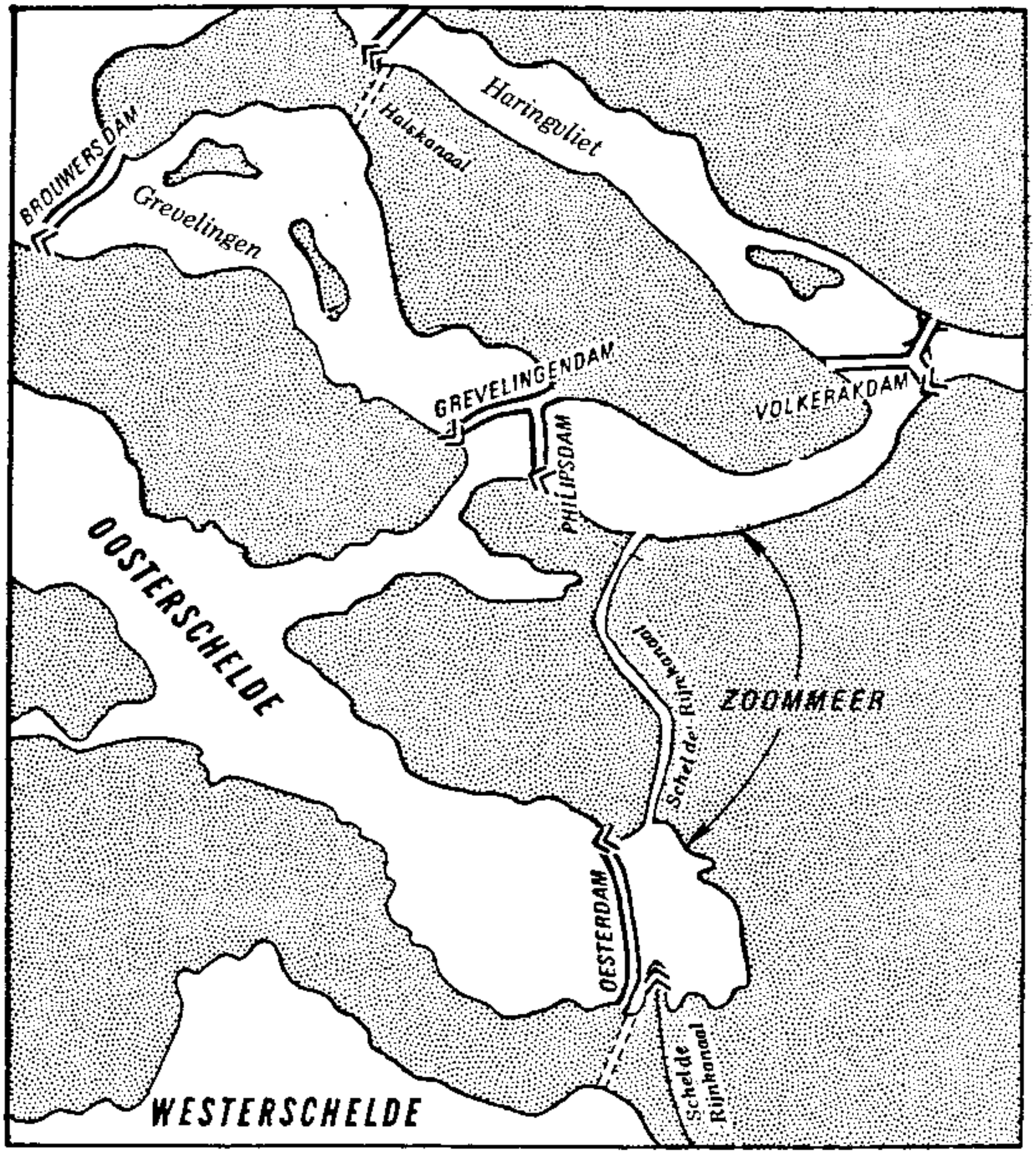

Fig. 2.4--Detail of area around the Zoommeer and Grevelingen

The Philipsdam and Oesterdam, which will separate the Zoommeer from the Western Basin of the Oosterschelde, are in the process of being constructed. Our analysis, therefore, assumed that the Zoommeer will be fresh. In order to maintain a fresh Zoommeer, water will have to be flushed from the Haringvliet through the Northern and Eastern Basins to the Westerschelde. The flushing policy that we used in our analysis is described in Sec. 3.6. In Sec. 9.2, we examine the benefits that are likely to accrue to agriculture from having a fresh Zoommeer and implementing waterboard plans to enable areas around the lake to extract water for sprinkling their crops.

Another part of the Delta Project involved the closure of the Grevelingen estuary. This estuary has already been closed off (the Grevelingendam was completed in 1965, and the Brouwersdam was completed in 1972), but a decision about whether to make the Grevelingen a freshwater lake has not yet been made. In our analysis we assumed that the Grevelingen would remain a saltwater lake. As a result, we did not examine the implications of having to flush the lake with fresh water from the Zoommeer and/or Haringvliet (which would reduce the amount of water available for flushing the Nieuwe Waterweg, thus increasing the salinity problem in the Midwest). As part of our analysis, we did examine the benefits to agriculture in Schouwen-Duiveland of making the Grevelingen fresh and implementing a waterboard plan that would make most of the cultivated area of the island eligible for sprinkling water extracted from the Grevelingen (see Sec. 9.3).

2.2.4. Assumptions for Shipping Fleet and Shipment of Goods

For purposes of screening, we used scenario variables related to shipping that reflected the projected 1985 environment. The variables specified were:

- Characteristics of the shipping network.
- Size and distribution by class and type of the Dutch and total shipping fleets.
- Specification of goods to be shipped between origins and destinations by type of commodity.
- Size and type of vessels used in carrying each type of commodity between each origin-destination pair.
- Maximum load factors for goods, by type and class of ship, for each origin-destination pair.

The shipping network was the easiest of the scenario variables to specify. Since major projects require long periods of planning, financing, and construction, large changes to the infrastructure can be predicted. Thus, the shipping network in 1985 was defined to look like the network of today, with the addition of the changes currently planned and under construction, and some others now under consideration.

Specification of the other scenario variables was more difficult. The 1985 fleet analysis was based on a shipping cost study produced by the Dienst Verkeerskunde (DVK) of the Rijkswaterstaat, the Nederlands Vervoerswetenschappelijk Instituut (NVI), and the Economisch Bureau voor het Weg- en Watervervoer (EBW).[10] The predictions of goods production and distribution, as well as transport mode selection, were made by the NVI and EBW for an earlier study commissioned by the European Economic Community (EEC). Table 2.8 compares projections of the 1985 total shipment of goods with actual data for 1976.

Values of the other scenario variables were specified using trend equations tempered by expert judgment. Further information on the specification of the 1985 scenario for the shipping fleet and shipment of goods is given in Vol. IX.

Table 2.8

TRANSPORT OF GOODS BY INLAND SHIPPING:
ACTUAL SITUATION IN 1976
AND PROJECTION FOR 1985

Component	Annual Cargo (million tons) 1976	1985
Domestic	94.116	119.265
International (in)	43.523	74.040
International (out)	93.793	176.286
International (through)	28.877	26.283
Total	260.309	395.874

2.3. OTHER SCENARIO VARIABLES

2.3.1. Markerwaard

Toward the end of the 1800s, C. Lely, a civil engineer of the Rijkswaterstaat, developed a plan for closing off the Zuiderzee estuary and converting it into a freshwater lake (the IJsselmeer), and for draining parts of the lake and converting them into polders. Five large polders were envisioned, which were to increase the area of the Netherlands by 6 percent. Four of the polders have already been completed (Wieringermeer, 1930; Noordoost, 1942; Oostelijk Flevoland, 1957; and Zuidelijk Flevoland, 1968).

The first phase of the construction of the fifth polder (the Markerwaard) has already been carried out--a dike from Enkhuizen to Lelystad has been constructed (the Houtribdijk) that divides the IJsselmeer into two lakes, the so-called Small IJsselmeer (which we have referred to as the IJsselmeer in our analysis) and the Markermeer. However, changing views on, among other things, modification of the environment and population growth, have caused reconsideration of the plans for a Markerwaard. In our analysis, we assumed that a Markerwaard would not be implemented.

If the Markerwaard were to be built, the most important impact on water management would be on policies for setting the target levels of the IJsselmeer and Markermeer. As part of our analysis of level management policies for these lakes (Sec. 11.4), we examined the implications of a Markerwaard.

2.3.2. Second Oostvaardersdijk

If the Markerwaard were to be constructed, the Houtribdijk would be continued in a southwestern direction, parallel to the western dike of Flevoland that is called the Oostvaardersdijk.[11] That part of the Markerwaard dike is generally referred to as the second Oostvaardersdijk.

However, even if a Markerwaard is not built, the construction of this dike might still produce various benefits. If connected to the mainland of Noord-Holland north of Amsterdam, it would give additional protection against flooding to Flevoland, and it would separate a relatively fresh Markermeer from a more saline IJmeer; the difference in salinity would stem from the discharge of saline water from Flevoland into the IJmeer. Presumably, the agricultural area in Noord-Holland that depends on the Markermeer for part of its surface water supply would benefit from a lower salinity in that lake.

Since no decision on building this dike has yet been made, in our analysis we assumed that there was no second Oostvaardersdijk. That is, we assumed an open connection between the IJmeer and Markermeer. However, we did include the construction of a second Oostvaardersdijk as a possible water management tactic, and compared its costs to its expected benefits (see Sec. 11.3).

2.3.3. Prices for Agricultural Products

The benefits that accrue to agriculture as a result of the implementation of tactics depend directly on the prices farmers receive for their products. Ignoring the effects of inflation, these prices vary from year to year depending on such factors as the amount of rainfall in the Netherlands, the amount of rainfall in the rest of Europe, and policies of the European Economic Community. We specified a price scenario for each of the four external supply scenarios to reflect the impact on crop prices of reduced production caused by insufficient rainfall. Among other things, the scenarios take into account changes in both demand and supply caused by changes in prices.

Prices were specified for each of 13 aggregate crop types in terms of value per hectare. Instead of estimating crop values separately for each of the four supply scenarios, separate estimates were made for the driest (DEX) and wettest (1967) scenarios, and linear interpolation was used crop-by-crop to determine crop values for the two intermediate scenarios. (The crop values in each intermediate year were chosen so that their relationship to the crop values in DEX and 1967 was the same as the relationship of the crop losses in the intermediate year to those in DEX and 1967.) Table 2.9 presents the crop values that were used in our analysis. All values are given in 1976 guilders.[12]

Table 2.9

CROP VALUES FOR EXTERNAL SUPPLY SCENARIOS (Dfl/ha)

Crop Type	DEX	1959	1943	1967
Grass	10,070	8,750	6,710	6,040
Consumption potatoes	16,250	14,300	11,030	10,000
Milling potatoes	5,830	5,210	4,160	3,830
Seed potatoes	20,300	18,180	14,620	13,500
Sugar beets	5,200	5,200	5,200	5,200
Cereals	3,150	3,150	3,150	3,150
Cut corn	6,000	5,250	3,990	3,600
Bulbs	30,140	29,290	27,850	27,400
Open-air vegetables	20,280	18,820	16,370	15,600
Pit and stone fruits	10,400	10,400	10,400	10,400
Trees	42,800	42,800	42,800	42,800
Glasshouse vegetables	278,400	263,650	239,590	232,000
Glasshouse flowers	412,250	434,950	472,990	485,000

NOTES

1. We divide each month of the year into three decades: the first two decades of each month contain exactly 10 days; the third decade contains as many days as are needed to fill in the month (8, 9, 10, or 11 days).
2. The net deficit for a decade is potential evapotranspiration minus rainfall. The cumulative net deficit in decade k is the sum of the successive net deficits from the first decade through kth decade of the period under consideration. The maximum cumulative net deficit is the largest value of the net deficit over all decades in the time interval.
3. A set of probabilities based on low water shipping losses was developed late in the study, after most of our analysis was completed (see Vol. IX). We used the probabilities based on agriculture salinity losses in our analysis to estimate the benefits from tactics that would reduce shipping losses. The probabilities based on low water shipping losses place lower weights on the drier years. Thus, our analysis tends to overestimate the benefits from tactics that reduce low water shipping losses.
4. Further details are provided in Vol. XI and Ref. 2.2.

5. Information on the proposed treaty can be found in Ref. 2.3.
6. At the point in the Waal where the extraction into the Merwedekanaal would take place, no effects on shipping due to sedimentation are expected to occur.
7. A complete description of the development of the sprinkler scenarios is given in Vol. XII.
8. See Vol. XIV for complete details of the methodology.
9. The scenario for 1990 industrial surface water extractions (see Table 2.6) should have also included 60 million m^3/yr from the IJsselmeer (to be transported from Enkhuizen through a pipeline to industries in IJmuiden) and 10 million m^3/yr from the Damsterdiep at Loppersum for industries in northeast Groningen. The extraction for industries in Groningen is small, and our results would not be changed if they were included in our analysis. Including the extraction from the IJsselmeer in our analysis would enhance the attractiveness of tactics we found promising for increasing the storage capacity of the lake.
10. De Kosteneffecten voor de Binnenscheepvaart van Wateronttrekkingen aan Rivieren en Kanalen in Nederland (N.901/654), NVI/EBW/ACB (Administratie Centrum voor het Beroepsvervoer), Rijswijk, April 1979.
11. "Eastfarers Dike," after the seamen who left Amsterdam for the Orient in past centuries through the Zuiderzee.
12. A complete description of how the price scenarios were developed is given in Vol. X.

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2.1. Quade, E. S., Analysis for Public Decisions, American Elsevier Publishing Company, Inc., New York and Amsterdam, 1975, p. 214.

2.2. MR-293 (unpublished PAWN memorandum), "Scenarios for Salt Loads in the Rijn at Lobith," June 1979.

2.3. Unpublished information from the Rijkswaterstaat, Directie Limburg, concerning the water supply of the Julianakanaal (PAWN file DW-292).

2.4. Unpublished information from Instituut voor Culuurtechniek en Waterhuishouding (ICW) concerning sprinkling and irrigation in the Netherlands in 1976, Wageningen, May 1977 (PAWN file DW-251).

2.5. Unpublished report containing the results of a waterboard survey on water supply conducted by the Union of Waterboards, February 1978 (PAWN file DW-470).

2.6. VEWIN, Tienjareplan 1978, samenvatting (Ten-Year Plan, 1978, Summary), June 1978.

Chapter 3

MANAGERIAL RULES

Managerial rules describe the operation of the water distribution infrastructure under various supply and demand conditions. These rules, together with the schematization of the water distribution network, form the "model" of the water management system in which various changes to the infrastructure are evaluated. Managerial rules take different forms: among them are weir control rules, lake level management rules, rules for extractions from the national distribution system into the regional systems, and rules for cutbacks in desired extractions under conditions of insufficient water availability.

Managerial rules are associated with the operation of the current water distribution infrastructure, as well as with any future infrastructure that may result from the implementation of some of the technical tactics discussed in this volume. In this chapter we describe the managerial rules that were used in the Distribution Model runs that were made to evaluate various technical tactics. We were able to screen out some tactics without making any Distribution Model runs. Although provisions were made in the Distribution Model for various managerial rules associated with the implementation of these tactics, we do not discuss those rules here since they do not relate to the analysis reported in this volume. For a complete description of all of the managerial rules implemented in the Distribution Model, the reader is referred to Vol. XI.

In the remainder of this chapter, we first discuss the rules for managing various elements in the national system, where decisions made by the responsible government agencies determine the distribution of surface water. We then discuss the rules applied within the various regional systems.

3.1. NATIONAL SYSTEM

The national distribution system consists of the primary waterways in the country, i.e., those waterways that are of more than only regional significance. Included in the national system are, first of all, the principal natural waterways and bodies of water: the major rivers (Rijn, Waal, Neder-Rijn, IJssel, and Maas); the waterways in the Delta (the Rotterdamse Waterweg, the Haringvliet, the Zoommeer, and the various connecting waterways); and the lakes in the north-central part of the Netherlands (IJsselmeer, Markermeer, and border lakes). Also included in the national system are some of the country's major canals: the Amsterdam-Rijnkanaal, the Noordzeekanaal, the Betuwe section of the Merwedekanaal, the Lekkanaal, the Julianakanaal, the Maas-Waalkanaal, and the connection between the Waal and the Maas at St. Andries (hereafter called the St. Andries Connection). We now describe the various managerial rules associated with the national distribution system.

3.1.1. The Weir in the Neder-Rijn at Driel

The Rijn, after entering the Netherlands from Germany, splits into three branches--the Waal, the Neder-Rijn, and the IJssel. The weir in the Neder-Rijn at Driel controls the flow along this river: closure of the weir causes the Rijn flow to be divided between the Waal and the IJssel only, while an open weir results in the natural division among all three branches. An intermediate position of the weir causes a larger than "natural" flow on the Waal and the IJssel, and a lesser flow on the Neder-Rijn.

The rule for controlling the weir that is used in the Distribution Model simulates the policy used in reality. Under this policy, the weir is closed if the natural division would cause the IJssel flow to be less than 285 m^3/s. The weir can be closed to allow a flow of as little as 25 m^3/s on the Neder-Rijn.[1] The degree of closure of the weir is aimed at establishing an IJssel flow of precisely 285 m^3/s: this flow rate will be exceeded only if leaving the weir open leads to a flow above 285 m^3/s; and a flow less than 285 m^3/s occurs only when the Rijn flow is so low that even reducing the flow on the Neder-Rijn to 25 m^3/s will not produce this target flow on the IJssel.

3.1.2. Extractions from the Waal at Tiel and Gorinchem and from the Lek at Wijk bij Duurstede

In Sec. 2.1.4 we mentioned that water can be extracted from the Waal at Tiel and sent along the Betuwe section of the Amsterdam-Rijnkanaal (the section between the Waal and the Lek) to increase the flow on the Lek River and/or the flow on the section of the Amsterdam-Rijnkanaal north of Wijk bij Duurstede. The managerial rules specify how the extractions from the Waal and the Lek are determined.

The rules are based on the requirements of a minimum flow of 20 m^3/s on the northernmost section of the Amsterdam-Rijnkanaal and a minimum flow of 5 m^3/s on the westernmost section of the Lek. The minimum flow on the Amsterdam-Rijnkanaal is induced by the need for cooling water for the power plants along that canal and along the Noordzeekanaal. The minimum flow on the Lek is based on water quality considerations. The extraction rule from the Lek at Wijk bij Duurstede is to send just enough water northward to obtain the 20 m^3/s flow on the Amsterdam-Rijnkanaal north of Diemen. If, after that extraction, the remaining flow on the Lek is insufficient to provide for the 5 m^3/s flow west of Schoonhoven, water is transported from the Waal at Tiel through the Amsterdam-Rijnkanaal to Wijk bij Duurstede to supplement the Lek flow.

We evaluated a technical tactic that would enable the Merwedekanaal to be used for transporting water between the Waal and the Lek. A slightly different rule is used in runs with this tactic implemented. Again, the extraction policy at Wijk bij Duurstede is to provide for a minimum flow of 20 m^3/s north of Diemen. This flow is provided by the Neder-Rijn supplemented by an extraction at Tiel when necessary.

However, if the extraction at Wijk bij Duurstede leads to an insufficient Lek flow west of Schoonhoven, the Betuwe section of the Merwedekanaal is used to supplement the Lek flow. Additional extraction from the Waal at Tiel occurs if the Merwedekanaal capacity is insufficient to generate the minimum Lek flow.

3.1.3. Use of the Haringvliet Sluices

The Haringvliet sluices are used to discharge water from the Haringvliet into the North Sea. Closure of the sluices takes place under either of two conditions: (1) when the areas along the Haringvliet and farther eastward must be protected against flooding due to storm surges on the North Sea (a lower than natural level will then result on the Haringvliet); (2) when the total outflow through the Haringvliet sluices and the Rotterdamse Waterweg is less than 1500 m^3/s. In the latter case, a minimum flow of 5 m^3/s is maintained through the sluices, leading to a higher than natural level on the Haringvliet and an increased flow on the Rotterdamse Waterweg. This is the only condition that is relevant in our analysis, since the Distribution Model sees the North Sea only as a depository for the water from the various waterways that terminate along the Dutch coast. Under the low flow condition, the rule used in the Distribution Model closes the sluices enough to establish a flow through the Rotterdamse Waterweg of precisely 1500 m^3/s: This flow rate will not be exceeded, and a flow less than 1500 m^3/s on the Waterweg will occur only when the flow on the Rijn is so low that complete closure of the sluices is not able to produce the target flow on the Rotterdamse Waterweg.

3.1.4. Levels of IJsselmeer, Markermeer, and Border Lakes[2]

The management rules for the IJsselmeer, Markermeer, and border lakes depend upon three critical levels for each lake that vary over the year:

- Target level
- Emergency level for flushing
- Emergency level for sprinkling

In addition, minimum levels have been defined for the lakes. When a lake reaches its target level, any overflow is discharged to the North Sea via the Afsluitdijk and the Noordzeekanaal, or to the other lakes, subject to capacity constraints. When a lake falls below its emergency level for flushing, extractions from the lake for flushing of polders and boezems, for salinity control at salt-fresh locks, and for cooling water at power plants are reduced to minimum levels or low enough that the emergency level can be reestablished. If a lake drops below its emergency level for sprinkling, the extraction demands for sprinkling are also cut back, until the emergency level is reestablished or until water supplied for sprinkling has been reduced to zero. When a lake drops below its minimum level, no further action is taken.

Table 3.1 gives the critical levels for the lakes that were used in the analysis. When we were analyzing tactics for increasing the storage capacity of the lakes by either raising their summer target levels or decreasing their minimum levels, the emergency levels for sprinkling and the minimum levels of all lakes in decades 10-30 were decreased to NAP - 50 cm.

Table 3.1

IJSSELMEER LAKE CRITICAL LEVELS
(cm relative to NAP)

Decades	Critical Level	IJsselmeer	Markermeer, Gooimeer, IJmeer	Veluwemeer
1-9	Target	-40	-40	-30
	Emerg/fl.	-40	-40	-30
	Emerg/sp.	-40	-40	-30
	Minimum	-40	-40	-30
10-12	Target	-20	-25	-10
	Emerg/fl.	-36	-36	-28
	Emerg/sp.	-38	-38	-28
	Minimum	-40	-40	-40
13-27	Target	-20	-25	-10
	Emerg/fl.	-30	-30	-30
	Emerg/sp.	-38	-38	-28
	Minimum	-40	-40	-40
28-30	Target	-20	-25	-10
	Emerg/fl.	-36	-36	-28
	Emerg/sp.	-38	-38	-28
	Minimum	-40	-40	-40
31-36	Target	-40	-40	-30
	Emerg/fl.	-40	-40	-30
	Emerg/sp.	-40	-40	-30
	Minimum	-40	-40	-30

When the net inflow into the lakes is insufficient for all lakes to reach their target level, but sufficient to bring the lakes to their emergency levels for flushing, two actions are taken:

- The level of the Veluwemeer is raised to bring it as close as possible to its target level.

- Any remaining positive net inflow is then used to raise the levels of the other lakes in such a way that they are either brought to their target levels or to 1 cm below the level of the IJsselmeer, whichever is lower.

When the net inflow into the lakes is insufficient for the lakes to reach their emergency level for flushing, even after accounting for the cutbacks in extractions as described above, the net inflow is distributed among the lakes in such a way that all lakes are raised to the same level.

3.1.5. Flushing of the Markermeer

Typically, the IJsselmeer is less saline than the Markermeer, and the Markermeer is less saline than the Noordzeekanaal. Since a number of districts extract water for sprinkling crops from the Markermeer, an attempt is made to reduce its salinity by flushing it with large amounts of IJsselmeer water. Water from the Markermeer then passes through the IJmeer and the Noordzeekanaal. Thus, salinity is reduced all along the discharge route. The flow also provides water for flushing the canals in Amsterdam, and provides cooling water for the Hemweg power plant at Amsterdam and the Velsen power plant at IJmuiden along the Noordzeekanaal.

Under the current flushing rules, a minimum of 10 m^3/s is extracted from the IJmeer by the Zeeburg pumping station to flush the canals of Amsterdam. In addition, whenever the IJsselmeer is less saline than the Markermeer and the lakes are above their emergency level for flushing, additional water is extracted from the IJsselmeer through the Houtribsluizen and the Krabbegatsluizen and sent through the Oranjesluizen to the Noordzeekanaal in order to reduce the salinity of the Markermeer. The desired additional amount at the Oranjesluizen is 20 m^3/s in the winter half-year (October-March) and 60 m^3/s in the summer half-year. Less than the desired amount is flushed only if, by flushing more, the lakes would fall below their emergency level for flushing.

In an early stage of our analysis, we found that there are some serious problems with these flushing rules. In dry years, flushing early in the summer when the inflow into the lakes is insufficient to retain the target levels leads to cutbacks in extractions from the lakes later in the summer, causing considerable agriculture shortage losses. An analysis of these flushing rules is presented in Sec. 11.2. We decided to perform the screening analysis with a slightly modified set of flushing rules that did not lead to such high agriculture shortage losses. The rules are the same as the current rules except that more than 10 m^3/s are flushed only when the lakes are at their target levels. An evaluation of the modified rules is also contained in Sec. 11.2.

3.1.6. Cutbacks in Extractions from the National Distribution System

During dry periods there are times when there is insufficient surface water available at appropriate locations in the national system to satisfy all demands generated within the regional systems. Consequently, managerial rules are needed to distribute this shortage over the various uses of water within the affected regions. First, we reduce the amount of surface water used to flush the boezems and waterways in the regional systems and to cool power plants by cutting flows from their desired rate to a minimum rate. If the resulting demand for surface water in a region still exceeds the available supply, the use of surface water for open-air sprinkling is reduced, and, if necessary, eliminated. The version of the Distribution Model that we used does not allow for further reduction of the extraction demands. In reality, if the reduced demands still exceed the available supply, there is no choice but to allow the surface water levels in the districts to fall below their target levels.

The above description represents the general pattern of demand reduction in view of limited surface water availability. The specific rules applied to the flushing of boezems and for cutting back on the flows past power plants are given in Vol. XI. In the following subsections we describe the rules used for cutting back the flushing of waterways and surface water sprinkling in the various regions.

3.2. THE NORTH

The cutback rules applied in the North are all related to the availability of water in the IJsselmeer. When its level falls below the emergency level for flushing,[3] the extractions from the lake for cooling the power plants at Bergum and Groningen and for flushing boezems in Groningen and Friesland are reduced or eliminated. In addition, extractions for flushing the salt-fresh locks in the North are reduced from their target rates to the minimum rates shown in Table 3.2, or reduced proportionally until the emergency level for flushing has been reestablished.

Table 3.2

FLUSHING RATES AT SALT-FRESH LOCKS IN THE NORTH

Location	Flushing Rate (m^3/s) Target	Flushing Rate (m^3/s) Minimum
Van Harinxmakanaal (Harlingen)	8.0	2.0
Eemskanaal (Delfzijl)	2.0	1.0
Westerwoldse A (Nieuwe Statenzijl)	0.5	0.5

When the IJsselmeer drops below the emergency level for sprinkling,[3] the extraction demands for sprinkling are eliminated or cut back until the emergency level is reestablished.

The cutbacks in the assignment of surface water to canals (for flushing) and to districts (for sprinkling) occur proportionally. However, it should be noted that the capacity of the Van Starkenborghkanaal at Gaarkeuken is sometimes too small to satisfy the demands for surface water in Groningen, which forces reductions in flushing and sprinkling rates in that province in addition to those dictated by the cutback policy described above. The cutbacks in Groningen are therefore occasionally higher than those in Friesland. Similar cutbacks due to capacity constraints rather than managerial rules occur in all regions, but are not discussed any further here.

3.3. THE NORTHEAST HIGHLANDS

The only managerial cutbacks in the Northeast Highlands affect open-air sprinkling under conditions of limited availability of water in the IJsselmeer. There is no boezem flushing to be cut back since there are no boezems in the region, and no flushing of regional waterways takes place in this region because it does not border the North Sea or the Waddenzee.

During dry periods, when rainfall and the flows from rivers passing through the region are not able to satisfy the region's demand for surface water, the Northeast Highlands obtains additional water from two sources: the IJssel River and the IJsselmeer. The IJssel River is the source for Twenthe, Salland, and some areas in northern Overijssel, while South and Central Drenthe are supplied mainly from the IJsselmeer. For the purpose of the formulation of the management policies, the IJssel River and the IJsselmeer are considered a single source of water, since the IJsselmeer receives practically all its water from the IJssel River during dry periods. Thus, as far as the overall availability of surface water for the region is concerned, it does not make any difference whether water is extracted from the river or the lake.

The cutback rules for open-air sprinkling are basically the same as those described above for the North. When the IJsselmeer drops below its emergency level for sprinkling, the demands for extractions from the IJssel River and IJsselmeer for sprinkling are eliminated or cut back until the emergency level of the lake is reestablished. The cutbacks are applied proportionally to all districts in the region. Of course, the limited supply capacities of the supply routes from the IJssel and the IJsselmeer can also lead to sprinkling cutbacks. These cutbacks will differ from district to district, depending on the waterway(s) used to supply the district.

3.4. NORTH HOLLAND

The managerial rules for North Holland involve cutbacks in both flushing and sprinkling, in response to limited availability of water in the IJsselmeer and the Markermeer. When the Markermeer level falls below the emergency level for flushing, extractions for boezem flushing are reduced or eliminated. In addition, the extraction for flushing the salt-fresh lock at Den Helder is reduced from its target rate to the minimum rate indicated in Table 3.3, or proportionally until the emergency level for flushing has been reestablished.

Table 3.3

FLUSHING OF SALT-FRESH LOCK IN NORTH HOLLAND

	Flushing Rate (m^3/s)	
Location	Target	Minimum
Noordhollandsch Kanaal (Den Helder)	4.0	2.0

When the IJsselmeer and the Markermeer drop below the emergency level for sprinkling, the extraction demands for open-air sprinkling are eliminated or cut back proportionally until the emergency level is reestablished.

3.5. MIDWEST AND UTRECHT

The management rules for this region involve modifications of the route for supplying surface water to the region and cutbacks in the supply of fresh water to the midwestern part of the region under conditions when use of the primary supply route (the Hollandsche IJssel) is unattractive. (This is the case when the Hollandsche IJssel contains very saline water due to salt intrusion from the North Sea along the Rotterdamse Waterweg and the Nieuwe Maas.) The cause and extent of the salt intrusion problem are described in more detail in Sec. 8.1. In this section, we will limit ourselves to a description of the management rules that are followed whenever the Hollandsche IJssel is "salted up."

When this condition occurs, the water managers in the region attempt to keep the highly saline water out of the boezems of the western part of the region (Rijnland, Delfland, Schieland) by replacing the Hollandsche IJssel as the main supply route with a number of "emergency supply facilities." These facilities are inlet points for the region, located along the Lek and the Amsterdam-Rijnkanaal, together with the waterways that connect them with the boezems in the western part of the region. The connecting waterways are small and contain a number of sections with very low throughput capacities. Under normal conditions, they are used for local water supply only.

The emergency supply routes are shown in Fig. 8.3. The total extraction capacity at the various inlet points is about 25 m^3/s. Due to throughput capacity limitations and extractions into the areas of the Vecht, the Lopikerwaard, and Woerden, the net supply capacity to Rijnland is about 10 m^3/s.

The emergency supply facilities are used whenever the salt wedge from the Rotterdamse Waterweg reaches the inlet point for the Midwest at Gouda. In the Distribution Model we have used the magnitude of the difference between the salinity of the lower part of the Lek and the salinity at Gouda to trigger the use of the emergency facilities.[4] Our managerial rule was to use the emergency facilities whenever this difference was greater than 50 ppm.

The need for use of the alternative supply routes occurs generally only during very dry periods; under these conditions the demand for surface water in the Midwest may exceed the net supply capacity of 10 m^3/s. When this is the case, the demands for boezem flushing are reduced or eliminated, and flushing of the waterways is reduced from the target rates to minimum rates as indicated in Table 3.4.

Table 3.4

FLUSHING OF WATERWAYS IN MIDWEST
AND UTRECHT

Location	Flushing Rate (m^3/s) Target	Minimum
Halfweg and Spaarndam	5.0	3.0
Katwijk	3.0	1.0
Scheveningen	0.4	0.4
Rotterdam and Maassluis	5.6	4.0

If, after the flushing reductions, the demands for extractions into the Midwest still exceed the net supply capacity provided by the emergency facilities, the shortfall is met by extracting from the (saline) Hollandsche IJssel. Cutbacks in open-air sprinkling were considered too difficult to implement in this region, given the ample (albeit saline) supply of surface water.

In addition to capacity constraints in the emergency supply facilities, an important capacity limitation applies to the Rijn-Schiekanaal, the main supply route to Delfland. The limited capacity of the pumping station at Leidschendam, located along this canal, sometimes forces cutbacks in flushing at Parksluis and Maassluis and, if the demands in Delfland are high, cutbacks in open-air sprinkling in Delfland.

3.6. WEST BRABANT AND SOUTHERN DELTA

In Sec. 2.2.3 we outlined the changes in the water management infrastructure that are being carried out in this part of the Netherlands. On the basis of these prospective changes, we have assumed, for the purpose of our analysis, that the Zoommeer is a freshwater lake, enclosed by the Volkerakdam on the north, the Grevelingendam and the Philipsdam on the west, and the Oesterdam on the south (see Fig. 2.4). We have further assumed the presence of a canal between the southern section of the Zoommeer and the Westerschelde, to be used to flush the Zoommeer.

Both the level and the flushing rate of the fresh Zoommeer are dependent on managerial rules. The rules we have used are designed to reduce extractions through the Volkerakdam into the Zoommeer (and thereby increase the flow through the Rotterdamse Waterweg) whenever the salt wedge in the Rotterdamse Waterweg is about to penetrate into the Hollandsche IJssel and reach Gouda. The rules prescribe that if the target extraction for flushing the Zoommeer (50 m^3/s) would cause the Gouda salinity criterion to be exceeded, the flushing rate is reduced to 25 m^3/s, and other extractions from the Haringvliet are limited to (1) providing for extractions from the Zoommeer to supply the surrounding areas, and (2) maintaining a (minimum) level of NAP - 1 m rather than a (target) level of NAP in the Zoommeer.

3.7. THE SOUTHEAST HIGHLANDS

The distribution of surface water in the Southeast Highlands is governed by a number of managerial rules. Near Maastricht, a short distance from where the Maas enters the Netherlands, the flow of this river is distributed among (1) the Julianakanaal, (2) the continuation of the river itself along the border between the Netherlands and Belgium (this section of the river is also known as the Grensmaas or "border" Maas), and (3) the Zuid-Willemsvaart (see Fig. 2.3). The extraction into the Zuid-Willemsvaart is governed by a treaty with Belgium; some details about the provisions of this treaty are given in Sec. 10.1.

In our analysis we have used a managerial rule that distributes the water from the Maas at Maastricht according to the following priority schedule. The first 13 m^3/s of water is sent down the Zuid-Willemsvaart. Of this, 2 m^3/s returns to the Netherlands at Lozen, to satisfy the demands in the area that depends on the Zuid-Willemsvaart and the connecting canals (the Wessem-Nederweertkanaal, the Noordervaart, and the Wilhelminakanaal) for its water supply. Any additional flow in the Maas is first used to secure the minimum level on the southern section of the Julianakanaal, and the minimum flow on the Grensmaas and the Julianakanaal, in that priority order. On the Grensmaas, the minimum flow is set at 1 m^3/s; it serves to maintain a minimum standard of water quality on that river. The minimum flow on the Julianakanaal is 4 m^3/s. This flow, together with the 5-m^3/s pumping capacity at Maasbracht and the 13-m^3/s capacity at Born, provides a flow of 9 m^3/s through the locks, which is the lowest flow that will enable ships in the canal to keep moving. Any lower flow will lead to an increasing backlog of ships needing to be locked through. Table 3.5 gives the minimum flows on the Julianakanaal and the Grensmaas.

Table 3.5

TARGET AND MINIMUM FLOWS ON THE JULIANAKANAAL AND THE GRENSMAAS (m^3/s)

	Julianakanaal	Grensmaas
Target flow	22	10
Minimum flow	4	1

After the minimum flows on the three waterways are secured, any remaining Maas flow is divided among the Julianakanaal, the Zuid-Willemsvaart, and the Grensmaas in a 2:4:1 ratio until the Zuid-Willemsvaart reaches its desired flow rate. If there is still a remaining flow on the Maas to be allocated, it is allocated to the Julianakanaal and the Grensmaas in a 2:1 ratio until the flow on the Julianakanaal reaches its target value, after which any remaining Maas flow is sent down the Grensmaas.

A target level, an emergency level, and a minimum level have been defined for each of the weir ponds in the canalized portion of the Maas and on the Julianakanaal. Under conditions of low flows on the Maas, maintaining the minimum flow on the Julianakanaal receives first priority, even if the levels in the weir ponds must be lowered to their minimum. Any additional water is then used to increase the levels in the sections to their emergency level, and then to their target levels. After that, the flows on the Julianakanaal and the Grensmaas are allowed to exceed their minimum values. Table 3.6 shows the various critical levels on sections of the Maas and Julianakanaal.

Table 3.6

CRITICAL LEVELS ON MAAS AND JULIANAKANAAL

	Levels (cm above NAP)		
Section	Minimum	Emergency	Target
Above Born and Borgharen	4320	4370	4400
Born-Maasbracht	3145	3195	3265
Maasbracht-Linne	1960	2010	2090
Linne-Roermond	1625	1675	1675
Roermond-Belfeld	1350	1400	1400
Belfeld-Sambeek	1005	1055	1075
Sambeek-Grave	680	730	750
Grave-Lith	380	430	460

Finally, various managerial rules determine the way in which central and eastern Noord-Brabant and northern Limburg are supplied with surface water, and how cutbacks in supply are effected if supply capacity limitations apply or insufficient water is available in the Maas. Surface water for this area is primarily supplied through the Zuid-Willemsvaart, i.e., by way of Belgium. When this route is transporting the maximum amount possible, or when the Maas flow at Maastricht is too low, the additional supply capacity at Panheel, in the form of the pumping station at the Wessem-Nederweertkanaal, is used. In this case, water-saving measures are taken at the Panheel lock, reducing the lock loss from 2 m^3/s to 1 m^3/s. If the resulting supply rate is still insufficient to satisfy the demand, three demand-reducing measures are taken in the following order. First, flushing is eliminated in the districts depending on the Zuid-Willemsvaart. Then, locking operations are curtailed, reducing the lock losses from target rates to minimum rates. If a supply shortfall persists after these two measures have been instituted, open-air sprinkling in the region is cut back or eliminated.

NOTES

1. The weir is never fully closed: a minimum flow of 25 m^3/s is always maintained on the Neder-Rijn for water quality reasons.
2. This section provides an overview of the management rules for lake levels. A more detailed description is given in Vol. XI.
3. See Sec. 3.1.4.
4. We refer to this difference as the <u>Gouda-salinity criterion</u>.

Chapter 4

PRE-SCREENING OF TACTICS

4.1. WATERBOARD PLANS

4.1.1. Overview

Total surface water demand in the Netherlands is closely linked to the demand by agriculture for water. For example, Table 1.1 shows that agricultural uses accounted for over 80 percent of the surface water used in the country in 1976. This demand arises directly, as water is withdrawn for sprinkling, and indirectly, as water infiltrates from canals and ditches into the soil, where it may become available to agriculture. Both direct and indirect demand can result in a demand on the national surface water system only if the agricultural area under consideration has a local surface water system that can be supplied from the national system. Hence, to determine agricultural water demand from the surface water system in the present and future situations for use in the screening analysis, two key questions must be answered:

1. To what extent can various agricultural areas be supplied with surface water (what is the extent of the local surface water systems that can be supplied from the national system)?
2. What parts of the areas that can be supplied will have sprinkler equipment installed (i.e., what is the *sprinkler intensity* in the various areas)?

There are a number of plans to expand or improve surface water supply possibilities in the Netherlands. These have been drawn up by the various *waterboards* throughout the country. Waterboards are governmental bodies that are responsible for local water management. There are about two hundred waterboards in the Netherlands, and many of them have made plans to improve the water supply situation in their areas. Based on a survey carried out by the country's Union of Waterboards, an inventory of 65 such plans was made [4.1]. A list of these plans is given in Table B.1 of App. B.

The following sections of this chapter describe how these 65 waterboard plans were pre-screened in order to determine a subset of promising waterboard plans. The objective of the pre-screening process was to eliminate from further consideration in the screening analysis those plans that were unlikely to be implemented based on a comparison of costs and (potential) benefits. The plans that are actually implemented increase the area that is eligible for surface water sprinkling, which is one of the components of the sprinkler scenario (see Sec. 2.2.1). The other component is the sprinkler intensity by crop and location. Assumptions about sprinkler intensities also play a major role in the pre-screening of the waterboard plans. A description of the waterboard plan data that were collected and the way they were processed to make them useful for pre-screening is given in App. B.

4.1.2. Steps in the Pre-screening Process

At first glance it would appear that the methodology to be used in the screening of tactics can also be applied to the screening of waterboard plans--a cost/benefit analysis of each plan, using the Distribution Model and the various supply and demand scenarios. Operationally, however, such an approach was deemed to be prohibitively expensive. Pre-screening, then, was designed as a relatively inexpensive first pass through the waterboard plan data. Its results would yield a set of unpromising plans which could be rejected outright, while a final judgment on the remaining plans would be withheld until a more accurate assessment of their worth could be made in the regular screening process.

For each plan, pre-screening strived to answer the same question as was being asked in the screening of tactics: Over the long term, would the sprinkling enabled by the plan's implementation be expected to reduce crop losses enough to offset the cost of the plan and the fixed and variable costs of the new sprinkling equipment? If it would not, the plan would be rejected; otherwise it would be tentatively identified as being promising.

The expected annual benefits from implementation of a waterboard plan are, therefore, the difference between the net benefits from the increase in sprinkling made possible by the plan and the annualized investment cost of the plan. Roughly, then, pre-screening of a waterboard plan involves carrying out the following computation:

$$\text{PLAN.BEN} = \text{SPR.BEN} - \text{PLAN.COST},$$

where PLAN.BEN = the expected annual net plan benefits,
SPR.BEN = the expected annual net benefits from sprinkling resulting from the plan, and
PLAN.COST = the annualized fixed cost of the plan.

If PLAN.BEN is negative, then the plan is rejected.

<u>4.1.2.1. Calculation of SPR.BEN</u>. The calculation of the expected annual net benefits from sprinkling resulting from implementation of a waterboard plan (SPR.BEN) involves estimating the expected annual reduction in crop losses and deducting the costs of sprinkling (both variable and fixed). The key factor in determining both the reduction

in losses and the sprinkling costs is the extent of sprinkling in the area made eligible by the plan, that is, the proportion of the newly eligible area in which farmers actually install sprinkler equipment. This proportion is called the sprinkler intensity.[1] The sprinkler intensity affects the per-hectare benefits from sprinkling in the newly eligible area in two ways: directly, by determining the portion of the area that is sprinkled due to the implementation of the plan, and indirectly, through economies of scale that reduce the per-hectare cost of sprinkling when high sprinkler intensities occur. Both of these effects are reflected in the computation of SPR.BEN.

Several different sets of sprinkler intensities were used in PAWN (their development is described in Vol. XIV). It was decided that in pre-screening the SPRHI intensities should be used, i.e., a high level of sprinkling that farmers might optimistically be anticipated to reach in the future. Their use ensures that the estimate of benefits for a plan represents an upper bound on the expected annual benefits, which is consistent with our aim of rejecting only those plans that are clearly unpromising.

Generally, there is a mix of crops in the area made eligible by a waterboard plan. Sprinkling produces different benefits for different crops. SPR.BEN is, therefore, obtained by summing the benefits over all crops in the plan area (the area made eligible by the plan). In order to facilitate this calculation, the plan area for each plan was allocated among the subdistricts affected by the plan.[2] The fraction of the area of each subdistrict that was made eligible by the plan was calculated and tabulated (see App. B). For a given subdistrict, the benefits to each crop that would be obtained by implementing the plan are estimated using the following expression:

$$\text{CROP.BEN} = \text{PERHA.BEN} * \text{ELIG.FRAC} * \text{CROP.AREA} * \text{SPR.INTENS},$$

where CROP.BEN = the expected annual net benefits from sprinkling the crop, made possible by the plan in the subdistrict,
PERHA.BEN = the expected annual net benefits from sprinkling one hectare of the crop in the subdistrict,
ELIG.FRAC = the fraction of the crop area in the subdistrict made eligible by the plan,
CROP.AREA = the total cultivated area for the crop in the subdistrict,
SPR.INTENS = the sprinkler intensity for the crop in the subdistrict (i.e., the fraction of the eligible area on which sprinkling equipment is actually installed).

Calculating CROP.BEN for all crops in all subdistricts in a plan area, and summing the results, produces SPR.BEN for that waterboard plan.[3]

In the above equation, CROP.AREA is a data element in the data base for our agricultural models. The determination of ELIG.FRAC is described in App. B of this volume. SPR.INTENS was calculated for the SPRHI scenario from an analysis that determined the level to which farmers should sprinkle their crops to maximize their expected net benefits. This analysis is described in detail in Vol. XIV.

The expected annual net benefits from sprinkling a crop in a subdistrict (PERHA.BEN) is obtained as a by-product of the sprinkler intensity analysis. Its calculation involves estimating on a per-hectare basis the expected annual reduction in crop losses, and subtracting the expected annual operating cost and annualized fixed cost of sprinkling the crop. This calculation can be expressed as:

$$\text{PERHA.BEN} = \text{CROP.LOSRED} - (\text{VAR.SPRCST} + \text{FIX.SPRCST}),$$

where CROP.LOSRED = the expected annual reduction in crop losses per hectare,
VAR.SPRCST = the expected annual operating cost of sprinkling the crop per hectare,
FIX.SPRCST = the annualized fixed cost of sprinkling the crop per hectare.

CROP.LOSRED and VAR.SPRCST were determined by using an agricultural model known as the Demand Generator (described in Vol. XII) to estimate the crop losses in each subdistrict both with sprinkling and without. By comparing the two results for a given crop in a given year, one can obtain the reduction in crop losses that would result from sprinkling and the amount of sprinkling necessary to bring about this reduction. Ideally we would have liked to compute the expected annual reduction in losses and the expected annual sprinkling cost by averaging the losses and costs for many different years. However, this approach would have been extremely expensive. Instead, on the basis of a sample of representative crop areas, we derived regression formulas that enabled us to compute the expected values based on the results for only four years. By running the Demand Generator for all crop areas in these four years and then applying the regression formulas, we obtained for each crop/subdistrict combination an estimate of the expected annual reduction in crop losses (CROP.LOSRED) and the expected amount of sprinkling that would produce this reduction. Expected annual sprinkling amounts were then translated into expected annual sprinkler operating cost (VAR.SPRCST) using cost parameters supplied by the sprinkling cost analysis (discussed in Vol. XIII). The annualized fixed cost of sprinkling (FIX.SPRCST) is also obtained from the sprinkling cost analysis. A complete description of the procedure that was used to obtain PERHA.BEN is contained in Vol. XIV.

It should be remarked that this procedure tends to overestimate the computed benefits from sprinkling, because the Demand Generator assumes that there are no constraints on the water supplied from the national system for sprinkling, and that there are no internal capacity constraints within districts and subdistricts.

4.1.2.2. Calculation of PLAN.COST. The final item we need in order to calculate the expected annual net benefits of a plan (PLAN.BEN) is the annualized fixed cost of the plan (PLAN.COST). We assumed that the annualized fixed cost was 10 percent of the total investment cost of the plan. The investment costs, which were obtained from the waterboard survey, are discussed in App. B.

4.1.3. Results

The calculations described above were applied to each of the 65 waterboard plans identified in the waterboard survey. Tables 4.1 and 4.2 present the results of this pre-screening analysis. Nineteen of

Table 4.1

COSTS AND BENEFITS (1000s OF Dfl) OF
REJECTED WATERBOARD PLANS

Region	Plan ID(a)	Expected Annual Benefits (SPR.BEN)	Annualized Investment Cost (PLAN.COST)	Net Annual Benefits (PLAN.BEN)	Benefit/ Cost Ratio
1	5	523	1400	-877	0.4
	6	45	190	-145	0.2
	7	85	90	-5	0.9
	12	739	3000	-2261	0.2
	20	485	568	-83	0.9
	29	0	50	-50	0.0
	31	223	500	-277	0.4
	71	272	450	-178	0.6
2	25	121	500	-379	0.2
	26	85	188	-103	0.5
	27	467	2500	-2033	0.2
	35	1574	1660	-86	0.9
	38	1520	2500	-980	0.6
	39	1902	2750	-848	0.7
	40	843	1250	-407	0.7
3	41	1	47	-46	0.0
	42	45	2000	-1955	0.0
	44	58	246	-188	0.2
4	46	0	180	-180	0.0

(a) Appendix B contains a complete description of each of the waterboard plans and a map that shows their general locations.

Table 4.2

COSTS AND BENEFITS (1000S OF Dfl) OF PROMISING WATERBOARD PLANS

Region	Plan ID(a)	Expected Annual Benefits (SPR.BEN)	Annualized Investment Cost (PLAN.COST)	Net Annual Benefits (PLAN.BEN)	Benefit/ Cost Ratio
1	1	283	200	83	1.4
	2	1073	800	273	1.3
	3	68	17	51	4.0
	4	39	30	9	1.3
	8/9	1867	1000	867	1.9
	10/11	868	500	368	1.7
	17	67	56	11	1.2
	18(b)	365	169	196	2.2
	19	496	192	304	2.6
	28(b)	638	478	160	1.3
	30	84	80	4	1.1
	72	7111	370	6741	19.2
	74	176	42	134	4.2
	Total	13135	3934	9201	3.3
2	13	14	12	2	1.2
	14	478	155	323	3.1
	15	322	151	171	2.1
	16	251	118	133	2.1
	21	186	88	98	2.1
	22/23	211	175	36	1.2
	24	628	350	278	1.8
	32	1129	340	789	3.3
	33/34	715	500	215	1.4
	36	195	30	165	6.5
	37	1032	110	922	9.4
	70	170	20	150	8.5
	Total	5331	2049	3282	2.6
3	43	23	3	20	7.7
	45	48	5	43	9.6
	73	1818	247	1571	7.4
	Total	1889	255	1634	7.4
5	47	941	75	866	12.5
6	48(b)	1269	250	1019	5.1
7	49	1228	300	928	4.1
	50	1329	400	929	3.3
	51	919	600	319	1.5
	52	3118	2900	218	1.1
	53(b)	1185	168	1017	7.1
	54/55	13319	3000	10319	4.4

Table 4.2 (continued)

Region	Plan ID(a)	Expected Annual Benefits (SPR.BEN)	Annualized Investment Cost (PLAN.COST)	Net Annual Benefits (PLAN.BEN)	Benefit/ Cost Ratio
	56	1441	324	1117	4.4
	57	1149	333	816	3.5
	Total	23688	8025	15663	3.0
8	58	2501	648	1853	3.9
	59	2047	560	1487	3.7
	60-63	4128	3324	804	1.2
	64	2923	574	2349	5.1
	65	1021	362	659	2.8
	66	3287	987	2300	3.3
	67/68	3089	500	2589	6.2
	69	2567	425	2142	6.0
	Total	21563	7380	14183	2.9
Nation		67816	21968	45848	3.1

(a) Appendix B contains a complete description of each of the waterboard plans and a map that shows their general locations.

(b) These waterboard plans affect areas in more than one region. In this table they have been assigned to the region they affect the most.

the plans were screened out (see Table 4.1 and Fig. B.1). Among the plans screened out were the only plan proposed for Region 4 (North Holland) and, with one exception, all plans in Regions 1, 2, 3, and 4 (the northern half of the country) that had annualized investment costs of 10 Dflm or more. In a number of cases in which a waterboard plan was rejected, we predicted that implementation of the plan would result in little or no increase in sprinkling in the newly eligible area. In these cases the expected annual net benefits were very small (see, for example, plans 29, 41, and 46 in Table 4.1). In other cases, the plans produced substantial reductions in crop losses, but the reductions were not large enough to offset the cost of the plans. In three cases (plans 7, 20, and 35) the benefits were only slightly below the costs.

A total of 46 waterboard plans were screened in (see Table 4.2 and Fig. B.1), including all 18 plans in Regions 5, 6, 7, and 8 (the southern half of the country). In Region 7 the promising plans supply water from a fresh Grevelingen (Plan 49) and Zoommeer (all other plans) to agricultural areas around these lakes. The net annual benefits from implementing the promising plans in Regions 7 and 8 are almost 30 Dflm, about twice the expected annual benefits from the promising plans in all the other regions combined.

There is considerable variation in the benefit/cost ratio among the promising plans. On the average, their benefit/cost ratio is an attractive 3.1. However, 11 plans have a ratio of under 1.5, while 4 plans have a ratio of over 9.0. The high ratios are most likely due to overestimates of the eligible areas or underestimates of the costs. As explained below, we made these optimistic assumptions in order to be sure that the waterboard plans screened out were truly not worth considering any further.

All of the promising plans except Plan 49 were used in the RALL sprinkler scenario in the remainder of the screening analysis. Plan 49 was used only to evaluate the tactic that would make the Grevelingen a freshwater lake.

4.1.4. Sensitivity Analysis

The purpose of pre-screening the waterboard plans was to reject any proposed plan that was clearly unpromising. This was done by taking a rather optimistic view of the world. When uncertainties arose and assumptions had to be made, we always tried to be conservative, either by overestimating benefits or underestimating costs. We performed some analyses to test the sensitivity of the results to certain of these assumptions.

4.1.4.1. Sensitivity to the Benefit Viewpoint. It could be argued that the waterboard plan benefits should be looked at from the point of view of the farmer and not the nation.[4] This is because it may be the farmers belonging to a waterboard who decide on and pay the complete cost of implementing a waterboard plan. Pre-screening was therefore repeated taking this different benefit viewpoint into account. This was done by:

1. Including tax payments, deductions, and credits when calculating the expected annual benefits from sprinkling.
2. Assuming that farmers could deduct the annualized investment cost of a waterboard plan from their income taxes. (A marginal tax rate of 40 percent was assumed. See Vol. X for a discussion of tax rate assumptions.)

Happily, this change in assumptions did not change the results of the analysis. The same plans were accepted and rejected as in the original analysis.

4.1.4.2. Sensitivity to Plan Cost Estimates. We had some reason to believe that the estimates of the costs of the waterboard plans are low (perhaps underestimated by as much as 50 percent). To investigate the effect of different cost estimates, our pre-screening analysis was repeated with plan costs that were 25 and 100 percent higher than the costs in the original analysis.
Increasing the costs by 25 percent results in screening out four more plans (plans 13, 17, 30, and 52). If plan costs are doubled, ten more plans drop out (those identified as 1, 2, 4, 8/9, 10/11, 24, 28, 33/34, 51, and 60-63). In this case, 32 plans survive and 33 plans are

screened out. This information is summarized in Fig. B.1 in App. B. The results indicate a sizable, but not extreme, sensitivity to the waterboard plan cost estimates.

4.1.5. Benefits from Implementing Promising Plans

The analysis described above, which resulted in the identification of 46 promising waterboard plans, did not consider the limitations imposed on the plan benefits by low river flows, lake levels, or supply capacities. We were interested in determining whether the 46 waterboard plans would still be considered promising if cutbacks due to limited availability of water and/or limited supply capacity were taken into account. We therefore used the Distribution Model to estimate the benefits from implementing the promising waterboard plans under the four supply scenarios, and for the low and high sprinkler intensities. We calculated upper and lower bounds on the expected annual benefits from the waterboard plans, using inequalities similar to those described in Sec. 2.1.1. These calculations were made for the 46 promising plans overall and by region, but not for individual plans.

For each sprinkler intensity, the benefit calculation involved running the Distribution Model eight times: twice for each of the four supply scenarios (once with all of the promising waterboard plans implemented (RALL) and once with none of them implemented (RNONE)). The gross benefit for any given supply scenario is the reduction in shortage losses obtained by implementing the waterboard plans, less the increase in salinity losses that arise from sprinkling the (previously unsprinkled) crops with somewhat saline water. From these gross benefits we then deducted the annualized investment costs for implementation of the waterboard plans and purchase of the sprinkling equipment, and the estimated labor and energy costs of operating it. This produced an estimate of the net benefits for the given supply scenario.

Estimates of the upper and lower bounds on the expected annual net benefits were obtained by applying formulas similar to those of Sec. 2.1.1 to the net benefits from the four external supply scenarios. The formulas of Sec. 2.1.1 were modified slightly to take into account the fact that although the formula for the lower bound on expected annual benefits assumes that no benefits are obtained from the waterboard plans in a year wetter than 1967, the investment costs must be amortized over all years, resulting in negative benefits in a wet year. Thus, letting WET stand for any year wetter than 1967 and letting B(y) be the net benefits obtained in year y from implementing the waterboard plans, the formulas for upper and lower bounds on the expected annual net benefits (EAB) are:

$$\begin{aligned} &.02B(\mathrm{DEX}) + .05B(1959) + .14B(1943) + .42B(1967) + .37B(\mathrm{WET}) \\ &\qquad < \mathrm{EAB} < .07B(\mathrm{DEX}) + .14B(1959) + .42B(1943) + .37B(1967). \end{aligned}$$

Table 4.3 presents the analysis of net benefits for the low sprinkler intensity scenario (SPRLO). Table 4.4 presents the analysis for high

Table 4.3

COSTS AND BENEFITS OF IMPLEMENTING WATERBOARD PLANS: LOW SPRINKLER INTENSITY (Dflm)

						Bounds	
	DEX	1959	1943	1967	WET	Upper	Lower
Benefits:							
Decrease in shortage losses	366.5	285.5	99.6	40.2	0.0		
Increase in salinity losses	11.3	4.6	1.6	(0.2)	0.0		
Gross benefits	355.2	280.9	98.0	40.4	0.0		
Costs:							
Waterboard plans investment costs	21.7	21.7	21.7	21.7	21.7		
Sprinkler investment costs	12.8	12.8	12.8	12.8	12.8		
Labor	15.5	16.0	9.5	5.6	0.0		
Energy	7.2	7.5	4.5	2.6	0.0		
Total costs	57.2	58.0	48.5	42.7	34.5		
Net benefits	298.0	222.9	49.5	(2.3)	(34.5)	72.0	10.3

Table 4.4

COSTS AND BENEFITS OF IMPLEMENTING WATERBOARD PLANS: HIGH SPRINKLER INTENSITY (Dflm)

						Bounds	
	DEX	1959	1943	1967	WET	Upper	Lower
Benefits:							
Decrease in shortage losses	699.2	586.3	208.1	95.0	0.0		
Increase in salinity losses	29.7	8.6	3.0	(0.1)	0.0		
Gross benefits	699.5	577.7	205.1	95.1	0.0		
Costs:							
Waterboard plans investment costs	21.7	21.7	21.7	21.7	21.7		
Sprinkler investment costs	40.0	40.0	40.0	40.0	40.0		
Labor	47.2	47.2	31.1	21.6	0.0		
Energy	15.1	15.3	10.1	7.1	0.0		
Total costs	124.0	124.2	102.9	90.4	61.7		
Net benefits	545.5	453.5	102.2	4.7	(61.7)	146.3	27.0

sprinkler intensity (SPRHI). The tables show that, for either scenario, implementation of the promising waterboard plans would produce significant benefits for the country. The benefits increase as the sprinkler intensity increases.

Although, overall, implementation of the 46 promising waterboard plans produces large expected net benefits, the benefits per plan vary from region to region. Table 4.5 shows the net benefits from the waterboard plans by region. It shows that the net benefits per plan for the 18 waterboard plans in Regions 7 and 8 are considerably higher than for the plans in the other regions. There are no waterboard plans for Region 4, and the plans for Regions 5 and 6 appear to be of marginal value.

Table 4.5

UPPER AND LOWER BOUNDS ON EXPECTED ANNUAL NET BENEFITS FROM WATERBOARD PLANS BY REGION (Dflm)

Region	No. of Plans(a)	Low Spr. Intensity UB	Low Spr. Intensity LB	High Spr. Intensity UB	High Spr. Intensity LB
1	13	13.9	2.1	20.7	2.7
2	14	5.8	-0.1	12.2	-0.1
3	3	4.2	1.5	7.0	2.3
4	0	0	0	0	0
5	1	-0.1	-0.1	2.3	0.8
6	1	0.7	0.2	1.6	0.5
7	7	23.4	1.9	53.0	8.8
8	11	24.6	4.9	50.8	12.5

(a) Some waterboard plans affect more than one region. In this table they are included in each region they affect.

4.2. TACTICS AFFECTING THE NATIONAL AND REGIONAL DISTRIBUTION SYSTEMS

Rainfall, stored soil moisture, and infiltration of groundwater and surface water into the root zone of plants are almost sufficient to meet the total needs of agriculture for water in most years. In addition, in most areas the existing water management infrastructure is able to supply sufficient additional water for sprinkling crops so that large crop losses can generally be avoided in drier years. (Our estimates of agriculture shortage losses for the 47 years 1930-1976 indicate that in 80 percent of all years less than 15 percent of the nation's crops would be lost because of water shortages.)

However, in certain parts of the country at certain times, either the water management infrastructure does not have sufficient capacity, or there is insufficient water available nearby to supply the surface water needed to avoid shortage losses. Before proceeding with a detailed evaluation of a large number of technical tactics for reducing shortage losses, we chose to carry out a more macro analysis to identify those regions and scenario assumptions for which the costs of implementing tactics were likely to be more than offset by the expected annual benefits in terms of reduced crop losses.

Our approach was to estimate for each region and set of scenario assumptions the agriculture shortage losses that would occur (1) with the existing water management infrastructure, and (2) if the infrastructure were expanded so that the surface water sprinkling demand could be fully met. (There would still be shortage losses in the latter case, since most cultivated land is not sprinkled; but there would be no shortage losses among sprinkled crops.) The difference between the two estimates of shortage losses would be the maximum amount of losses that the implementation of tactics would be able to prevent. We call this difference the preventable losses for the given region and set of scenario assumptions.

We calculated preventable losses for each region for the four supply scenarios (DEX, 1959, 1943, and 1967) and the four combinations of sprinkler intensity and eligible area (sprinkler scenarios). Figures 4.1-4.4 show how preventable losses vary by geographical area and by sprinkler scenario for the DEX supply scenario. Each figure indicates, for each agricultural district, the percentage that the preventable losses are of the total value of the crops in the district.

For any given sprinkler scenario (e.g., SPRLO-RALL), we used the technique described previously for estimating the upper bound on expected annual benefits (see Sec. 2.1.1) to obtain an upper bound on the expected annual agriculture shortage losses that could be prevented in the region by the implementation of technical tactics. Letting L(y) be the preventable losses in year y, the upper bound on the expected annual preventable losses (UB) is given by

$$UB = .07L(DEX) + .14L(1959) + .42L(1943) + .37L(1967).$$

This upper bound represents the maximum benefits that could be expected to be obtained from any tactics designed to reduce water shortages in the region. If the maximum benefits for a case are small (as is true in many cases), we did not consider tactics for that case any further. Thus, we were able to screen out a large number of potential tactics without evaluating them explicitly.

Table 4.6 presents the maximum benefits by region for each of the four sprinkler scenarios. Two important conclusions can be drawn from the results in this table. First, preventable losses (and hence the potential usefulness of technical tactics) are generally greater with waterboard plans implemented (RALL) than without them (RNONE); and they are greater with a high sprinkler intensity (SPRHI) than with a low intensity (SPRLO). The reason for this is as follows: The presence of preventable losses under the SPRLO-RNONE scenario implies that there are agricultural areas sprinkled with surface water that are unable to get all of the water they need in order to prevent crop

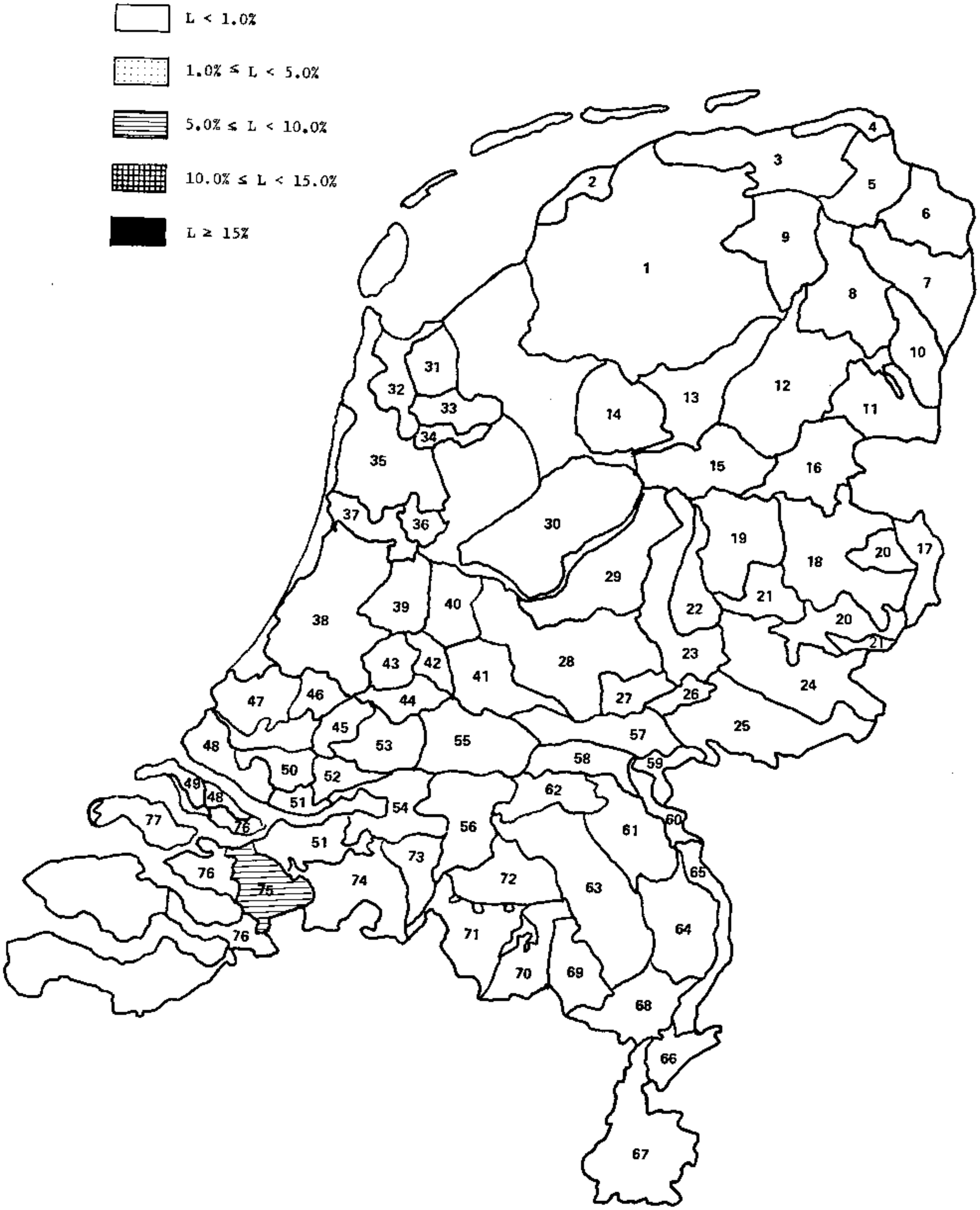


Fig. 4.1--Preventable losses as a percentage of total crop value (SPRLO-RNONE scenario)

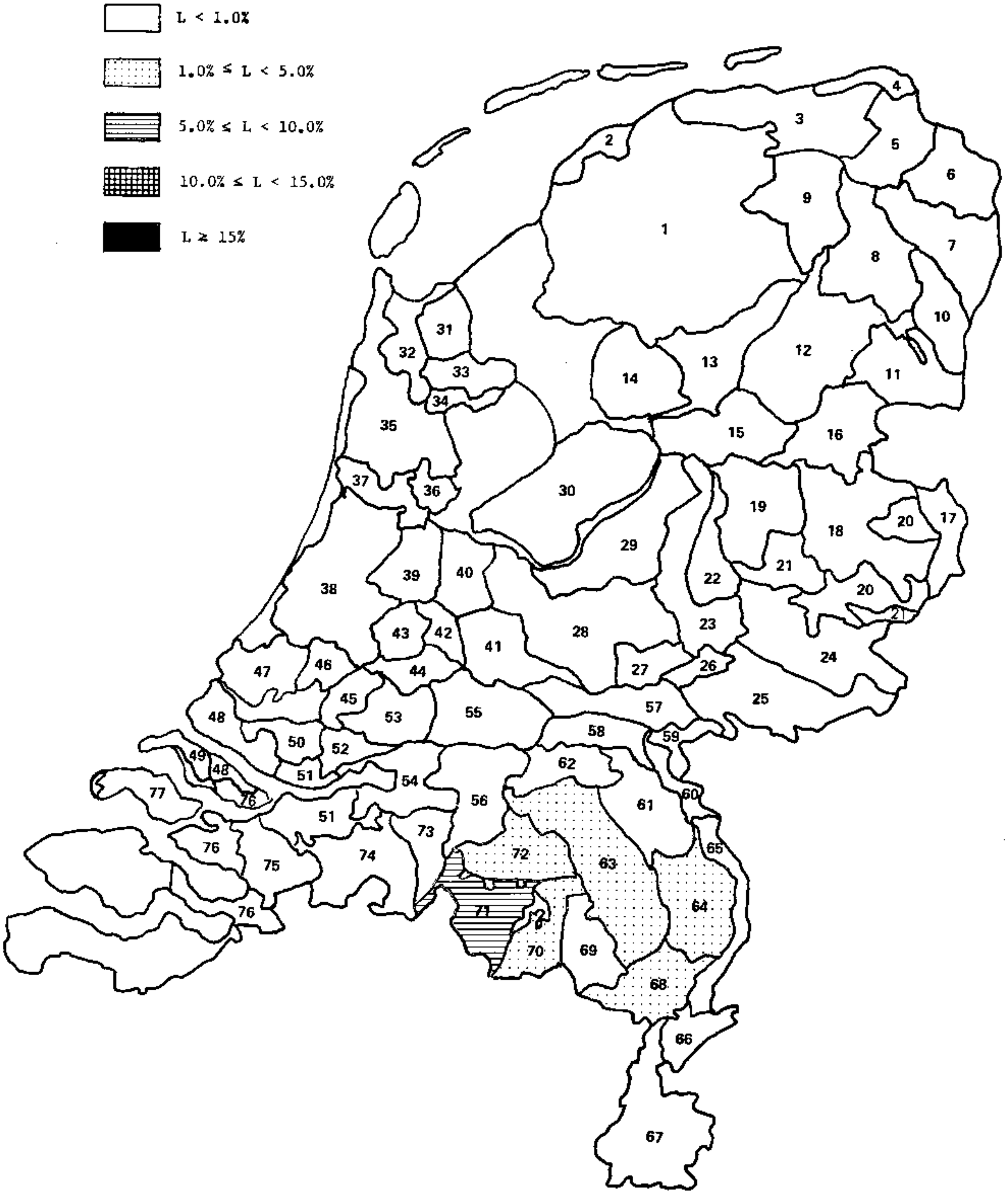


Fig. 4.2--Preventable losses as a percentage of total crop value (SPRLO-RALL scenario)

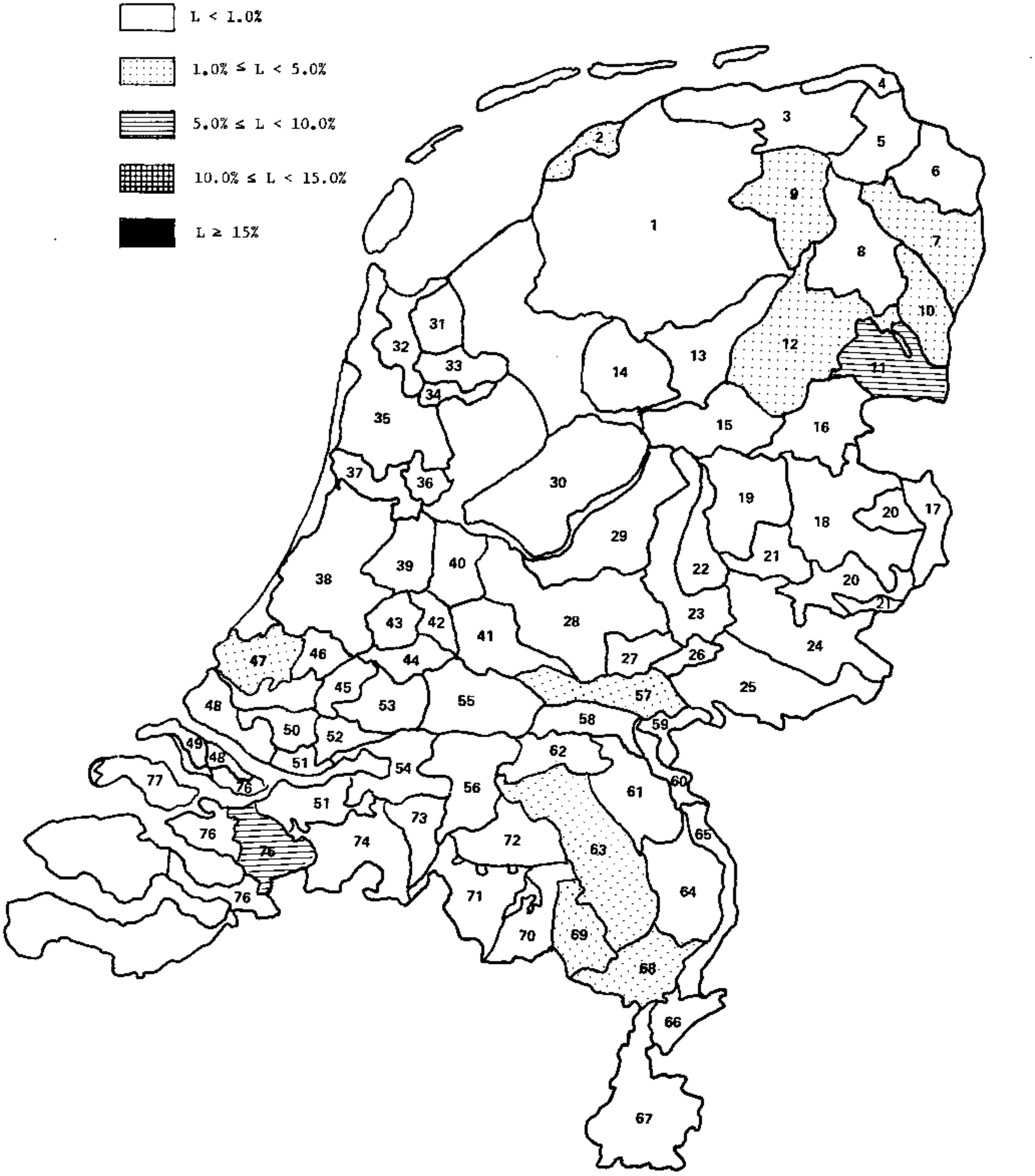


Fig. 4.3--Preventable losses as a percentage of total crop value (SPRHI-RNONE scenario)

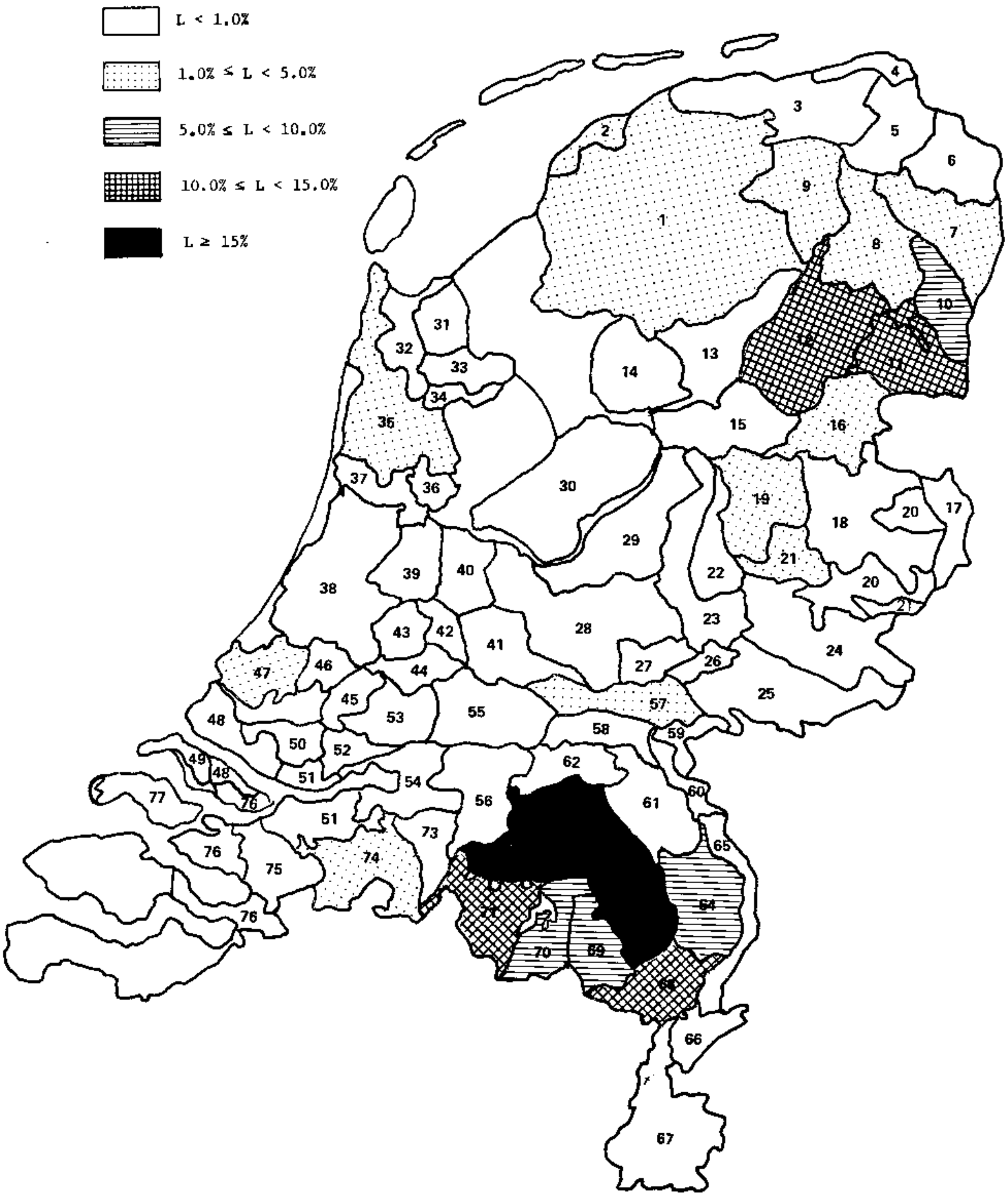


Fig. 4.4--Preventable losses as a percentage of total crop value (SPRHI-RALL scenario)

damage. Increasing the amount of sprinkler equipment in the region (by expanding the eligible area or by increasing the sprinkler intensity) without increasing the supply capacity leads to larger potential benefits from increasing the supply capacity to that area. These potential benefits are what we have called the preventable losses.

In Region 7 the preventable losses decrease with the implementation of waterboard plans. This is due to the fact that the main purpose of the waterboard plans in that region is to create supply capacity to the eligible area from the fresh Zoommeer. Since that supply capacity can be made large enough to supply all the demands for Zoommeer water, preventable losses in the region are reduced to near zero in the RALL cases. (There are still some preventable losses in West Brabant in the SPRHI-RALL case.)

Table 4.6

UPPER BOUND ON EXPECTED ANNUAL PREVENTABLE LOSSES (Dflm)

Region	Low Spr. Intensity Without WB Plans	Low Spr. Intensity With WB Plans	High Spr. Intensity Without WB Plans	High Spr. Intensity With WB Plans
(1) North	0.0	0.0	2.8	7.5
(2) N.E. Highlands	0.2	0.6	6.8	19.9
(3) Flevoland and Veluwe	0.0	0.0	0.0	0.2
(4) North Holland (a)	0.0	0.0	0.4	0.7
(5) Midwest and Utrecht	0.8	0.8	4.2	4.2
(6) Large Rivers and N. Delta	0.0	0.0	0.3	0.3
(7) W. Brabant and S. Delta	1.4	0.0	1.7	0.5
(8) S.E. Highlands	0.5	3.7	2.9	28.1
Total	2.9	5.1	19.1	61.4

(a) Because of some inaccuracies in the Distribution Model related to the extraction of water from the Markermeer, the upper bounds for North Holland are slight underestimates.

The second conclusion to be drawn from Table 4.6 is that, with the exception of Regions 7 and 8, the potential benefits from technical tactics are almost nil under the low sprinkler intensity scenarios. Since the low sprinkler intensity was chosen to correspond roughly to the current level of sprinkling in the Netherlands, this result implies that few if any technical tactics are needed to alleviate agriculture shortage losses in the present situation. In the detailed screening of tactics, we therefore limited our analysis to the high sprinkler intensity scenario, except for tactics involving Regions 7 and 8. Since the maximum benefits for Regions 3 and 6 in all cases was very low, we did not analyze any technical tactics for these two regions.

Even for those regions with large maximum benefits in the high sprinkler intensity case, almost all of the benefits would be derived only in extremely dry years. Table 4.7 shows the estimated preventable losses for the four external supply scenarios in the case with high sprinkler intensity and all waterboard plans.

Table 4.7

PREVENTABLE LOSSES (Dflm) FROM TACTICS
(High Sprinkler Intensity, with Waterboard Plans)

Region	DEX	1959	1943	1967	U.B.
(1) North	80.2	4.1	3.2	0.0	7.5
(2) N.E. Highlands	111.3	37.8	16.3	0.0	19.9
(3) Flevoland and Veluwe	2.6	0.0	0.0	0.0	0.2
(4) North Holland	10.6	0.0	0.0	0.0	0.7
(5) Midwest/Utrecht	30.4	8.6	1.8	0.4	4.2
(6) Large Rivers/N. Delta	4.9	0.0	0.0	0.0	0.3
(7) W. Brabant/S. Delta	6.0	0.6	0.0	0.0	0.5
(8) S.E. Highlands	200.8	58.9	13.8	0.0	28.1

NOTES

1. More generally, sprinkler intensity is defined as the fraction of an eligible area in which sprinkler equipment is installed. Thus a sprinkler intensity of 0.6 in an eligible area of 200 ha means that sprinkler equipment is installed on 120 ha.
2. A subdistrict is part of an agricultural district that has certain unique characteristics, such as type of landform (highlands or lowlands), and type of soil (e.g., loam or silty clay). Crop areas in PAWN were assigned to subdistricts. Therefore, the calculation of crop benefits had to be done by subdistrict. For additional information on subdistricts, see Vol. XII.
3. It is important to note the assumption with regard to the actual location of crops within a subdistrict that is implicit in the equation for estimating CROP.BEN. The equation is valid only if all crops are distributed uniformly within the subdistricts. This is one of the basic assumptions of the PAWN agricultural models. In pre-screening, however, it may lead to misestimations of plan benefits. If some areas of a subdistrict already have access to surface water for sprinkling, it is more likely that the valuable crops would be located in these areas, in which case our formula will overestimate plan benefits. On the other hand, the proposed waterboard plans are likely to be directed toward increasing the sprinkling of the more valuable crops, in which case plan benefits would be underestimated by our formula.
4. This means that taxes would not be treated as transfer payments. The farmer would be required to pay taxes on the increased crop yield resulting from sprinkling but would also be allowed to take

tax reductions and credits on certain expenses relating to sprinkling. The difference between the farmer's and nation's viewpoint as it relates to sprinkling benefits is discussed more fully in Vol. XIV.

REFERENCE

4.1. Unpublished report containing the results of a waterboard survey of water supply conducted by the Union of Waterboards, February 1978 (PAWN file DW-470).

Chapter 5

SCREENING OF TACTICS FOR THE NORTH

5.1. OVERVIEW

The North (Region 1) covers the provinces of Groningen and Friesland and parts of the provinces of Drenthe and Overijssel. The region consists mostly of lowlands, although some highlands in Friesland and Drenthe are included. The predominant soil types in the area are loamy sand and clay. Farmland covers 70 percent of the region's area. Of the farmland, 65 percent is pastureland and 15 percent is devoted to growing various cereals. The remaining 20 percent is allocated to a number of different crops. Less than 5 percent of the region is urban area, and almost 20 percent is nature area. ("Nature areas" include woods, fallow land, marshes, parks, playing fields, etc.) Table 5.1 shows the distribution of the land in the region among its various uses in more detail.

Table 5.1

LAND USE IN THE NORTH

Use	Area (ha)	Percentage of Farmland	Percentage of Total Area
Farmland:			
Grass	365,069	65.6	
Cereals	82,684	14.9	
Milling potatoes	36,947	6.6	
Sugar beets	35,225	6.3	
Seed potatoes	15,880	2.9	
Consumption potatoes	7,026	1.3	
Vegetables (open air)	6,856	1.2	
Cut corn	3,892	0.7	
Other crops	3,009	0.5	
Total farmland	556,588	100.0	70.2
Nature	149,379		18.9
Urban	35,732		4.5
Surface water	50,675		6.4
Total region	792,374		100.0

The demand for water in the North depends on the extent to which sprinkler equipment is used by farmers. In Table 5.2 we show the number of hectares that are sprinkled under each of the demand scenarios. It shows that without implementation of waterboard plans, the area sprinkled with surface water can increase up to threefold in the future, from 10.1 percent of the farmland to 29.5 percent. Implementation of the promising waterboard plans can increase the sprinkled area to 11.9 percent of the farmland (for low sprinkler intensity) or to 33.7 percent (for high sprinkler intensity).

Table 5.2

SPRINKLED AND UNSPRINKLED FARMLAND (ha) IN THE NORTH UNDER FOUR DEMAND SCENARIOS

	Low Intensity		High Intensity	
Type of Area	No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
Farmland:				
Without sprinkling	497,718	487,646	390,008	366,453
With SW sprinkling	56,355	66,427	164,065	187,620
With GW sprinkling	2,515	2,515	2,515	2,515
Total	556,588	556,588	556,588	556,588

Table 5.3 indicates the agricultural demands for extractions from the surface water distribution network that result from these scenarios. Four measures of demand are shown: the average decade and the driest decade for both the 1943 and DEX supply scenarios; the average decade demands are averages over decades having a positive demand. (Many decades have zero demands--those that fall outside the growing season and those in which rainfall is sufficient to supply all of the demands of agriculture for water.)

Table 5.3

DEMANDS FROM NORTH FOR EXTRACTIONS FROM NATIONAL SURFACE WATER DISTRIBUTION NETWORK (m^3/s)

	Low Intensity		High Intensity	
Type of Decade	No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
1943: Average decade	25.9	27.0	36.5	38.8
Driest decade	72.0	78.6	125.6	135.7
DEX: Average decade	32.2	34.7	48.8	52.7
Driest decade	76.1	83.0	132.4	143.6

Figure 5.1 is a map drawn to scale showing the major waterways in the North, and Fig. 5.2 is the schematization of the surface water distribution network for the region that was used in the Distribution Model. Figure 5.2 also shows the borders of the agricultural districts comprising the region. The sources for the supply of surface water to the region are the IJsselmeer and (to a much lesser extent) the Zwartemeer, one of the border lakes of the IJsselmeer. Surface water from the IJsselmeer enters the boezem system of Friesland at three

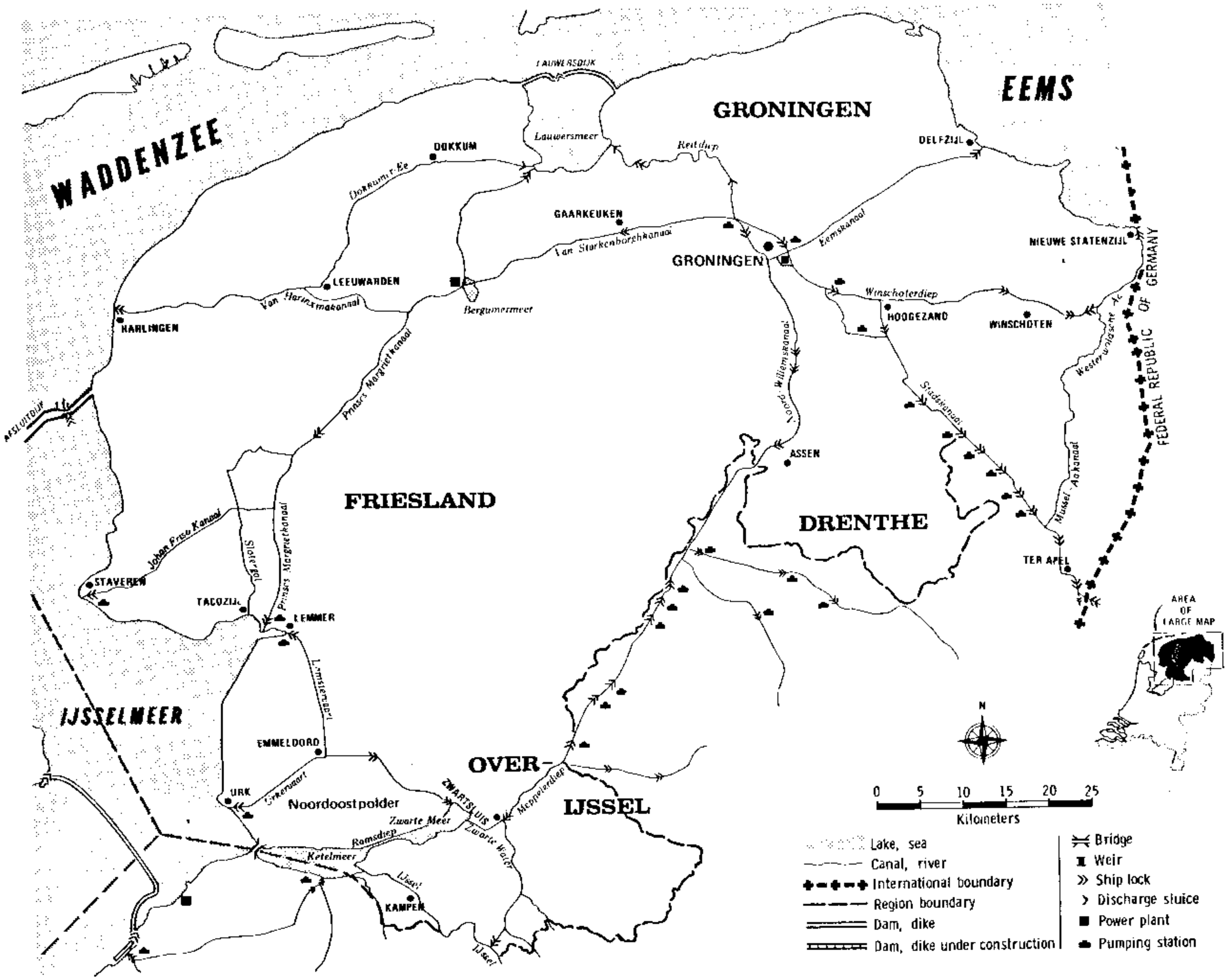


Fig. 5.1--Map of the North (Region 1)

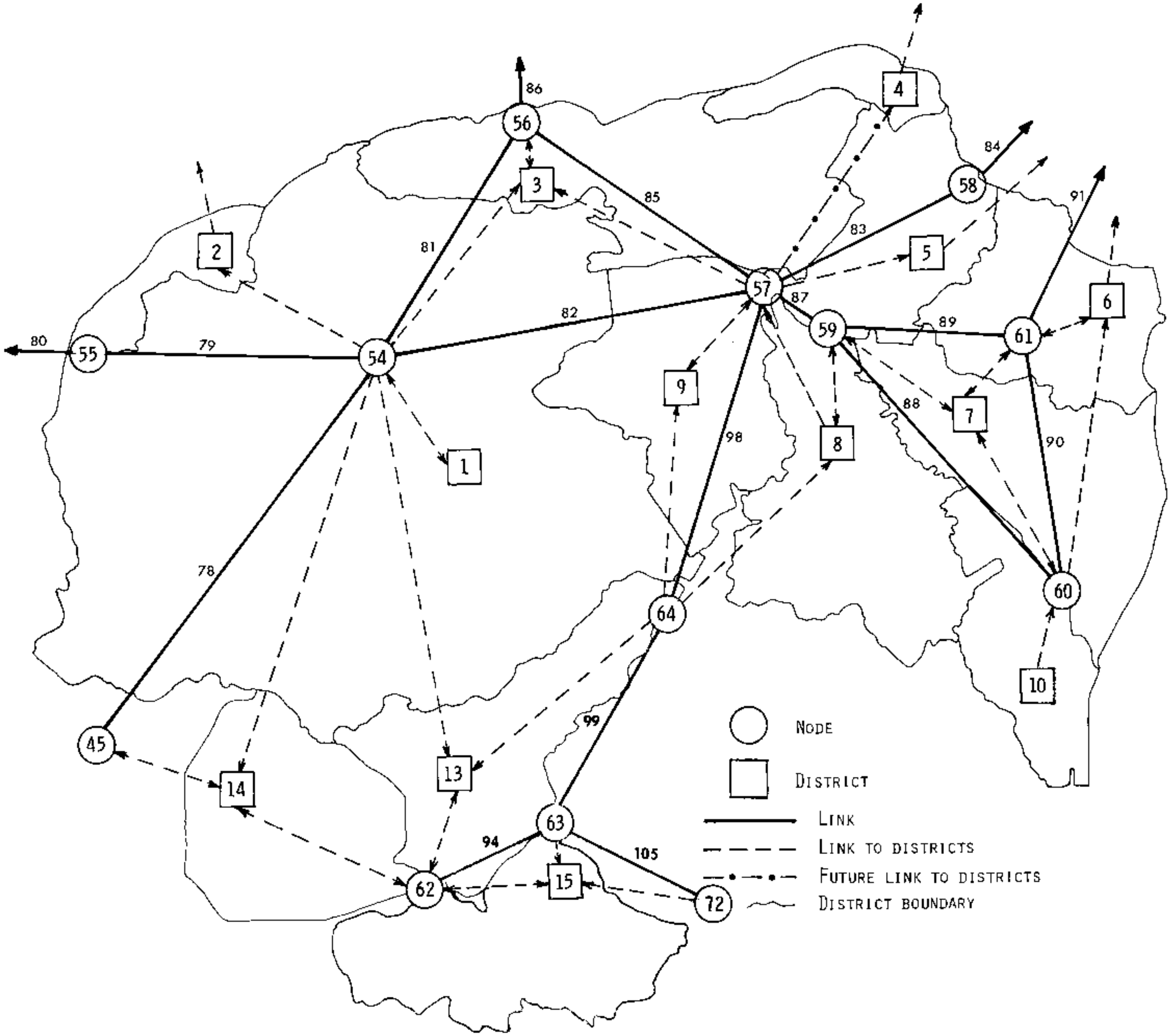


Fig. 5.2--Surface water distribution network for the North

locations: Staveren, Tacozijl, and Teroelsterkolk. This boezem system provides access to surface water for most of the province of Friesland. In addition, it forms part of the supply route for the province of Groningen--the Prinses Margrietkanaal, which continues in Groningen as the Van Starkenborghkanaal. Except for some runoff from higher areas in Drenthe, all of the surface water supply to the province of Groningen is carried along this route. Inside that province, the Winschoterdiep carries the water farther to the east, and the Stadskanaal carries the water to the southeast.

The other inlet locations for this region are of minor importance. Some areas in northwest Overijssel receive their surface water from the Zwartemeer, which has an open connection with the IJsselmeer. Moreover, the Noordoostpolder receives most of its water from the IJsselmeer through its inlet at Lemmer; the remainder comes from the Zwartemeer.

In this region, two problems are associated with the supply and the management of the surface water distribution network. The first problem is that of the salinity in the waterways. This salinity is due mostly to the seepage of brackish water that occurs in all low-lying areas of the Netherlands. The high salinity level of the Rijn compounds this problem because the IJsselmeer, which is the principal source of surface water for the region during dry periods, is fed by the IJssel River, a branch of the Rijn. Finally, salt intrusion from the Waddenzee[1] occurs at various locations along the coast, notably at Harlingen and Delfzijl. The current policy for reducing the salinity in the waterway system due to seepage and salt intrusion is to flush it with relatively fresh water from the IJsselmeer. No specific tactics have been defined that would be directed at further reducing the salinity of the waterways in the North. We did consider several tactics that would reduce the IJsselmeer salinity, but they would have only limited impact on the salinity of the water in the North.

The second water management problem is that, during dry periods, a sufficient flow of surface water into the region cannot always be maintained. There are two parts to this problem. First is the issue of the availability of surface water in the IJsselmeer for extraction into the region. Second is the limited capacity of the Margrietkanaal/Van Starkenborghkanaal route. A number of tactics have been designed to address each part of the problem.[2]

The availability issue is related to the fact that the IJsselmeer level is allowed to vary between a maximum level (the so-called target level) and a minimum level. When the lake approaches its minimum level (caused by low flows coupled with high extractions and evaporation), the extractions must be cut back (see Sec. 3.1.1).

The capacity of the Margrietkanaal/Van Starkenborghkanaal is limited by the throughput capacity at the ship lock at Gaarkeuken (located close to the provincial border of Groningen and Friesland). The current throughput capacity at this ship lock is about 16 m^3/s [5.1], which is lower than the peak demands in 1943 and DEX of the area that depends on the Van Starkenborghkanaal for its supply of surface water.

Table 5.4 shows the extraction demands for agriculture generated by the area depending on the Van Starkenborghkanaal; the categories of demand are the same as the ones presented in Table 5.3. Similarly, Table 5.5 shows the agricultural extraction demands of the total area that depends on the Prinses Margrietkanaal and the Van Starkenborghkanaal for its surface water supply. The last line of Tables 5.4 and 5.5 shows the area's demand for flushing. Since the level of the waterways in the distribution network is not allowed to vary from its target level, the demands for flushing must be added to the agriculture extraction demands to obtain the total agricultural demands at Gaarkeuken and at the Margrietkanaal inlet, respectively.[3]

Table 5.4

EXTRACTION DEMANDS AT GAARKEUKEN (m^3/s)

	Low Intensity		High Intensity	
Type of Decade	No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
1943: Average decade	9.0	8.5	10.9	10.7
Driest decade	18.5	18.2	28.1	28.4
DEX: Average decade	9.9	9.4	12.8	12.6
Driest decade	19.8	19.4	29.7	30.0
Flushing	2.5	2.5	2.5	2.5

Table 5.5

EXTRACTION DEMANDS AT MARGRIETKANAAL INLET (m^3/s)

	Low Intensity		High Intensity	
Type of Decade	No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
1943: Average decade	22.9	22.9	33.2	34.5
Driest decade	59.7	62.3	111.9	118.3
DEX: Average decade	27.4	28.0	43.7	45.4
Driest decade	62.5	65.1	117.3	124.2
Flushing	16.1	16.1	16.1	16.1

Table 5.4 shows that, for all four demand scenarios, only the demands in an average decade in 1943 and DEX can be fully satisfied with a throughput capacity of 16 m^3/s at Gaarkeuken. The peak demands in both years exceed the available capacity. The current capacity of the inlets to the Friesland boezem varies between 98 m^3/s (at an IJsselmeer level of NAP - 0.40 m) and 129 m^3/s (at a lake level of NAP - 0.20 m).[4] Table 5.5 shows that this capacity is sufficient under practically all conditions. Only under the high sprinkler intensity

demand scenarios do the peak demands in 1943 and DEX exceed the available capacity. To give an idea of the magnitude of the shortage and salinity problems in the region, Table 5.6 presents, for each of the four demand scenarios, the losses to agriculture that occur under the 1943 and DEX supply scenarios. In addition to total shortage losses, we also show the preventable shortage losses--those losses that can be prevented by the implementation of technical tactics (see Sec. 4.2 for a more complete explanation).

Table 5.6

AGRICULTURE LOSSES IN THE NORTH (Dflm)

	Low Intensity		High Intensity	
	No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
1943:				
Total shortage losses	410	389	275	241
Preventable shortage losses	--	--	1	3
Total salinity losses	20	22	20	22
DEX:				
Total shortage losses	1469	1398	1046	969
Preventable shortage losses	--	--	33	80
Total salinity losses	28	34	28	33

The table shows that preventable losses of any importance occur only under the high intensity demand scenarios; the analysis of the technical tactics is therefore limited to these scenarios.

5.2. EXPAND SUPPLY CAPACITY TO GRONINGEN

The agriculture shortage losses in this region are caused by a number of factors. In the driest year (DEX) a sizable portion of the losses can be traced to cutbacks in extractions from the IJsselmeer due to low lake levels. These losses can be prevented by raising the summer target level of the lake (see Sec. 11.4). Most of the remaining preventable losses in the region occur in Groningen. We, therefore, looked for tactics that might reduce these losses. Two tactics designed for this purpose are discussed below.

5.2.1. Expand Throughput Capacity of Van Starkenborghkanaal

In the worst case scenario (DEX, SPRHI-RALL), if the summer target level of the IJsselmeer were raised so that cutbacks could be avoided, the limited throughput capacity at Gaarkeuken would be constraining the supply of water to Groningen in six of the seven decades in the period from the first decade in May through the first decade in July. Even with the 1943 scenario (which is a "21-percent dry year") the throughput capacity would be constraining in six of the ten decades in the period from the second decade in May through the second decade in August. It is almost never constraining in the low sprinkler intensity scenario (SPRLO). It therefore appeared likely that it would be promising to increase the throughput capacity of the Van Starkenborghkanaal at Gaarkeuken for the high sprinkler intensity scenario (SPRHI).

In order to choose an appropriate throughput capacity to evaluate, we considered the demands for surface water and the costs of various capacity expansions. The maximum demand for surface water in Groningen in the worst case scenario was 32.5 m^3/s (in the first decade of July). The demand was above 25 m^3/s in only two decades in DEX. In the 1959 scenario, the demand was above 20 m^3/s in several decades, but never above 25 m^3/s. On the cost side, expansion of the throughput capacity to 25 m^3/s requires improving the lock bypass at Gaarkeuken and increasing the capacity of the pumping station at the Oostersluis. These changes have an annualized fixed cost of 0.6 Dflm.[5],[6] Expansions greater than 25 m^3/s would be significantly more costly, since the Prinses Margrietkanaal itself would have to be expanded in various places. We therefore chose to evaluate the expansion of the throughput capacity to 25 m^3/s.

The benefits of this tactic depend on whether or not a sufficient supply of water is available in the IJsselmeer to satisfy the increased extraction demands. The increased demands from this and other tactics for the high sprinkler intensity scenario could be met if the summer target level of the IJsselmeer and Markermeer were raised to NAP - 0.10 m from NAP - 0.20 m. We found this tactic to be promising (see Sec. 11.4).

Our analysis of the tactic to expand throughput capacity of the Van Starkenborghkanaal assumed that the summer target level of the lakes would be increased. If the lake levels are not increased, implementation of this tactic will increase the agriculture shortage losses in very dry years in all areas that depend on the IJsselmeer and Markermeer for their surface water supply, since additional cutbacks in extractions from these lakes will be needed.

Table 5.7 shows the reduction in shortage losses in Groningen that would result from implementing this tactic. Results are presented for each of the four supply scenarios and for the two high sprinkler intensity demand scenarios (RNONE and RALL). We see from the table that this tactic (expansion of the throughput capacity of the Van Starkenborghkanaal at Gaarkeuken to 25 m^3/s) is promising for both high sprinkler intensity demand scenarios if it is implemented in conjunction with an increase in the summer target level of the IJsselmeer and Markermeer.

Table 5.7

REDUCTIONS IN AGRICULTURE SHORTAGE LOSSES IN GRONINGEN (Dflm)
FROM INCREASING THROUGHPUT CAPACITY OF THE
VAN STARKENBORGHKANAAL TO 25 m^3/s
(High Sprinkler Intensity)

					Expected Annual Benefits		Annualized Fixed Cost
	DEX	1959	1943	1967	UB	LB	(Dflm)
RNONE	9.1	0.3	0.8	0	1.0	0.3	0.6
RALL	12.8	2.0	1.9	0	2.0	0.6	0.6

5.2.2. Expand Pumping Capacity along Stadskanaal

The Stadskanaal carries water from the Winschoterdiep in the vicinity of Groningen to the highlands in the southeastern part of the province. Its current throughput capacity is 5 m^3/s, which is the capacity of the pumping stations along the canal. Large portions of two districts (Districts 6 and 7) are supplied by water from the Stadskanaal. It has been felt that some of the agriculture shortage losses in these districts could be prevented if the pumping capacity along the canal were expanded.

A Distribution Model run was made for the worst case scenario (DEX, SPRHI-RALL) to determine the maximum amount of water that these two districts would like to extract from the Stadskanaal if the capacity could be expanded. We found that preventable agriculture shortage losses, although sizable (4.35 Dflm), were due to the capacity constraint at Gaarkeuken rather than insufficient capacity on the Stadskanaal. In only two decades of this run was the maximum amount of water that Districts 6 and 7 would have liked to extract greater than 5 m^3/s. In one of the decades the desired extraction was 6.4 m^3/s, and in the other it was 5.9. However, only part of these desired extractions would have to come from the Stadskanaal. Between 1 m^3/s and 2 m^3/s would be extracted below the first pumping station on the canal. Therefore, even if the throughput capacity at Gaarkeuken is expanded so that these demands might be able to be satisfied, it is unlikely that the overall benefits from increasing pumping capacity along the canal would be high enough to justify the costs.

5.3. REDUCE NOORDOOSTPOLDER'S CONTRIBUTION TO IJSSELMEER SALINITY

The IJsselmeer and Markermeer supply fresh water to districts containing over 40 percent of the nation's cultivated area. The salinity of the water in these lakes is, therefore, an important factor in the nation's agriculture salinity losses. Although the salinity of the lakes is determined to a large extent by the salinity of the Rijn, about one-third of the salt that enters the lakes in an average year comes from other sources--primarily from polders that discharge their drainage water into the lakes. This water tends to be considerably more saline than the lake water.

We examined three sets of tactics for reducing salinity in the IJsselmeer and/or the Markermeer that results from polder discharges.

In this section we discuss the salinity contributed by the Noordoostpolder. Section 7.3 deals with a tactic for reducing the salinity contributed by the Wieringermeerpolder. Section 11.3 discusses tactics designed to divert Flevoland's discharges from the Markermeer.

Discharges from the Noordoostpolder are pumped into the IJsselmeer at Lemmer and at Urk (see Fig. 5.1). In an average year, these discharges constitute about 5 percent of the total salt load entering the IJsselmeer and Markermeer. The salinity of the water is sometimes above 660 ppm, whereas the IJsselmeer salinity rarely exceeds 300 ppm. In order to reduce this source of salinity, it has been suggested that the Nordoostpolder drainage water be pumped through a pipe under the Ketelmeer, across Flevoland, and into the IJmeer or the Oostvaardersdijk.

A side effect of this tactic would be to increase the salinity of the IJmeer and, unless the second Oostvaardersdijk were to be built, of the Markermeer. Since an increased Markermeer salinity would lead to higher salinity losses in North Holland, this tactic could lead to an increase in total salinity losses to agriculture.

In our analysis of this tactic, we considered a pipeline that would begin at the southern border of the Noordoostpolder (near the town of Nagele), run under the Ketelmeer, and discharge into the Flevoland canal system at Ketelhaven, a total length of about 4 km (see Fig. 5.3). A pumping station was included to pump the water through the pipeline. Since the Flevoland canal system has been designed to accommodate discharges in wet periods, it has excess capacity under average and dry conditions; it would therefore be able to process the Noordoostpolder's discharge under our four supply scenarios. We determined the capacity requirements for the pipeline by examining data produced by the Distribution Model on the discharges from the Noordoostpolder, using the 1967 external supply scenario (an "average" year) for two sprinkler scenarios: low sprinkler intensity without waterboard plans (SPRLO-RNONE) and high sprinkler intensity with waterboard plans (SPRHI-RALL). These discharges (in m^3/s, averaged over the month) were:

1967	SPRLO-RNONE	SPRHI-RALL
January	14.8	14.8
February	14.8	14.8
March	11.3	11.3
April	9.7	9.7
May	6.0	5.8
June	4.8	4.7
July	4.5	4.5
August	5.0	4.8
September	7.8	9.9
October	19.0	20.7
November	21.1	21.1
December	20.5	20.5
Average	11.6	11.9

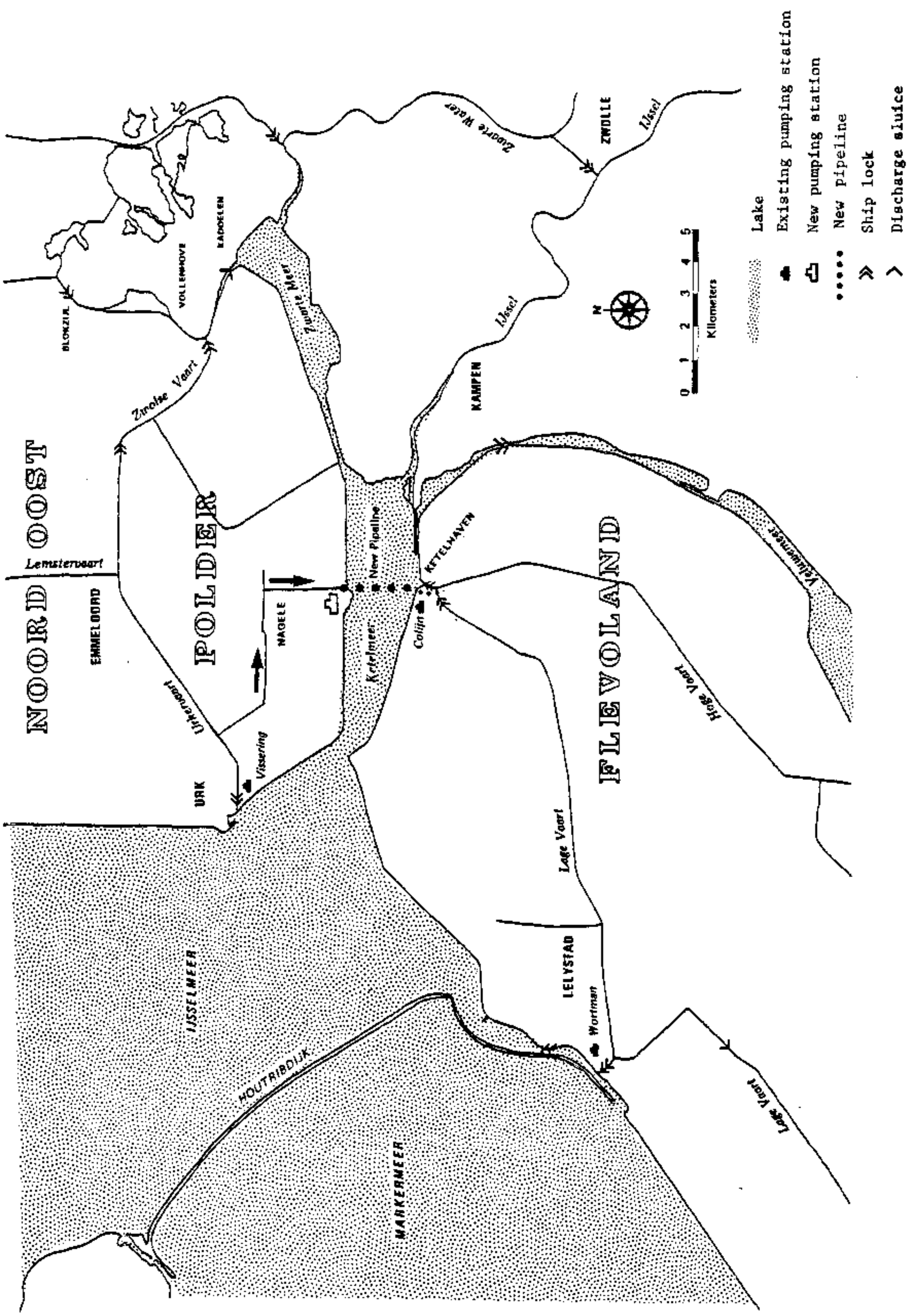


Fig. 5.3--Pipeline from Noordoostpolder to Flevoland

In order to keep the cost of the pipeline down, we assumed that it should be able to handle most normal discharges, but that excess discharges during peak periods could be released into the IJsselmeer. We therefore chose a capacity of 15 m^3/s, resulting in an estimated total investment cost of 39.9 Dflm and an annualized fixed cost of 4.2 Dflm.

The benefits from the construction of the pipeline accrue to farmers whose crops suffer less salinity damage because of the reduced salinity of the water in the IJsselmeer. In order to estimate the magnitude of these benefits, we made two runs with the Distribution Model. In each case, the quantities of water and salt that were extracted from and discharged to the IJsselmeer, Markermeer, and IJmeer were those that were actually experienced in 1976 (the scenario year in which the damage to agriculture from salinity in the IJsselmeer was greatest).[7] The only difference between the two runs was that in one the Noordoostpolder discharged into the IJsselmeer, and in the other it discharged into the IJmeer. The resulting reduction in IJsselmeer salinity was never more than 5 ppm in any decade, and the reduction in salinity damage to agriculture over the entire year was under 300,000 Dfl.

The expected annual benefits of building a pipeline from the Noordoostpolder to Lelystad are less than 300,000 Dfl, which is considerably below the annualized fixed cost of 4.2 Dflm. We have, therefore, concluded that construction of such a pipeline is not a promising tactic.

5.4. SUMMARY OF CONCLUSIONS

The North experiences problems related to both agriculture shortage losses and agriculture salinity losses. The preventable shortage losses not caused by insufficient water in the IJsselmeer occur almost exclusively in the province of Groningen and are caused by insufficient throughput capacity on the Van Starkenborghkanaal at Gaarkeuken. Losses could be eliminated in all but the driest decades of the driest years by expanding the pumping capacity to 25 m^3/s. It would be worthwhile to implement this tactic if the sprinkler intensity becomes sufficiently high, but only in conjunction with the tactic to raise the summer target level of the IJsselmeer.

The dumping of the discharges from the Noordoostpolder into the IJsselmeer increases agriculture salinity losses in districts that extract water from the IJsselmeer. However, the tactic that we examined for pumping the discharges from this polder through a pipe to the IJmeer or Oostvaardersdiep was found to cost too much compared with its expected benefits.

NOTES

1. The part of the North Sea that lies between the Friesland/Groningen coast and the string of islands north of that coast is called the Waddenzee.
2. The tactics that can increase the availability of surface water in the IJsselmeer are discussed as national tactics in Sec. 11.4.
3. The flushing demands are based on current practice and have not been analyzed in our study. The discharge locations for the water used in flushing are Harlingen, Lauwersoog, and Delfzijl.
4. After our analysis had been completed and this report mostly written, the Rijkswaterstaat revised the information they had given us on the capacity of the inlets to the Friesland boezem. According to this new information, the capacity varies between 53 m^3/s (at an IJsselmeer level of NAP - 0.40 m) and 97 m^3/s (at a lake level of NAP - 0.20 m). The new information makes it desirable to redo the analysis of the tactic to expand the capacity of the Van Starkenborghkanaal (see Sec. 5.2.1 for the description of our analysis), since it may reverse our conclusion. We believe that the conclusions about other tactics that are discussed in this volume are unaffected by the new information.
5. A complete description of how the costs of this tactic and all other tactics treated in this volume were estimated is provided in Vol. XVI. The tables in App. A list the costs of all the tactics and provide cross-references to the appropriate places in Vol. XVI where the reader can find out how the costs were obtained.
6. The annualized fixed cost of this tactic is lower than the cost presented at the final PAWN briefing held in the Netherlands in December 1979 because we subsequently discovered a mistake that had been made in estimating the investment and labor costs of the pumping station at the Oostersluis.
7. The data on extractions and discharges were taken from Ref. 5.2.

REFERENCES

5.1. Unpublished report from the Rijkswaterstaat, Directie Groningen, describing the drought of 1976 in the province of Groningen (PAWN file DW-305).

5.2. Rijkswaterstaat, WW, District Noord, De totale hoeveelheid water en chloride die in 1976 op het IJsselmeer/Markermeer zijn uitgeslagen en vanuit beide meren zijn ingelaten (The Total Amount of Water and Chloride That Was Discharged into the Markermeer and IJsselmeer in 1976, and the Amount That Was Extracted from the Lakes), October 1978.

Chapter 6

SCREENING OF TACTICS FOR NORTHEAST HIGHLANDS

6.1. OVERVIEW

The Northeast Highlands (Region 2) covers most of the provinces of Drenthe and Overijssel and the portion of Gelderland east of the IJssel River. The predominant soil type in the area is loamy sand. Farmland covers 65 percent of the region's area. Of the farmland, over 70 percent is pastureland and almost 10 percent is devoted to growing milling potatoes. The remaining 20 percent is allocated to a number of different crops. Approximately 5 percent of the region is urban area and almost 30 percent is nature area. Table 6.1 shows the distribution of the land in the region among its various uses in more detail.

Table 6.1

LAND USE IN THE NORTHEAST HIGHLANDS

Use	Area (ha)	Percentage of Farmland	Percentage of Total Area
Farmland:			
Grass	276,830	71.9	
Milling potatoes	34,048	8.8	
Cereals	27,365	7.1	
Cut corn	26,729	7.0	
Sugar beets	13,884	3.6	
Consumption potatoes	2,414	0.6	
Seed potatoes	2,021	0.5	
Other crops	1,970	0.5	
Total farmland	385,261	100.0	64.8
Nature	164,563		27.7
Urban	30,986		5.2
Surface water	13,618		2.3
Total region	594,428		100.0

The demand for water in the Northeast Highlands depends on the extent to which sprinkler equipment is used by farmers. Table 6.2 shows the number of hectares that are sprinkled under each of the demand scenarios. It shows that even without implementation of waterboard plans, the area sprinkled with surface water might increase more than sixfold in the future, from 2.4 percent of the farmland to 15.0 percent. Implementation of waterboard plans will not have quite so dramatic an effect, increasing the sprinkled area to 4.3 percent of the farmland (low sprinkler intensity) or 22.0 percent (high sprinkler intensity).

Table 6.2

SPRINKLED AND UNSPRINKLED FARMLAND (ha) IN THE NORTHEAST HIGHLANDS UNDER FOUR DEMAND SCENARIOS

	Low Intensity		High Intensity	
Type of Area	No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
Farmland:				
Without sprinkling	356,470	349,185	308,377	281,114
With SW sprinkling	9,334	16,619	57,427	84,690
With GW sprinkling	19,457	19,457	19,457	19,457
Total	385,261	385,261	385,261	385,261

Table 6.3 indicates the demands for extraction from the surface water distribution network that result from these scenarios. Four measures of demand are shown: the average decade and the driest decade for both the 1943 and DEX supply scenarios. (The average decade demands are averages over decades having a positive demand.)

Table 6.3

DEMANDS FROM NORTHEAST HIGHLANDS FOR EXTRACTIONS FROM NATIONAL SURFACE WATER DISTRIBUTION NETWORK (m^3/s)

		Low Intensity		High Intensity	
Type of Decade		No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
1943:	Average decade	3.1	2.5	6.8	9.9
	Driest decade	6.6	8.9	21.2	31.7
DEX:	Average decade	3.4	4.2	7.1	11.9
	Driest decade	7.3	11.0	23.7	37.0

Figure 6.1 is a map showing the major waterways in the Northeast Highlands, and Fig. 6.2 is the schematization of the surface water distribution network for the region that was used in the Distribution Model. Figure 6.2 also shows the borders of the agricultural districts comprising the region. The Overijsselsche Vecht is a natural source for the supply of surface water to the region. There are currently two artificial supply routes: one begins at the IJssel River, and the other at the IJsselmeer. These two routes currently serve different areas (eastern Overijssel and south/central Drenthe, respectively), although in 1976 Drenthe received some water from the Overijssel route by using a temporary pumping facility. The principal extraction location along the IJssel River is at Eefde, where IJssel water can be pumped into the Twenthekanaal. The Twenthekanaal is connected to the Overijsselsch Kanaal at Almelo. There are at least two locations along the Overijsselsch Kanaal where connecting waterways can transport surface water farther westward into the region: at Coevorden the

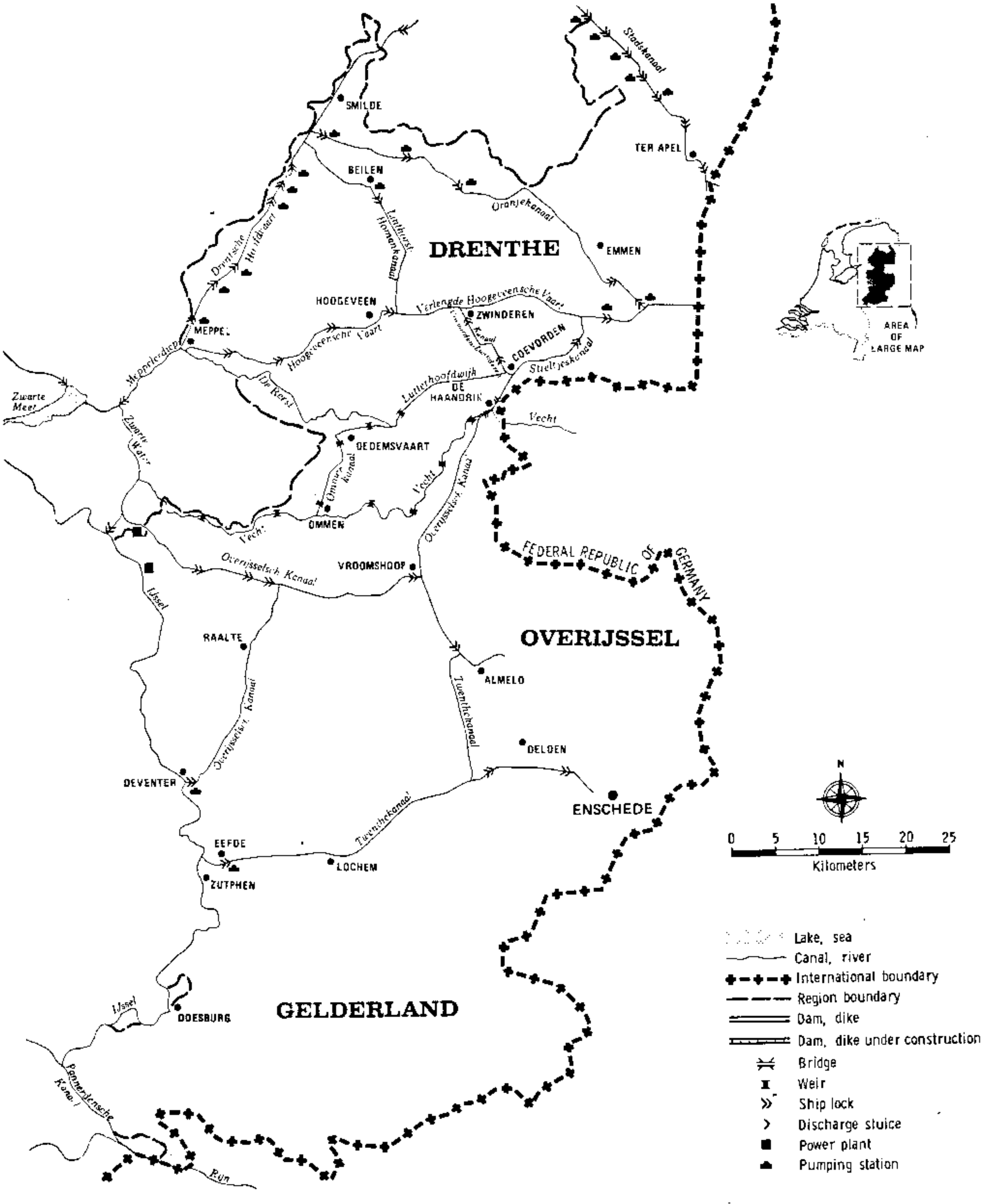


Fig. 6.1--Map of the Northeast Highlands (Region 2)

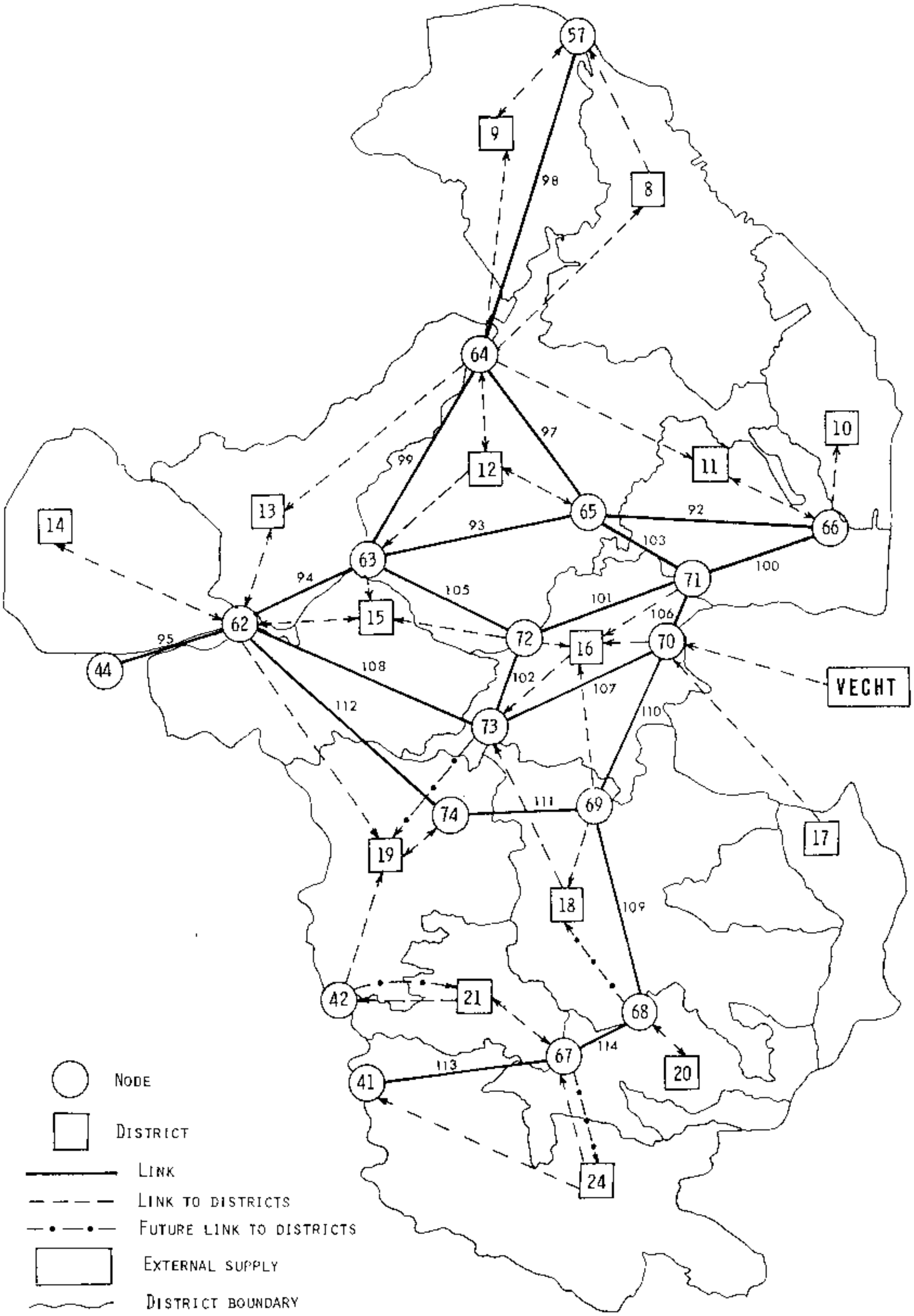


Fig. 6.2--Surface water distribution network for the Northeast Highlands

connecting waterway is the Lutterhoofdwijk, and at De Haandrik, the Vecht. In following sections and chapters, this water supply route will be referred to as the Twenthekanaal route.

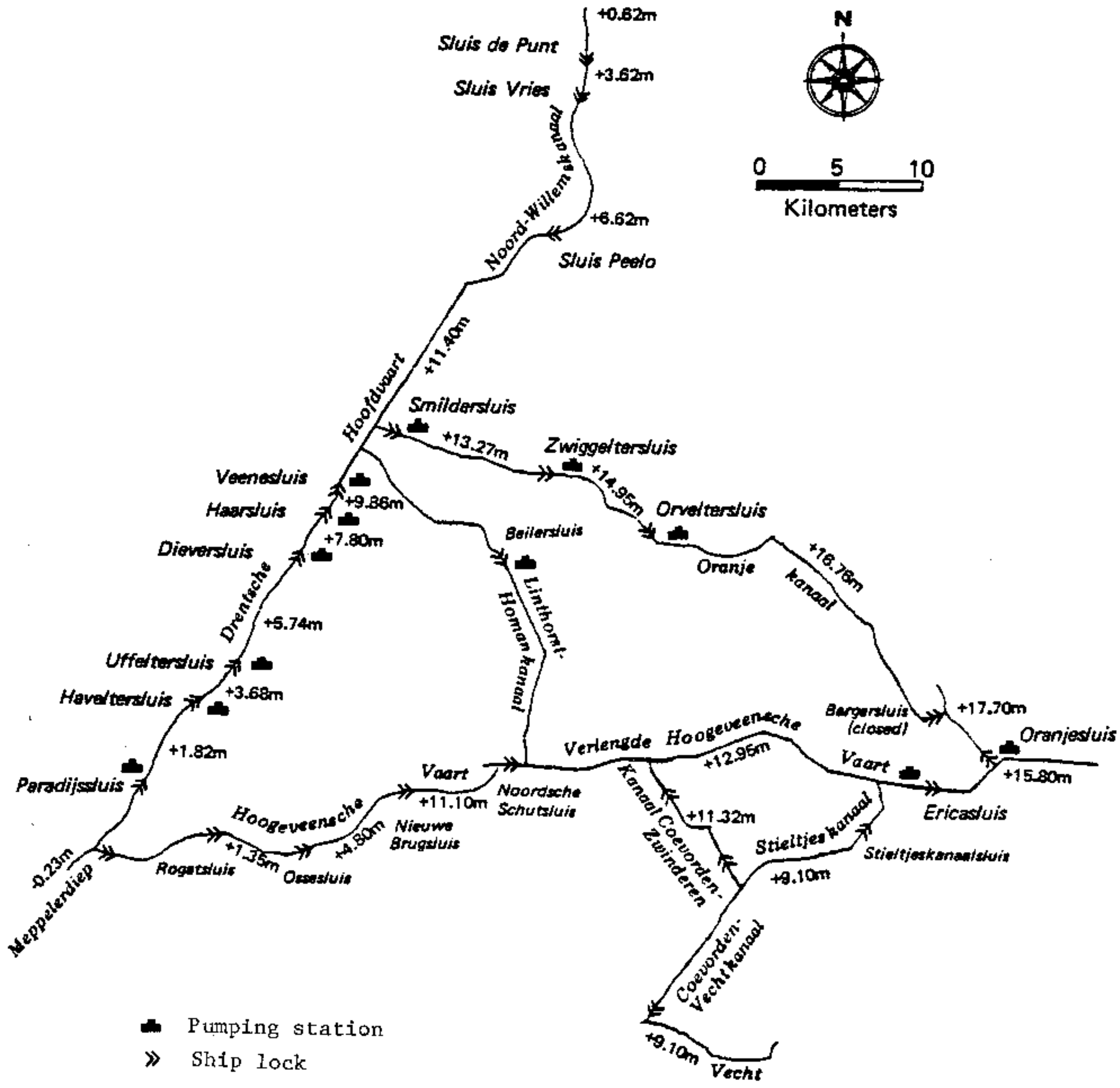
The IJsselmeer is the second source of surface water for the Northeast Highlands. The current supply route from the IJsselmeer (actually, from the Zwartemeer) begins at the Zwarte Water and continues along the Meppelerdiep and the Drentsche Hoofdvaart (see Fig. 6.3). From there, two paths can be distinguished: the Oranjekanaal takes water farther into central Drenthe, and the Linthorst-Homankanaal, followed by the Verlengde Hoogeveensche Vaart, provides access to the southern part of that province. The route from the IJsselmeer in its entirety will be referred to as the Drentsche Hoofdvaart route.

Equally important as the supply routes are the routes for draining water out of the region. Since adequate drainage is no longer a major problem in this part of the country and has not been considered in our analysis, it suffices to say that the Twenthekanaal, the Overijsselsche Vecht, and the Meppelerdiep are the principal waterways used for discharge of excess water.

The major water management problem in the Northeast Highlands is how to supply a sufficient flow of surface water to the region in dry periods. Our tactics have therefore been designed to reduce the likelihood and extent of surface water shortages in the region. Two parts of this problem can be distinguished. First is the issue of the availability of surface water for extraction into the region. Second, the two current water supply routes have limited capacities for the transportation of surface water.

As discussed in Sec. 5.1, the availability issue is related to the fact that extractions from the IJsselmeer are cut back when the lake approaches its minimum level. Because the IJssel River is the principal source of water for the IJsselmeer, reductions in extractions from the IJsselmeer apply equally to extractions from the IJssel River. An additional reason for limiting extractions from the IJssel River is that they cause sedimentation in the river. Sedimentation tends to impede ship traffic and is more generally undesirable from the standpoint of river management.

Even if the availability of water in the IJssel River and the IJsselmeer is sufficient to meet extraction demands, the supply capacities of the two routes may be insufficient, thereby forcing cutbacks in the extraction demands. The critical points in the Twenthekanaal route are the pumping station at Eefde (capacity 11 m^3/s) and the lock at Almelo (5 m^3/s). (The Almelo lock connects the Twenthekanaal with the Overijsselsch Kanaal.) In the Drentsche Hoofdvaart route, the pumping stations on the Drentsche Hoofdvaart are the major limiting factors. The capacity of each one is 4.3 m^3/s. Tables 6.4 and 6.5 show how the extraction demands that were presented in Table 6.3 are divided between the two routes.



Numbers refer to level of land relative to NAP

Fig. 6.3--Water distribution system in Drenthe

Table 6.4

EXTRACTION DEMANDS FOR AREA DEPENDENT ON DRENTSCHE HOOFDVAART ROUTE (m^3/s)

Type of Decade	Low Intensity No W/B Plans	 With W/B Plans	High Intensity No W/B Plans	 With W/B Plans
1943: Average decade	2.3	1.7	4.3	6.6
Driest decade	4.5	5.7	13.4	19.9
DEX: Average decade	2.0	1.9	4.5	6.7
Driest decade	4.8	6.4	14.9	22.4

Table 6.5

EXTRACTION DEMANDS FOR AREA DEPENDENT ON TWENTHEKANAAL ROUTE (m^3/s)

Type of Decade	Low Intensity No W/B Plans	 With W/B Plans	High Intensity No W/B Plans	 With W/B Plans
1943: Average decade	0.8	0.8	2.5	3.3
Driest decade	2.1	3.2	7.8	11.8
DEX: Average decade	1.4	2.3	2.6	5.2
Driest decade	2.5	4.6	8.8	14.6

Table 6.4 shows that, for the low sprinkler intensity scenarios, the demands (slightly) exceed the supply capacity in the driest decades. For the high sprinkler intensity scenarios, the capacity shortfall seems more severe, and tactics to expand the supply capacity may be needed. From Table 6.5, we conclude that the demands can always be met, except in the driest decades for the SPRHI-RALL scenario.

The aforementioned results are confirmed by Table 6.6, in which we show, for each of the four demand scenarios, the losses to agriculture that occur in the Northeast Highlands under the 1943 and DEX supply scenarios. The preventable shortage losses are shown to be of importance only under the high intensity demand scenarios.

Tables 6.7a and 6.7b present, for the high sprinkler scenario, the agriculture shortage losses that resulted from the unavailability of water in the IJsselmeer in DEX (the only year there was a shortage of water in the IJsselmeer) and from the lack of sufficient transport capacity in the region in DEX, 1959, and 1943 (there were negligible preventable losses in 1967). The losses are allocated to the three provinces associated with the region. The tables show that almost all of the region's losses occurred in Drenthe and resulted from a lack of sufficient capacity to transport water to that province. Our

Table 6.6

AGRICULTURE LOSSES IN NORTHEAST HIGHLANDS (Dflm)

	Low Intensity		High Intensity	
	No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
1943:				
Total shortage losses	361	351	323	299
Preventable shortage losses	--	--	6	16
Salinity losses	--	--	--	--
DEX:				
Total shortage losses	1350	1319	1224	1182
Preventable shortage losses	2	5	42	111
Salinity losses	--	--	--	--

Table 6.7a

PREVENTABLE LOSSES (Dflm) FOR NORTHEAST HIGHLANDS BY PROVINCE
(High Sprinkler Intensity, without Waterboard Plans)

	DEX				
Province	IJsselmeer Level	Transportation Capacity	Total Losses	1959	1943
Drenthe	0.0	40.5	40.5	8.7	6.3
Overijssel	0.2	0.2	0.4	0.1	0.0
Gelderland	0.0	0.6	0.6	0.3	0.0
Northeast Highlands	0.2	41.3	41.5	9.1	6.3

Table 6.7b

PREVENTABLE LOSSES (Dflm) FOR NORTHEAST HIGHLANDS BY PROVINCE
(High Sprinkler Intensity, with Waterboard Plans)

	DEX				
Province	IJsselmeer Level	Transportation Capacity	Total Losses	1959	1943
Drenthe	0.0	96.0	96.0	32.7	14.9
Overijssel	3.3	10.5	13.8	5.1	1.3
Gelderland	0.8	0.7	1.5	0.0	0.1
Northeast Highlands	4.1	107.2	111.3	37.8	16.3

analysis, therefore, concentrated on tactics that addressed this problem.

The scenario "low sprinkler intensity, no waterboard plans" reflects the current situation most closely. Although the DEX demands shown for this scenario in Tables 6.4 and 6.5 are mostly below the supply capacities (and DEX is designed to reflect 1976 demands), the actual 1976 experience was different. In that year, the supply capacity of the Twenthekanaal was barely sufficient to meet the demands for extractions, and the supply capacity of the Drentsche Hoofdvaart route was insufficient. The discrepancy between the actual demands in 1976 and the demands generated for DEX reflect losses from the surface water distribution system that are not taken into account in our models. The cause and nature of the discrepancy in the demands are more extensively discussed in Vol. XII. At this point, it suffices to say that the four demand scenarios used in our models seem to somewhat underestimate the actual demands. As a consequence, we underestimate the benefits of tactics that expand the supply capacity. Such tactics therefore would actually be somewhat more promising than we find them to be if the demands were to be adjusted upward appropriately.

6.2. EXPAND SUPPLY CAPACITY TO NORTHEAST HIGHLANDS

Five groups of tactics for increasing the supply capacity to the Northeast Highlands were evaluated. Two of the five would expand the existing supply routes (the Twenthekanaal and Drentsche Hoofdvaart routes). The other three would create new supply routes. All five of the alternatives include tactics for expanding the throughput capacity to 2 m^3/s along the western portion of the Oranjekanaal (by expanding the pumping capacity at Smildersluis, Zwiggeltersluis, and Orveltersluis), to 5 m^3/s along the eastern portion of the Oranjekanaal (by expanding the pumping capacity at Oranjesluis), and to 7 m^3/s along the eastern portion of the Verlengde Hoogeveensche Vaart (by expanding the pumping capacity at Ericasluis). (See Fig. 6.3.) These expansions were specified in such a way that the throughput capacity to Districts 10 and 11 in southeastern Drenthe would be large enough to meet most of their surface water demands in the high sprinkler intensity scenario no matter which of the alternative routes were implemented. The five routes are shown on the schematized map in Fig. 6.2 and are briefly described below. A more complete description of the changes to the infrastructure that would be required by the routes and their costs is given in Vol. XVI.

Using the information presented in Tables 6.3, 6.4, and 6.5, we decided that a suitable expansion for the region's supply capacity would be 10 m^3/s for the SPRHI-RNONE demand scenario and 15 m^3/s for the SPRHI-RALL scenario. This expansion would provide sufficient capacity to meet the entire demands of the region in all but the worst decades of the driest years.

6.2.1. Description of Alternative Routes

Route 1: Twenthekanaal (See Fig. 6.4.)

As mentioned above, the capacity of the Twenthekanaal route is limited by the pumping station at Eefde, which has a capacity of 11 m^3/s, and the lock at Almelo, which has a capacity of 5 m^3/s. Expansion of the supply capacity of this route would, therefore, require expansions of these two facilities. These two expansions alone, however, would enable water from the Twenthekanaal to be used only to increase the supply of water to the province of Overijssel, and not to the province of Drenthe. Without additional improvements, the water could not be transported beyond Coevorden, in southeast Drenthe. In order to transport it farther north, a pumping station would have to be built on the Stieltjeskanaal to bring the water to the Verlengde Hoogeveensche Vaart. The annualized fixed costs for these changes (including the changes along the Oranjekanaal and the Verlengde Hoogeveensche Vaart) are shown in Table 6.8, which presents the comparable costs for enabling each of the five alternative routes to expand the supply capacity to the Northeast Highlands by 10 m^3/s and 15 m^3/s.[1] It should be noted that the annualized fixed costs are the only significant costs for all alternatives besides this one. The Twenthekanaal route extracts water from the IJssel River, which is an important shipping route. These extractions decrease the depth of the river, which may prevent some ships from transporting goods along the river during periods of low river flows. As a result, shipping costs are increased, reducing the attractiveness of the route. The increased shipping costs must therefore be considered in the analysis of this route.

Route 2: Hoogeveensche Vaart (See Fig. 6.5.)

There are two alternative ways of increasing the capacity for distributing throughout the province of Drenthe water that comes from the Zwartemeer through the Meppelerdiep. One is to increase the capacity of the current supply route, which uses the Drentsche Hoofdvaart (see Route 4, below). The other is to add pumping capacity to the Hoogeveensche Vaart, which currently has none. This alternative would require building four pumping stations on the Hoogeveensche Vaart. The annualized fixed costs for this route are shown in Table 6.8.[2]

Route 3: Van Starkenborghkanaal (See Fig. 6.6.)

It is possible to get water to Drenthe by transporting it through the provinces of Friesland and Groningen. This path would extract water from the Van Starkenborghkanaal and transport it through the Noord-Willemskanaal to Drenthe. Just as in the case of the expansion of supply capacity to Groningen (see Sec. 5.2), this route would require expanding the throughput capacity of the Van Starkenborghkanaal at Gaarkeuken. Since there is currently no pumping capacity on the Noord-Willemskanaal, this route would also require building three new pumping stations along that canal. These improvements would be

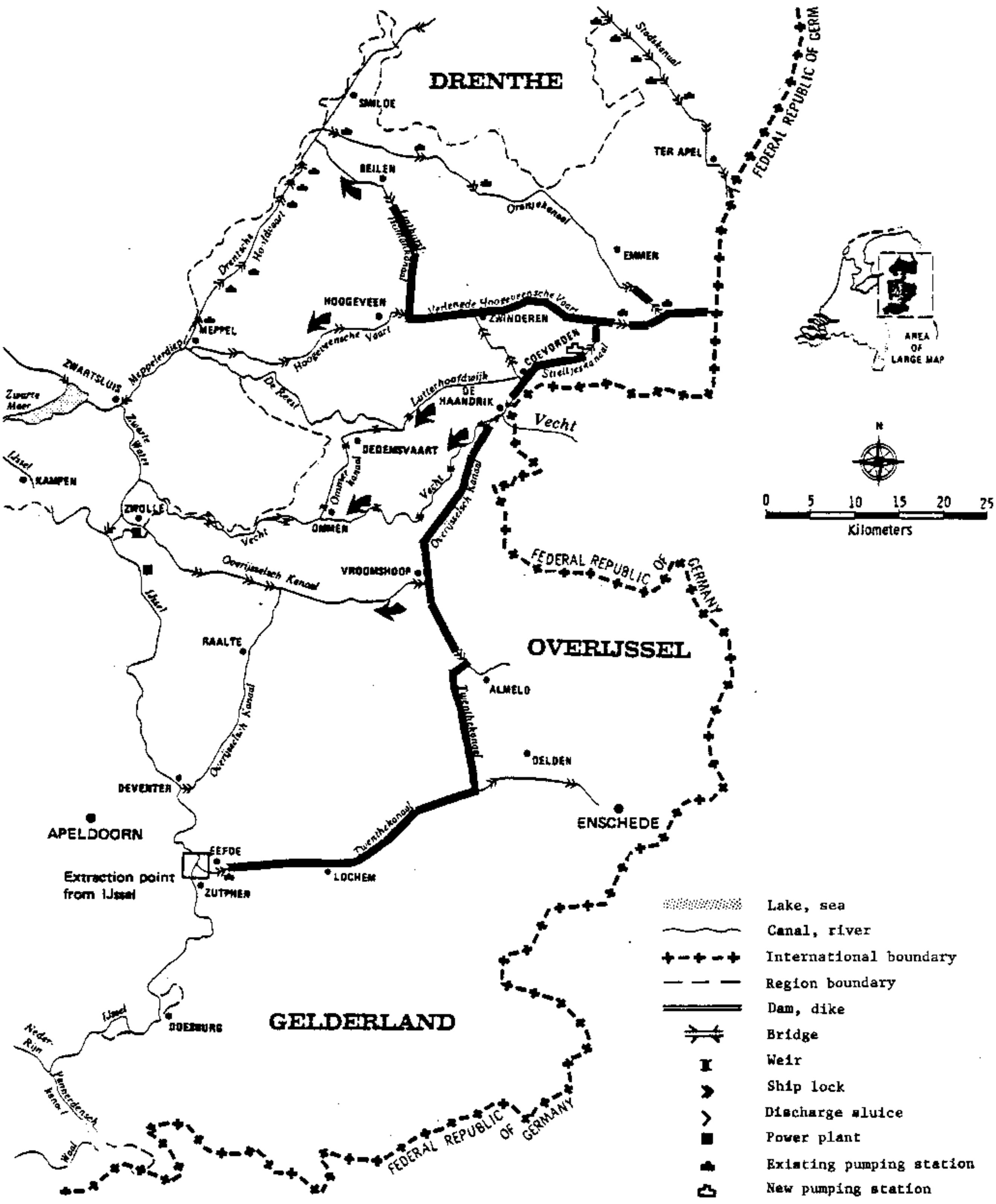


Fig. 6.4--Twenthekanaal supply route

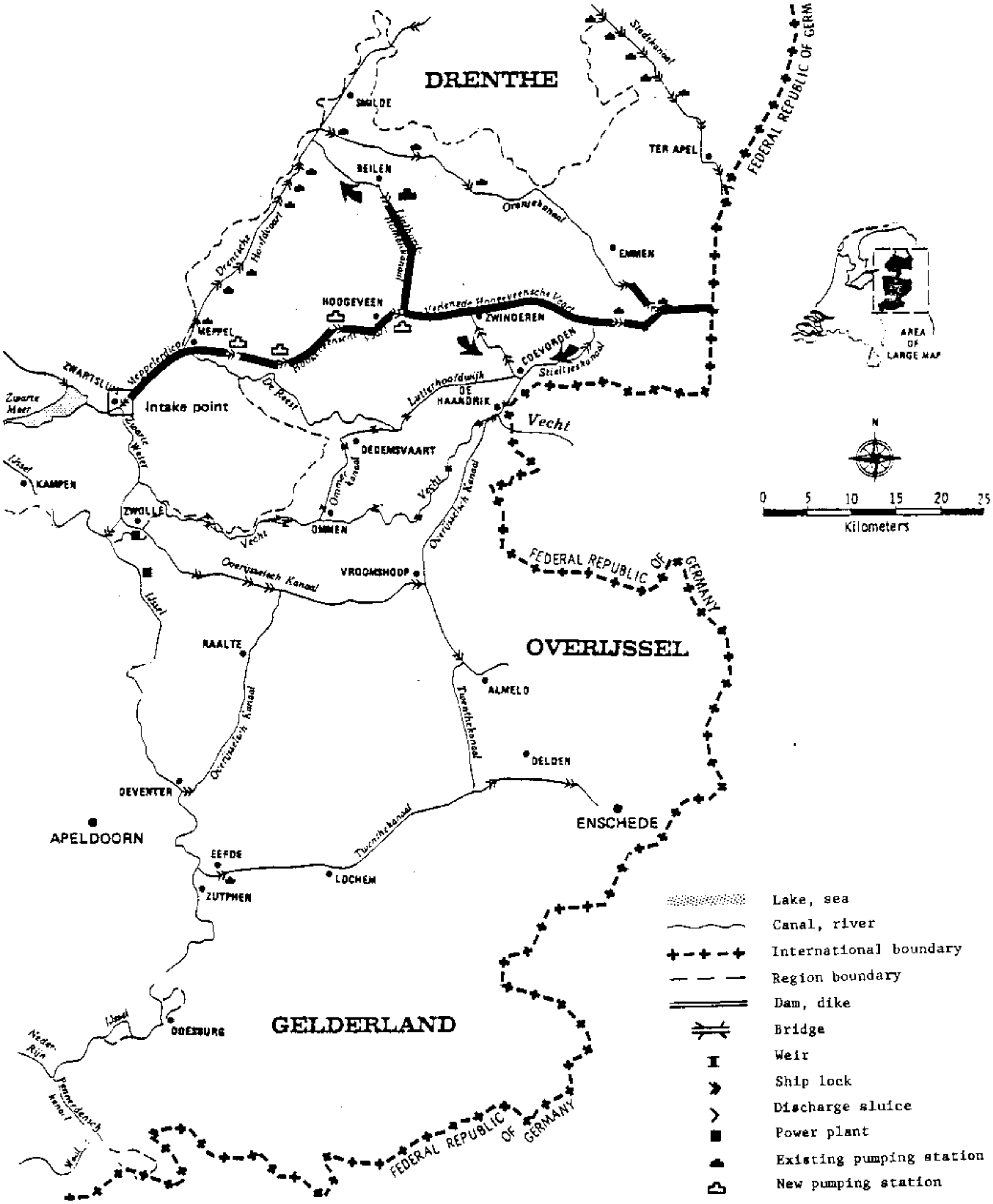


Fig. 6.5--Hoogeveensche Vaart supply route

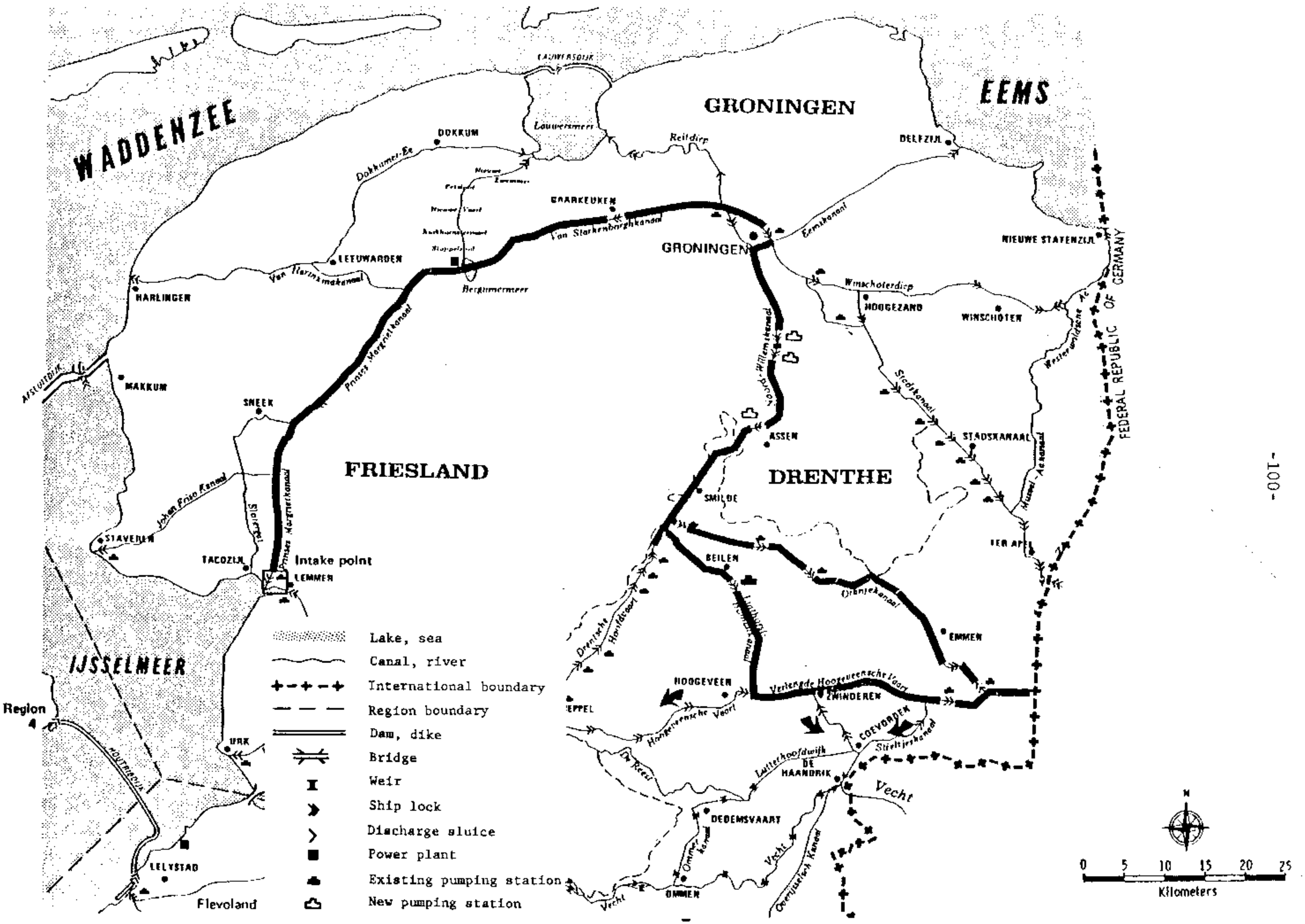


Fig. 6.6—Van Starkenborghkanaal supply route

sufficient to bring the additional water to Smilde. However, in order to distribute it throughout Drenthe, the pumping capacity along the Linthorst-Homankanaal (at Beilersluis) would also have to be expanded. The annualized fixed costs for this route are shown in Table 6.8. Expanding the throughput capacity of the Van Starkenborghkanaal by 15 m^3/s would involve expanding the carrying capacity of the Prinses Margrietkanaal in various places. The cost of these expansions has not been included in the cost of this tactic. Thus, the annualized fixed cost of 5.06 Dflm given in Table 6.8 underestimates the tactic's true cost.

Route 4: Drentsche Hoofdvaart (See Fig. 6.7.)

This is one of the two routes currently used for supplying water to the Northeast Highlands. The capacity of this route is limited by the capacities of the pumping stations on the Drentsche Hoofdvaart. Expanding the supply capacity of this route would therefore require expanding the pumping capacity of the six pumping stations along the Drentsche Hoofdvaart. Distribution of the additional water throughout Drenthe would also require expanding the pumping capacity along the Linthorst-Homankanaal (at Beilersluis). The annualized fixed costs for this route are shown in Table 6.8.

Route 5: Overijsselsche Vecht (See Fig. 6.8.)

An alternative to the Meppelerdiep for transporting water from the Zwartemeer to Drenthe is to send the water through the Zwarte Water, upstream along the Overijsselsche Vecht, and then through the Coevorden-Vechtkanaal. This route would require building pumping stations on the Overijsselsche Vecht, which currently has none. Once in Drenthe, the water would be transported through the Stieltjeskanaal, the Verlengde Hoogeveensche Vaart, and the Oranjekanaal. A pumping station on the Stieltjeskanaal would need to be built. The annualized fixed costs for this route are shown in Table 6.8.

6.2.2. Analysis of Alternative Routes

Routes 1 and 5 bring additional water to the southeastern part of Drenthe through the Stieltjeskanaal, allowing the current supply capacity along the Drentsche Hoofdvaart, the Oranjekanaal (western sections), and the Linthorst Homankanaal to be used exclusively for central and southwestern Drenthe. Routes 2, 3, and 4, on the other hand, involve an expansion of the supply capacity to central and southwestern Drenthe; from there, additional water is transported to southeastern Drenthe through the Verlengde Hoogeveensche Vaart.

We first eliminated three of the alternative routes from detailed consideration by showing that each of them was dominated by one of the remaining two alternatives. In particular, Routes 3 and 4 are dominated by Route 2, and Route 5 is dominated by Route 1, as will be shown below.

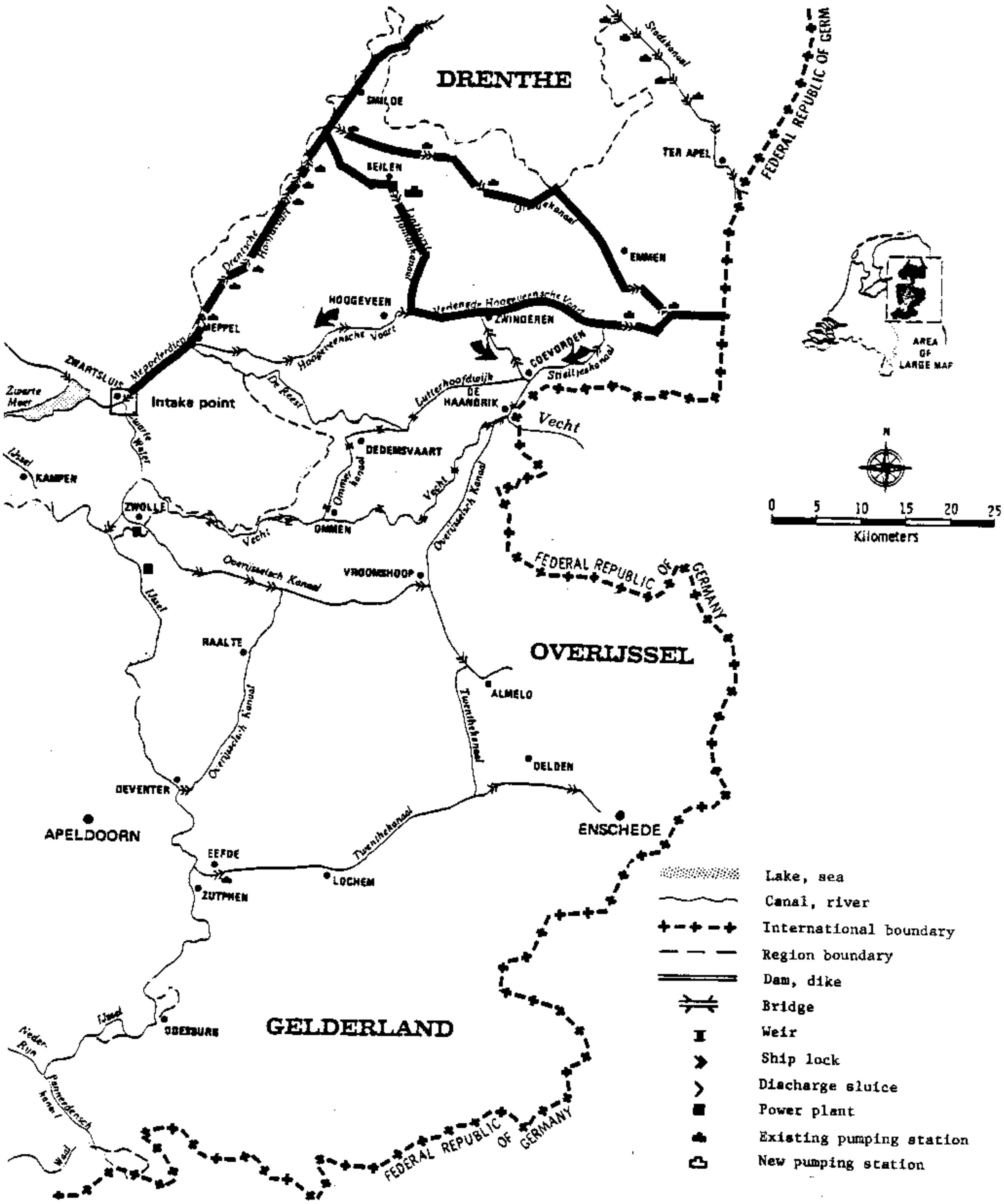


Fig. 6.7--Drentsche Hoofdvaart supply route

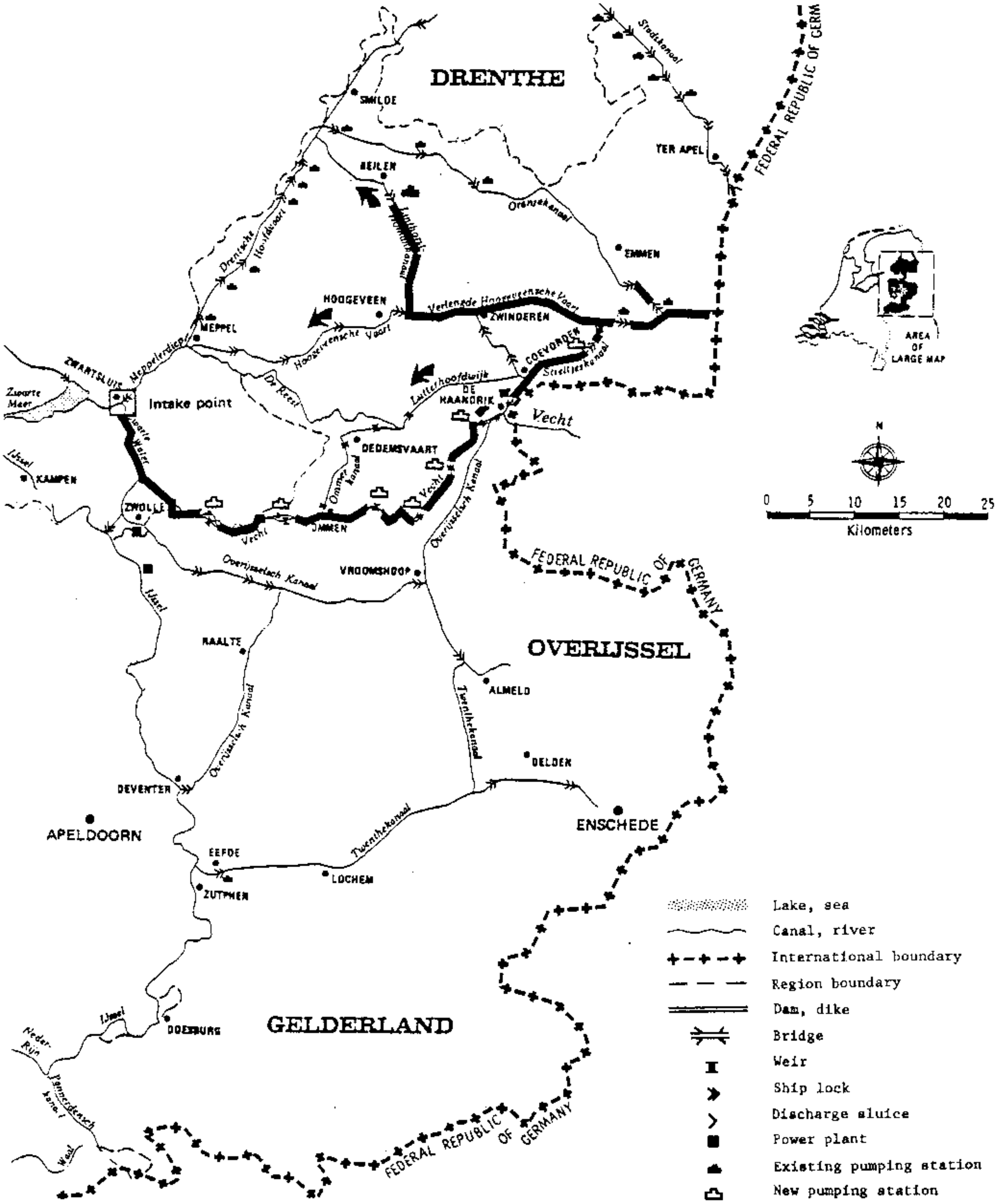


Fig. 6.8—Overijsselsche Vecht supply route

Table 6.8

ANNUALIZED FIXED COSTS OF ALTERNATE SUPPLY ROUTES FOR NORTHEAST HIGHLANDS (Dflm)

Route No.	Route Name	Tactics	Annualized Fixed Cost 10 m^3/s	Annualized Fixed Cost 15 m^3/s
1	Twenthekanaal	Twenthekanaal: P(a)	0.31	0.61
		Almelo Lock: B	0.06	0.06
		Stieltjeskanaal: P	0.30	0.59
		Oranjekanaal West: P	0.24	0.24
		Oranjesluis: P	0.24	0.24
		Ericasluis: P	0.31	0.31
		Total	1.46	2.05
2	Hoogeveensche Vaart	Hoogeveensche Vaart: P	2.38	3.57
		Oranjekanaal West: P	0.24	0.24
		Oranjesluis: P	0.24	0.24
		Ericasluis: P	0.31	0.31
		Total	3.17	4.36
3	Van Starkenborghkanaal	Gaarkeuken: B, P	0.60	1.21
		Noord-Willemskanaal: P	1.78	2.67
		Linthorst-Homankanaal: P	0.39	0.39
		Oranjekanaal West: P	0.24	0.24
		Oranjesluis: P	0.24	0.24
		Ericasluis: P	0.31	0.31
		Total	3.57	5.06
4	Drentsche Hoofdvaart	Drentsche Hoofdvaart: P	3.56	5.35
		Linthorst-Homankanaal: P	0.39	0.39
		Oranjekanaal West: P	0.24	0.24
		Oranjesluis: P	0.24	0.24
		Ericasluis: P	0.31	0.31
		Total	4.74	6.53
5	Overijsselsche Vecht	Overijsselsche Vecht: P	4.57	5.35
		Stieltjeskanaal: P	0.30	0.59
		Oranjekanaal West: P	0.24	0.24
		Oranjesluis: P	0.24	0.24
		Ericasluis: P	0.31	0.31
		Total	4.66	6.73

(a) P means build new pumping capacity or expand existing capacity. B means build a bypass.

Over 85 percent of the preventable losses in the Northeast Highlands occurs in Districts 10, 11, and 12, which comprise most of the province of Drenthe. Thus, all five routes are designed primarily to expand the supply capacity for these districts. Routes 3 and 4 bring the required water to Smilde, in the northeast part of the province, from where it is distributed throughout the province. Route 2 supplies those same districts from the south. All three routes can be expected to provide approximately the same benefits for the same increases in capacity. However, the annualized fixed costs of Routes 3 and 4 are higher than that of Route 2. Thus, if we find that Route 2 is not promising, we can conclude that Routes 3 and 4 are not promising. If Route 2 turns out to be promising, we can determine whether Routes 3 and 4 are likely to be promising by comparing their annualized fixed cost with the expected annual benefits from Route 2.

Roughly the same sort of reasoning can be used to eliminate Route 5 from detailed consideration. Routes 1 and 5 can supply additional water to districts in Overijssel and Drenthe. The annualized fixed cost for Route 1 is considerably below that of Route 5. However, the water for Route 1 is extracted from the IJssel River, which might cause additional losses to shipping during periods of low flows on the river. If these shipping losses average more than 3.2 Dflm for the case without waterboard plans (RNONE) or more than 4.7 Dflm for the case with waterboard plans (RALL), Route 5 would be more attractive than Route 1. However, in our analysis we found that the increased shipping losses are not this high. We can therefore conclude that, if we find Route 1 not to be promising, Route 5 will not be promising either. If Route 1 turns out to be promising, a comparison of its expected annual benefits with the annualized fixed costs of Route 5 will show whether or not Route 5 is also promising.

The remainder of this section is devoted to a comparison of the costs and benefits associated with Route 1 (the Twenthekanaal route) and Route 2 (the Hoogeveensche Vaart route).

Information with which to evaluate the benefits from Routes 1 and 2 was obtained from 18 separate runs of the Distribution Model. All runs were made for the high sprinkler intensity scenario (SPRHI), since the pre-screening analysis had shown that the preventable losses in the region were almost negligible in the low sprinkler intensity case. The runs were made assuming that there would always be enough water in the IJsselmeer to supply all demands; that is, we assumed that the tactic to increase the summer target level of the IJsselmeer to NAP - 0.10 m from NAP - 0.20 m would be implemented (see Sec. 11.4). If the lake level is not increased, implementation of either of the alternative routes will increase the agriculture shortage losses in very dry years in all areas that depend on the IJsselmeer and Markermeer for their surface water supply, since additional cutbacks in extractions from these lakes will be needed.

Table 6.9 compares the costs and benefits from the Twenthekanaal route with those from the Hoogeveensche Vaart route. Both routes provide roughly the same benefits (even after the increased shipping losses for the Twenthekanaal are taken into account^3), and, since the annualized fixed cost is less than the upper bound of expected annual benefits in both cases, both routes are promising. But the annualized fixed cost of the Twenthekanaal route is considerably less than that of the Hoogeveensche Vaart route, which suggests that the Twenthekanaal route is the most promising of all five routes. However, it is also one of the longest routes. The water for Drenthe must first pass through Gelderland and Overijssel. So, considerations besides costs and benefits might make the Hoogeveensche Vaart more attractive.

Table 6.9

COMPARISON OF COSTS AND BENEFITS (Dflm) FOR TWO ALTERNATIVE NORTHEAST HIGHLANDS SUPPLY ROUTES
(High Sprinkler Intensity)

Without Waterboard Plans

Route						Expected Benefits		Ann. Fixed Cost
No.	Name	DEX	1959	1943	1967	UB	LB	
1	Twenthekanaal	32.5	8.5	6.1	0.0	6.0	1.9	1.5
2	Hoogeveensche Vaart	33.5	8.8	6.4	0.0	6.3	2.0	3.2

With Waterboard Plans

Route						Expected Benefits		Ann. Fixed Cost
No.	Name	DEX	1959	1943	1967	UB	LB	
1	Twenthekanaal	84.3	29.2	13.4	0.0	15.6	5.0	2.1
2	Hoogeveensche Vaart	91.7	29.9	14.4	0.0	16.7	5.3	4.4

NOTE: Benefits for Route 2 are reductions in agriculture shortage losses. Benefits for Route 1 are reductions in agriculture shortage losses less increased shipping losses.

If we assume that the expected annual benefits from Routes 3 and 4 would be approximately the same as those for Route 2, and those from Route 5 would be approximately the same as those for Route 1, Tables 6.7 and 6.8 indicate that all five alternative supply routes are promising (i.e., their annualized fixed cost is less than the upper bound on their expected annual benefits) for both the RNONE and RALL scenarios. The tactics, however, must be implemented in conjunction with an increase in the summer target level of the IJsselmeer and Markermeer.

6.3. SUMMARY OF CONCLUSIONS

The increased demands for surface water envisioned in the high sprinkler intensity scenarios (with or without waterboard plans) lead to significant preventable agriculture losses in the Northeast Highlands. These preventable losses are caused primarily by insufficient capacity in the region's existing supply routes. Almost all of the losses occur in the three districts comprising central and southern Drenthe.

Five alternative routes for increasing the region's supply capacity were examined. All five were found to be promising for the high sprinkler intensity scenario (with or without waterboard plans). The most attractive alternative appears to be the route referred to as the Twenthekanaal route. It has the lowest annualized fixed cost of all the routes and provides approximately the same benefits as all of them do. Compared to the second most attractive route (the Hoogeveensche Vaart route), the Twenthekanaal route has the additional advantage of expanding the supply capacity to districts in Overijssel. Its primary disadvantage is its length. Water destined for farms in Drenthe would have to travel through waterways under the authority of different jurisdictions before reaching Drenthe. Water supplied via the Hoogeveensche Vaart route would have to travel only through waterways under the authority of the Provincial Government of Drenthe. This would undoubtedly make the Hoogeveensche Vaart route more attractive to the authorities in Drenthe.

Another disadvantage of the Twenthekanaal route is the fact that it extracts its water from the IJssel River, thus increasing shipping losses during periods of low flow on the river. However, according to the shipping loss functions we used in our analysis, these increased shipping losses are likely to be small.

NOTES

1. The annualized fixed costs presented in Table 6.8 differ from those presented at the final PAWN briefing held in the Netherlands in December 1979 because of subsequent corrections of errors and improvements in our information about the tactics. The changes in costs have not led to changes in any of our conclusions.
2. The tactic that uses the Hoogeveensche Vaart route to expand the supply capacity to the Northeast Highlands by 15 m^3/s corresponds to the plan labeled "Tussenplan -10 alteratief a" in Ref. 6.1.
3. The annual increase in shipping losses caused by additional extractions from the IJssel River for the Twenthekanaal route averaged less than 150,000 Dfl for the case without waterboard plans (RNONE) and less than 250,000 Dfl for the case with waterboard plans (RALL).

REFERENCE

6.1. Water naar Drenthe (The Water Supply of Drenthe), Report of the Study Committee for Water Supply to Drenthe, April 1979.

Chapter 7

SCREENING OF TACTICS FOR NORTH HOLLAND

7.1. OVERVIEW

The region called North Holland (Region 4) is that part of the province of Noord-Holland lying above the Noordzeekanaal. It consists entirely of lowlands. The predominant soil types in the region are clay and peat. Farmland covers 62 percent of the region's area. Of the farmland, about 62 percent is pastureland, and another 10 percent is devoted to growing various cereals. Over 10 percent of the region is urban area, and almost 20 percent is nature. Table 7.1 shows the distribution of the land in the region among its various uses in more detail.

Table 7.1

LAND USE IN NORTH HOLLAND

Use	Area (ha)	Percentage of Farmland	Percentage of Total Area
Farmland:			
Grass	71,733	61.9	
Cereals	11,708	10.1	
Sugar beets	7,774	6.7	
Vegetables (open air)	7,279	6.3	
Bulbs	7,013	6.1	
Seed potatoes	4,689	4.0	
Consumption potatoes	3,685	3.2	
Pit and stone fruits	1,454	1.2	
Other crops	565	0.5	
Total farmland	115,900	100.0	62.0
Nature	37,000		19.8
Urban	19,143		10.2
Surface	15,004		8.0
Total region	187,047		100.0

The demand for water in North Holland depends on the extent to which sprinkler equipment is used by farmers. In Table 7.2 we show the number of hectares that are sprinkled in the low and high sprinkler intensity demand scenarios. Since no waterboard plans in this region have been identified as promising, the number of hectares sprinkled does not vary with the implementation of waterboard plans. The table shows that the area sprinkled with surface water might increase by about 50 percent, from 29.0 percent of the farmland to 45.1 percent.

Table 7.2

SPRINKLED AND UNSPRINKLED FARMLAND (ha) IN NORTH HOLLAND UNDER TWO DEMAND SCENARIOS

Type of Area	Low Intensity	High Intensity
Farmland:		
Without sprinkling	81,545	62,881
With SW sprinkling	33,648	52,311
With GW sprinkling	707	707
Total	115,900	115,900

Table 7.3 shows the demands for extractions from the surface water distribution network that result from these scenarios. Four measures of demand are shown: the average decade and the driest decade for both the 1943 and DEX supply scenarios; the average decade demands are averages over decades having a positive demand.

Table 7.3

DEMAND FROM NORTH HOLLAND FOR EXTRACTIONS FROM NATIONAL SURFACE WATER DISTRIBUTION NETWORK (m^3/s)

Type of Decade		Low Intensity	High Intensity
1943:	Average decade	9.2	10.5
	Driest decade	27.8	36.3
DEX:	Average decade	12.2	14.8
	Driest decade	30.3	39.3

Figure 7.1 is a map showing the major waterways in North Holland, and Fig. 7.2 is the schematization of the surface water distribution network for the region that was used in the Distribution Model. The sources for the supply of surface water to the region are the Markermeer and the IJsselmeer. Water is extracted from these lakes at a number of points. The extractions at most of these points are small and supply relatively small areas located along the lakes. The area that depends on the Schermerboezem for its water supply forms the largest agricultural district in the region. It extracts its surface water at three points along the Markermeer: Edam, Lutjeschardam, and Monnickendam. The extensive system of waterways behind these inlet points allows access to the extracted surface water for the Schermerboezem area, as well as for five other districts in the region. The northern part of the region depends on the Amstelmeerboezem for its water. It receives its water from the IJsselmeer at Den Oever, just south of the point where the Afsluitdijk[1] joins the Noord-Holland mainland.

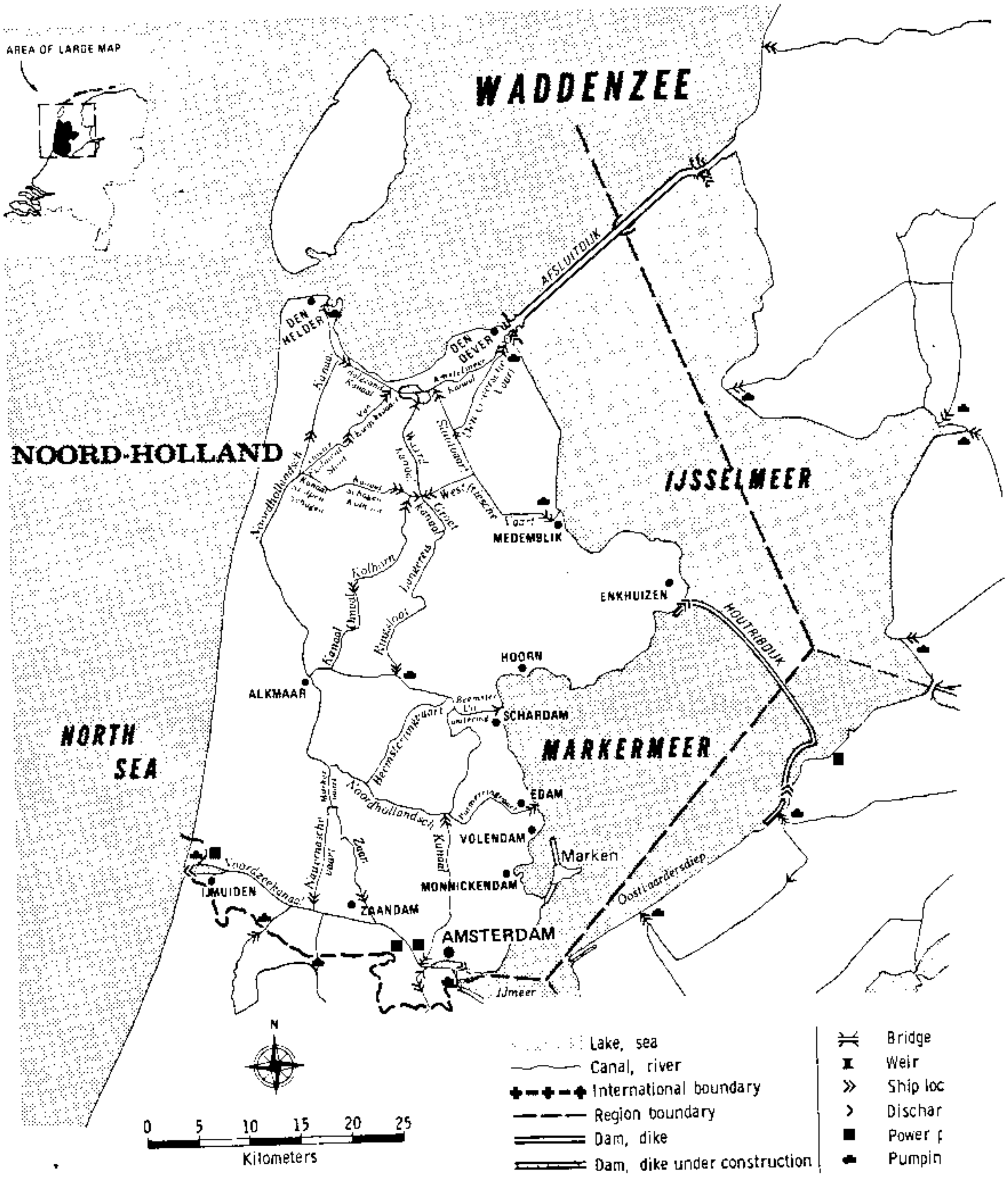


Fig. 7.1--Map of North Holland (Region 4)

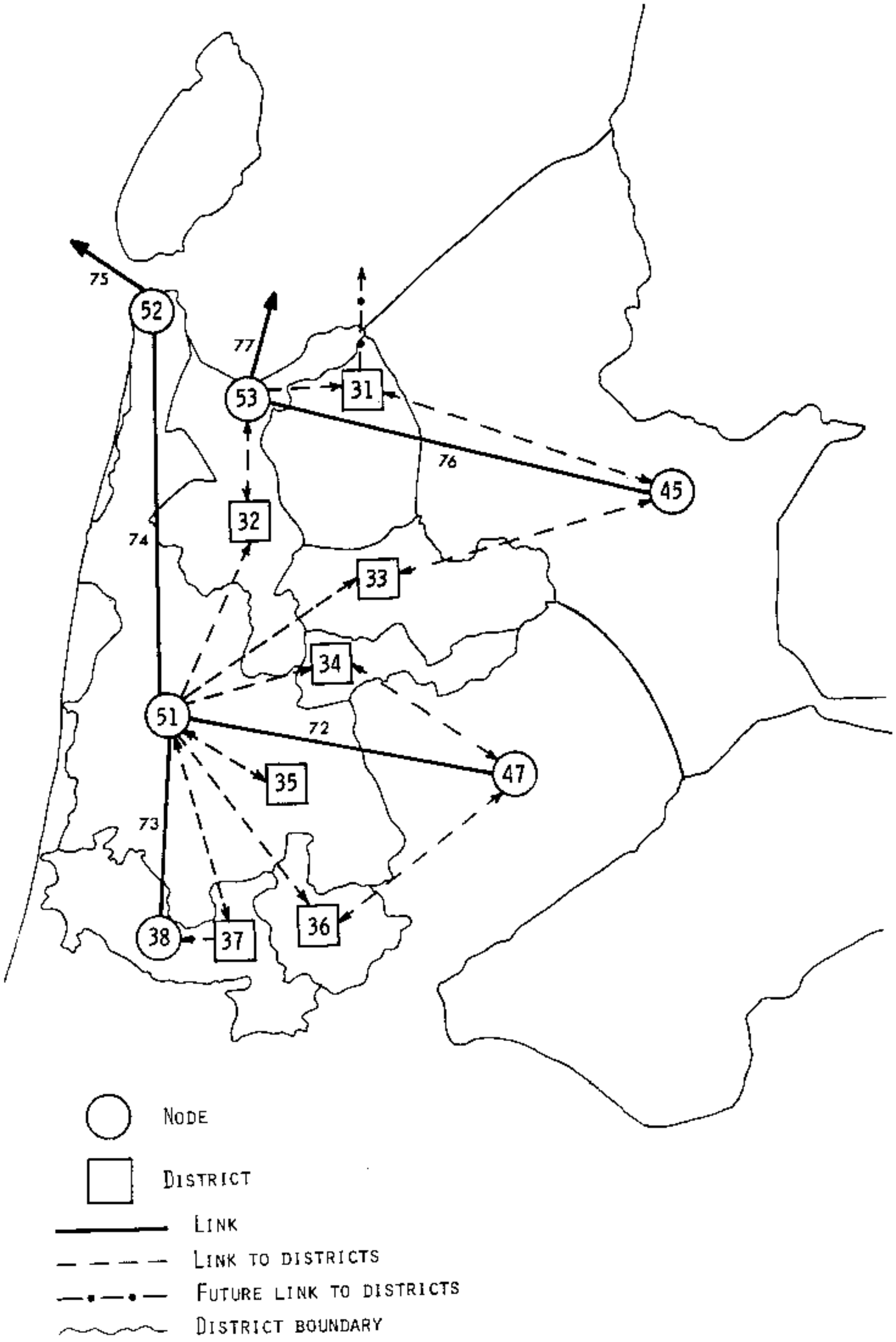


Fig. 7.2--Surface water distribution network for North Holland

In this region, two problems exist with respect to the supply and the management of the surface water distribution network. They are the same two problems that occur in Region 1, which were discussed in Sec. 5.1: the salinity of the waterways and the supply capacity to the region. North Holland's salinity problem is almost identical to that of the North: seepage is the principal cause of the high salinity level, while the Markermeer/IJsselmeer salinity and some salt intrusion from the North Sea and the Noordzeekanaal contribute to it. Due to a combination of high salinity and the occurrence of a salt-sensitive crop (1900 ha of bulbs), the salinity problem is most pressing in the northern part of the region. We evaluated one tactic that was designed to alleviate the salinity problem in North Holland.

The supply capacity problem is also similar to that in the North. First, the issue of the availability of surface water in the IJsselmeer and the Markermeer is equally relevant (see Sec. 5.1). Second, the throughput capacity of the canal system behind the three inlet locations for the Schermerboezem area is about 30 m^3/s, which is, in very dry decades, insufficient to satisfy the demand of the large area that depends on these inlet points. Table 7.4 shows the extraction demands for agriculture generated by the area that depends on these inlet locations for its supply of surface water; the categories of the demands are the same as the ones used in Table 7.3. The table also indicates a demand for flushing, which must be added to the demands on the upper lines of the table in order to obtain the desired capacity of the three inlet works and the adjoining canal system.[2] Table 7.4 shows that, at the current sprinkler intensity (i.e., for SPRLOW), the current supply capacity is sufficient to satisfy all demands for surface water of the area dependent on the three major inlet locations along the Markermeer. For the high sprinkler intensity scenario (SPRHI), the current supply capacity is barely sufficient for 1943 and insufficient for DEX.

Table 7.4

EXTRACTION DEMANDS AT INLET LOCATIONS
FOR SCHERMERBOEZEM AREA (m^3/s)

Type of Decade	Low Intensity	High Intensity
1943: Average decade	7.6	8.8
Driest decade	22.2	28.5
DEX: Average decade	9.6	11.8
Driest decade	23.9	31.3
Desired flushing	11.0	11.0
Minimum flushing	9.0	9.0

Table 7.5 shows, for both the low and the high sprinkler intensity scenarios, the losses to agriculture that occur under the 1943 and DEX

supply scenarios. This table confirms that, for the low sprinkler scenario, the inlet capacity to the region is sufficient, since no preventable losses are shown, and that, for the high sprinkler scenario, the inlet capacity is insufficient in DEX.

Table 7.5

AGRICULTURE LOSSES IN NORTH HOLLAND (Dflm)

	Low Intensity	High Intensity
1943:		
Total shortage losses	33	22
Preventable shortage losses	--	--
Total salinity losses	25	25
DEX:		
Total shortage losses	188	128(a)
Preventable shortage losses	--	5(a)
Total salinity losses	42	45

(a) Due to the effect of waterboard plans outside the region, the losses are higher for RALL: 133 and 11.

7.2. EXPAND SUPPLY CAPACITY TO SCHERMERBOEZEM

The supply capacity to the Schermerboezem is limited by the capacity of the inlet works and the adjoining canal system. The capacity of the inlet works varies depending on the level of the Markermeer (the higher the level, the greater the capacity). But at levels reflecting current lake management policies (NAP - 40 cm to NAP - 10 cm), the current supply capacity is approximately 30 m^3/s.

In the previous section, we showed that the current supply capacity to the Schermerboezem area is insufficient in very dry periods under the high sprinkler intensity scenario. A number of plans have been considered for increasing the supply capacity. Among these plans is the construction of a new canal from Lutjeschardam to Alkmaar [7.1]. Another, less costly, plan involves an expansion of one or more of the inlet works and/or the construction of a pumping station at the inlets so that water could be extracted if the lake levels were below NAP - 40 cm.

In DEX, agriculture shortage losses of 5.4 Dflm could be prevented by expanding the supply capacity to the Schermerboezem and surrounding areas. The lower and upper bounds on the expected annual benefits that could be derived by expanding the supply capacity are, therefore, 100,000 and 400,000 Dfl (see Table 7.6). This means that no tactic for increasing the supply capacity to the Schermerboezem is likely to be promising, since all plans under consideration have an annualized fixed cost in excess of 400,000 Dfl.

Table 7.6

REDUCTIONS IN AGRICULTURE SHORTAGE LOSSES (Dflm) FROM INCREASING SUPPLY CAPACITY TO THE SCHERMERBOEZEM
(High Sprinkler Intensity)

					Expected Annual Benefits	
	DEX	1959	1943	1967	UB	LB
RNONE	5.4	0.0	0.0	0.0	0.4	0.1
RALL	5.4	0.0	0.0	0.0	0.4	0.1

7.3. REDUCE WIERINGERMEERPOLDER'S CONTRIBUTION TO IJSSELMEER SALINITY

As noted in Sec. 5.3, reducing the salinity of the IJsselmeer and Markermeer would reduce agriculture salinity losses in 40 percent of the nation's cultivated area. The discharges of the Wieringermeerpolder are the most saline of any of the polder discharges entering the IJsselmeer lakes. In DEX, the salinity of the discharges averaged approximately 2500 ppm, and was over 3300 ppm in the driest decades. By contrast, the salinity of the discharges from the Noordoostpolder and Flevoland never exceeded 800 ppm in these scenarios. In an average year, discharges from the Wieringermeerpolder contribute about 10 percent of the total salt load entering the Ijsselmeer and Markermeer.

Since the Wieringermeerpolder is so close to the Waddenzee (see Fig. 7.3), it has been proposed that the discharges from the polder be diverted there. Such a change would require the modification of the outlet of the polder so that the discharge occurs directly adjacent to the Afsluitdijk discharge sluices rather than at the current location; in the existing situation a considerable degree of mixing of Wieringermeer drainage water with IJsselmeer water takes place. The annualized fixed cost of these changes is estimated to be 1.38 Dflm.

The primary beneficiaries of this tactic would be farmers in the Anna Paulownapolder (District 32 on the map in Fig. 7.2), whose water for irrigation is extracted from a point adjacent to the Wieringermeerpolder's discharge location. There would also be benefits to farmers in the Wieringermeerpolder (District 31), but we found that these benefits would be only about 5 percent of the benefits in District 32, so we disregarded them in the remainder of the analysis. An analysis of this tactic carried out by the RWS found that diversion of the Wieringermeerpolder's discharges to the Waddenzee would reduce the salinity of the intake water for District 32 by between 350 and 600 ppm [7.2]. We used the District Hydrologic and Agriculture Model

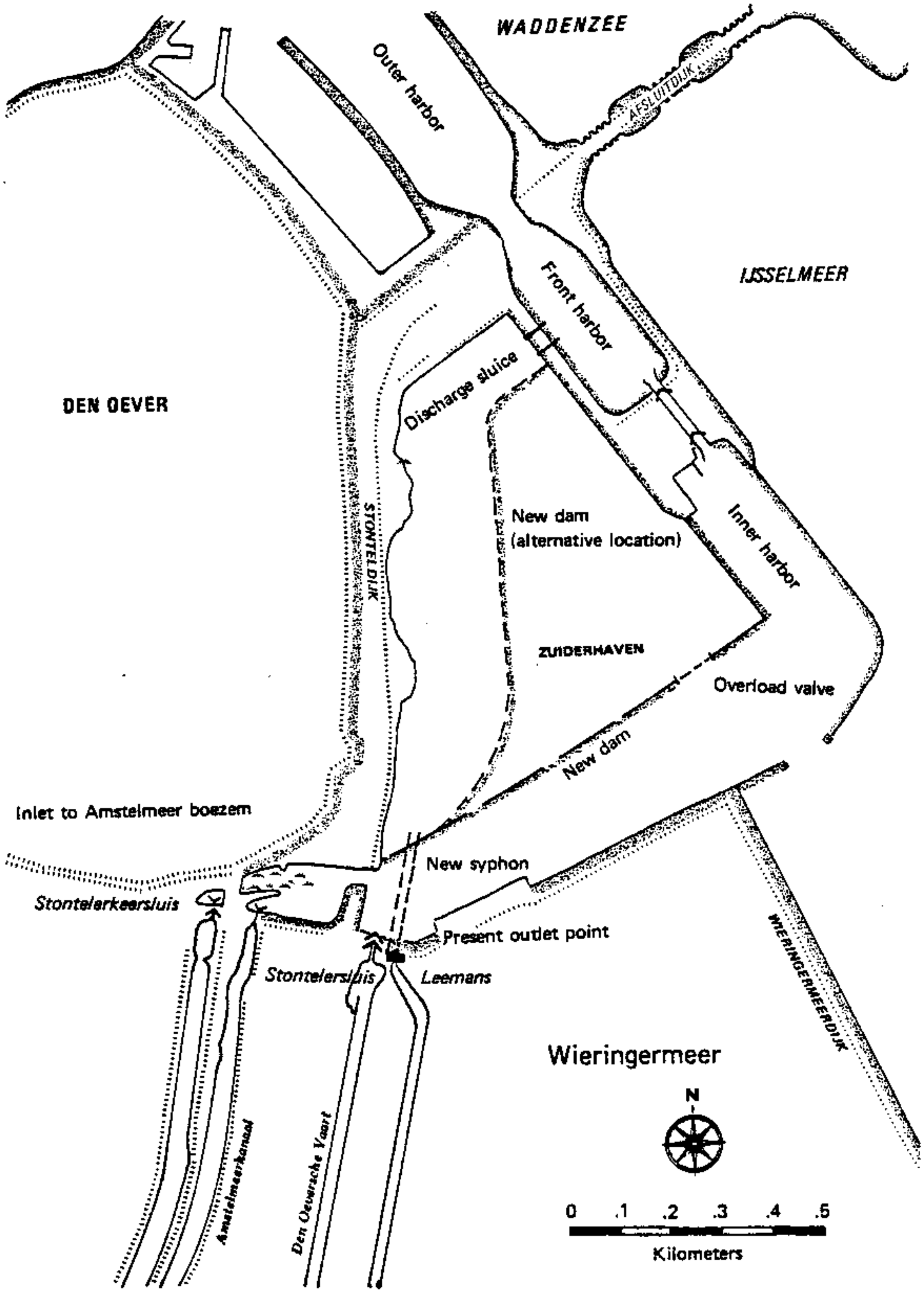


Fig. 7.3--Alternatives for redirecting Wieringermeerpolder discharges to Waddenzee

(see Vol. XII) to estimate the reductions in salinity losses that would result from such changes in the salinity of this district's intake water.

The District Hydrologic and Agriculture Model was run using intake water salinities varying between 250 and 1000 ppm for the four supply scenarios (DEX, 1959, 1943, and 1967). The sprinkling scenario used was SPRHI-RALL. The results of these runs are summarized in Table 7.7. The table shows that the change in salinity losses is practically linear with the change in the salinity of the intake water for all four supply scenarios. We therefore estimated that the benefits per 150-ppm salinity reduction would be 1.37 Dflm in DEX, 0.94 Dflm in 1959, 0.57 Dflm in 1943, and .26 Dflm in 1967. Applying the formulas of Sec. 2.1.1, we found that the expected annual benefits per 150-ppm salinity reduction in District 32's intake water are between .26 Dflm and .56 Dflm. Thus, even if the reduction in salinity were only 370 ppm (near the low end of the range given in the RWS report), the upper bound on expected annual benefits to District 32 would be about the same as the annualized fixed cost of the tactic (1.38 Dflm). If the benefits to farmers in other districts are also included, the annualized fixed cost of the tactic would be less than the upper bound on the expected annual benefits even if the salinity reduction were only 350 ppm. We, therefore, found it to be a promising tactic.[3]

Table 7.7

REDUCTIONS IN AGRICULTURE SALINITY LOSSES (Dflm) IN DISTRICT 32
FROM DIVERTING WIERINGERMEERPOLDER DISCHARGES TO THE WADDENZEE
(High Sprinkler Intensity)

Reduction in Salinity (ppm)						Expected Annual Benefits	
From	To	DEX	1959	1943	1967	UB	LB
1000	850	1.39	0.96	0.55	0.26		
850	700	1.43	0.95	0.57	0.26		
700	550	1.45	0.91	0.58	0.25		
550	400	1.29	0.93	0.60	0.26		
400	250	1.29	0.96	0.57	0.27		
1000	250	6.85	4.71	2.87	1.30		
Average per 150 ppm		1.37	0.94	0.57	0.26	0.56	0.26
Expected for 350 ppm						1.31	0.61
Expected for 600 ppm						2.24	1.04

7.4. SUMMARY OF CONCLUSIONS

There are no serious water management problems associated with this region. The only agricultural shortage losses occur in extremely dry years because of insufficient supply capacity to the Schermerboezem. However, the losses are not large enough to justify the cost of making changes to the infrastructure to expand this supply capacity.

The dumping of the discharges from the Wieringermeerpolder into the IJsselmeer increases agriculture salinity losses in districts that extract from the IJsselmeer. The reduction in salinity losses in one of these districts (the area dependent on the Amstelmeer boezem) from diverting the discharges to the Waddenzee is likely to be sufficiently large to more than offset its cost. Constructing facilities to redirect the Wieringermeerpolder discharges to the Waddenzee is, therefore, a promising tactic.

NOTES

1. The Afsluitdijk is the barrier dam that connects Noord-Holland with Friesland, thereby closing off the IJsselmeer from the Waddenzee.
2. The water used for flushing is discharged at Den Helder, Zaandam, and Nauerna.
3. We presented our original analysis of this tactic at the PAWN project's final briefing, which was held in the Netherlands in December 1979. After that briefing, information brought to our attention about the impact of the tactic on the salinity of the intake water for several polders led us to revise the analysis and change our conclusion. In this volume we present the revised analysis.

REFERENCES

7.1. Heidemij Nederland B.V., Kanaal Lutjeschardam-Alkmaar (Canal from Lutjeschardam to Alkmaar), February 1975.
7.2. Unpublished information from the Rijkswaterstaat regarding the redirection of discharges from the Wieringermeerpolder, March 1978 (PAWN file DW-335).

Chapter 8

SCREENING OF TACTICS FOR MIDWEST AND UTRECHT

8.1. OVERVIEW

The region called Midwest and Utrecht (Region 5) covers the southern part of the province of Noord-Holland (the portion south of the Noordzeekanaal), the northern part of the province of Zuid-Holland (the portion north of the Lek and the Rotterdamse Waterweg), and the entire province of Utrecht. Only the eastern part of Utrecht is highlands. The remainder of the region is lowlands and includes the lowest point in the Netherlands--NAP - 6.7 m at a point northeast of Rotterdam. The predominant soil types in the region are clay and peat.

The country's three largest cities are in this region: Amsterdam, The Hague, and Rotterdam. As a result, almost 15 percent of the region is urban area. Farmland covers just over half of the region. Of the farmland, about three-quarters is pastureland. The remaining 25 percent is used for raising various crops. Among these crops, the ones of major economic importance are vegetables under glass (mainly tomatoes, cucumbers, and lettuce) and flowers under glass (mainly roses, carnations, and chrysanthemums), which are grown in heated glasshouses in the Westland, south of The Hague. The region also contains the famous bulb fields, located behind the dunes to the south of Haarlem. Table 8.1 shows the distribution of the land in the region among its various uses in more detail.

Table 8.1

LAND USE IN MIDWEST AND UTRECHT

Crop	Area (ha)	Percentage of Farmland	Percentage of Total Area
Farmland:			
Grass	114,978	74.9	
Cereals	10,647	6.9	
Sugar beets	5,954	3.9	
Bulbs	3,741	2.4	
Pit and stone fruits	3,334	2.2	
Vegetables (open air)	3,212	2.1	
Consumption potatoes	3,106	2.0	
Vegetables under glass	2,941	1.9	
Flowers under glass	2,561	1.7	
Other crops	3,135	2.0	
Total farmland	153,609	100.0	51.6
Nature	76,670		25.7
Urban	42,214		14.2
Surface water	25,276		8.5
Total region	297,769		100.0

As in other regions, the demand for water for agriculture depends on the extent to which sprinkler equipment is used by farmers. Table 8.2 shows the number of hectares that are sprinkled under each of the demand scenarios. It shows that the area sprinkled with surface water might double in the future, from 18.4 percent of the farmland to 37.3 percent (38.6 percent if the single waterboard plan is implemented). Note that if the sprinkler intensity does not increase, implementation of the waterboard plan has no effect because in the affected area the current sprinkling intensity is zero, except for one crop which is fully sprinkled.

Table 8.2

SPRINKLED AND UNSPRINKLED FARMLAND (ha) IN MIDWEST AND UTRECHT UNDER FOUR DEMAND SCENARIOS

	Low Intensity		High Intensity	
Type of Area	No W/B Plan	With W/B Plan	No W/B Plan	With W/B Plan
Farmland:				
Without sprinkling	124,110	124,110	95,064	93,143
With SW sprinkling	28,272	28,272	57,318	59,239
With GW sprinkling	1,227	1,227	1,227	1,227
Total	153,609	153,609	153,609	153,609

Table 8.3 indicates the demands for extraction from the surface water distribution network that result from these scenarios. As before, the four measures of demand shown are the demands during the average and the driest decade for both the 1943 and DEX supply scenarios; the average decade demands are averages over decades having a positive demand.

Table 8.3

DEMAND FROM MIDWEST AND UTRECHT FOR EXTRACTIONS FROM NATIONAL SURFACE WATER DISTRIBUTION NETWORK (m^3/s)

			High Intensity	
Type of Decade		Low Intensity	No W/B Plan	With W/B Plan
1943:	Average decade	10.5	11.9	11.9
	Driest decade	24.6	31.7	31.7
DEX:	Average decade	14.3	16.9	16.9
	Driest decade	29.2	39.5	39.5

Figure 8.1 is a map showing the major waterways in the Midwest and Utrecht, and Fig. 8.2 is the schematization of the surface water distribution network for the region that was used in the Distribution Model. The sources for the supply of surface water to the region are the Nieuwe Maas, the Lek, and the Amsterdam-Rijnkanaal. The principal inlet point for the region's boezems is located along the Hollandsche IJssel at Gouda (we call this the Gouda inlet); the Hollandsche IJssel receives most of its water in turn from the Nieuwe Maas. The Gouda inlet provides the surface water supply for half of the farmland in the region--an area under the jurisdiction of the Rijnland, Delfland, and Schieland waterboards, which we refer to collectively as the Midwest (the shaded area in Fig. 8.3). (The economically important area of the Westland is located within the territory of the Delfland waterboard.)

The remainder of the region is supplied from various inlet points along the Lek (Wijk bij Duurstede, Vreeswijk, Schoonhoven) and the Amsterdam-Rijnkanaal (Jutphaas, Utrecht, Abcoude). Most of the time, these inlet points provide water only to the area directly adjacent to them. Under certain exceptional circumstances, however, they are also used for the supply of Rijnland, Delfland, and Schieland; these inlets, together with the waterways that link them with the boezems of the Midwest, comprise what are referred to as the Midwest emergency supply facilities (see Fig. 8.3).

The major water management problem in the region is the high salinity of the surface water in the regional waterway system, notably in that part of the system that is dependent on the Gouda inlet. This salinity causes considerable losses to the important crops in the Westland and, to a lesser extent, in Rijnland. The most valuable crops grown here tend to be very sensitive to salt--glasshouse vegetables, glasshouse flowers, and bulbs in particular. For glasshouse cucumbers, salinity damage begins when the salinity in the root zone is as little as 250 ppm. Above that level, studies suggest that yields decrease by 6 percent on a yearly basis for every additional 100 ppm of average salinity during the growing season. By contrast, for grass, the most valuable crop in all other regions of the country, damage to yields starts to occur when the salinity reaches 1000 ppm in the root zone. Above 1000 ppm, the physical yield decreases by about 1 percent for every additional 100 ppm of average salinity during the growing season.

The causes of the high salinity are the same as in other low-lying areas: seepage, salt intrusion from the North Sea, and the salt load of the Rijn. The seepage problem is more severe than in some other low-lying areas because this area lies entirely below sea level (except for the dunes, but these are not relevant for our analysis). The current policy for reducing the salinity in the canal system due to seepage is to flush it with relatively fresh water from the Lek.

Two recent developments have reduced the effectiveness of this flushing policy. First, the salinity of the Rijn has been steadily increasing.[1] Since the salinity of the Rijn is a lower bound on the boezem salinity that can be achieved through flushing, the latter has increased as the salinity of the Rijn has increased.[2]

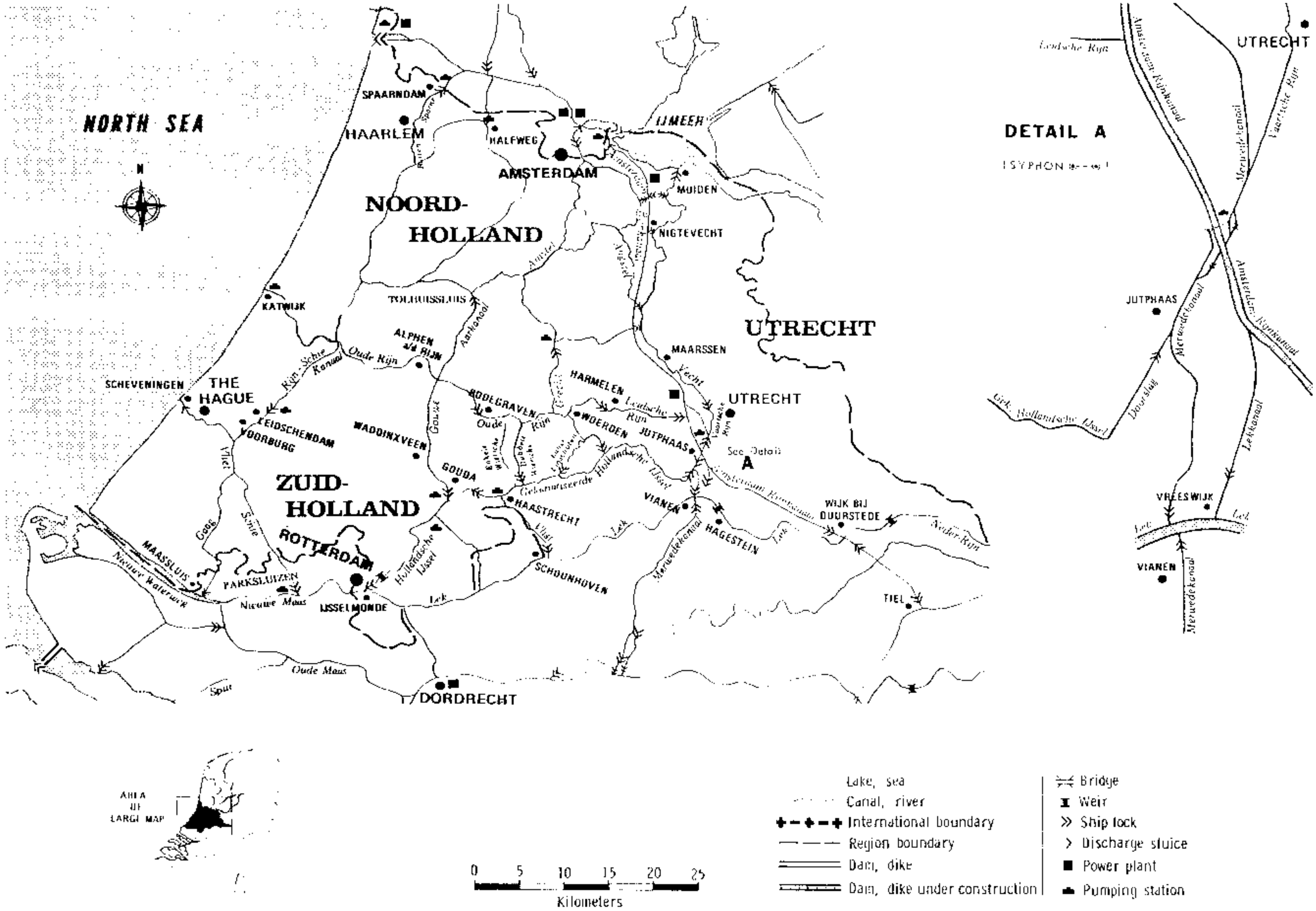


Fig. 8.1--Map of the Midwest and Utrecht (Region 5)

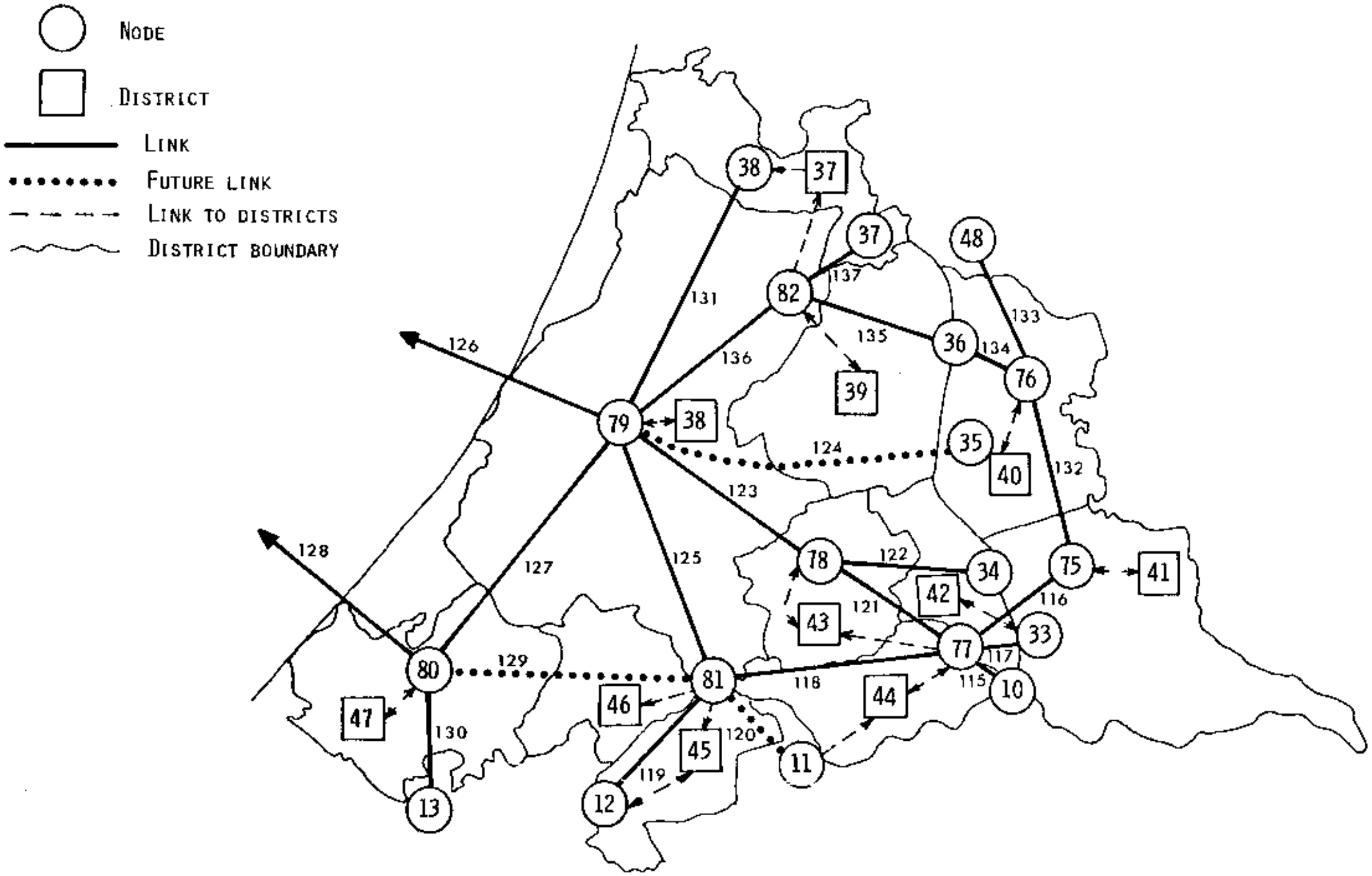


Fig. 8.2--Surface water distribution network for the Midwest and Utrecht

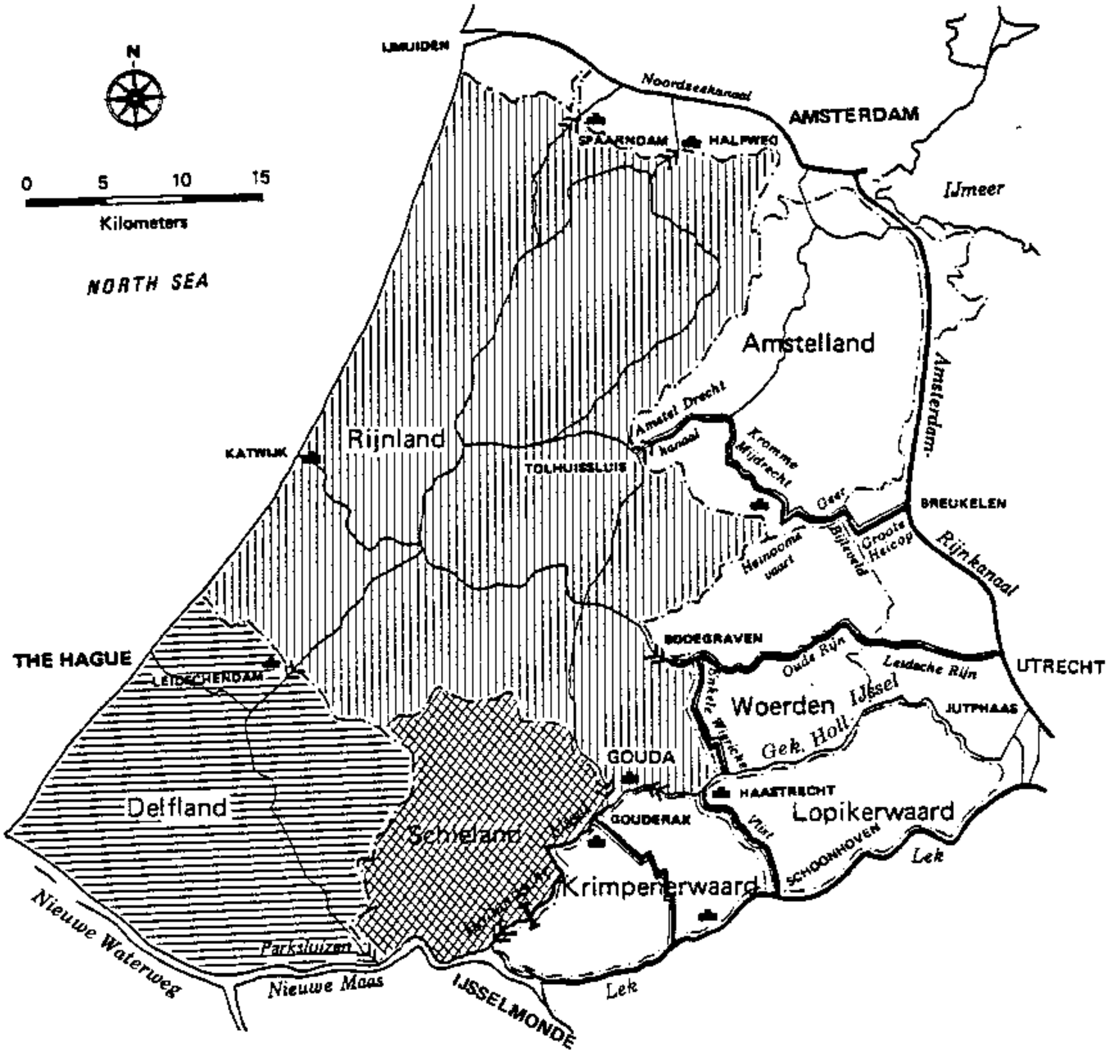


Fig. 8.3--Midwest, showing emergency supply routes

The second development that decreases the effectiveness of flushing has been the increase in salt intrusion from the North Sea along the Rotterdamse Waterweg due to a continual deepening of that waterway. The deepening was necessary in order to keep Rotterdam and the Europoort accessible for seagoing vessels, the average draft of which has been increasing in the recent past. The salt intrusion is now of such magnitude that the salt wedge occasionally reaches the mouth of the Hollandsche IJssel; in 1976, this occurred in three decades, when the Rijn flow at the border decreased to less than 900 m^3/s (the lowest observed flow was 782 m^3/s). Under such conditions, the emergency supply facilities are used to capacity in order to avoid sending the extremely saline water from the Hollandsche IJssel to the boezems behind the Gouda inlet. In addition, the flushing of these boezems is reduced to its absolute minimum. However, the net supply capacity of the emergency facilities to Rijnland, Delfland, and Schieland is only about 10 m^3/s (the capacity of the Gouda inlet is about 30 m^3/s). If this capacity is insufficient to keep the boezems at their target levels, saline water is let in at Gouda, since maintenance of boezem target levels is considered an absolute necessity. The question that the three waterboards in this area face is therefore how to secure a flow of relatively fresh water to the salt-sensitive crops in their territory or, at least, how to limit the salinity of the surface water to that of the Rijn. We have examined several tactics that address this issue.

Table 8.4 gives the water demand at the Gouda inlet for the four decades that were used in Table 8.3. The average decade demands are averages over decades having a positive demand. The last line of the table indicates the minimum flow that must be maintained for flushing in order to combat salt intrusion at the borders of the region. These minimum flushing demands must be added to the demands in the first four lines of the table to obtain the minimum extraction demands at the Gouda inlet.

Table 8.4

DEMANDS AT GOUDA INLET FOR EXTRACTIONS FROM THE HOLLANDSCHE IJSSEL (m^3/s)

Type of Decade		Low Intensity	High Intensity
1943:	Average decade	8.5	9.7
	Driest decade	22.1	27.6
DEX:	Average decade	12.1	14.4
	Driest decade	25.1	34.6
Desired flushing		14.0	14.0
Minimum flushing		8.5	8.5

The table shows that even the minimum demands exceed the capacity of the emergency supply facilities during most of the decades in which the Midwest needs to extract surface water for agriculture. As a result, saline water is let in at Gouda, and agriculture experiences considerable salinity losses.

There are some high agriculture shortage losses in the region. However, only a small part of these losses can be prevented by an expansion of the supply capacity. All preventable shortage losses occur in Delfland. Before the deepening of the Rotterdamse Waterweg, Delfland was able to extract its water directly from the Nieuwe Maas and the Nieuwe Waterweg, and an ample supply capacity was available. Now that the salt wedge penetrates much farther inland, Delfland can receive its water only via the Gouda inlet, after which it has to pass through the waterways of Rijnland before it arrives in Delfland. The canal that carries the water from Rijnland to Delfland (the Rijn-Schiekanaal) has a bottleneck at the Leidschendam pumping station, where the throughput capacity is 8 m^3/s. This bottleneck is the cause of all of the preventable shortage losses in Delfland.

In Table 8.5, we show for each of the demand scenarios the losses to agriculture that occur under the 1943 and DEX supply scenarios. The table shows that the salinity losses are very high, not only in DEX but also in less dry years. The preventable shortage losses all occur in Delfland.

Table 8.5

AGRICULTURE LOSSES IN MIDWEST AND UTRECHT (Dflm)

		High Intensity	
	Low Intensity	No W/B Plan	With W/B Plan
1943:			
Total shortage losses	36	22	19
Preventable shortage losses	--	2	2
Total salinity losses	210	214	214
DEX:			
Total shortage losses	278	191	181
Preventable shortage losses	8	30	30
Total salinity losses	292	315	329

8.2. REDUCE SALINITY LOSSES IN MIDWEST

As noted above, agriculture in this region incurs considerable salinity losses, even in relatively wet years. This is due to the sensitivity to salt of the most valuable crops, on one hand, and the high salinity levels in the region's waterways, on the other hand.

We considered two approaches for reducing the salinity problem in the boezems of the Midwest:

- Build a new canal as an alternative to the Hollandsche IJssel for transporting water from the Lek or the Amsterdam-Rijnkanaal to the boezem system of the Midwest.
- Reduce the chances that the salt wedge would reach the mouth of the Hollandsche IJssel by closing one or more of the river branches that empty into the Nieuwe Waterweg or by constructing a bubble screen or a groin in the Nieuwe Waterweg.

These two sets of tactics are evaluated and contrasted below. Three additional tactics that are specifically designed to reduce shortage and salinity problems in Delfland are discussed in Sec. 8.3.

8.2.1. Construct a New Canal To Replace the Hollandsche IJssel Supply Route

Four different tactics were considered for transporting Rijn-salinity water to the Midwest when the Hollandsche IJssel is salted up. They differ primarily with respect to

- Where they extract the Rijn-salinity water.
- How much new construction is required compared with expansion of existing facilities.
- The net amount of water that can be transported to the boezems of Rijnland, Delfland, and Schieland.

A number of characteristics of these tactics are summarized in Table 8.6. We briefly discuss each of the four tactics below.

Table 8.6

CHARACTERISTICS OF TACTICS FOR CARRYING RIJN-SALINITY WATER TO MIDWEST

Tactic No.	Tactic Name	Extracts from	Capacity (m^3/s)	Annualized Fixed Cost (Dflm)
1.	Build canal through Lopikerwaard	Lek	20.0	2.3
2.	Build canal through Lopikerwaard and expand Leidsche Rijn and Oude Rijn	Lek and Amsterdam-Rijnkanaal	30.0	3.9
3.	Build canal through Krimpenerwaard	Lek	40.0	5.7
4.	Build canal from Maarssen to Bodegraven	Amsterdam-Rijnkanaal	40.0	12.8

8.2.1.1. Build a Lopikerwaardkanaal. In this tactic, proposed by a working group in 1979,[3],[4] the supply of water for Rijnland comes from the Lek. The water would be extracted at a point approximately 7 km upstream from Schoonhoven. It would be transported across the Lopikerwaard and discharged into the Gekanaliseerde Hollandsche IJssel just east of Haastrecht (see Fig. 8.4). From there, part of the water would flow westward to the inlet at Gouda. The remainder would be transported through the Enkele Wiericke to the Oude Rijn, which would then carry it farther into Rijnland.

Half of the transport way through the Lopikerwaard will require digging a new canal (from the inlet point on the Lek to Polsbroek). The route from Polsbroek to the Gekanaliseerde Hollandsche IJssel follows existing waterways whose capacities have to be expanded. On the Lek at Wiel the inlet works would have to be expanded, and at Haastrecht the capacity of the existing pumping station would have to be increased. There are several alternative capacities that have been suggested for this route. We evaluated a tactic that would be able to bring a maximum of 20 m^3/s to the Gekanaliseerde Hollandsche IJssel, enabling the throughput capacity to Rijnland to be increased from 10 m^3/s to 20 m^3/s. Its annualized fixed cost is 2.3 Dflm.

8.2.1.2. Build a Lopikerwaardkanaal; Expand Leidsche Rijn Route. This is another tactic that was proposed in the 1979 report.[5] It expands the throughput capacity to Rijnland to 30 m^3/s--10 m^3/s more than does the preceding tactic. It would increase the extraction of water from both the Lek and the Amsterdam-Rijnkanaal. The route from the Lek would be the same as in Tactic 1. In addition, water would be extracted from the Amsterdam-Rijnkanaal at Utrecht. It would then follow the existing route to Rijnland--flowing through the Leidsche Rijn and the Oude Rijn (see Fig. 8.3). This route can currently carry up to 2.5 m^3/s from the Amsterdam-Rijnkanaal to Rijnland. The tactic would expand this capacity to 10 m^3/s.

The expansion would require making a number of small changes to the existing infrastructure, such as deepening canals, building pumping stations, and expanding locks. The most costly of these changes would be expanding the ship lock in the Oude Rijn that lies in the middle of the town of Bodegraven. All together, the improvements to the Leidsche Rijn route have an annualized fixed cost of 1.7 Dflm, resulting in an annualized fixed cost for the tactic of 3.9 Dflm.

8.2.1.3. Build a Krimpenerwaardkanaal. Although this tactic was considered by the 1979 working group,[6] it had been proposed earlier as a possible alternative to the Hollandsche IJssel for transporting water to Gouda.[7] There currently is a route from the Lek to the Hollandsche IJssel through the Krimpenerwaard that consists of many small polder canals and ditches. These waterways are a part of the existing emergency supply facilities. However, their capacity is only 5 m^3/s.

There are a large number of alternative designs for a new canal through the Krimpenerwaard presented in Ref. 8.3. The design we selected for

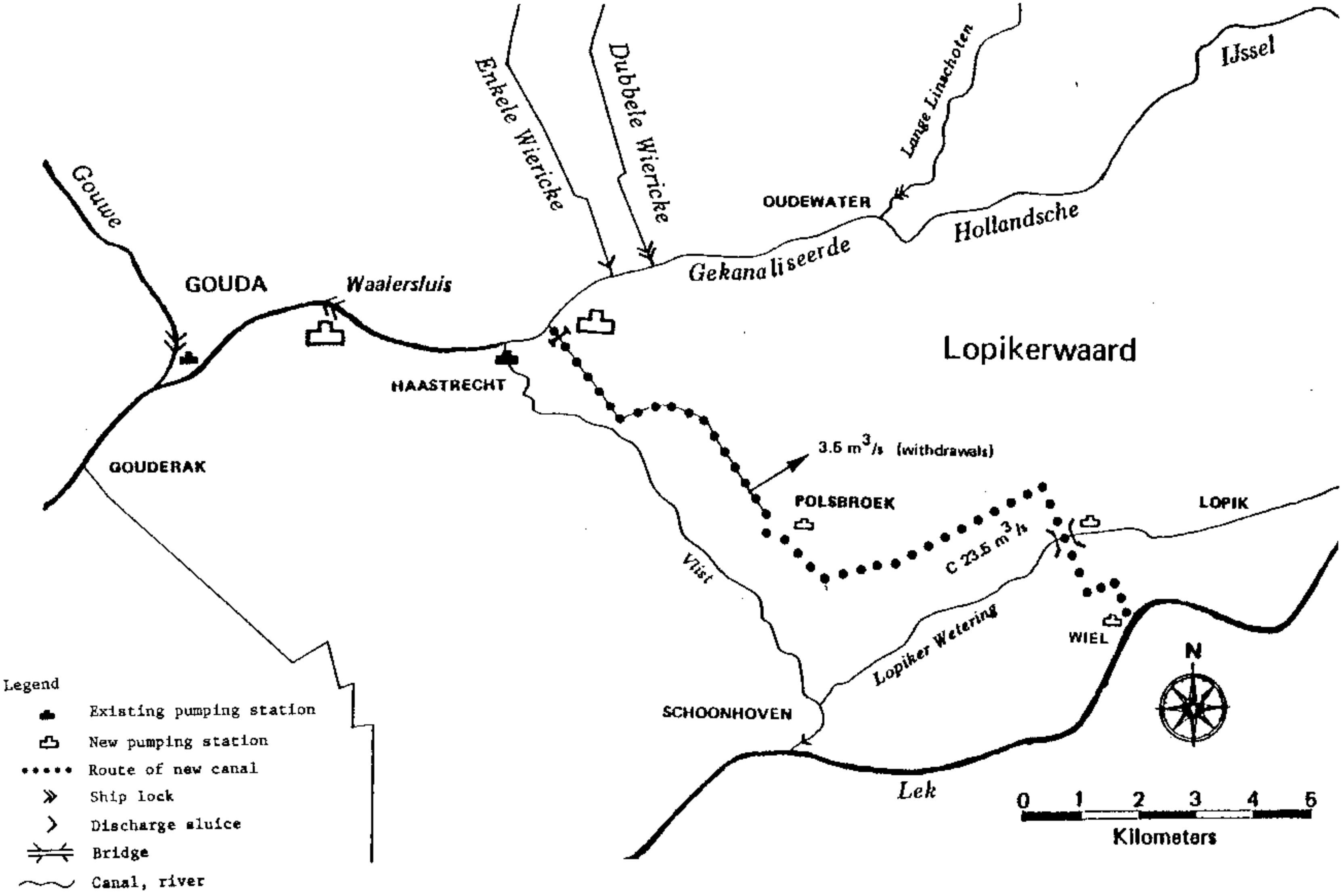


Fig. 8.4--Lopikerwaardkanaal route

evaluation was the design favored in the 1979 report for a canal with a capacity of 40 m^3/s [8.1]. It is a 13.0-km canal that extracts water from the Lek at a point approximately 6 km downstream from Schoonhoven, and empties into the Hollandsche IJssel at the entrance to the Gouwe (see Fig. 8.5). It would be built alongside the road from Bergambacht to Gouda for most of its length, and would include portions of existing canals (which would have to be widened). The canal would increase the throughput capacity to Rijnland to 40 m^3/s, and its annualized fixed cost is estimated to be 5.7 Dflm.

8.2.1.4. Build a Maarssen-Bodegravenkanaal. One of the earliest proposals for reducing the salinity of the water in the Midwest boezems was to extract water from the Amsterdam-Rijnkanaal at Maarssen and transport it to a point northwest of Bodegraven, where it would empty into the Oude Rijn. It is mentioned in the 1968 Nota De Waterhuishouding van Nederland [8.4]. Subsequently, a study group was formed to examine this tactic and other alternative tactics [8.1, 8.2, 8.5, 8.6].

The 1979 working group considered two basic routes for the canal, and also two different capacities (20 m^3/s and 40 m^3/s). We chose to evaluate a 20.9-km low canal with gravel banks, a pumping station at the Oude Rijn, and a capacity of 40 m^3/s.[8] The canal would extract its water from the Amsterdam-Rijnkanaal at a point approximately 1 km north of Maarssen, and transport it west to a point northwest of Zwammerdam, where the water would be discharged into the Oude Rijn[9] (see Fig. 8.6). In addition to the inlet and outlet works, and the canal itself, several crossings have to be built: the canal crosses 8 roads, 2 railways, 2 dikes, and a river.[10] The canal would increase the throughput capacity to Rijnland to 40 m^3/s, and its annualized fixed cost would be 12.8 Dflm.

8.2.1.5. Analysis of the Four Alternative Tactics. Tactics 1-4 all have the same objective: to provide an alternative route for transporting surface water to the Rijnland boezem when the Hollandsche IJssel is too saline due to the salt wedge. After implementation of any of these tactics, however, the Hollandsche IJssel would probably still remain the preferred source when the salt wedge has not penetrated that far inland. All of the four tactics require additional water to be transported from the Waal to the Lek through the Amsterdam-Rijnkanaal, because there would not always be enough water available on the Lek in the section along which the extraction points for the tactics are located. Extraction of this additional water from the Waal at Tiel would result in increased low water shipping losses during periods of low flows on the Waal.[11] The extractions also would lead to increased sedimentation in the Waal below Tiel which (we assume) would be dredged away, increasing the cost of the tactics even more.

Table 8.7 presents the results of Distribution Model runs made to evaluate the relative benefits and costs of the four tactics. Tactic 3 (Krimpenerwaardkanaal) and Tactic 4 (Maarssen-Bodegravenkanaal) have approximately the same benefits, so only one set of Distribution Model

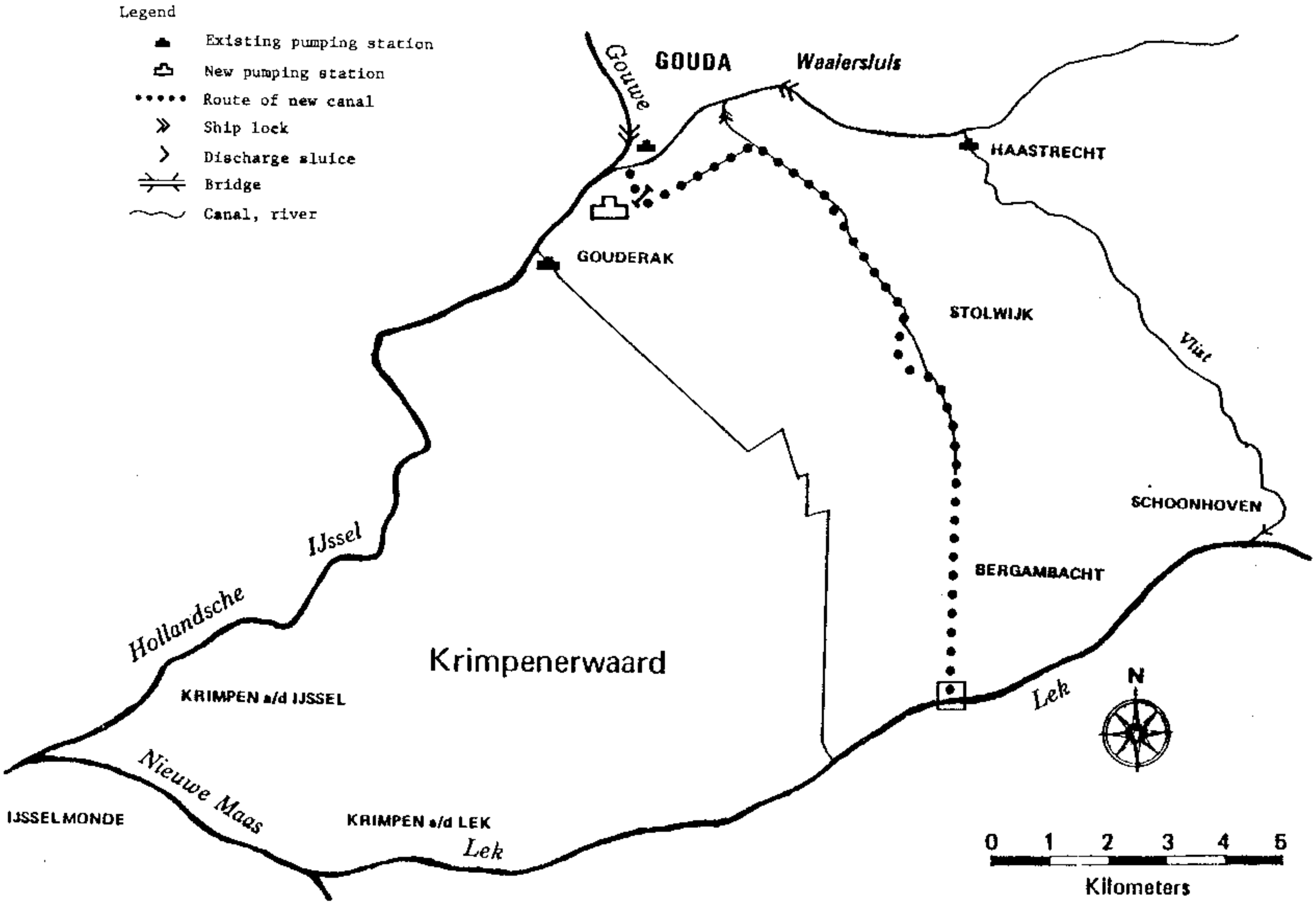
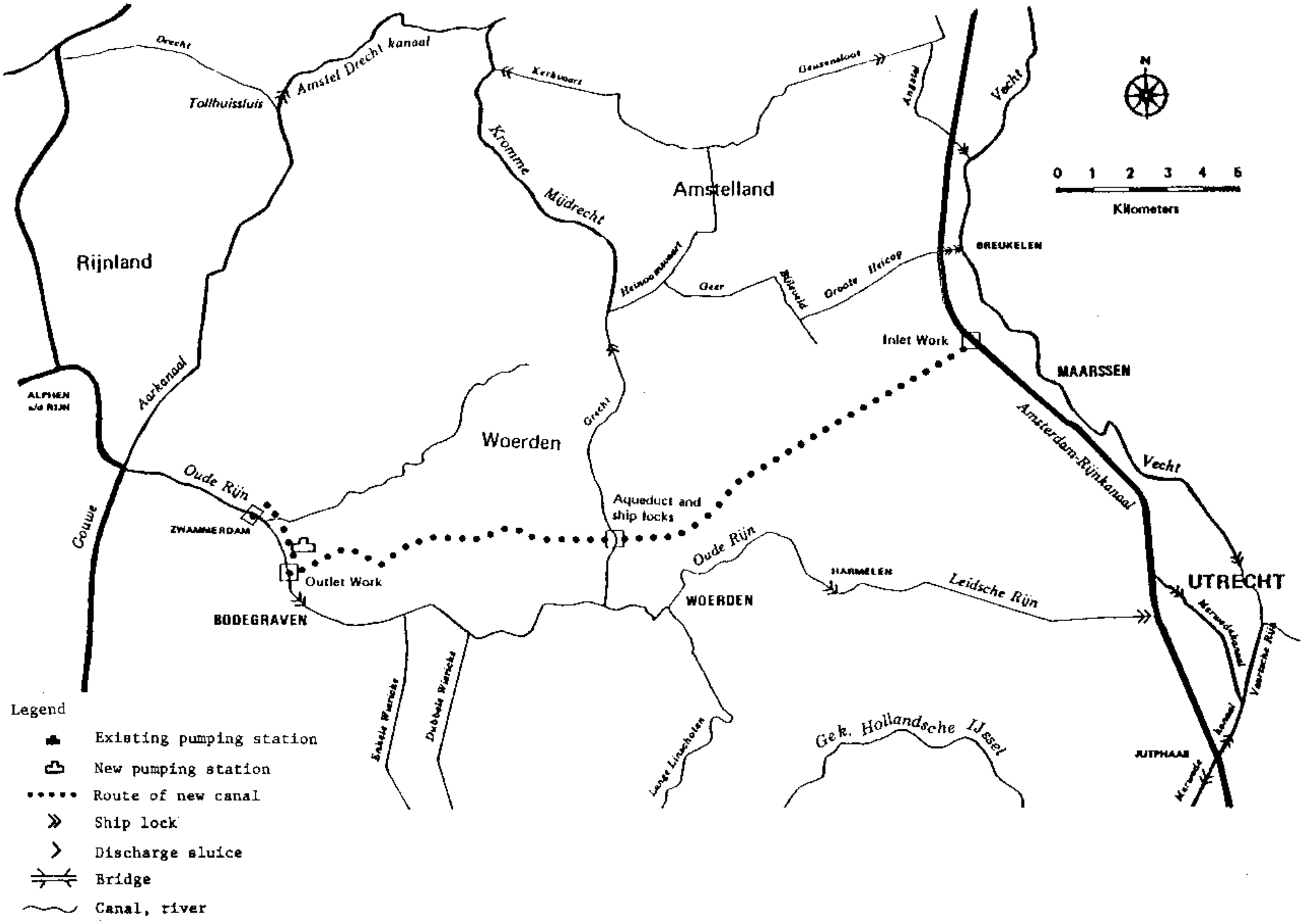


Fig. 8.5--Krimpenerwaardkanaal route



Legend

- ▲ Existing pumping station
- ⌂ New pumping station
- ••••• Route of new canal
- » Ship lock
- › Discharge sluice
- ╪ Bridge
- ~ Canal, river

Fig. 8.6--Maarssen-Bodegravenkanaal route

runs was made for them. Results are shown only for the worst case demand scenario (SPRHI-RALL). The benefits from the tactics are considerably lower for the other three demand scenarios.

Table 8.7

COMPARISON OF BENEFITS AND COSTS (Dflm) OF FOUR TACTICS FOR REDUCING MIDWEST SALINITY LOSSES
(High Sprinkler Intensity, with Waterboard Plans)

Tactic No.	Type of Benefit	External Supply Scenario DEX	1959	1943	1967	Expected Annual Benefits UB	LB	Annualized Fixed Cost
1	Salinity	32.6	0.4	0.2	0.0			
	Shipping	(3.9)	(1.7)	(1.0)	0.0			
	Dredging	(0.1)	0.0	0.0	0.0			
	Net	28.6	(1.3)	(0.8)	0.0	2.2	0.4	2.3
2	Salinity	41.7	0.4	0.1	0.0			
	Shipping	(6.1)	(2.3)	(1.1)	0.0			
	Dredging	(0.1)	0.0	0.0	0.0			
	Net	35.5	(1.9)	(1.0)	0.0	2.7	0.5	3.9
3	Salinity	41.5	0.2	0.0	0.0			
	Shipping	(6.9)	(2.4)	(0.3)	0.0			
	Dredging	(0.1)	0.0	0.0	0.0			
	Net	34.6	(2.2)	(0.3)	0.0	2.9	0.5	5.7
4	Net	34.6	(2.2)	(0.3)	0.0	2.9	0.5	12.8

One important conclusion that can be drawn from the reductions in salinity losses shown in Table 8.7 is that the salt wedge may not be as big a problem as many have believed. The only significant losses from the salt wedge occur in DEX, when Rijn flows are extremely low. The salt wedge caused increases in salinity of over 100 ppm in the water reaching Gouda in only three decades in 1959 and none in 1943. (There were nine such decades in DEX.) Salinity losses depend as much on the durations of high salinity levels as on their frequencies. The salinity level at Gouda exceeded Rijn salinity by more than 100 ppm for three decades in a row three times in DEX. This difference from Rijn salinity occurred only once for three decades in a row in 1959 at the very end of the growing season (so the resulting damage was small). Table 8.7 also shows that the increased losses to shipping on the Waal from these tactics are significant, and in 1959 and 1943 outweigh the reductions in salinity losses that the tactics achieve.

A comparison of the expected annual benefits with the annualized fixed costs of the four tactics shows that none of the four is promising. For Tactics 2, 3, and 4, the costs are clearly higher than the benefits. The case of Tactic 1 is not so clear cut. If only reduction of salinity losses were considered, the tactic would be promising. The increase in shipping losses that results from implementing the tactic turns this decision around. The increases in shipping losses could be eliminated if the Merwedekanaal were used instead of the Amsterdam-Rijnkanaal for transporting water from the Waal to the Lek for supply to the Midwest. However, such a change would require making improvements to this section of the Merwedekanaal. (These improvements have an annualized fixed cost of 0.9 Dflm.) The combination of the Merwedekanaal tactic with a Lopikerwaardkanaal is discussed further in Sec. 11.6.3.

8.2.2. Close River Branches in Delta

The tactics in the above section, accepting the fact that the salt wedge will push beyond the entrance to the Hollandsche IJssel from time to time, attempt to provide alternative routes for getting Rijn-salinity water to the Midwest. The tactics in this section and in Secs. 8.2.3 and 8.2.4 seek to prevent the salt wedge from reaching the entrance to the Hollandsche IJssel.

In this section we discuss the possibilities of permanently or temporarily closing one of the three major rivers in the delta region: the Spui, the Oude Maas, or the Nieuwe Maas (see Fig. 8.7). Closure of the Spui or Oude Maas would increase the discharge through the Nieuwe Maas, thereby forcing the salt wedge back. Closing the Nieuwe Maas would be designed to place a physical barrier in the path of the salt wedge in order to prevent it from extending beyond that point. Closing any of the three rivers would also serve to reduce the amount of backward salt intrusion carried from the Nieuwe Maas through the Oude Maas and the Spui to the Haringvliet.

Closure of the Spui has been extensively studied by the Delta Service of the RWS [8.7, 8.8]. They recommended permanent closure with a dam containing a shipping lock. Closure of the Oude Maas is mentioned in the 1968 Nota [8.2], which suggests temporary closure with caissons that can be moved into place when the flow rate in the Rijn is low. Closure of the Nieuwe Maas, which would be more expensive than either of the other closures, has not yet been studied in depth. We did, however, obtain a cost estimate for temporary closure of the river with caissons. The annualized fixed costs of the most likely configurations for the three closures are:

Permanent closure of Spui with dam and ship lock	2.0 Dflm
Temporary closure of Oude Maas with caissons	19.6 Dflm
Temporary closure of Nieuwe Maas with caissons	26.3 Dflm

If any of the tactics were entirely successful in eliminating salinity losses in the Midwest boezem caused by the salt wedge, then its benefits would be the same as those obtained by implementing the Krimpenerwaardkanaal--i.e., the upper bound on expected annual benefits would be 3.7 Dflm (the upper bound on the expected annual reduction in salinity losses). Eliminating the backward intrusion of salt into the Haringvliet would result in reduced salinity losses in the area

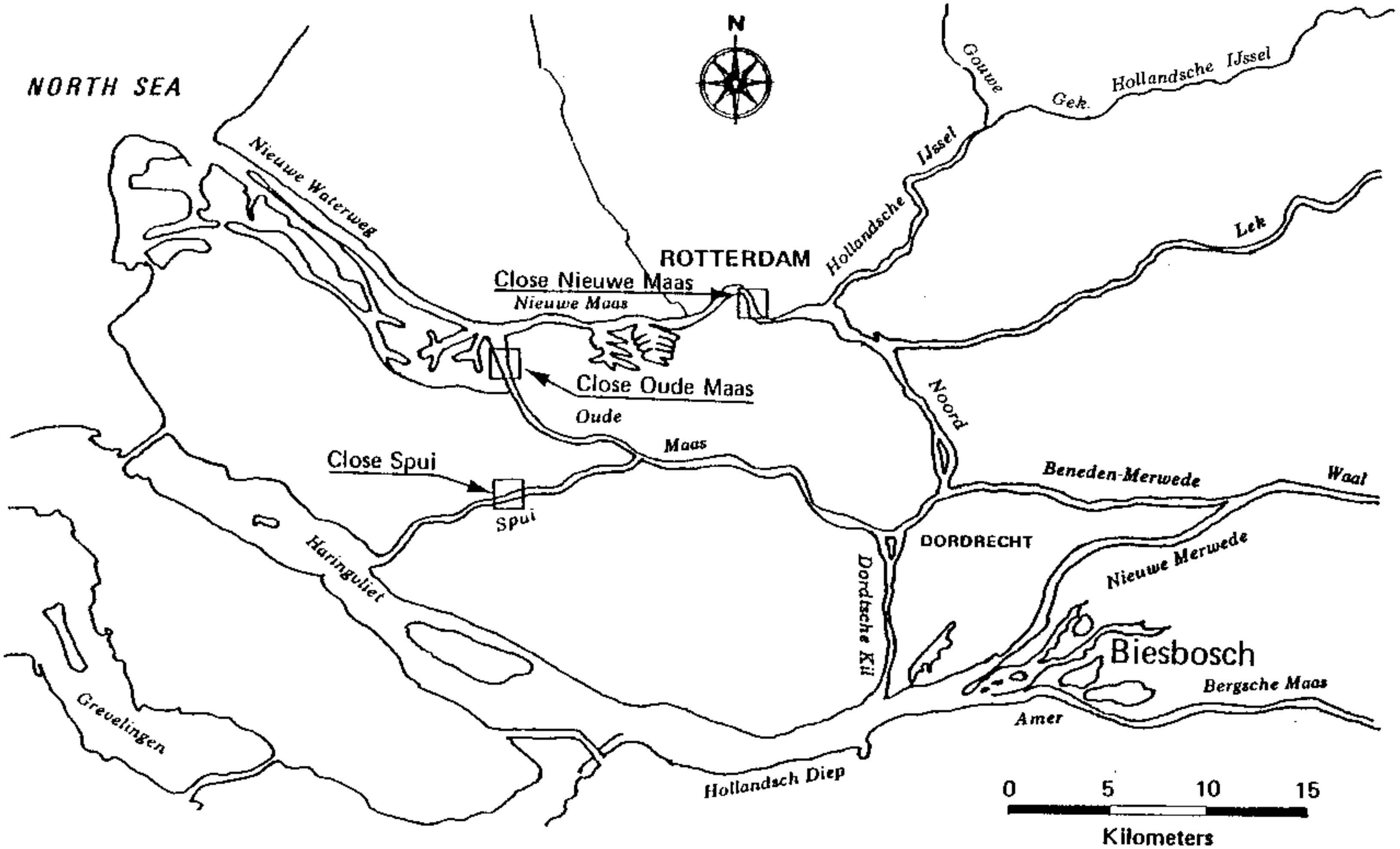


Fig. 8.7--Closure of rivers to combat salt intrusion in Northern Delta

surrounding the Zoommeer. However, the salinity reduction would be small, and the resulting benefits negligible.

Comparing the annualized fixed costs given above with the 3.7 Dflm upper bound on annual benefits, we see that closure of the Oude Maas and closure of the Nieuwe Maas are not promising tactics. Closure of the Spui might be promising. Whether it is or not depends upon how effective the tactic is in preventing the salt wedge from reaching the Gouda inlet. Evaluation of its performance requires changing the Distribution Model to reflect the new pattern of flows in the Delta area and their impact on the salt wedge. There was insufficient time on the PAWN project to make these changes. Further investigation of this tactic is warranted.

8.2.3. Construct Groin in Nieuwe Waterweg

A groin is a rigid structure built out from the shore of a waterway that can be used to direct a current. In the case of the Nieuwe Waterweg, construction of a groin is expected to have the same effect on preventing salt intrusion into the Rotterdamse Waterweg as increasing the flow on the Oude Maas by 20 m^3/s, and on the Nieuwe Maas by 10 m^3/s.[12] Thus, the salt wedge would not be able to penetrate quite so far east during periods of low Rijn flow. Construction of the groin has an annualized fixed cost of only 0.7 Dflm. If it were able to eliminate even half of the salinity losses due to the salt wedge, it would be a promising tactic.

In order to estimate the benefits that would be obtained from construction of a groin in the Nieuwe Waterweg, we made Distribution Model runs with and without the groin, and compared the resulting salinity losses in the districts affected by the salt wedge (Rijnland, Schieland, Delfland, and the Krimpenerwaard). All runs were made for the demand scenario with high sprinkler intensity and waterboard plans (SPRHI-RALL). The results are presented in Table 8.8.

Table 8.8

REDUCTION IN SALINITY LOSSES (Dflm) FROM CONSTRUCTING
GROIN IN NIEUWE WATERWEG
(High Sprinkler Intensity, with Waterboard Plans)

District	DEX	1959	1943	1967	Expected Annual Benefits UB	Expected Annual Benefits LB	Annualized Fixed Cost
Rijnland	6.8	0.1	0.1	0.0			
Schieland	8.0	0.1	0.1	0.0			
Delfland	14.8	0.2	0.2	0.0			
Krimpenerwaard	0.4	0.0	0.0	0.0			
Total	30.0	0.4	0.4	0.0	2.9	0.6	0.7

Table 8.8 shows that constructing a groin in the Nieuwe Waterweg is a promising tactic. Our models estimate that it would eliminate approximately 75 percent of the salinity losses from the salt wedge. Its expected annual benefits are comparable to those obtained from constructing a Krimpenerwaard or Maarssen-Bodegravenkanaal, but its cost is a small fraction of the cost of either canal.

8.2.4. Construct Bubble Screen in Nieuwe Waterweg

A bubble screen injects air bubbles into a waterway. Injecting the air at a point where salt is pushing in from the sea significantly reduces the salt intrusion. Bubble screens have already been constructed at a number of salt/fresh shipping locks, including the locks at IJmuiden. One of the drawbacks of bubble screens is that, in addition to their initial investment costs, they have high operating costs due to high energy requirements.

Construction of a bubble screen in the Nieuwe Waterweg has been mentioned as an alternative way of limiting the intrusion of salt into the Hollandsche IJssel. It is expected that a bubble screen will be able to achieve about the same salinity reductions in the Midwest boezems as would be achieved with construction of a groin. However, its annualized fixed cost alone (1.2 Dflm) is almost twice that of the groin. Its energy cost is estimated to be over 1000 Dfl/hr [8.9]. It is, therefore, clear that the bubble screen is not as attractive a tactic as the groin. Nonetheless, it is likely to be a promising tactic, since it would have to be used for over 1500 hr (more than 60 full days) per year for its costs to exceed the upper bound on its expected benefits.

8.3. REDUCE SHORTAGE AND SALINITY LOSSES IN DELFLAND

In a dry year, when the Hollandsche IJssel becomes salted up several times, the salinity losses in Delfland comprise almost half of the total salinity losses in the Midwest and Utrecht region. In DEX, we estimated salinity losses in Delfland to be over 150 Dflm, while the entire region's salinity losses were about 330 Dflm. Even in a relatively wet year like 1967, Delfland's salinity losses are estimated at 66 Dflm, over one-third of the region's total. In addition, because of the capacity of the pumping station at Leidschendam (8 m^3/s) on the transport route between Rijnland and Delfland, Delfland is the only district in the region that experiences preventable shortage losses. In DEX these losses were over 30 Dflm. Table 8.9 summarizes Delfland's agriculture shortage and salinity losses for the demand scenario with high sprinkler intensity and waterboard plans.

The tactics for reducing salinity losses due to the salt wedge, which we examined in the preceding section, will all reduce agricultural salinity losses in Delfland. However, because of the disproportionately high agricultural losses in Delfland, we examined

Table 8.9

AGRICULTURE SALINITY AND SHORTAGE LOSSES (Dflm) IN DELFLAND
(High Sprinkler Intensity, with Waterboard Plans)

	DEX	1959	1943	1967
Salinity	158.5	92.4	83.7	65.8
Percent of region's total	48.2	42.1	39.1	34.4
Shortage	30.4	8.6	1.8	0.4

three tactics that are designed specifically to alleviate Delfland's shortage and salinity problems. They are discussed in the following three subsections.

8.3.1. Build a Pipeline from the Maas to Delfland

The salinity of the Maas is considerably lower than the salinity of the Rijn--typically between 10 percent and 25 percent of Rijn salinity. Even in a very dry year such as DEX, we estimate that Maas salinity would rarely exceed 100 ppm, and would average about 70 ppm. If Maas water could be transported to Delfland, salinity losses in Delfland could be reduced considerably. And these reductions would occur not only in dry years, or when the Hollandsche IJssel were salted up, but every day of every year.

We therefore investigated the possibility of transporting Maas water to Delfland through a pipeline. For comparability with the current system (and to keep the cost of the tactic reasonably low), we chose a throughput capacity of 8 m^3/s (the same as the current throughput capacity at Leidschendam). This capacity is enough to satisfy agriculture's total demand for surface water in Delfland in all but the worst two decades of the worst year (DEX, SPRHI-RALL). In those decades, neither of the demands was above 10.1 m^3/s.[13] The flushing demand and any excess extraction demand over 8 m^3/s could be satisfied by water sent through Leidschendam.

Costs were developed for two alternative pipeline designs:

1. Three parallel pipelines, each with a capacity of 2.7 m^3/s, with a pumping station at the beginning of each pipeline.
2. A single 8-m^3/s-capacity pipeline with a pumping station at the beginning and pumping stations located at three points along the route. All pumping stations have a capacity of 8 m^3/s.

The pipelines would extract water from the Bergsche Maas, just above the Biesbosch, and discharge it just north of the Parksluizen. The length of each of the pipelines would be approximately 50 km. The costs for each tactic are summarized in Table 8.10. Since energy represents a significant portion of the total cost of the tactics, we have included estimated annual operating costs as well as annualized fixed costs in evaluating these tactics. The total annual cost for the three-pipeline alternative is 37.8 Dflm, and for the single-pipeline alternative it is 29.5 Dflm.

Table 8.10

COSTS OF ALTERNATIVE PIPELINES FROM MAAS TO DELFLAND (Dflm)

	Alternative 1 (3 pipelines)	Alternative 2 (1 pipeline)
Annualized fixed cost	34.7	15.5
Annual energy cost	1.4	13.0
Annual maintenance and labor cost	1.8	1.0
Total annual cost	37.9	29.5

We evaluated the tactic for the demand scenario with high sprinkler intensity and waterboard plans (no promising waterboard plans were identified for Delfland). The results are presented in Table 8.11. They show significant reductions in Delfland's salinity losses for all four supply scenarios. A comparison of the upper bound on expected annual benefits with the total annual cost of the tactic shows that both of the alternative pipeline designs are promising.

Table 8.11

COMPARISON OF BENEFITS AND COSTS (Dflm) OF PIPELINE
FROM MAAS TO DELFLAND
(High Sprinkler Intensity, with Waterboard Plans)

					Expected Annual Benefits	
	DEX	1959	1943	1967	UB	LB
Delfland salinity losses						
Without pipeline	158.5	92.4	83.7	65.8		
With pipeline	65.7	32.4	28.5	33.7		
Benefits	92.8	60.0	55.2	32.1	48.8	22.4
Total annual cost						
(1) 3 pipelines					37.9	
(2) 1 pipeline					29.5	

One potential problem with this tactic is that sometimes the flow on the Amer (the final portion of the Maas) is not sufficient to supply the required 8 m^3/s to Delfland. Under the worst case scenario (SPRHI-RALL), this happened in DEX in four decades and in 1959 in two decades. In the case of DEX with the demand scenario that reflects the current situation most closely (DEX, SPRLO-RNONE), the average decade flow on the Amer never fell below 9 m^3/s. If the flow on the Amer is insufficient to supply the required 8 m^3/s, the operation of the pipeline should probably be interrupted temporarily unless the salt wedge has reached Gouda and/or the capacity at Leidschendam is insufficient. Of course, the problem caused by an insufficient Amer flow could be avoided altogether by the construction of additional reservoir capacity at the Biesbosch. Such a measure, however, has not been analyzed in this study.

8.3.2. Expand Throughput Capacity at Leidschendam[14]

Currently all of Delfland's surface water is transported from Rijnland along the Rijn-Schiekanaal (see Fig. 8.8). Midway along this route (at Leidschendam) there is a pumping station with a capacity of 8 m^3/s. During dry periods, the demand for surface water beyond this pumping station often exceeds 8 m^3/s. This demand is made up of two major components: water for level control and sprinkling of crops, and water for flushing the boezems.

The demand for level control and sprinkling alone rarely exceeds 8 m^3/s (it remained below 8 m^3/s in all decades for the scenario DEX, SPRLO, and in all but two decades for DEX, SPRHI). However, keeping the salinity of the boezems at a reasonable level requires flushing with a minimum of 4.4 m^3/s. As a result, less than 4 m^3/s is actually available for sprinkling Delfland's crops. Cutbacks in sprinkling, therefore, occur fairly often in DEX (12 of the 15 decades from April through August for SPRLO), causing high agriculture shortage losses.

Expanding the capacity of the pumping station at Leidschendam to about 20 m^3/s would eliminate these shortage losses. However, sending additional (saline) water through the region's boezems, and sprinkling more of Delfland's crops with (saline) water increases agriculture salinity losses. We made a number of Distribution Model runs to determine whether, on balance, it would be worthwhile to expand the throughput capacity at Leidschendam. The results, presented in Table 8.12, show that the upper bound on the expected annual reduction in shortage losses exceeds the upper bound on the expected annual increase in salinity losses by 2.0 Dflm. The annualized fixed cost for expanding the pumping capacity at Leidschendam to 20 m^3/s is estimated to be 0.7 Dflm. Therefore, we found this tactic to be promising.

An alternative way of reducing agriculture shortage losses in Delfland without making any changes to the infrastructure would be to change the managerial rule that allocates water between flushing and sprinkling of crops. We evaluated a rule that would reduce the minimum flushing of the Delfland boezem from 4 m^3/s to 1 m^3/s. This flushing combats

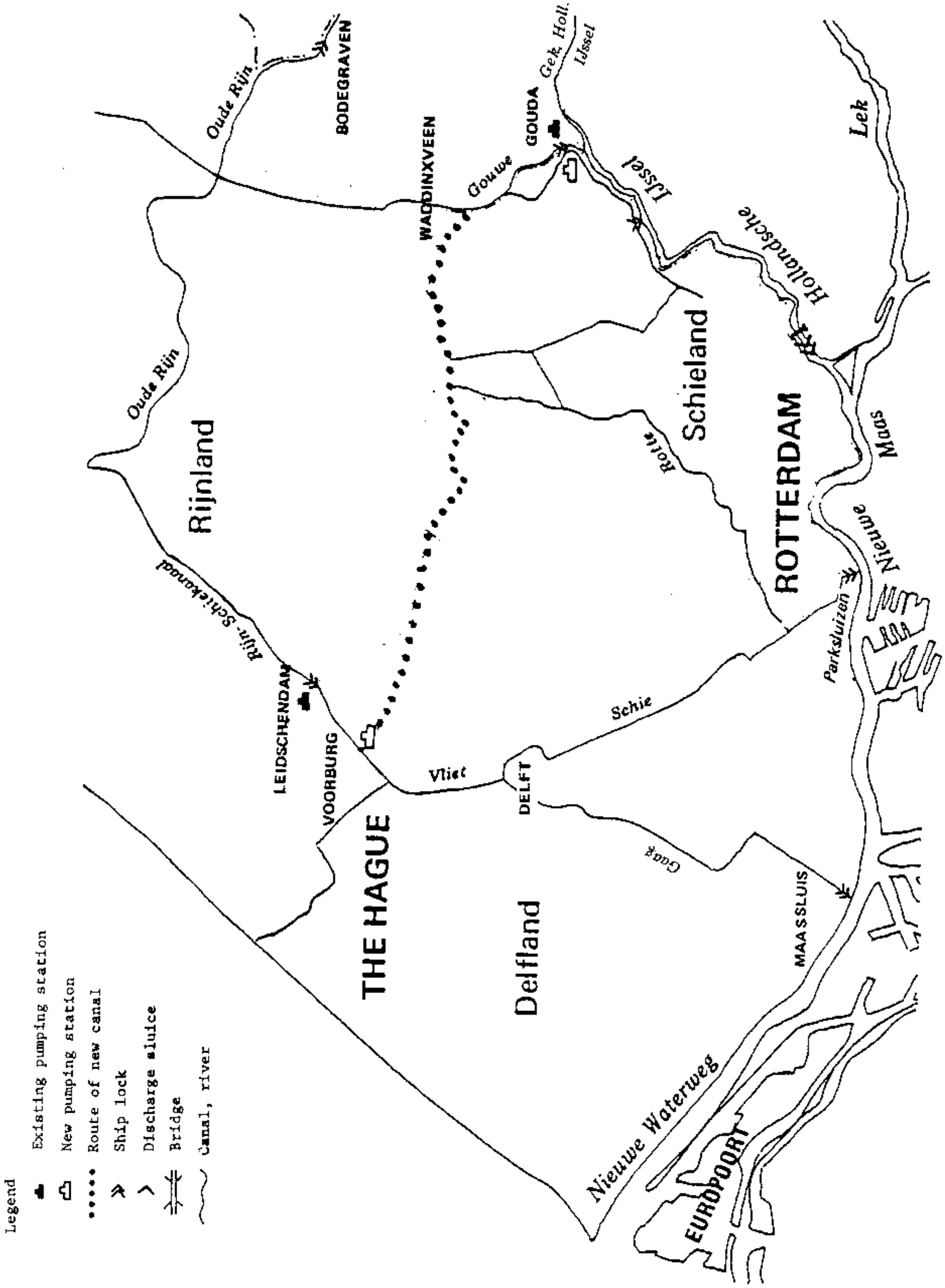


Fig. 8.8--Waddinxveen-Voorburgkanaal route

Table 8.12

COMPARISON OF BENEFITS AND COSTS (Dflm) OF EXPANDING THROUGHPUT CAPACITY AT LEIDSCHENDAM
(High Sprinkler Intensity, with Waterboard Plans)

	DEX	1959	1943	1967	Expected Annual Benefits UB	Annualized Fixed Cost
Reduction in shortage losses	30.4	8.6	2.8	0.4	4.2	
Increase in salinity losses:						
Delfland	11.4	2.4	1.7	0.4		
Other districts	1.6	0.1	0.0	0.0		
Total	13.0	2.5	1.7	0.4	2.2	
Benefits	17.4	6.1	0.1	0.0	2.0	0.7

salt intrusion from the Nieuwe Waterweg at Rotterdam (the Parksluizen). When flushing is reduced, salinity losses due to salt intrusion at locations along the Nieuwe Waterweg increase. In addition, the salinity in Delfland's boezem increases (because of less boezem flushing), and salinity in Rijnland, Schieland, and Krimpenerwaard decreases (because less salt enters their boezems). The impacts of this change in the flushing rule are summarized in Table 8.13. The table

Table 8.13

EFFECT OF REDUCING FLUSHING OF THE DELFLAND BOEZEM ON AGRICULTURE LOSSES (Dflm) IN MIDWEST AND UTRECHT
(High Sprinkler Intensity, with Waterboard Plans)

	DEX	1959	1943	1967	Expected Annual Benefits	
					UB	LB
Reduction in shortage losses	27.5	8.5	1.8	0.4	4.0	1.4
Increases in salinity losses						
Due to salt intrusion	7.2	4.8	1.5	0.4		
Due to salinity in Delfland boezem	10.1	5.0	2.1	0.0		
Due to salinity in other districts	(5.5)	(0.2)	0.0	0.0		
Total	11.8	9.6	3.6	0.4	3.0	1.1
Benefits	15.7	(1.1)	(1.8)	0.0	1.0	0.3

shows that, in DEX, reducing flushing in order to make more water available for sprinkling results in an overall reduction in agriculture losses. In other years the decreases in shortage losses are just about the same as the increases in salinity losses. Overall, the new rule (or a refinement of it) appears to be promising. Its implementation would obviate the need for expansion of the pumping capacity at Leidschendam (since preventable shortage losses in Delfland are practically eliminated).[15]

8.3.3. Build a Waddinxveen-Voorburgkanaal

Even when the salt wedge has not reached the mouth of the Hollandsche IJssel (so Rijn-salinity water is still reaching Gouda), the salinity of the water reaching Delfland is often above Rijn salinity. This is due to the fact that before arriving in Delfland the water first passes through the Rijnland boezem, which is more saline than the Rijn when Rijn flows are high. (When Rijn flows are low, the boezem water dilutes the highly saline Rijn water.)

As late as 1968 Delfland was able to obtain its water directly from the Nieuwe Maas through the Parksluizen. However, as the port zone along the Nieuwe Waterweg grew in size and importance, changes were made along the Waterweg that led to a substantial increase in its depth.[16] The increased depth caused the salt wedge to intrude farther inland, which led to the abandonment of the Parksluizen as an inlet point; thus the only acceptable supply route was that from the Gouda inlet through Rijnland. To compensate Delfland's farmers for the closure of the Parksluizen inlet, the Dutch government promised to build a canal that would connect Delfland directly with the Gouwe River just north of the Gouda inlet. It would extract its water from the Gouwe near the town of Waddinxveen and carry it west, discharging it into the Vliet near Voorburg, just south of Leidschendam (see Fig. 8.8). The purposes of the canal would be to reduce the salinity of Delfland's surface water supply and to provide sufficient supply capacity (between 10 m^3/s and 20 m^3/s) to eliminate agriculture shortage losses in Delfland.

We evaluated a Waddinxveen-Voorburgkanaal with a length of 21 km, a capacity of 15 m^3/s, and an annualized fixed cost of 12.8 Dflm. This capacity would be sufficient to satisfy the surface water needs of Delfland and the minimum flushing of the Vliet in all decades of the worst case scenario (DEX, SPRHI-RALL). If additional water were needed to meet the desired flushing of the Vliet (desired flushing needs were not met in two decades in this scenario), water could be let in through Leidschendam to make up the shortfall. The Waddinxveen-Voorburgkanaal is discussed briefly in Ref. 8.10. There is presently a study group preparing a new report on the canal.

Results from Distribution Model runs made to evaluate the Waddinxveen-Voorburgkanaal are presented in Table 8.14. It is somewhat surprising that the results show that the primary objective of the tactic--to reduce salinity losses in Delfland--is satisfied only in relatively wet years. In dry years, salinity losses actually increase. (In DEX, salinity losses in Delfland are increased by over 100 Dflm.) Part of the increase in salinity losses in dry years can be explained in the same way as was the increase in salinity losses in Delfland when the pumping capacity is expanded at Leidschendam. More crops are being sprinkled (shortage losses are eliminated), but the water is saline, so more crops are damaged by salt. In DEX, most of the increase in salinity losses is due to the fact that the Hollandsche IJssel becomes salted up several times, so highly saline water is being extracted at the Gouda inlet and transported to Delfland.

Table 8.14

COMPARISON OF BENEFITS AND COSTS (Dflm) OF BUILDING
THE WADDINXVEEN-VOORBURGKANAAL
(High Sprinkler Intensity, with Waterboard Plans)

	DEX	1959	1943	1967	Expected Annual Benefits UB	Annualized Fixed Cost
Reduction in shortage losses	30.4	8.6	1.8	0.4	4.2	
Reduction in salinity losses						
Delfland	(108.4)	(8.5)	(2.7)	5.9		
Other districts	4.7	0.0	(0.1)	(0.6)		
Total	(103.7)	(8.5)	(2.8)	5.3	(8.6)	
Benefits	(73.3)	0.1	(1.0)	5.7	(4.4)	12.8

With respect to salinity losses in other districts, the pattern is opposite to that in Delfland. Salinity losses are decreased in the driest year, and increased slightly in wetter years. This is due to the fact that less water is flowing through these districts. In dry years, less water passing through the Rijnland boezem means less salt entering the boezem, resulting in a lower salinity. In wet years, the Rijn water is less saline, and the decreased flushing causes the boezem salinity to go up.

Table 8.14 shows that the increases in salinity losses in DEX overwhelm the decreases in shortage losses and other decreases in salinity losses, so that the expected annual benefits from the Waddinxveen-Voorburgkanaal are negative. It thus becomes clear that the canal does not eliminate the losses to Delfland caused by the inland penetration of the salt wedge beyond Rotterdam. We have, however, explored two possibilities for avoiding large salinity losses in Delfland in dry years. Both possibilities employ the Waddinxveen-Voorburgkanaal, since the canal is necessary (although not sufficient to bring Rijn-salinity water to Delfland.

First, whenever the Hollandsche IJssel becomes salted up, water can be transported to Delfland over the existing supply route. In this case, shortage losses will be increased over those that occur when the Waddinxveen-Voorburgkanaal is always used, but these increased losses may be more than offset by the reduction in salinity losses. The results from this policy are presented in Table 8.15. The table indicates, for example, that in DEX, Delfland's shortage losses would increase by 28.1 Dflm compared with the results in Table 8.14, but the region's salinity losses would decrease by 103.9 Dflm. Overall, however, although the upper bound on expected annual benefits is positive for this implementation of the tactic, the annualized investment cost is still considerably higher than the expected benefits.

Table 8.15

COMPARISON OF BENEFITS AND COSTS (Dflm) OF BUILDING A
WADDINXVEEN-VOORBURGKANAAL AND NOT USING IT WHEN
EMERGENCY SUPPLY FACILITIES ARE USED
(High Sprinkler Intensity, with Waterboard Plans)

	DEX	1959	1943	1967	Expected Annual Benefits UB	Annualized Fixed Cost
Reduction in shortage losses	2.3	7.8	1.8	0.4	2.2	
Reduction in salinity losses						
Delfland	(3.0)	(2.3)	(2.7)	5.9		
Other disticts	3.2	0.2	(0.1)	(0.6)		
Total	0.2	(2.1)	(2.8)	5.3	1.0	
Benefits	2.5	5.7	(1.0)	5.7	3.2	12.8

The other possible way of avoiding high salinity losses in Delfland due to the salt wedge when the Waddinxveen-Voorburgkanaal is implemented is to also build a supply canal to the Rijnland boezem (such as a Krimpenerwaardkanaal or Lopikerwaardkanaal). Table 8.16 compares the costs and benefits of this combination of tactics (a Krimpenerwaardkanaal is assumed). The results show that the benefits from this set of tactics are higher than for either of the other two ways of implementing a Waddinxveen-Voorburgkanaal, but it is also the most costly way. The expected annual benefits are not even sufficient to cover the annualized investment cost of the Waddinxveen-Voorburgkanaal alone, much less the cost of the two new canals.

Table 8.16

COMPARISON OF BENEFITS AND COSTS (Dflm) OF BUILDING BOTH
A WADDINXVEEN-VOORBURGKANAAL AND KRIMPENERWAARDKANAAL
(High Sprinkler Intensity, with Waterboard Plans)

	DEX	1959	1943	1967	Expected Annual Benefits UB	Annualized Fixed Cost
Reduction in shortage losses	30.4	8.6	1.8	0.4	4.2	
Reduction in salinity losses						
Delfland	(16.6)	(8.5)	(2.7)	5.9		
Other districts	21.8	0.0	(0.1)	(0.6)		
Total	5.2	(8.5)	(2.8)	5.3	1.2	
Benefits	35.6	0.1	(1.0)	5.7	5.4	18.5

8.4. SUMMARY OF CONCLUSIONS

In Sec. 8.2 we considered two approaches for reducing the salinity problem in the Midwest:

- Build a new canal as an alternative to the Hollandsche IJssel for transporting water from the Lek or the Amsterdam-Rijnkanaal to the boezem system of the Midwest.
- Reduce the chances that the salt wedge would reach the mouth of the Hollandsche IJssel by closing one or more of the river branches that empty into the Nieuwe Waterweg or by constructing a bubble screen or a groin in the Nieuwe Waterweg.

The analysis of these approaches suggested that the salt wedge problem was not as bad as had been thought, and that expensive solutions (such as the construction of a new canal) were unlikely to produce benefits that would exceed their costs. Only two of the tactics evaluated were found to be promising--construction of (1) a groin or (2) a bubble screen in the Nieuwe Waterweg. We estimated that either would eliminate approximately 75 percent of the salinity losses from the salt wedge. However, construction of a groin is the less expensive tactic, and therefore is more attractive. Another tactic--closure of the Spui--was found to deserve further investigation.

In Sec. 8.3 we examined three tactics specifically designed to reduce agricultural losses in Delfland:

- Build a pipeline from the Maas to Delfland.
- Expand throughput capacity at Leidschendam.
- Build a Waddinxveen-Voorburgkanaal.

Our analysis suggests that Delfland's salinity problems are primarily due to the high salinity of the Rijn and, in very dry years, to salinity from the salt wedge. A small proportion of its salinity losses are due to the salt added to the water as it is transported from Gouda to Delfland. A promising tactic for reducing salinity losses is the pipeline from the Maas to Delfland. This would provide Maas-salinity water to Delfland's crops year-round, which would yield significant benefits even in wet years.

If the pipeline is not built, Delfland's shortage losses could be alleviated by expanding the capacity of the pumping station at Leidschendam. Although salinity losses would increase the reduction in shortage losses would be more than enough to offset the salinity losses and cover the investment costs for the expansion. If the pipeline is built, its capacity together with the existing capacity at Leidschendam should be sufficient to prevent shortage losses in Delfland.

NOTES

1. Section 2.1.2 describes how the amount of salt dumped in the Rijn has increased from 40 kg/s in 1930 to over 300 kg/s in 1976; for flows of 2000 and 900 m^3/s (average and low, respectively), this corresponds to increases in the river salinity from 45 mg/l (average flow) and 70 mg/l (low flow) in 1930 to 175 mg/l (average flow) and 370 mg/l (low flow) in 1976.
2. The salinity includes 25 mg/l as the natural salinity of the Rijn.
3. Tactic A-4 in Ref. 8.1, which considers 16 tactics for reducing agriculture salinity losses in the Midwest.
4. The working group that issued the 1979 report [8.1] is named the Technische Werkgroep Kanaal Maarssen-Bodegraven.
5. Tactic B-2 in Ref. 8.1.
6. Tactic C-7 in Ref. 8.1.
7. It is mentioned in Ref. 8.2 and examined in detail in Ref. 8.3.
8. Tactic C-6 in Ref. 8.1. The route was the one preferred by the study group.
9. Some of the water would be discharged into the Oude Rijn at a point just north of Bodegraven.
10. A syphon will be used to get across the river (the Grecht).
11. These shipping losses could be avoided if the Merwedekanaal were used to transport water from the Waal to the Lek. But this would require changes to the infrastructure that have an annualized fixed cost of 0.9 Dflm (see Sec. 11.6.3).
12. This expectation is subject to considerable uncertainty. It was derived from experiments with a physical model of the waterways around the mouth of the Rijn that were conducted by the Delft Hydraulics Laboratory.

13. In the current world (SPRLO-RNONE), the maximum demand for surface water in Delfland in the DEX scenario (excluding flushing) was 5.6 m^3/s.
14. The analysis presented in this section is different from that presented in the final PAWN briefing. Here, we have separately analyzed tactics for expanding the throughput capacity at Leidschendam and reducing the flushing of the Delfland boezem. In the briefing, our results represented the combined impacts of implementing both tactics.
15. This managerial tactic requires more detailed analysis. In the Distribution Model, Delfland is represented by a single node and a single agriculture district. This schematization is not adequate for the full assessment of the impacts of a reduction in the flushing of the Delfland boezem.
16. For example, between 1958 and 1964 the depth of the Nieuwe Waterweg rose by an average of 2 m on the Hoek van Holland--Maassluis section [8.4].

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Chapter 9

SCREENING OF TACTICS FOR WEST BRABANT AND SOUTHERN DELTA

9.1. OVERVIEW

The region called West Brabant and Southern Delta (Region 7) consists of the western part of Noord-Brabant and portions of Zeeland (Schouwen-Duiveland, Tholen, and parts of Goeree-Overflakkee and Zuid-Beveland). The region consists mostly of lowlands, although some highlands in Southwest Brabant are included. The predominant soil types in the area are loam and loamy sand. Farmland covers almost 70 percent of the region's area. Of the farmland, about one-third is pastureland, and one-quarter is devoted to growing various cereals. Approximately 20 percent of the region is nature area, and 6 percent is urban. Table 9.1 shows the distribution of the land in the region among its various uses in more detail.

Table 9.1

LAND USE IN WEST BRABANT AND SOUTHERN DELTA

Use	Area (ha)	Percentage of Farmland	Percentage of Total Area
Farmland:			
Grass	54,971	32.7	
Cereals	40,943	24.4	
Sugar beets	22,666	13.5	
Consumption potatoes	15,850	9.4	
Vegetables (open air)	15,830	9.4	
Cut corn	8,292	4.9	
Pit and stone fruits	5,440	3.3	
Seed potatoes	1,726	1.0	
Other crops	2,408	1.4	
Total farmland	168,126	100.0	68.0
Nature	55,032		22.3
Urban	15,315		6.2
Open water	8,602		3.5
Total region	247,075		100.0

The demand for water in the region depends on whether the Zoommeer and/or Grevelingen are able to be used as sources of fresh water, and on the extent to which sprinkler equipment is used by farmers. In Table 9.2 we show the number of hectares that are sprinkled under each of the demand scenarios. The Grevelingen is assumed to be saline in each of the demand scenarios, while water from a fresh Zoommeer can be used to sprinkle crops only if waterboard plans are implemented (RALL). The table shows that, without implementation of waterboard plans, the area sprinkled with surface water might increase over twofold in the future, from 5.9 percent of the farmland to 14.3 percent. Implementation of the promising waterboard plans might increase the sprinkled area to 12.1 percent of the farmland (for low sprinkler intensity) or to 35.6 percent (for high sprinkler intensity).

Table 9.2

SPRINKLED AND UNSPRINKLED FARMLAND (ha) IN WEST BRABANT AND SOUTHERN DELTA UNDER FOUR DEMAND SCENARIOS

	Low Intensity		High Intensity	
Type of Area	No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
Farmland:				
Without sprinkling	150,933	140,489	136,883	100,974
With SW sprinkling	9,950	20,394	24,000	59,909
With GW sprinkling	7,243	7,243	7,243	7,243
Total	168,126	168,126	168,126	168,126

Table 9.3 indicates the demands for extraction from the surface water distribution network that result from these scenarios. The four measures of demand shown are the demands during the average and the driest decade for both 1943 and DEX river flows and rainfall; the average decade demands reflect averages over decades having a positive demand.

Table 9.3

DEMANDS FROM WEST BRABANT AND SOUTHERN DELTA FOR EXTRACTIONS FROM NATIONAL SURFACE WATER DISTRIBUTION NETWORK (m^3/s)

	Low Intensity		High Intensity	
Type of Decade	No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
1943: Average decade	2.0	10.9	2.3	13.6
Driest decade	3.5	19.4	5.1	28.1
DEX: Average decade	2.5	14.8	3.4	20.7
Driest decade	5.4	25.5	7.9	40.8

Figure 9.1 is a map showing the major bodies of water and waterways in West Brabant and the Southern Delta, and Fig. 9.2 is the schematization of the surface water distribution network for the region that was used in the Distribution Model.

West Brabant's outside sources for surface water currently are the Donge and the Wilhelminakanaal. From these sources, water is

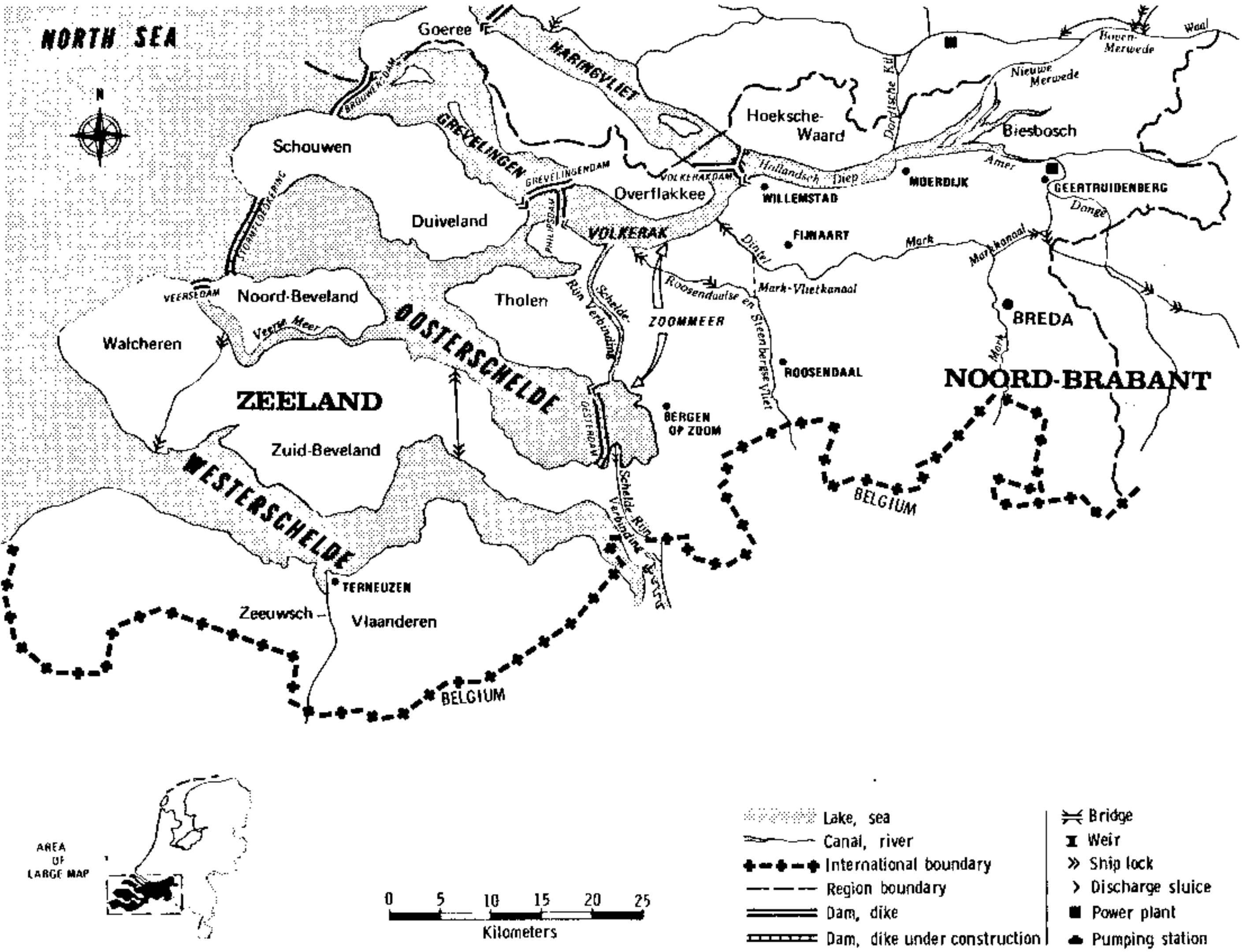

Fig. 9.1--Map of West Brabant and Southern Delta (Region 7)

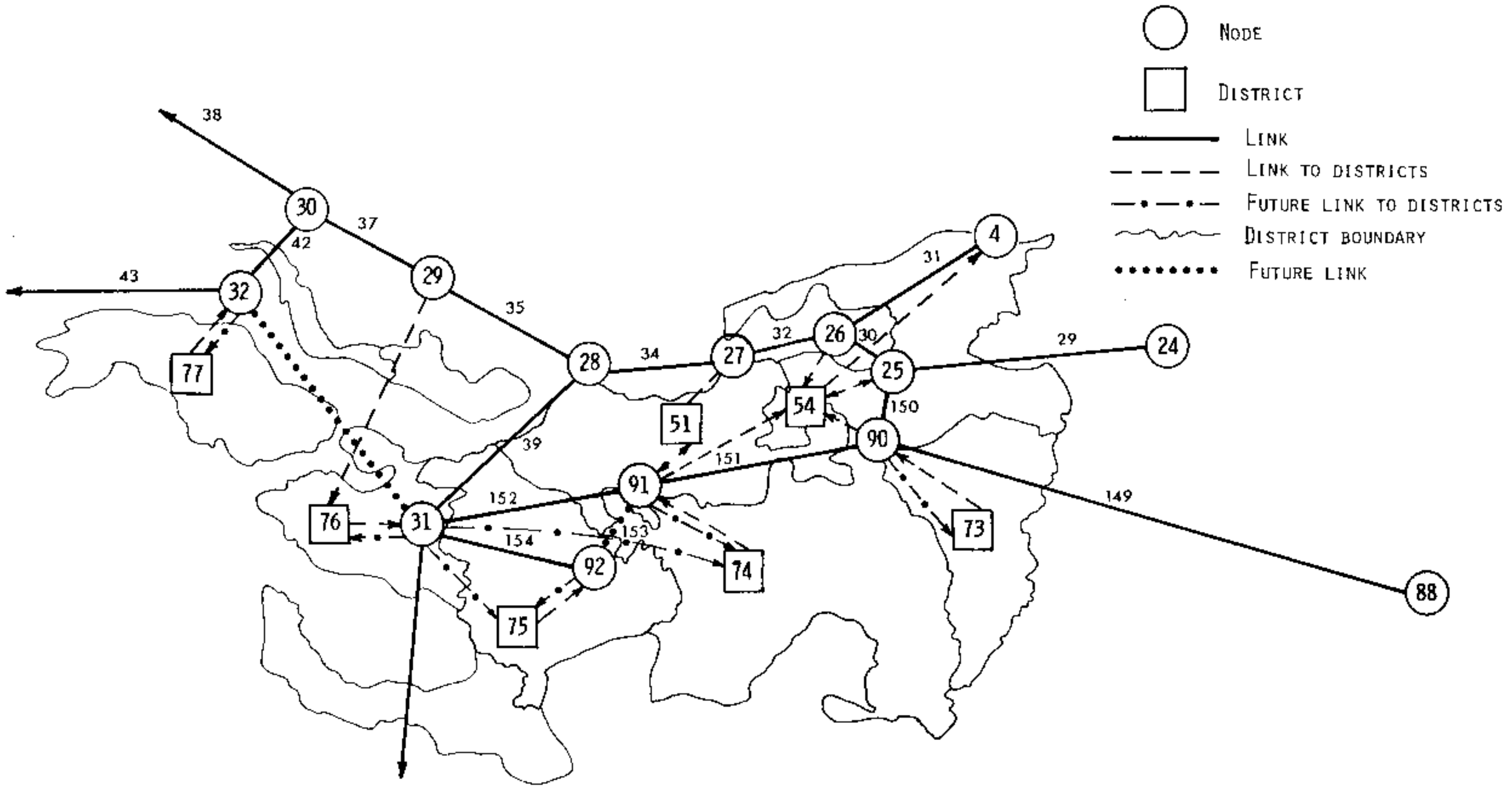

Fig. 9.2--Surface water distribution network for West Brabant and Southern Delta

transported into West Brabant via the Markkanaal and, subsequently, the Mark River. The water enters the various districts from different extraction points along the Mark. The inlet capacity into the Markkanaal is 8 m^3/s. The current situation will undergo a considerable change when the Zoommeer becomes fresh and waterboard plans are implemented. The area that is eligible for sprinkling will then increase greatly, and an important flow of fresh water from the Zoommeer will enter West Brabant. In Table 9.4, we show West Brabant's demands for surface water from the Mark and the Zoommeer under the four demand scenarios. The water for the scenarios without waterboard plans comes exclusively from the Markkanaal. For the scenarios with waterboard plans, water from the Markkanaal would be supplemented with water from the Zoommeer. The four measures of demand shown are the demands during the average and the driest decade for both 1943 and DEX river flows and rainfall; as before, the average decade demands reflect averages over decades having a positive demand.

Table 9.4

DEMANDS FROM WEST BRABANT FOR EXTRACTIONS
FROM MARK AND ZOOMMEER (m^3/s)

		Low Intensity		High Intensity	
Type of Decade		No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
1943:	Average decade	1.3	2.9	1.5	5.0
	Driest decade	2.6	7.7	4.0	12.9
DEX:	Average decade	1.9	5.9	2.8	9.8
	Driest decade	3.7	12.0	6.0	19.8

The table shows that, under the current conditions (no supply from the Zoommeer), the Markkanaal inlet capacity of 8 m^3/s is sufficient, and that even a high sprinkler intensity would not cause a capacity shortfall. Implementation of the waterboard plans will lead to demands for water from the Zoommeer. With the high sprinkler intensity, these demands would be at least 5 m^3/s for the driest decades under the 1943 supply scenario, and 12 m^3/s under the DEX supply scenario.

The remainder of the region, the Southern Delta, consists of various islands in Zuid-Holland and Zeeland. These islands cannot currently be supplied with fresh water from sources outside the region, with the exception of a small area on Goeree-Overflakkee, which receives water from the Haringvliet.

About 60 percent of the area (parts of Goeree-Overflakkee, Tholen, and Zuid-Beveland) will obtain access to the Zoommeer once it has become fresh and various waterboard plans have been implemented. The maximum extraction demands for this area will be 9 m^3/s in 1943 and 14 m^3/s in DEX. Most of the remaining 40 percent of the area is the island of Schouwen-Duiveland. The potential outside source of surface water for the island is the Grevelingen. In most of our analysis we have assumed that the Grevelingen will remain a salt lake, but we have estimated the benefits to agriculture of a fresh Grevelingen. If the lake will be made fresh, the maximum extraction demands from Schouwen-Duiveland will be about 6 m^3/s in both 1943 and DEX. The results of our analysis of a fresh Grevelingen are described below.

We also analyzed a tactic for making more cooling water available at a large power plant that is located in West Brabant along the Amer. This power plant is cooled by water, extracted from the Amer. The flow along the Amer is not always sufficient to absorb the heat discharged by the power plant and remain within the Dutch excess temperature standard for rivers. We discuss one tactic that was intended to resolve this problem.

9.2. AGRICULTURAL BENEFITS FROM THE FRESH ZOOMMEER

Section 2.2.3 described the assumptions we made with respect to the Zoommeer in our analysis. In particular, we assumed that the Zoommeer is going to be fresh. This assumption was based on the fact that the Dutch Parliament has already decided on this course of action. There are many reasons for their decision, some of which are unrelated to water management. In this section we examine the reductions in agriculture shortage and salinity losses that would result from a fresh Zoommeer.

Creation of a fresh Zoommeer does not automatically lead to a reduction in agriculture losses. It is necessary to implement waterboard plans to carry the fresh water into the areas where it is to be used. In particular, the RALL scenario includes six waterboard plans that would use the water from a fresh Zoommeer. The six plans affect three different districts--Districts 74, 75, and 76 (see Fig. 9.2). The annualized fixed cost of those portions of the plans relating to the Zoommeer is estimated to be 5.6 Dflm.

Keeping the Zoommeer fresh requires continual flushing with fresh water. The water used for flushing the Zoommeer would not be available for pushing back the salt wedge. However, the flushing policy we used in our analysis (which is described in Sec. 3.6) interrupted Zoommeer flushing whenever the salt wedge was approaching the mouth of the Hollandsche IJssel. Hence, salinity losses in the Midwest and Utrecht region were not increased by having a fresh Zoommeer.

The reductions in agriculture losses from having a fresh Zoommeer are presented in Table 9.5. The reductions, even in a relatively wet year, are considerable. In the high sprinkler scenario, the lower bound on expected annual benefits is almost 20 Dflm; the upper bound is over 50 Dflm. Of course there are other benefits and disbenefits (e.g., to shipping, to fishing, and to the ecology) from making the Zoommeer fresh that we have not considered. There also are considerable construction costs that were not included (e.g., to build the dams that will separate the Zoommeer from the Western Basin of the Oosterschelde). However, since the decision has already been made to make the Zoommeer fresh, we concentrated on the marginal costs of supplying the fresh water to agriculture in the areas around the lake (the costs of implementing the waterboard plans), and the marginal benefits from supplying it (reductions in agriculture shortage and salinity losses).

Table 9.5

REDUCTION IN TOTAL AGRICULTURE LOSSES (Dflm)
FROM A FRESH ZOOMMEER

					Expected Annual Benefits		Annualized Fixed Cost of W/B Plans
	DEX	1959	1943	1967	UB	LB	
Low sprinkler intensity	114.0	64.1	18.5	3.4	26.0	9.5	5.6
High sprinkler intensity	237.5	127.2	37.1	8.3	53.1	19.8	5.6

9.3. CREATE FRESH GREVELINGEN

We assumed as a scenario variable in our analysis that the Grevelingen would remain a saltwater lake because the Dutch government has yet to decide whether to make the lake fresh or not. To provide some guidance in making this decision, we examined the benefits that would accrue to agriculture in the area around the Grevelingen and compared these benefits with the associated investment costs.

Because of the short amount of time available to perform this analysis, we were unable to fully implement a fresh Grevelingen in the Distribution Model. Instead we simulated the tactic by having the single district that would extract water from a fresh Grevelingen (District 77) extract its water directly from the Haringvliet (see Figs. 9.1 and 9.2). We feel that the resulting salinity losses in District 77 are approximately correct, although we have not been able to verify the results. (Seepage in the Grevelingen, salt intrusion through the ship lock at Bruinisse and discharges from District 77 tend to increase the salinity of the Grevelingen relative to that of the Haringvliet. But rainfall on the lake tends to decrease it.)

The reductions in agriculture losses from having a fresh Grevelingen are presented in Table 9.6 (these are the combined reductions in salinity and shortage losses). The benefits are sizable, although they are only about 10 percent of the benefits to agriculture from having a fresh Zoommeer.

Table 9.6

REDUCTION IN TOTAL AGRICULTURE LOSSES (Dflm) FROM A FRESH GREVELINGEN

					Expected Annual Benefits		Annualized Fixed Cost of Tactic
	DEX	1959	1943	1967	UB	LB	and W/B Plan
Low sprinkler intensity	21.6	7.5	1.2	0.4	3.2	1.1	0.7
High sprinkler intensity	37.2	13.2	2.1	0.7	5.6	2.0	0.7

There are two components to the cost of implementing a fresh Grevelingen and making its water available to the surrounding area. First, in order to offset the (considerable) seepage of salt water into the lake, it must be continually flushed with fresh water. Various ways of doing this have been proposed. The simplest would be to send water through an inlet structure to be built in the Grevelingendam, which separates the Grevelingen from the Zoommeer, and discharge this water into the North Sea through the sluice in the Brouwersdam. More complicated, and probably more effective, approaches would build a "Halskanaal," i.e., a canal from the Haringvliet to the Grevelingen through the narrowest part of Goeree-Overflakkee. This canal, in combination with a Grevelingendam inlet, would allow for flushing in various directions, including eastward toward the Zoommeer. In our estimate of the annualized fixed cost of the tactic in Table 9.5, we have assumed that only a Grevelingendam inlet would be built. The annualized fixed cost of this inlet facility is estimated to be 0.4 Dflm.

The second cost component relates to the fact that a waterboard plan would have to be implemented to carry the fresh water to the agricultural areas in District 77. The annualized fixed cost of the waterboard plan is estimated to be 0.3 Dflm. Hence, the total annualized fixed cost would be 0.7 Dflm.

The annualized fixed cost is below the lower bound on the expected annual benefits to agriculture from the tactic and is significantly below the upper bound on expected annual benefits. The tactic, therefore, appears to be promising. However, the analysis has omitted certain important considerations (e.g., change in the ecology) and has not modeled others accurately (e.g., salinity of the Grevelingen). So, further investigation of this tactic appears to be warranted.

9.4. EXPAND COOLING WATER SUPPLY FOR AMER POWER PLANT

The largest power plant in the Netherlands is located northwest of Geertruidenberg, just downstream from the mouth of the Donge (see Fig. 9.3). It has an effective generating capacity of over 1700 megawatts (about 13 percent of the country's total capacity). Operating at full capacity, the plant discharges nearly 500 million calories of waste heat per second into the Amer. The flow of water in the Amer past the

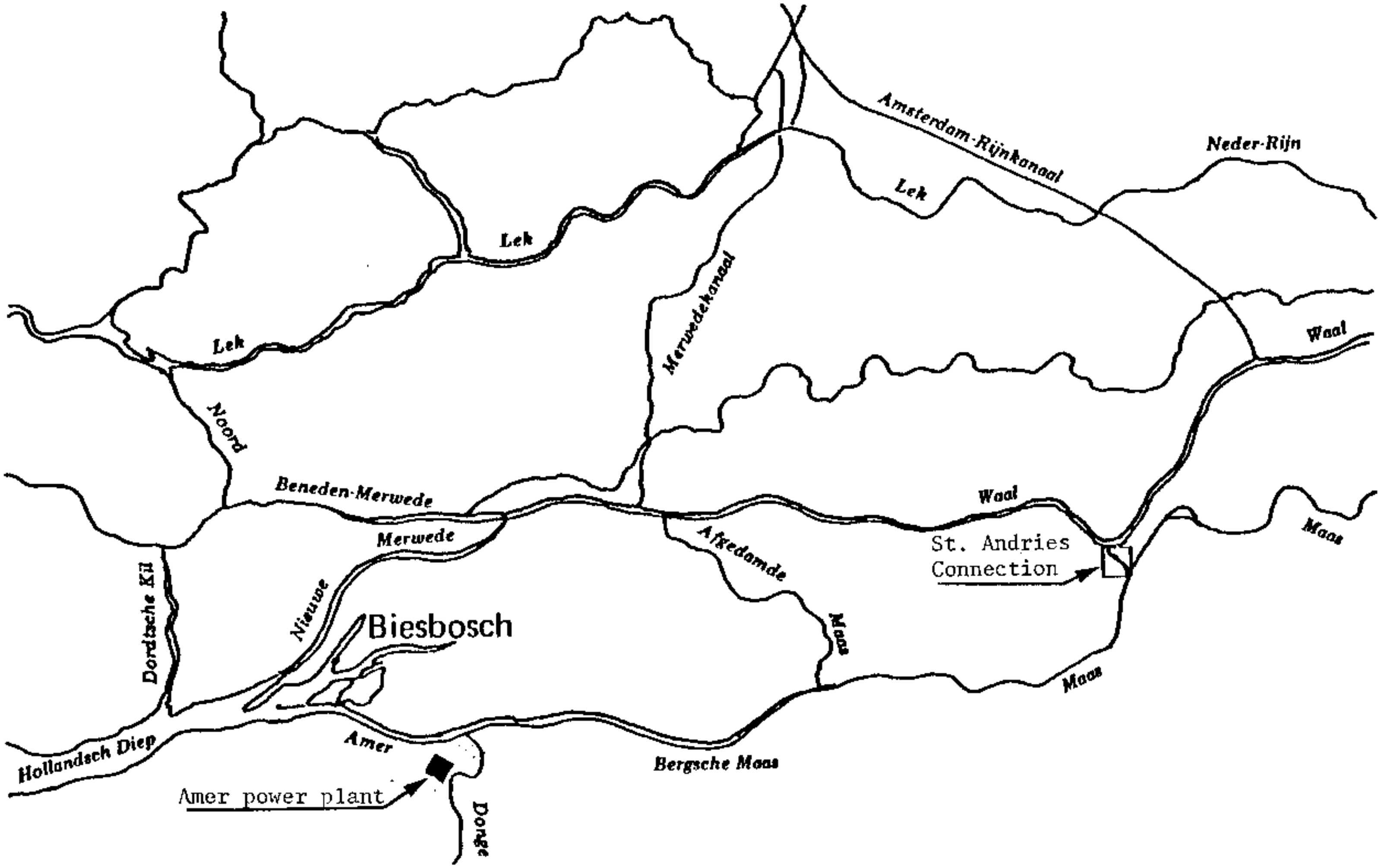

Fig. 9.3--St. Andries Connection and Amer power plant

power plant is used to cool the discharges. In so doing, the temperature of the Amer water is raised. The magnitude of the temperature increase depends on the flow in the Amer. If the flow is high, the increase will be small; if the flow is low, the increase will be large.

The Dutch presently apply a standard of 3 deg C to the excess temperature in their major river branches. (Excess temperature is the increase in temperature of a water body above its natural temperature.) PAWN models estimate that, with 1976 demands for electricity and the 1976 power plant inventory, the excess temperature on the Amer just below the power plant would be approximately 7.5 deg C during a dry decade (Vol. V, Sec. 5).

There are two possible approaches for bringing the excess temperature at the Amer power plant in line with the thermal standard. The first is to reduce the heat discharges from the power plant. Two ways of doing this are evaluated in Vol. V, Sec. 5. The second is to increase the flow of cooling water past the power plant.

One way of increasing the flow on the Amer is to transport Waal water to the Maas during periods of low flow on the Maas. A tactic that we examined for accomplishing this was to build a bypass of the lock connecting the Waal and the Maas at St. Andries (see Fig. 9.3). Since the water level in the Waal is higher than the water level in the Maas at that point, no pumping station would be required. The annualized investment cost for a bypass with a capacity of 17 m^3/s is estimated to be 0.7 Dflm.

The benefits from having more cooling water available on the Amer from this tactic are counterbalanced by the detrimental effects. The transportation of water from the Waal to the Maas has two such effects. First, it causes sedimentation to build up in the Waal at St. Andries, which obstructs shipping at times of low flows. (A description of this phenomenon is given in Vol. XVIII.) Second, the mixture of Waal and Maas water has a higher salinity than the Maas alone. The high salinity will force interruptions of the intake of drinking water into the Biesbosch reservoirs, which in turn decreases the reliability of the reservoirs. We have estimated the shipping losses associated with this tactic, but have not attempted to estimate the losses related to the decrease of the Biesbosch reservoir reliability. Since the tactic was screened out (see below), any such losses will only strengthen our conclusion about the tactic.

If cooling water in sufficient quantities is not available on the Amer, maintenance of the 3-deg standard requires that the amount of power generated at the power plant be reduced. In order to meet the demand for electricity, such a reduction must be compensated for by an increase at a plant in a location where the heat discharge is more acceptable. But the reallocation of power generation loads and the increase in power transmission distances have costs associated with them. In PAWN, we developed a model called EPRAC (Electric Power Redistribution and Cost), which determines the best way to redistribute the power generation and calculates the resulting increases in costs. The EPRAC model is described in detail in Vol. XV. We used the model to estimate the reduction in power generation and transmission costs that would be realized if a connection between the Waal and Maas were constructed at St. Andries.

The results of our analysis are presented in Table 9.7. We estimated the benefits of the tactic for two of the supply scenarios: DEX and 1943. In each of these years, we used the bypass only in decades that showed relatively large additional power generation and transmission costs due to the low Maas flows. This was done in order to limit the shipping losses in the Waal that result from this tactic. Nevertheless, the reduction in power generation and transmission costs was more than offset by the increase in shipping losses on the Waal in both years. The expected benefits from the tactic are therefore negative, so that it was screened out.

Table 9.7

BENEFITS AND COSTS (Dflm) OF CONNECTING THE
WAAL AND MAAS AT ST. ANDRIES
(High Sprinkler Intensity, with Waterboard Plans)

	DEX	1943
Reduction in power generation and transmission costs	5.1	1.6
Increase in shipping losses	9.1	5.8
Benefits	(4.0)	(4.2)
Annualized fixed cost	0.7	0.7

9.5. SUMMARY OF CONCLUSIONS

This chapter has dealt with water management problems in the southern Delta area and in West Brabant. The major problems in the region concerned agriculture salinity and shortage losses in the areas that could potentially be supplied with water from a fresh Zoommeer or fresh Grevelingen. We showed that, once the Zoommeer is created, it would be worthwhile to implement the waterboard plans to supply the surrounding districts with fresh water for sprinkling their crops. We also concluded that making the Grevelingen a freshwater lake appeared to be a promising tactic from the standpoint of agriculture. However, because of time constraints, our analysis of the tactic omitted a number of important considerations. More detailed analysis of the tactic is, therefore, warranted.

An additional problem we addressed in West Brabant concerned thermal pollution of the Amer caused by the waste heat discharged by the power plant located there. We investigated a tactic to bring Waal water to the Maas during periods of low flows on the Maas. Our analysis showed that the benefits obtained from increasing the flow on the Amer were more than offset by the increase in shipping losses on the Waal that result from sedimentation building up near the extraction point.

Chapter 10

SCREENING OF TACTICS FOR SOUTHEAST HIGHLANDS

10.1. OVERVIEW

The Southeast Highlands (Region 8) covers all of the highlands areas in the southern portion of the country (all of the province of Limburg and the central and eastern portions of Noord-Brabant). The predominant soil type in the area is loamy sand. Farmland covers just over half of the region. Of the farmland, about 60 percent is pastureland; the remaining 40 percent is used for raising various crops. Over one-third of the region is nature area. Table 10.1 shows the distribution of land among its uses in more detail.

Table 10.1

LAND USE IN THE SOUTHEAST HIGHLANDS

Use	Area (ha)	Percentage of Farmland	Percentage of Total Area
Farmland:			
Grass	203,642	62.1	
Cut corn	40,575	12.4	
Cereals	29,563	9.0	
Sugar beets	24,079	7.3	
Vegetables (open air)	11,104	3.4	
Consumption potatoes	9,596	2.9	
Pit and stone fruits	6,640	2.0	
Other crops	2,886	0.9	
Total farmland:	328,085	100.0	54.1
Nature	207,299		34.2
Urban	57,094		9.4
Surface water	14,107		2.3
Total region	606,585		100.0

The demand for water in the Southeast Highlands depends on the extent to which sprinkler equipment is used by farmers. In Table 10.2 we show the number of hectares that are sprinkled under each of the demand scenarios. Without implementation of the waterboard plans, the area sprinkled with surface water can increase up to twofold in the future, from 7.0 percent of the farmland to 13.8 percent. Implementation of the promising waterboard plans would have a very considerable effect in this region: the area sprinkled with surface water could be expected to increase to 12.0 percent of the farmland (for the low sprinkler intensity scenario) or to 30.2 percent (for high sprinkler intensity).

Table 10.2

SPRINKLED AND UNSPRINKLED FARMLAND (ha) IN THE SOUTHEAST HIGHLANDS UNDER FOUR DEMAND SCENARIOS

	Low Intensity		High Intensity	
Type of Area	No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
Farmland:				
Without sprinkling	272,647	255,978	250,181	196,553
With SW sprinkling	22,849	39,518	45,315	98,943
With GW sprinkling	32,589	32,589	32,589	32,589
Total	328,085	328,085	328,085	328,085

Table 10.3 shows the demands for extractions from the surface water distribution network that result from these scenarios. Four measures of demand are shown: the average decade and the driest decade for both the 1943 and DEX supply scenarios; the average decade demands reflect averages over decades having a positive demand. The total demands for extractions from the Maas include the losses at ship locks on the canals that are used to transport water into the region (about 5 m^3/s) and losses from these canals due to seepage (about 1.5 m^3/s). The number in the last line in the table (6.5 m^3/s) must therefore be added to the agriculture demands in the upper lines in order to calculate the total demands for extraction from the Maas.

Table 10.3

DEMANDS FROM SOUTHEAST HIGHLANDS FOR EXTRACTIONS FROM NATIONAL SURFACE WATER DISTRIBUTION NETWORK (m^3/s)

	Low Intensity		High Intensity	
Type of Decade	No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
1943: Average decade	1.7	4.0	2.8	9.9
Driest decade	3.6	9.3	8.2	23.7
DEX: Average decade	2.9	7.0	4.2	11.8
Driest decade	4.9	14.1	11.7	34.0
Lock losses and seepage from canals	6.5	6.5	6.5	6.5

The Maas River is the main source of surface water for the region. In addition, the Roer River supplements the Maas flow with a minimum of 10 to 12 m^3/s. This amount is small relative to that supplied by the Maas when its flows are average to high. But when the flows on the upper part of the Maas at Maastricht are low (0 to 20 m^3/s), as they are during exceptionally dry periods, the supply from the Roer is important.

The Maas divides the region into two parts. The districts on the right bank cannot extract water from the river since the terrain is very steep and there are no canals there. The cost of building facilities to supply these districts would be prohibitive. In the remainder of this chapter, we therefore concentrate on the districts on the left bank of the Maas, where a system of canals is available to bring Maas water farther into the region.

Figure 10.1 is a map showing the major rivers and canals in the Southeast Highlands, and Fig. 10.2 is the schematization of the surface water distribution network for the region that was used in the Distribution Model. The waterway infrastructure in the region is relatively sparse. The major canals crossing the region are the Zuid-Willemsvaart, the Wessem-Nederweertkanaal, the Noordervaart, and the Wilhelminakanaal. Most of these were constructed in the nineteenth century for use by ships in order to provide opportunities for further development of the area, but they can also be used for the supply of surface water for agriculture. The system of ditches to transport the surface water from the canals to the farms is also sparse and is less developed than, for instance, that of the Northeast Highlands. As a result, in some parts of the region (e.g., the Peel) there are large agricultural shortage losses even in average years.

The Zuid-Willemsvaart. The Zuid-Willemsvaart is over 100 km long. About one-fourth of its length lies in Belgium; the remaining three-fourths is in the Netherlands. The Zuid-Willemsvaart begins at the Maas at Maastricht, and then flows northwest through Belgium to Lozen. In Lozen, it turns northeast, enters the Netherlands, and continues to Nederweert. At Nederweert, it turns northwest, passes Helmond, and continues to 's-Hertogenbosch, where it joins with the Dieze, which empties back into the Maas (see Fig. 10.1). The water levels in this canal are controlled by 19 locks, 14 of which are in the Netherlands between Nederweert and the Dieze; they are numbered from 0 upward in the upstream direction. The water levels drop successively, going from Maastricht to 's-Hertogenbosch. There are currently no pumping stations along this canal.

The Wessem-Nederweertkanaal. The Wessem-Nederweertkanaal is about 14 km long and joins the Zuid-Willemsvaart at Nederweert with the Maas at Panheel. There is a single lock on this canal located at Panheel, just west of the Maas. At that lock, the level of the canal drops 8 m to the level of the Maas. There is a pumping station with a capacity of 3 m^3/s at the Panheel lock.

The Noordervaart. The Noordervaart begins at the Zuid-Willemsvaart at Nederweert and runs northeast along the southern edge of the Peel region. For PAWN purposes, the part of this canal east of the point where it intersects the Helenavaart, about 13 km from Nederweert, is of no interest. This canal carries some shipping, but it is also important because it supplies agricultural water to the Peel region. There is a single lock on this canal just northeast of Nederweert where the canal level becomes 3 m higher than the Zuid-Willemsvaart level; there is no pumping station at this lock. Water can be brought into

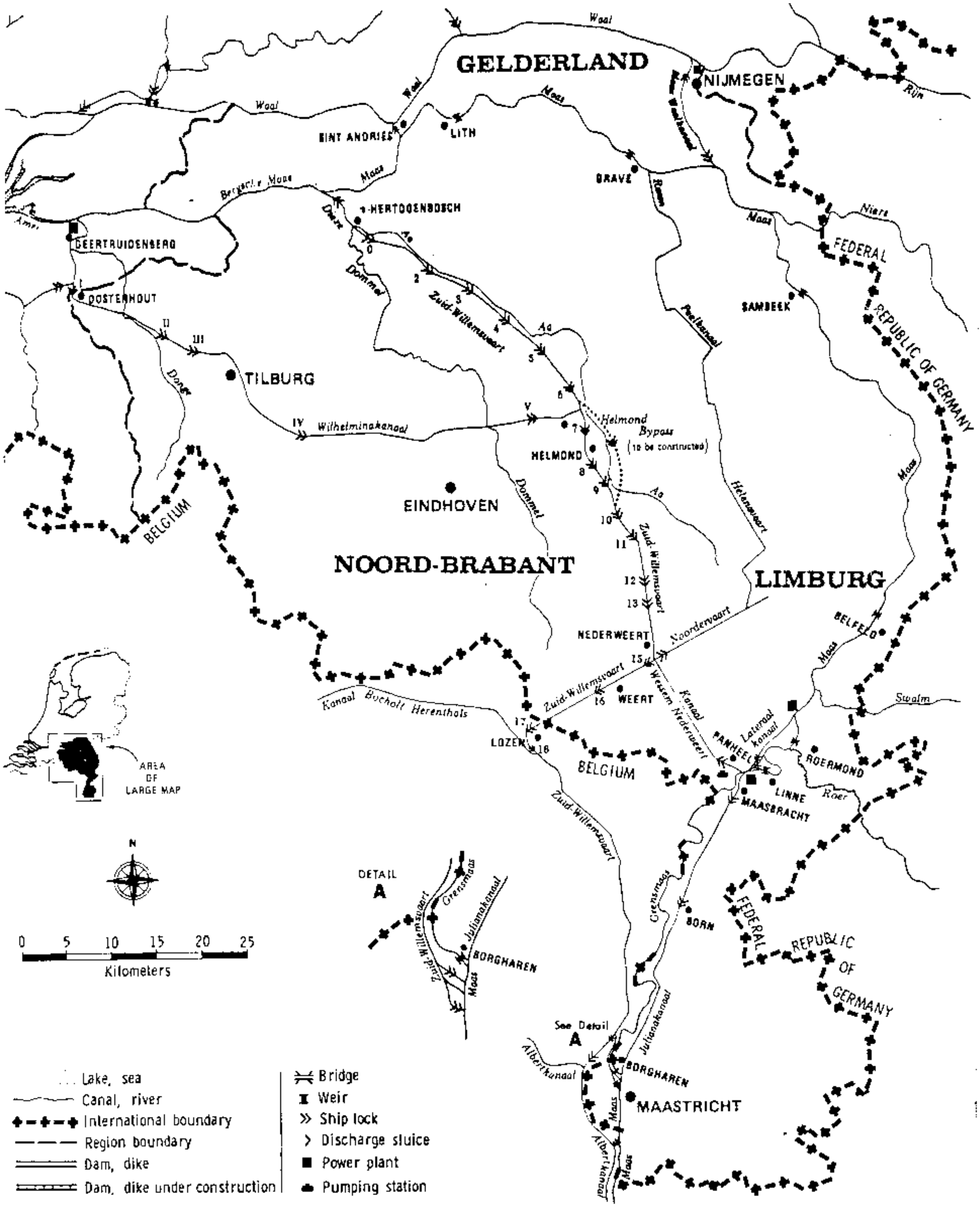

Fig. 10.1--Map of the Southeast Highlands (Region 8)

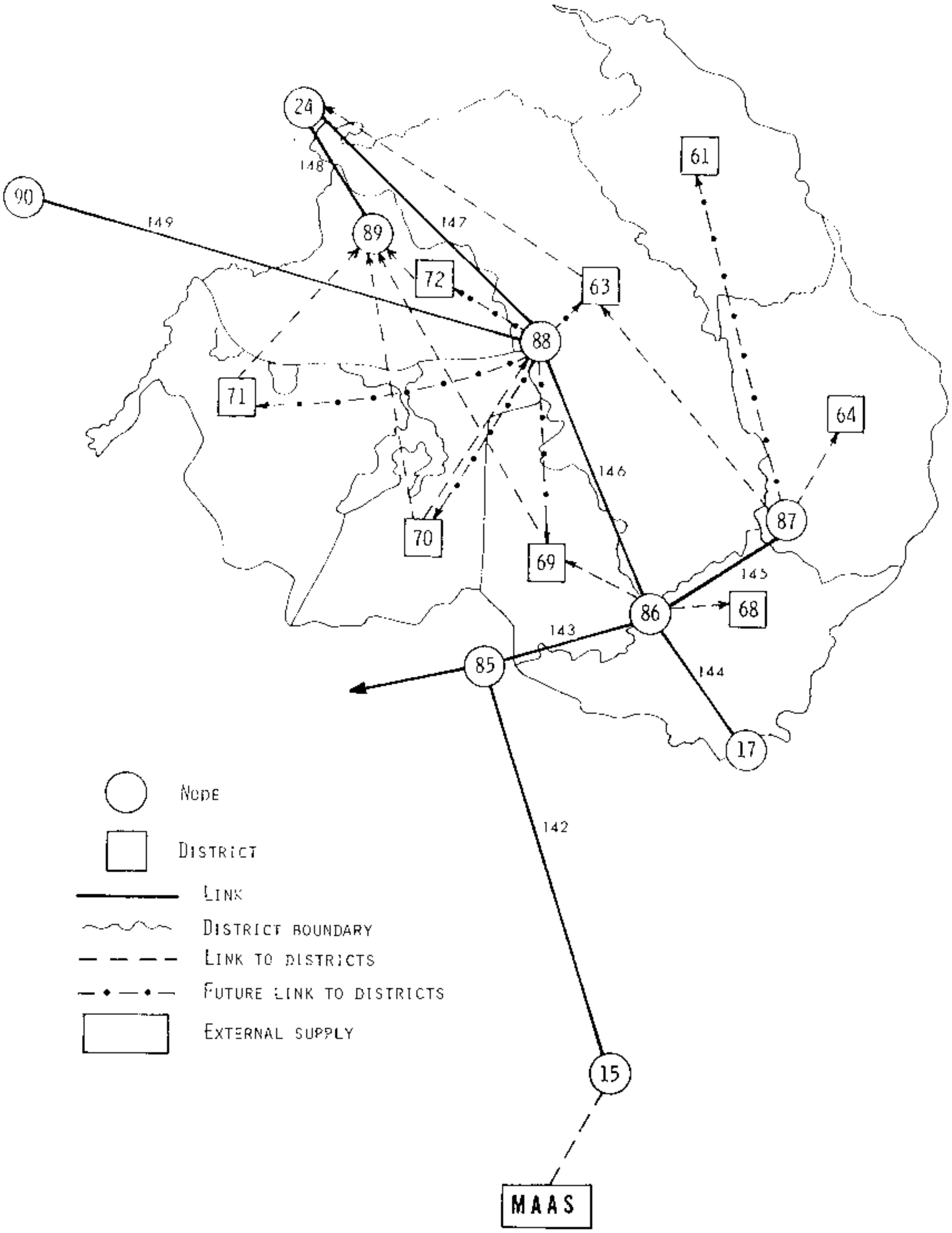

Fig. 10.2--Surface water distribution network for the Southeast Highlands

the canal only through a syphon from the next higher section of the Zuid-Willemsvaart, just above Lock 15. Water passes through this syphon by gravity.

The Wilhelminakanaal. The Wilhelminakanaal branches off the Zuid-Willemsvaart north of Helmond and runs west for about 60 km to Oosterhout. Here, it turns north and joins the Donge about 5 km above Oosterhout; the Donge then empties into the Bergsche Maas. There are five locks along this canal, numbered I through V in the upstream direction. The water levels in the canal drop in the successive sections, going from east to west. There are no pumping stations along this canal.

The Julianakanaal. Apart from these four canals, we must also mention the Julianakanaal, which is used almost exclusively for shipping purposes. The canal parallels the first section of the Maas between Maastricht and Maasbracht, which is known as the Grensmaas (or "border Maas," since it serves as the border with Belgium). It is divided into two sections by two major lock complexes. The higher section runs from the Maas at Maastricht to Born, the lower section from Born to Maasbracht. Below Maasbracht, the canal rejoins the Maas. At Born there is a pumping station with a capacity of 13 m^3/s. There is no permanent pumping facility at Maasbracht; portable pumps with a capacity of 5 m^3/s are available, and are mounted on rented barges when pumping is needed to keep the canal at a suitable level for shipping. This need arises during very dry periods, when the Maas at Maastricht has less water available for the canal than is used in the locking operations at the two major ship locks. The pumping capacity of 5 m^3/s at Maasbracht, however, is not always sufficient to keep the lower section of the canal at its target level. In particular in 1976, considerable shipping losses were incurred because locking operations on the canal had to be curtailed due to low Maas flows at Maastricht and a low pumping capacity at Maasbracht.

Water Supply Routes. The current infrastructure, which has been described above, provides very few ways of supplying surface water to the region. There are only two major extraction locations along the Maas: the Zuid-Willemsvaart inlet at Maastricht and the Panheel pumping station at the entrance to the Wessem-Nederweertkanaal.

Water flowing down the Zuid-Willemsvaart from Maastricht to Lozen is divided between Belgium and the Netherlands according to a treaty concluded in 1863. The Netherlands is required to divert at least 10 m^3/s from the Maas to the Zuid-Willemsvaart.[1] Belgium, in turn, is required to return 2 m^3/s via Lozen to the Netherlands, plus any excess over 10 m^3/s that the Netherlands sends into the Zuid-Willemsvaart at Maastricht (see Fig. 2.3). Maas water that enters the Netherlands along this route can be extracted from the Zuid-Willemsvaart at lower sections, or can be transported to the Noordervaart (via the syphon to this canal) or to the Wilhelminakanaal. From the second inlet location along the Maas, i.e., the pumping station at Panheel, water can be sent along the Wessem-Nederweertkanaal to Nederweert and then along subsequent sections of the Zuid-Willemsvaart.

Various capacity limitations apply to this supply system. The throughput capacity of the Zuid-Willemsvaart downstream from Maastricht to Lozen is 20 m^3/s. From Lozen to the entrance of the syphon to the Noordervaart, the capacity is 7 m^3/s. The capacity of this syphon is 4 m^3/s, and the capacity of the Zuid-Willemsvaart between the syphon entrance and Lock 6 (north of the junction with the Wilhelminakanaal) is 5 m^3/s. The throughput capacity on the Wessem-Nederweertkanaal from the Maas toward Nederweert is 2 m^3/s.[2]

The Zuid-Willemsvaart, the Wilhelminakanaal, and the Wessem-Nederweertkanaal are quite old, have small water-carrying capacities, and many locks that cause delays for ships. Recently a study has been made to determine how the situation for shipping might be improved [10.1]. A number of alternative improvements were suggested, and their costs and benefits for shipping were examined. In substance, all of the alternatives involve increasing canal cross sections to increase ship-handling capacity and replacing old locks with fewer new locks to reduce shipping delays. If improvements are made for shipping, the capacity to move irrigation water will also be increased. We have therefore selected a minimum and a maximum shipping improvement scenario from the set of alternatives presented [10.1]. The minimum improvement scenario represents the least change from the present that is likely to be made, while the maximum improvement scenario assumes implementation of the most extensive alternative presented. In the latter case, the canal carrying capacity is approximately doubled.

The minimum improvement scenario assumes that the only improvement to be made to the existing infrastructure is the diversion of the Zuid-Willemsvaart around the city of Helmond. This portion of the Zuid-Willemsvaart (which we call the Helmond Bypass) will run from just north of the junction with the Wilhelminakanaal to a point about 17 km to the south, just north of Lock 10. One lock on the new route will replace three locks on the old route. The maximum improvement scenario is much more comprehensive. It calls for increasing the cross-sectional areas on the Zuid-Willemsvaart, the Wessem-Nederweertkanaal, and the Wilhelminakanaal, and for replacing numerous old locks with fewer new ones. If all these changes were made, the additional cost to increase the water transport capacity of the canals would be substantially lower than for the minimum improvement case.

Water Management Problems. The main problem in this region is that, in many years, agriculture cannot obtain all the water it needs. (Salinity is not a problem in this region.) Three factors are responsible for this situation. First, there is sometimes an insufficient flow of water on the Maas. During very dry periods, the Maas flow at Maastricht is not sufficient to simultaneously (1) supply the necessary flow on the Julianakanaal that compensates for the lock losses on this canal, (2) maintain a minimum flow of 1 or 2 m^3/s on the parallel stretch of the Maas, and (3) supply a flow to the Zuid-Willemsvaart that provides the required 10 m^3/s to Belgium and satisfies the needs of the region's highlands area for surface water. When the Maas flow is insufficient, two measures are taken: the pumping capacity along the Julianakanaal is used to reduce the water requirements for the canal, and water is pumped into the Wessem-Nederweertkanaal at Panheel to supplement the water sent to Northern Limburg and Central and Eastern Brabant along the Zuid-Willemsvaart. The second measure allows Maas water to be used both by shipping on the Julianakanaal and by agriculture in the highlands.[3] Maas flows that are low enough to cause this problem occur infrequently. In the 66 years for which we had data (1911-1976), they occurred in only 10 years, and then lasted an average of about one month. In 1976, the low flow period lasted over three months, by far the longest duration in the 66 years. Three tactics have been designed to deal with this problem. Two bring additional water to the Maas from other rivers. The other considers the expansion of pumping capacity on the Julianakanaal.

The second factor that prevents the Southeast Highlands from receiving all of the surface water demanded is insufficient throughput capacity on the various canals. With current demands this is not a major problem. Comparing the extraction demands presented in Table 10.3 with the current supply capacity of 9 m^3/s (7 m^3/s along the Zuid-Willemsvaart from Lozen, and 2 m^3/s along the Wessem-Nederweertkanaal from Panheel), we see that, under the current demand scenario (SPRLO-RNONE), the supply capacity to the region is almost sufficient to meet the average demand for extractions from the Maas in 1943 and DEX. However, with increases in the demand due to implementation of waterboard plans or more intensive use of sprinkler equipment by farmers, the demands will soon exceed the available supply capacity fairly often. We have evaluated six tactics that would increase the supply capacity of the waterway system in the highlands. These tactics have been analyzed in conjunction with the ones that are designed to augment the Maas flow.

The third factor that prevents the region from receiving all of the water it needs is the sparseness of the system of ditches that transports the surface water from the canals to the farms. The waterboard plans represent tactics to expand the system of ditches.

Because of the factors discussed above that limit the supply of surface water to the Southeast Highlands, the agriculture shortage losses in the region are high, both in absolute terms and in comparison with losses in other regions. In Table 10.4, we compare the shortage losses per hectare in the Southeast Highlands with the losses per hectare in two other regions (the North and the Northeast Highlands) that show shortage losses of a similar or higher magnitude. Table 10.4a shows this comparison for the 1943 supply scenario, and Table 10.4b for the DEX supply scenario. We can conclude from these two tables that the two highlands regions incur the highest shortage losses per hectare of all regions. If we compare the two highlands regions with each other, we see that the losses in the Southeast Highlands are up to 18 percent higher than those in the Northeast Highlands for the 1943 supply scenario, and up to 37 percent higher for the DEX supply scenario.

The preventable shortage losses in the three regions show a similar pattern. In Tables 10.5a and 10.5b, we compare the preventable shortage losses per hectare in the regions considered in the two previous tables. The tables show that the preventable shortage losses per hectare in the highlands are higher than elsewhere, and that, for the DEX supply scenario, the preventable losses per hectare in the Southeast Highlands generally exceed those in the Northeast Highlands.

Table 10.4a

SHORTAGE LOSSES PER HECTARE (Dfl) IN THREE REGIONS:
1943 SUPPLY SCENARIO

	Low Intensity		High Intensity	
Region	No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
North	737	699	494	433
Northeast Highlands	937	911	838	776
Southeast Highlands	1055	945	988	759

Table 10.4b

SHORTAGE LOSSES PER HECTARE (Dfl) IN THREE REGIONS:
DEX SUPPLY SCENARIO

	Low Intensity		High Intensity	
Region	No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
North	2639	2512	1879	1741
Northeast Highlands	3504	3424	3177	3068
Southeast Highlands	4599	4322	4365	3859

Table 10.5a

PREVENTABLE SHORTAGE LOSSES PER HECTARE (Dfl) IN THREE REGIONS:
1943 SUPPLY SCENARIO

	Low Intensity		High Intensity	
Region	No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
North	--	--	2	5
Northeast Highlands	--	--	16	42
Southeast Highlands	--	3	3	43

Table 10.5b

PREVENTABLE SHORTAGE LOSSES PER HECTARE (Dfl) IN THREE REGIONS: DEX SUPPLY SCENARIO

	Low Intensity		High Intensity	
Region	No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
North	--	--	59	144
Northeast Highlands	5	13	109	288
Southeast Highlands	9	119	94	613

In Table 10.6, we show the <u>total</u> shortage losses and the preventable shortage losses for the Southeast Highlands (i.e., <u>not</u> per hectare) under the 1943 and the DEX supply scenarios, for the four demand scenarios. The table shows that the preventable losses in DEX for the three highest demand scenarios are considerable. We therefore expected to find promising tactics to reduce or eliminate these losses.

Table 10.6

AGRICULTURE LOSSES IN SOUTHEAST HIGHLANDS (Dflm)

	Low Intensity		High Intensity	
	No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
1943:				
Total shortage losses	346	310	324	249
Preventable shortage losses	--	1	1	14
DEX:				
Total shortage losses	1509	1418	1432	1266
Preventable shortage losses	3	39	31	201

10.2. EXPAND SUPPLY CAPACITY TO THE SOUTHEAST HIGHLANDS

We explained in the previous section that there are three reasons why the Southeast Highlands agriculture areas cannot always receive the quantity of fresh water that they need for optimal crop production. First, there is not always enough flow on the Maas. Second, the major canals have a limited water transport capacity. Third, the infrastructure that connects the major canals with the farmland is insufficiently developed.

A number of waterboard plans have been drawn up in order to reduce the severity of the last problem; the implementation of the promising plans is reflected in the RALL demand scenarios. We have defined several tactics to resolve the first and second problems. Each of them generally involves a large number of changes to the current infrastructure. The tactics tend to overlap each other, i.e., some of the changes are part of more than one of the tactics. We have therefore made a distinction between elementary tactics and aggregate tactics. The aggregate tactics, which are the subject of our analysis, are combinations of elementary tactics. In the following two subsections we describe each of the elementary tactics. We were able to screen out some of these tactics by dominance without detailed analysis. In such cases, we mention this under the description. In Sec. 10.2.3 we present the analysis of the aggregate tactics.

10.2.1. Elementary Tactics To Expand the Supply Capacity

10.2.1.1. Increase Throughput Capacity along Zuid-Willemsvaart from Lozen to Nederweert. The purpose of this tactic is to increase the supply capacity to the areas that extract water from the Zuid-Willemsvaart at locations between the point where this canal reenters the Netherlands and the entrance to the syphon between the Zuid-Willemsvaart and the Noordervaart, just west of Lock 15. It also indirectly increases the supply capacity to areas extracting from the Noordervaart (notably the Peel region) by enabling the Noordervaart syphon to be used at full capacity continually. Under the current treaty with Belgium, and given the throughput capacity of the Zuid-Willemsvaart between Maastricht and Lozen, the maximum amount of water that can be returned to the Netherlands at Lozen is 9 m^3/s. This is, however, larger than the throughput capacity of the section of the canal between Lozen and the entrance to the Noordervaart syphon, which is the minimum of the discharge capacities of the first three locks on the canal (Locks 16-18).

Under the minimum shipping improvement scenario, Locks 16-18 have a discharge capacity of 7 m^3/s. For flows greater than 7 m^3/s, bypasses must be built at these locks; the total investment cost (not annualized) for increasing the throughput capacity to 9 m^3/s comes to 2.25 Dflm. Flows higher than 9 m^3/s are not achievable because they exceed the maximum possible supply of water.

Under the maximum shipping improvement scenario, Lock 16 is to be reconstructed without bypasses being built. Locks 17 and 18 are in Belgium and are not included in the shipping improvement plan. The throughput capacity of the canal section under this scenario is 3 m^3/s (the lock loss). If a bypass were built at Lock 16, the throughput capacity of the canal would become 7 m^3/s (i.e., the current throughput capacities of Locks 17 and 18). The investment cost would be 0.5 Dflm. If the bypasses at Locks 17 and 18 were also replaced (at a cost of 1.5 Dflm), the canal throughput capacity would become 9 m^3/s, the maximum supply available from Lozen. Thus, the total investment cost for increasing the throughput capacity to 9 m^3/s would be 2.0 Dflm.

10.2.1.2. Install Pumping Capacity along the Zuid-Willemsvaart from 's-Hertogenbosch to Helmond. The purpose of this tactic is to pump water from the Maas at 's-Hertogenbosch to the intersection of the Zuid-Willemsvaart and the Wilhelminakanaal in order to supply water to areas that can extract from the Wilhelminakanaal or the sections of the Zuid-Willemsvaart north of the intersection.

There is currently no pumping capacity on the Zuid-Willemsvaart. A throughput capacity of up to the present canal capacity of 12.1 m^3/s can be created by building pumping stations at the seven locks on this stretch of the canal. Upstream capacities greater than this capacity require not only the pumping stations above, but also dredging of the 31.4 km of canal between Lock 0 and the intersection with the Wilhelminakanaal. In addition, to achieve capacities in excess of 13.4 m^3/s, sheetpiling must be installed along the canal sides, and eight bridges must be modified. The annualized fixed cost for the tactic is estimated at 9.5 Dflm for a canal throughput capacity of 5 m^3/s, and at 13.8 Dflm for 15 m^3/s.

The maximum shipping improvement scenario assumes that Locks 0, 2, 3, 4, 5, and 6 are replaced by four new locks, and that the canal carrying capacity is increased to more than 30 m^3/s. This tactic would then require the construction of pumping stations at the mouth of the Dieze (at the ship lock) and at the four new ship locks along the Zuid-Willemsvaart. The annualized fixed cost for these five new pumping stations is estimated at 5.0 Dflm for a canal throughput capacity of 5 m^3/s, and at 5.3 Dflm for 15 m^3/s.

Since the purpose of this tactic is the same as that of the tactic described below in Sec. 10.2.1.6, which pumps water up the Wilhelminakanaal, but the costs are considerably higher, we have screened out this tactic.

10.2.1.3. Expand Syphon Capacity to the Noordervaart. The objective of this tactic is to deliver more water from the Zuid-Willemsvaart west of Lock 15 to the Noordervaart for use in the Peel region. This is accomplished by expanding the capacity of the existing syphon (see Fig. 10.3). The investment cost of expanding the capacity of the present syphon from 4 to around 9 m^3/s is 0.75 Dflm, the same amount that it costs to build a bypass at an existing lock.

10.2.1.4. Build a Pumping Station at the Noordervaart. The purpose of this tactic is to make it possible to pump water from the Wessem-Nederweertkanaal to the Noordervaart (see Fig. 10.3). Since there is currently no pumping station at the lock at the entrance to the Noordervaart, water for the Noordervaart cannot pass the lock in the upstream direction. A pumping station can be built for this purpose. The annualized fixed cost for creating a throughput capacity of 5 m^3/s is estimated at 1.3 Dflm.

10.2.1.5. Increase Throughput Capacity at Panheel. The purpose of this tactic is to make it possible to pump water from the Maas at Maasbracht to Nederweert via the Wessem-Nederweertkanaal. There is a pumping station at Panheel with a gross capacity of 3 m^3/s. We have

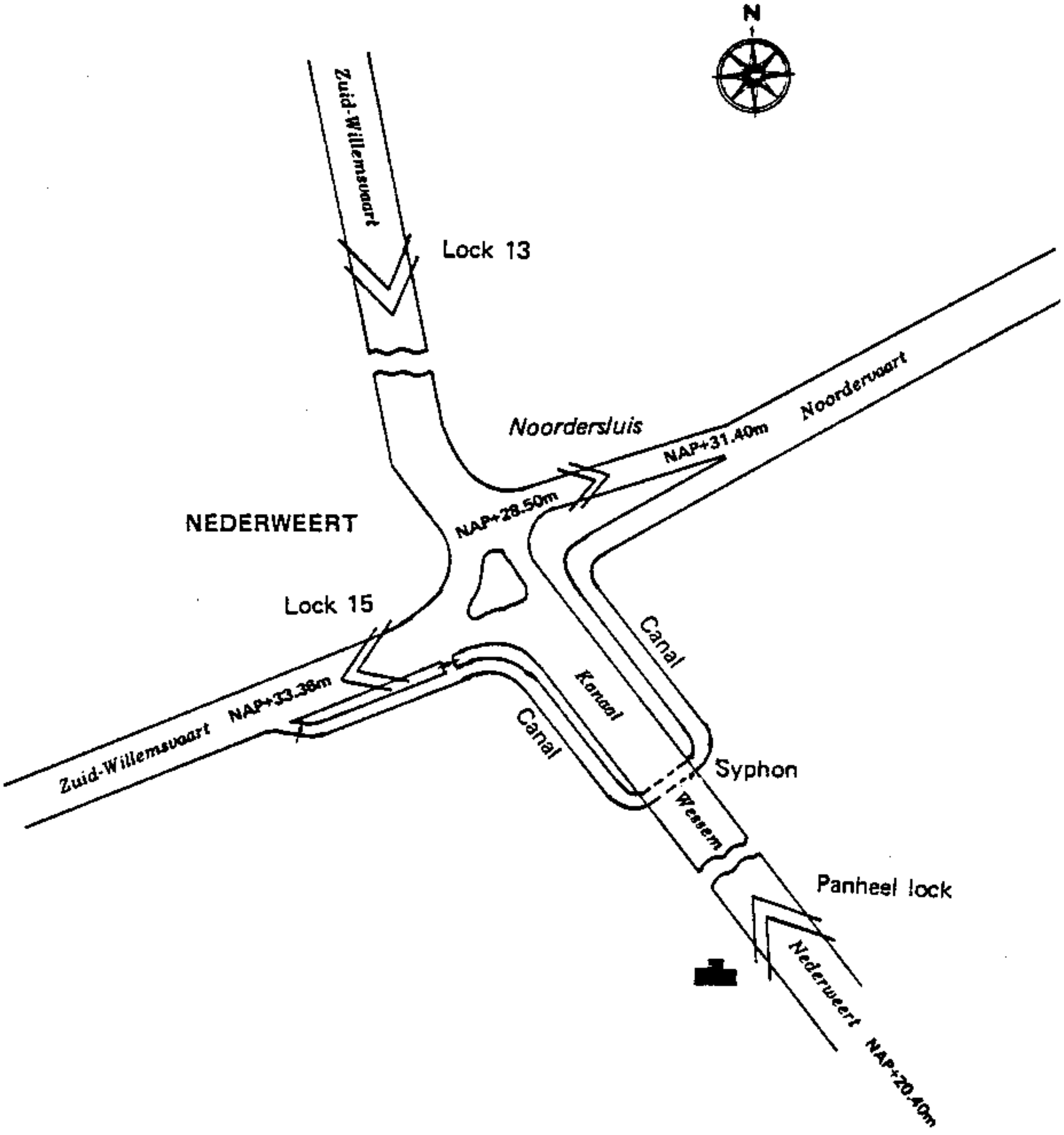

Fig. 10.3--The junction of waterways at Nederweert

assumed a net lock loss of 1 m^3/s, which is representative of the dry periods in which this tactic would be used. The present upstream capacity of this canal is the difference between the pumping capacity and the lock loss, or 2 m^3/s. To increase the upstream capacity by 5 m^3/s (to 7 m^3/s), the annualized fixed cost for expanding the pumping station is estimated at 1.6 Dflm; for an expansion by 15 m^3/s, the estimated cost is 2.4 Dflm.

Under the maximum shipping improvement scenario, the lock at Panheel will be rebuilt and the canal capacity increased. We assume that, in this case, the cost of expanding the pumping capacity is one-third less than that given above because it is added while the lock is under construction. Annualized fixed costs would be 1.1 Dflm for an expansion by 5 m^3/s, and 1.6 Dflm for an additional 15 m^3/s.

10.2.1.6. Install Pumping Capacity along the Wilhelminakanaal. The purpose of this tactic is to make it possible to pump water from the Bergsche Maas at Geertruidenberg to the Zuid-Willemsvaart. Just as for the tactic described in Sec. 10.2.1.2, this tactic will enable water to be supplied to areas that extract from the Wilhelminakanaal or the section of the Zuid-Willemsvaart north of Helmond. There is currently no pumping capacity on the Wilhelminakanaal. Under the tactic, pumping stations would have to be constructed at four locks (Lock V is always open). The annualized fixed cost for these four pumping stations is estimated at 5.4 Dflm for a canal throughput capacity of 5 m^3/s, and at 5.8 Dflm for a 15-m^3/s capacity.

Under the maximum shipping improvement scenario, Locks II-V are to be replaced with new locks (Lock I has been replaced already). We assume that, in this case, the cost of creating the pumping capacity is reduced by one-third. The annualized fixed cost of the tactic under this scenario is 4.1 Dflm for a throughput capacity of 5 m^3/s, and 4.4 Dflm for a capacity of 15 m^3/s.

We must note that the extraction of water for the Wilhelminakanaal at Geertruidenberg may occasionally force interruptions of the intake of drinking water into the Biesbosch reservoir. Interruptions will occur when the flow on the Bergsche Maas is insufficient to meet the extraction demands at Geertruidenberg and along the Amer, leading to a reversal of the river flow along the Amer. Our analysis has shown that only in DEX do the flows on the Bergsche Maas drop below 15 m^3/s (the maximum pumping capacity that we considered for the Wilhelminakanaal), and that this occurs in only four decades. We have not attempted to determine whether or not these drinking water intake interruptions are acceptable, given the reservoir capacities in the Biesbosch, nor did we attempt to quantify the associated monetary losses.

10.2.1.7. Build a Pipeline from the Julianakanaal to Panheel. This tactic will syphon water from the Born-Maasbracht section of the Julianakanaal (level NAP + 32.65 m) to the Wessem-Nederweertkanaal (level NAP + 28.50 m) west of the Panheel lock. A positive feature of this tactic is that Maas water can be brought to the Wessem-Nederweertkanaal without pumping. However, on the negative side, it depends on water from the Julianakanaal, and that is precisely where low flows cause high shipping losses during dry periods. A representative design of this pipeline provides a capacity of 4.2 m^3/s at an annualized fixed cost of 2.5 Dflm. Since this tactic is more expensive than the tactic that expands the pumping capacity at Panheel (see Sec. 10.2.1.5), and since its benefits (given the same capacity) are the same while it creates additional water supply problems on the Julianakanaal, we have screened this tactic out.

10.2.2. Elementary Tactics To Augment Maas Flow

10.2.2.1. Pump Water from Roer River along Maas to Panheel. The Roer is a tributary of the Maas. It flows into the Maas at the city of Roermond, 5 km northeast of Panheel. The minimum flow on the Roer is 10 to 12 m^3/s, which produces a sizable increase in the Maas flow below Roermond during the critical periods when the Maas flow at Maastricht is less than 20 m^3/s. Under these conditions, it would be beneficial to be able to bring water from the Roer to the section of the Maas between Maasbracht and Linne: this would create an additional source of supply for the highlands area through use of the Wessem-Nederweertkanaal.

The possibility to transport Roer water to the canal inlet at Panheel currently does not exist. Panheel and Roermond are located along adjacent sections of the Maas, so that a pumping station would have to be built at the weir that separates these two sections (at Linne) if this possibility is to be realized. The annualized fixed cost of such a pumping station is estimated at 1.2 Dflm for a capacity of 10 m^3/s.

10.2.2.2. Bring Waal Water to Maas through St. Andries. The purpose of this tactic is similar to that of the previous one: to bring additional water to extraction locations along the Maas. This tactic would involve the construction of a 1-km-long canal between the Waal and the Maas at St. Andries, about 10 km north of 's-Hertogenbosch. From the outlet of the canal at the Maas, the water could be allowed to flow by gravity to the Dieze or the Donge, from where it could be pumped into the highlands areas along the Zuid-Willemsvaart or the Wilhelminakanaal, employing previously described tactics. Alternatively, pumping stations could be built at the six weirs in the Maas between St. Andries and Panheel, so that the Waal water could be pumped upstream to Panheel and made available for transport along the Wessem-Nederweertkanaal. The annualized fixed cost of the tactic in the first design is estimated to be 0.7 Dflm. In the second design, the cost would be 6 to 7 Dflm, depending on the capacities of the pumping stations.

In the design in which the water flows downstream below St. Andries, some of the water can be used for cooling the Amer power plant. This use of the tactic has been discussed in Sec. 9.4. The benefits from the cooling of the power plant were found to be negative due to shipping losses incurred on the Waal at the extraction location, and the tactic was therefore screened out. Demands at the entrance to the

Wilhelminakanaal that would exceed the available flow on the Bergsche Maas above Geertruidenberg would occur very rarely. With our supply scenarios, only in DEX do the flows on the Bergsche Maas drop below 15 m^3/s (the maximum pumping capacity that we considered for the Wilhelminakanaal), and this occurs in only four decades. We therefore concluded that the tactic of bringing Waal water to the Maas through St. Andries would not be able to produce sufficient benefits to offset the shipping losses on the Waal (the net benefits for the tactic, shown in Sec. 9.4, were about -4 Dflm for both DEX and 1943). As a result, this design for the tactic was screened out.

The purpose of the design in which the Waal water would be pumped upstream (to make it available for extraction at Panheel) is the same as that of the tactic that employs the Roer as a source of additional water. However, the Roer tactic is much less expensive. Our analysis has shown that the flow of the Roer is sufficient to cover the demand for extractions from the Maas at Panheel under any scenario. For that reason, this design of the tactic was also screened out.

An alternative way of bringing Waal water to Panheel is to use the Maas-Waalkanaal to transport the water to the Maas. This tactic would require building a pumping station on the canal. The cost of bringing the water to Panheel along this route is about the same as it would be using the St. Andries route. However, the shipping losses on the Waal due to extractions at the north end of the Maas-Waalkanaal would be considerably higher than those at St. Andries. So, this tactic was also screened out.

10.2.3. Analysis of Aggregate Tactics

We have shown in Sec. 10.1 that under the current demand scenario (SPRLO-RNONE) the supply capacity to the region is practically sufficient to meet the average demand for surface water extraction from the Maas in DEX and 1943, but that the demands in the driest decades of these years exceed the supply capacity. Furthermore, we have presented evidence of rapidly increasing shortfalls in supply capacity when higher demand scenarios are considered. (Compare the demands for extraction, shown in Table 10.3, with the current supply capacity of 9 m^3/s.) This situation leads to large preventable losses in most of the demand scenarios, which suggests that we are likely to find promising tactics to reduce those losses. In this subsection we test this hypothesis. A complicating factor for our analysis is the number of elementary tactics. After the description and initial screening of the elementary tactics in Secs. 10.2.1 and 10.2.2, we are left with six elementary tactics to be evaluated, each of which can be associated with various capacities. These six elementary tactics are listed in Table 10.7, together with their range of feasible capacity expansions and cost estimates for one or more capacities in that range.

In order to evaluate an aggregate tactic, we must associate a particular capacity with each of the constituent elementary tactics.

Table 10.7

ELEMENTARY TACTICS TO EXPAND SUPPLY TO SOUTHEAST HIGHLANDS AFTER INITIAL SCREENING

			Annualized Fixed Cost (Dflm)		
Subsection Reference	Tactic Name	Range of Capacities (in m^3/s)	Minimum Shipping Improve.	Maximum Shipping Improve.	For Capacity (m^3/s)
10.2.1.1	Increase Throughput Capacity along Zuid-Willemsvaart from Lozen to Nederweert	7-9	0.18	0.18	9
10.2.1.3	Expand Syphon Capacity to the Noordervaart	4-9	0.06	0.06	9
10.2.1.4	Build a Pumping Station at the Noordervaart	0-10	1.35	1.35	5
10.2.1.5	Increase Throughput Capacity at Panheel	2-	1.62 2.01 2.41	1.09 1.35 1.61	7 12 17
10.2.1.6	Install Pumping Capacity along the Wilhelminakanaal	0-	5.44 5.76	4.11 4.36	5 15
10.2.2.1	Pump Water from Roer River along Maas to Panheel	0-	1.13 1.17	1.13 1.17	5 10

This leads to an almost infinite number of possible aggregate tactics that can be evaluated.

Confronted with a potentially overwhelming analysis, we chose an approach that is marked by two simplifications. First, for each demand scenario, we calculated the preventable losses and evaluated only aggregate tactics with an annualized fixed cost below the upper bound of the expected annual preventable losses. We have already shown these upper bounds in Table 4.6 of Sec. 4.2, where we explain this approach in more detail. Second, we chose a suitable supply capacity expansion for the entire region for each demand scenario, and then considered a limited number of aggregate tactics that provide such a supply capacity expansion. It should be remembered that the objective of our analysis was to provide a broad-brush evaluation of tactics. The results give an indication of which tactics are promising (i.e., deserve further investigation as far as detailed design and cost) and which tactics are not.

In Table 10.8, we show the preventable losses for each of the four supply scenarios, as well as the bounds on expected annual preventable losses that are derived from them.

Table 10.8

PREVENTABLE LOSSES IN THE SOUTHEAST HIGHLANDS FOR FOUR DEMAND SCENARIOS (Dflm)

Demand	Preventable Losses in				Expected Annual Preventable Losses	
Scenario	DEX	1959	1943	1967	UB	LB
SPRLO-RNONE	3.2	0.8	0.4	0.0	0.5	0.2
SPRLO-RALL	38.9	3.9	1.0	0.0	3.7	1.1
SPRHI-RNONE	31.4	3.7	0.4	0.0	2.9	0.9
SPRHI-RALL	200.8	58.9	13.8	0.0	28.1	8.9

We will now describe our analysis for each of the four demand scenarios.

10.2.3.1. Analysis for SPRLO-RNONE. According to the information in Table 10.8, aggregate tactics, if they are to be promising under this demand scenario, must have an annualized fixed cost of less than 0.5 Dflm. We can see from Table 10.7 that this leaves us with a very limited choice. Only the expansions of the Lozen-Nederweert section of the Zuid-Willemsvaart and the syphon to the Noordervaart meet the cost criterion. These two elementary tactics were combined into one aggregate tactic:

> Increase the throughput capacity along the Zuid-Willemsvaart between Lozen and Nederweert to 9 m^3/s and expand the syphon capacity to the Noordervaart by 5 m^3/s.

The tactic was, however, not found to be promising. In none of the analysis years did the tactic show any benefits. Water shortages in the region could not be prevented by this tactic because the water supply at Maastricht was limiting in the decades when the additional capacity could have made the difference. We can thus draw the conclusion that no tactics for this region will be promising unless the use of sprinkler equipment becomes more widespread--through the installation of additional equipment in currently sprinkled areas or through the implementation of waterboard plans.

10.2.3.2. Analysis for SPRLO-RALL. Table 10.8 shows that aggregate tactics to be evaluated under this demand scenario must have an annualized fixed cost under 3.7 Dflm. We chose to analyze two such tactics (the first tactic is the one that was evaluated under the SPRLO-RNONE scenario):

1. Increase the throughput capacity along the Zuid-Willemsvaart between Lozen and Nederweert to 9 m^3/s and expand the syphon capacity to the Noordervaart by 5 m^3/s.
2. Pump a maximum of 5 m^3/s from the Roer along the Maas to Panheel; increase pumping capacity at Panheel by 5 m^3/s; and build a pumping station at the Noordervaart with a 5-m^3/s capacity.

When designing the aggregate tactics for this demand scenario, we were looking for tactics that would add 5 to 10 m^3/s additional supply capacity to the region. Table 10.3 shows that, under this demand scenario, the average decade demands for extractions from the national distribution network for the 1943 and DEX supply scenarios are 10.5 m^3/s and 13.5 m^3/s, and that the peak decade demands are 15.8 m^3/s and 20.6 m^3/s, respectively. Since an additional supply capacity of 5 to 10 m^3/s would create a total supply capacity to the region of 14 to 19 m^3/s, such an expansion seemed sufficient to satisfy the agricultural demands in most decades. From information on the cost of the elementary tactics presented in Table 10.7, one can conclude that the two aggregate tactics defined above were the most suitable candidates. (Tactic 2 without the Roer tactic will also be discussed.) In Table 10.9, we show the benefits from the two tactics and their annualized fixed costs.

Table 10.9

REDUCTION IN AGRICULTURAL SHORTAGE LOSSES IN SOUTHEAST HIGHLANDS FROM TWO AGGREGATE TACTICS UNDER SPRLO-RALL SCENARIO (Dflm)

Tactic No.	DEX	1959	1943	1967	Expected Annual Benefits		Annualized Fixed Cost (By Shipping Improvement Scenario)	
					UB	LB	Minimum	Maximum
1	0.0	1.7	0.6	0.0	0.5	0.2	0.2	0.2
2	28.8	3.1	0.6	0.0	2.7	0.8	4.1	3.6

The results show that Tactic 1 is promising, and that Tactic 2 is not. The conclusion for Tactic 1 is opposite to the one we reached for it under the SPRLO-RNONE scenario. The reason for the change is that, under the SPRLO-RALL scenario, the capacity shortfalls are higher and more frequent, and the additional supply capacity can reduce these shortfalls.

Removal of the first elementary tactic from the definition of Tactic 2 (pump water from the Roer to Panheel) produces a tactic (Tactic 3) that might be promising. The costs of this tactic under the minimum and maximum shipping improvement scenarios are 3.0 Dflm and 2.4 Dflm. However, the benefits of the tactic will be at most 2.7 Dflm (the benefits of Tactic 2). We have not carried out an analysis of Tactic 3. However, we know that it can be promising only under the maximum shipping improvement scenario, and, if found promising under this scenario, the excess of the upper bound of the expected annual benefits over the costs would be very small.

10.2.3.3. Analysis for SPRHI-RNONE. From Table 10.8, we can see that the costs of potentially promising aggregate tactics for this demand scenario cannot exceed 2.9 Dflm. Furthermore, Table 10.3 shows that the demands for extractions from the national distribution network under this demand scenario are 1 to 3 m^3/s lower than those under the previously discussed scenario (SPRLO-RALL). Thus, no other tactics than the ones analyzed under the latter demand scenario need to be considered for the SPRHI-RNONE scenario. Tactic 2, however, can be screened out because its annualized fixed cost for either shipping improvement scenario exceeds the upper bound on the expected annual preventable losses. This is also true for Tactic 3 under the minimum shipping improvement scenario. Under the maximum improvement scenario, its annualized fixed cost exceeds what we estimate to be the upper bound on its expected annual benefits,[4] and the tactic is therefore also screened out. Thus, we conclude that the only aggregate tactic that stands a chance of being promising is Tactic 1: the tactic that expands the Lozen-Nederweert section of the Zuid-Willemsvaart and the syphon to the Noordervaart. Table 10.10 shows the results of the analysis of this tactic. The upper bound on the expected annual benefits is slightly above the annualized fixed cost under both shipping improvement scenarios. Thus, although it is unlikely that the expected annual benefits will exceed the annualized fixed cost, we did not screen the tactic out.

Table 10.10

REDUCTION IN AGRICULTURAL SHORTAGE LOSSES IN SOUTHEAST HIGHLANDS UNDER SPRHI-RNONE SCENARIO (Dflm)

Tactic No.	DEX	1959	1943	1967	Expected Annual Benefits		Annualized Fixed Cost (By Shipping Improvement Scenario)	
					UB	LB	Minimum	Maximum
1(a)	0.0	2.0	0.0	0.0	0.28	0.10	0.24	0.22

(a) As defined in Sec. 10.2.3.2.

10.2.3.4. Analysis for SPRHI-RALL. This demand scenario requires a larger supply capacity expansion than the previously discussed demand scenarios. Table 10.3 shows that the average decade demands for extractions from the national distribution network for the 1943 and DEX supply scenarios are 16.4 m^3/s and 18.3 m^3/s and that the peak decade demands are 30.2 m^3/s and 40.5 m^3/s. As a test case, we chose to design our tactics for a supply capacity expansion of about 15 m^3/s, leading to a total supply capacity of about 24 m^3/s. Our intention was to determine, on the basis of the losses prevented by the tactics, whether this additional supply capacity was appropriate, or whether more or less supply capacity would be more cost beneficial.

Under this scenario, the expected annual preventable losses are much higher than under the other three scenarios: they lie between an upper bound of 28.1 Dflm and a lower bound of 8.9 Dflm. From Table 10.7, we see that there are no elementary tactics whose costs exceed 6 Dflm, and that most of them are considerably smaller. Therefore, numerous aggregate tactics can be defined for evaluation whose costs do not exceed the upper bound of the expected annual benefits. We have chosen to analyze four aggregate tactics that, we feel, reflect reasonably well the range of potential combinations of elementary tactics:

4. Increase the throughput capacity along the Zuid-Willemsvaart between Lozen and Nederweert to 9 m^3/s; expand the syphon capacity to the Noordervaart by 5 m^3/s; and increase the throughput capacity at Panheel by 10 m^3/s.
5. Increase the throughput capacity along the Zuid-Willemsvaart between Lozen and Nederweert to 9 m^3/s; expand the syphon capacity to the Noordervaart by 5 m^3/s; increase the throughput capacity at Panheel by 5 m^3/s; and build pumping stations along the Wilhelminakanaal with capacities of 5 m^3/s.
6. Pump a maximum of 10 m^3/s from the Roer along the Maas to Panheel; increase throughput capacity at Panheel by 15 m^3/s; and build a pumping station at the Noordervaart with a 5-m^3/s capacity.
7. Build pumping stations along the Wilhelminakanaal with capacities of 15 m^3/s.

Table 10.11 presents the benefits from these four tactics and their annualized fixed costs. The table shows that all four tactics are promising. Note that the cost of each tactic is also exceeded by the lower bound on the expected annual benefits, and not just by the upper bound on these benefits. Further consideration of the costs and benefits presented in the table leads to various conclusions. First, Tactic 4 seems more attractive than Tactic 7 since it has both lower costs and higher benefits.

Table 10.11

REDUCTION IN AGRICULTURAL SHORTAGE LOSSES IN SOUTHEAST HIGHLANDS
UNDER SPRHI-RALL SCENARIO (Dflm)

Tactic					Expected Annual Benefits		Annualized Fixed Cost (By Shipping Improvement Scenario)	
No.	DEX	1959	1943	1967	UB	LB	Minimum	Maximum
4	147.6	49.0	13.2	0.0	22.7	7.3	2.3	1.6
5	173.4	55.8	13.4	0.0	25.6	8.1	7.3	5.4
6	172.6	51.3	13.3	0.0	24.9	7.9	4.9	4.1
7	139.1	37.6	10.1	0.0	19.2	6.1	5.8	4.4

In addition, if we compare the costs and benefits of Tactics 4, 5, and 6, we see that the marginal benefits from investing more money than what is required for Tactic 4 (the least expensive tactic) are more than offset by the additional costs. Thus, we can conclude that, of the four tactics considered, Tactic 4 is the most attractive. Overall, the results in Table 10.11 suggest that the capacities chosen for the aggregate tactics were about right, and that the aggregate tactics themselves were appropriate choices.

Could any other aggregate tactic be defined that would be more attractive than Tactic 4? We mentioned earlier in this section that, under this demand scenario, the expected annual preventable losses associated with the tactics are less than 28.1 Dflm. Our analysis shows that, for an expansion of the supply capacity to about 24 m^3/s, Tactic 4 is the most attractive tactic, reducing the preventable losses by about 80 percent. This tactic leaves remaining preventable losses of less than 5.4 Dflm. We believe that, to be more attractive than Tactic 4, any aggregate tactic would have to build on it. The remaining preventable losses are mostly due to low Maas flows at Maastricht under the DEX supply scenario. Therefore, modifying Tactic 4 to include an expansion of the throughput capacity at Panheel by an additional 2 to 5 m^3/s and, possibly, the construction of a pumping station to pump 2 to 5 m^3/s of Roer water along the Maas could provide benefits that would exceed the additional costs. However, the benefits from any measures in addition to those contained in Tactic 4 are likely to exceed their costs by a small margin at best.

10.3. REDUCE SHIPPING LOSSES ON JULIANAKANAAL

As discussed above in Sec. 10.1, one of the major water management problems in the Southeast Highlands is that the flows on the Maas are sometimes insufficient to supply all of the demands of users of the water. One of the consequences of these low flows is that shipping on the Julianakanaal experiences delays at the locks (particularly at Maasbracht), causing substantial economic losses. The water demand along the Julianakanaal arises almost exclusively from passing ships through the locks at Born and at Maasbracht. At Born up to 13 m^3/s can be pumped back for reuse in locking ships through. There is no such permanent pumping capacity at Maasbracht, although on an emergency basis up to 5 m^3/s can be pumped back using portable pumps that were acquired by the Rijkswaterstaat in 1977.

In 1976 the flows on the Maas were particularly low.[5] As an emergency measure, to prevent staggering losses to shipping and to the chemical plant located on the Julianakanaal, the RWS rented portable pumps with a total capacity of 5 m^3/s, placed them on a rented barge, and placed the barge in one of the three lock chambers at Maasbracht. The pumps were then operated to recycle the water used for locking through ships, so that ships could be locked through faster for a given flow on the Maas.

This emergency measure proved to be very successful.[6] As a result, the RWS decided to purchase five portable pumps, each with a pumping capacity of 1 m^3/s, for use in the future during periods of low Maas flows.

The 5 m^3/s of temporary emergency pumping capacity at Maasbracht is not sufficient to eliminate all shipping losses caused by low flows on the Julianakanaal. This would require a pumping capacity of 20 to 25 m^3/s with the 1976 level of shipping, and 30 to 32 m^3/s with the increased level of shipping expected in 1985. The shipping losses in 1976 due to low flows on the Julianakanaal were estimated at more than 4 Dflm, even with the 5 m^3/s of emergency pumping at Maasbracht. We therefore felt that it might be possible to identify a promising tactic for further reducing shipping losses on the Julianakanaal.

We examined four alternatives:

1. Do nothing beyond the continued use of the 5 m^3/s in portable pumping capacity at Maasbracht.
2. Increase the portable pumping capacity at Maasbracht to 10 m^3/s.
3. Construct a permanent pumping station at Maasbracht with a capacity of 5 m^3/s and continue to use the portable pumps when necessary (for a total pumping capacity of 10 m^3/s).
4. Construct a permanent pumping station at Maasbracht with a capacity of 10 m^3/s and dispose of portable pumps.

Alternatives 2, 3, and 4 all increase the pumping capacity at Maasbracht to 10 m^3/s. This capacity was chosen by examining the shipping loss functions (see Sec. 10.3.2). It was clear that increases in capacity beyond 10 m^3/s would not be cost beneficial.

The analysis of these tactics was performed with a methodology that differed in three ways from the one used for screening other tactics. First, we used a small, special-purpose simulation model that only simulated flows on the Julianakanaal and on the Maas between Maastricht and Panheel. We did this because the Distribution Model does not provide sufficient detail of the control of flows on these waterways to permit analysis of the tactics listed above. Second, because it was inexpensive to use the model, we simulated the 66 years of river flows between 1911 and 1976, instead of only four years. The expected annual benefits of the tactics were then estimated by taking the average of the benefits over these 66 years. Third, the analysis was performed for both the 1976 and 1985 shipping goods and fleet scenarios. (The analysis of all other tactics was performed for the 1985 scenario only.)

10.3.1. Water Supply

The water available at the entrance to the Julianakanaal varies considerably over time. We used data on the average Maas flows at

Monsin (south of the border with Belgium) by decade from 1911 to 1976, and took the flow on the Julianakanaal to be the Maas flow at Monsin plus the flow of the Jeker,[7] less the projected future extractions for the Albertkanaal (12 m^3/s) and the minimum extraction for the Zuid-Willemsvaart (13 m^3/s), and less the flow sent down the Grensmaas.

In addition to pumping some of the locking water back up at the locks, there are a number of managerial techniques that are available for reducing low water losses from shipping delays. Requiring more ships per lockage and operating the two locks at Maasbracht synchronously so as to facilitate syphoning of lock water are two ways to save water. (Syphoning means that some of the water of a downstream locking is used to help fill the lock chamber of an upstream locking.) The weir at Borgharen can be used to restrict flow into the Grensmaas. Reducing the level on the Julianakanaal and upstream can provide approximately 4 m^3/s of water for a decade. Our analysis assumed that all of these tactics were used.[8] Some of these (e.g., using water stored upstream) are costless tactics that postpone the need for more costly alternatives, if only temporarily.

10.3.2. Shipping Loss Functions

When there is less water available at a lock than is demanded, fewer lockings can occur, resulting in increased delays for the ships, and hence economic losses to the shippers.

In Vol. IX, loss functions are derived that relate incremental shipping losses due to low water flows at Maasbracht to the flow on the Julianakanaal for both the actual 1976 and expected 1985 shipping fleet and goods scenarios. (There are always some shipping losses due to locking delays. We are interested in the incremental losses due to low flows.) These relationships for both shipping scenarios are graphed in Fig. 10.4 and are shown in tabular form in Table 10.12. The table for each scenario contains two columns. The first column shows the estimated weekly losses from shipping delays assuming no pumping is done at Maasbracht. The second column contains the estimated shipping delay losses assuming a pumping capacity of 5 m^3/s at Maasbracht. All of the loss functions assume that the managerial tactics mentioned in Sec. 10.3.1 are used to conserve water at Maasbracht during periods of low flow.

The losses to shipping were developed on a weekly basis because the shipping data that were used to derive the loss functions are available on that basis. In order to carry out our analysis, we made the loss functions compatible with our river flow data, which were on a decade basis, by multiplying the weekly losses by 10/7.

The relationships in Table 10.12 assume that ships arriving in a given week will be locked through during that week, i.e., shipping delays in a certain week are independent of the delays in the previous week. In actuality, this is not the case. The correlation of shipping delays in successive weeks tends to cause our loss functions to

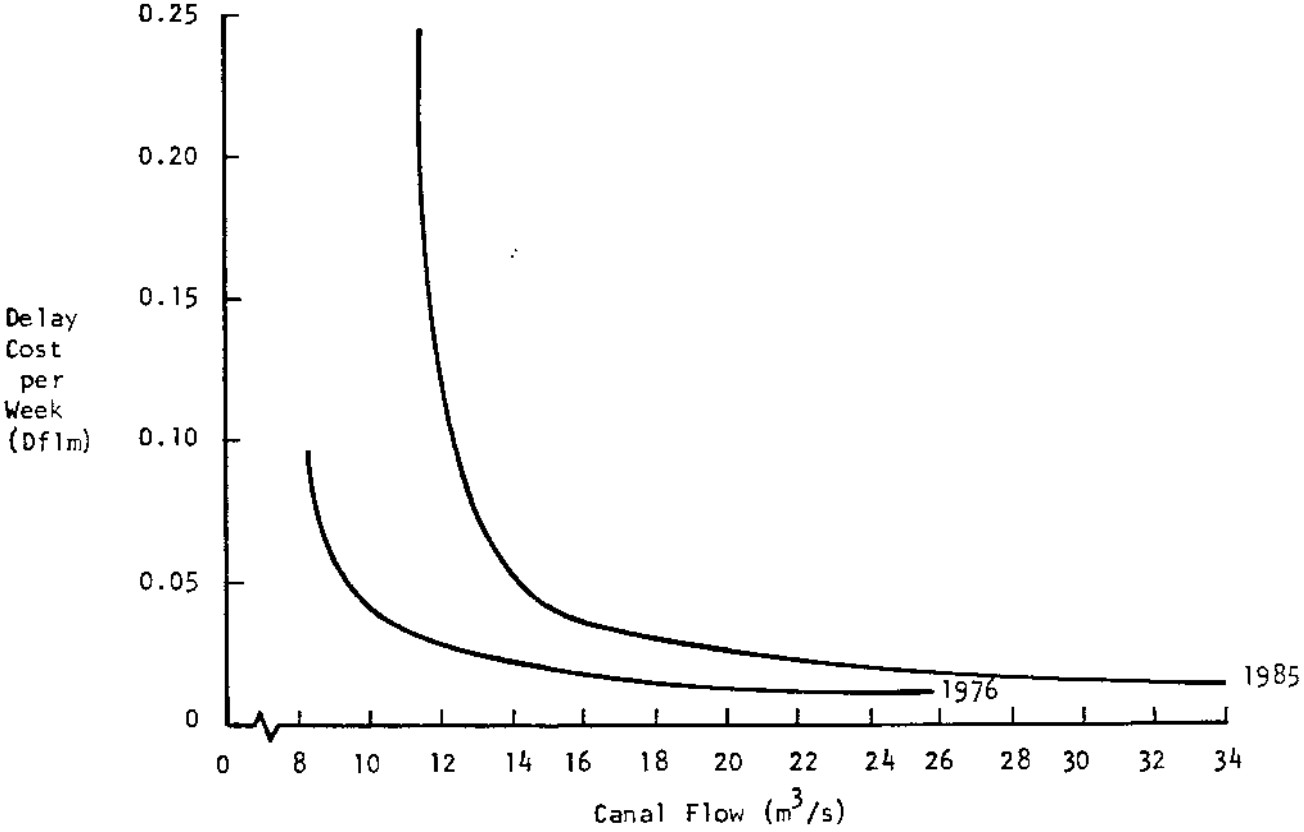

Fig. 10.4--Shipping delay loss functions for Maasbracht

underestimate the weekly delay costs, and thus to produce conservative estimates of the losses.

Use of the portable pumps entails a fixed setup cost of 8,240 Dfl and operating costs of 37,800 Dfl per decade. In developing the loss functions for the case with 5-m^3/s portable pumping capacity, we assumed that the portable pumps would be used only when the costs of setting up the pumps and operating them for a decade would be less than the shipping losses prevented by the pumping during that decade. This decision rule supposes foreknowledge of the average river flow for a decade at the beginning of that decade and leads to an overestimate of the net benefits of pumping. On the other hand, decisions to start pumping and to stop pumping can be made in reality on any day and not only at the beginning of a decade. Our supposition that once pumping is begun, it must last an integral number of decades thus leads to an underestimate of the net benefits of pumping. We assume that these two effects balance each other.

Table 10.12

RELATIONSHIP BETWEEN FLOW RATE ON JULIANAKANAAL
AND INCREMENTAL SHIPPING LOSSES
(Flows in m^3/s; losses in 1000s of Dfl/wk)

	1976 Fleet & Goods Shipping Losses		1985 Fleet & Goods Shipping Losses	
Flow	No Pumping	Pumping Beginning at 8 m^3/s	No Pumping	Pumping Beginning at 13 m^3/s
≥34	0.0	0.0	0.0	0.0
33	0.0	0.0	0.0	0.5
32	0.0	0.0	1.0	1.0
31	0.0	0.0	1.0	1.5
30	0.0	0.0	2.0	2.0
29	0.0	0.0	2.0	2.5
28	0.0	0.0	3.0	3.0
27	0.0	0.0	4.0	4.0
26	0.0	0.0	5.0	5.0
25	0.3	0.3	6.0	6.0
24	0.5	0.5	7.0	7.0
23	0.8	0.8	8.0	8.0
22	1.0	1.0	9.0	9.0
21	1.5	1.5	11.0	11.0
20	2.0	2.0	12.0	12.0
19	2.8	2.8	14.0	14.0
18	3.8	3.8	16.0	16.0
17	5.0	5.0	19.0	19.0
16	6.5	6.5	23.0	23.0
15	8.3	8.3	30.0	30.0
14	10.5	10.5	41.0	41.0
13	13.5	13.5	61.0	16.0
12	17.0	17.0	113.0	19.0
11	22.5	22.5	709.0	23.0
10	30.5	30.5	1509.0	30.0
9	46.0	46.0	1509.0	41.0
8	232.0	13.5	1509.0	61.0
7	1300.0	17.0	1509.0	113.0
6	1300.0	22.5	1509.0	709.0
5	1300.0	30.5	1509.0	1509.0
4	1300.0	46.0	1509.0	1509.0
3	1300.0	232.0	1509.0	1509.0
2	1300.0	1300.0	1509.0	1509.0
1	1300.0	1300.0	1509.0	1509.0

10.3.3. Analysis of Alternatives

The incremental shipping delay losses and the variable costs were estimated for the 5-m^3/s portable pumping alternative by simulating the Julianakanaal system by decade for the 66 years for which we had data.

The shipping delay losses were estimated using the function presented in Table 10.12. The cost of this alternative has three components: A fixed setup charge of 8,240 Dfl, operating costs of 37,800 Dfl per decade, and an annualized fixed cost (incurred whether the pumps are used or not) of 133,900 Dfl. For increasing the portable pumping capacity to 10 m^3/s, the additional costs for each of the three components are 4120 Dfl for setup, 20,640 Dfl per decade, and an annualized fixed cost of 260,220 Dfl.[9] The annualized fixed cost of the tactic to construct a permanent pumping station at Maasbracht with a capacity of 5 m^3/s to supplement the portable pumps (Alternative 3) is 0.8 Dflm, and the annualized fixed cost for a permanent pumping station with a capacity of 10 m^3/s (Alternative 4) is 1.1 Dflm.

Tables 10.13a and 10.13b present the results from the simulation runs for Alternative 1 (5-m^3/s portable pumping capacity). They show costs and losses averaged over all 66 years, and also costs and losses for each of the ten years during which the flows on the Maas were low enough to require the portable pumps to be set up and used.

Table 10.13a

ANNUAL COSTS AND BENEFITS (1000s OF Dfl) FROM HAVING 5-m^3/s
PORTABLE PUMPING CAPACITY AVAILABLE AT MAASBRACHT
(1976 Shipping Fleet and Goods)

Year	No. of Decades	Losses with No Pumping	Losses with Pumping	Variable Cost of Pumping	Annualized Fixed Cost	Net Benefit
1921	3	4264	335	122	134	3673
1934	8	14897	395	311	134	14057
1938	1	358	45	46	134	133
1943	1	1863	38	46	134	1645
1947	6	11290	452	235	134	10469
1959	1	1991	466	46	134	1345
1964	1	2096	271	46	134	1645
1971	2	2302	198	84	134	1886
1973	2	780	154	84	134	408
1976	10	18730	4246	386	134	13964
Average over 10 dry years						
	3.5	5857	660	141	134	4922
Average over 1911-1976						
	0.5	890	102	21	134	633

Table 10.13a shows that, under the 1976 shipping fleet and goods scenario, the shipping losses preventable by pumping at Maasbracht average only 0.9 Dflm per year and that the portable pumps can be expected to be used an average of 5 days per year. (They were not used at all in 85 percent of the years, and were used for an average of 3.5 decades per year in the 10 years that required pumping.) Even with

Table 10.13b

ANNUAL COSTS AND BENEFITS (1000s OF Dfl) FROM HAVING 5-m^3/s PORTABLE PUMPING CAPACITY AVAILABLE AT MAASBRACHT
(1985 Shipping Fleet and Goods)

Year	No. of Decades	Losses with No Pumping	Losses with Pumping	Variable Cost of Pumping	Annualized Fixed Cost	Net Benefit
1921	6	11376	1611	235	134	9396
1934	9	19472	8800	348	134	10190
1938	1	2303	170	46	134	1953
1943	1	2209	1066	46	134	963
1947	8	17344	9721	311	134	7178
1959	4	6487	1271	159	134	4923
1964	4	8976	1327	159	134	7356
1971	5	8606	1321	197	134	6954
1973	4	8763	400	159	134	8070
1976	13	28148	14452	500	134	13062
Average over 10 dry years						
	5.5	11368	4014	216	134	7004
Average over 1911-1976						
	0.8	1742	627	33	134	948

such rare use, the cost of the portable pumps is so low that the expected annual benefits exceed the expected annual costs by over 600,000 Dfl, which supports the decision of the RWS to purchase the portable pumps.

The portable pumps eliminate almost all of the preventable shipping losses under the 1976 shipping scenario. The remaining preventable shipping losses average only 102,000 Dfl per year. This is not enough to justify implementation of Alternative 2 (increasing the portable pumping capacity to 10 m^3/s). Since Alternative 3 is even more expensive, it is not promising either for this scenario. Alternative 4 is not promising, since the expected annual benefits from having that pumping capacity are only 0.9 Dflm, while the annualized fixed cost of the tactic is 1.1 Dflm.

We reach similar conclusions when we consider the 1985 shipping fleet and goods scenario (see Table 10.13b). In this case, the preventable losses are almost twice as great as under the 1976 scenario. Purchase of the portable pumps was clearly a cost-beneficial decision for this case also (the expected annual benefits exceed the expected annual costs by almost 1 Dflm). However, whereas the portable pumps under the 1976 scenario were able to cut preventable losses by almost 90 percent in the 10 years in which pumping was used, they reduce the preventable losses in these years by only 65 percent under the 1985 scenario. The remaining preventable losses, which would be practically eliminated if the pumping capacity at Maasbracht were 10 m^3/s, average over 600,000

Dfl per year. This is not enough to justify the construction of a supplemental permanent pumping station at Maasbracht with a capacity of 5 m^3/s. However, it is enough to justify the purchase of 5 m^3/s in additional portable pumping capacity, which would have an annualized fixed cost of about 260,000 Dfl.

Table 10.13b shows that, if there were no pumping back of water at Maasbracht, shipping losses on the Julianakanaal under the 1985 shipping scenario would be 1.7 Dflm. Assuming that a pumping capacity of 10 m^3/s at Maasbracht would eliminate practically all of these losses, all three of the alternatives to the current situation that we considered would be promising (since all three have costs that are below the expected benefits). However, as mentioned in the previous paragraph, since 5 m^3/s of portable pumping capacity is already available, only Alternative 2 has a cost that is lower than the average annual remaining losses (627,000 Dfl).

We should point out that the above analysis has assumed that the flow on the Grensmaas is reduced to 1 m^3/s whenever the flow on the Maas at the entrance to the Julianakanaal is less than 30 m^3/s. Normally, the minimum flow on the Grensmaas is 10 m^3/s, which is used to combat pollution. If a minimum flow of 10 m^3/s must be maintained at all times, the average annual shipping losses on the Julianakanaal in the situation with no pumping at Maasbracht (column 3 of Tables 10.13a and 10.13b) would increase by 1.3 Dflm under the 1976 shipping fleet and goods scenario, and 2.3 Dflm under the 1985 scenario. These increased losses would make all four alternatives promising under both scenarios.

10.4. SUMMARY OF CONCLUSIONS

The agriculture shortage losses in the Southeast Highlands are very high. For most combinations of supply and demand scenarios, the total shortage losses and the preventable shortage losses in the region exceed those in the Northeast Highlands (the region with the next highest losses) on a per-hectare basis by a considerable margin. Both total and preventable losses are particularly high in DEX. This is due to the fact that, under this scenario, the lack of supply capacity to the region in the form of insufficient canal throughput capacity coincides with very low Maas flows over a long period of time.

We analyzed a number of changes to the current infrastructure that would reduce preventable losses during dry periods. Most of these changes involve expansion of throughput capacity on the various canals, while others are intended to augment the Maas flows at the extraction locations during dry periods. We evaluated various aggregate tactics, each of which comprised a number of such changes to the infrastructure. We found that, for low sprinkler intensity, the implementation of the promising waterboard plans was a precondition for any tactics to be promising.

Under the SPRLO-RALL and the SPRHI-RNONE scenarios, the only tactic that was found to be promising was the one that expands the supply capacity to the region by way of the Zuid-Willemsvaart and the Noordervaart. This tactic involves an expansion of the throughput capacity of three ship locks downstream from Lozen and of the syphon that connects the Zuid-Willemsvaart with the Noordervaart. Through this tactic, the supply capacity to the region can be increased from the current 9 m^3/s to 14 m^3/s.

Under the assumption of high sprinkler intensity and waterboard plans implemented (SPRHI-RALL), the expected annual preventable losses are so high that many tactics were shown to be promising. We found, however, that the most cost-effective tactics all build on the tactic that was shown to be promising under the SPRLO-RALL and SPRHI-RNONE demand scenarios. Specifically, we evaluated and found most promising the addition to that tactic of an expansion of the throughput capacity of the Wessem-Nederweertkanaal to 10 m^3/s. We expect that a still larger expansion of the capacity of this canal (to 12 or 15 m^3/s) may also be promising, possibly in combination with the construction of a pumping station with a capacity of from 2 to 5 m^3/s to pump up Roer water along the Maas to the inlet of the Wessem-Nederweertkanaal. This pumping station would serve to augment the Maas flow at the inlet to the Wessem-Nederweertkanaal during periods in which the extraction demand at the inlet would exceed the river flow.

We also examined the problem caused by the lack of sufficient water to lock ships through expeditiously on the Julianakanaal. In particular, we considered several alternatives for recycling water at the Maasbracht lock on the canal. There is currently no permanent pumping capacity at that lock. On an emergency basis, portable pumps are placed on a barge, which is placed in one of the ship locks. This provides a temporary pumping capacity of 5 m^3/s. We found that, under the 1976 shipping fleet and goods scenario, this emergency procedure would eliminate almost all of the low water shipping losses on the canal, so no additional tactics were considered promising. Under the 1985 shipping fleet and goods scenario, we found that the remaining losses would be high enough to justify increasing the temporary pumping capacity to 10 m^3/s, but not high enough to justify construction of a permanent pumping station at Maasbracht.

NOTES

1. The treaty specifies both the flow that the Netherlands is required to divert and the way in which this flow is to be measured. Since the measurement method underestimates the flow, the actual minimum flow to be diverted is about 13 m^3/s. The return flow at Lozen remains 2 m^3/s.
2. The throughput capacity of 2 m^3/s on the Wessem-Nederweertkanaal is the difference between the pumping capacity at Panheel of 3 m^3/s and a net lock loss of 1 m^3/s. The net lock loss reflects a gross lock loss of 2 m^3/s and a saving of 1 m^3/s from recirculation of water lost in the locking operation.

3. Not all water extracted at Panheel has first passed through the Maas at Maastricht: a minimum of 3 to 4 m^3/s of additional water is available in the Maas at Panheel because groundwater flows into the river in the section above Panheel from high areas on its right bank.
4. We assume that under the SPRHI-RNONE demand scenario Tactic 3 would reduce the preventable losses by about the same percentage as under the SPRLO-RALL demand scenario. This assumption leads to an approximate upper bound on the expected annual benefits of the tactic of 2.2 Dflm.
5. In 1976, the flows at Maastricht (at the entrance to the Julianakanaal) averaged less than 15 m^3/s in 9 of the 18 decades in the summer half-year, and less than 10 m^3/s in 4 decades.
6. We estimate that the use of the portable pumps in 1976 prevented about 14.5 Dflm in shipping losses. The cost of renting and operating the equipment was about 2.2 Dflm.
7. The Jeker is a tributary of the Maas, and enters this river from its left bank at Maastricht.
8. More specifically, we assumed that a minimum of 10 m^3/s was sent down the Grensmaas to combat pollution unless the flow on the Maas at Maastricht was less than 30 m^3/s. When the flow on the Maas dipped below 30 m^3/s, the Grensmaas flow was reduced to 1 m^3/s.
9. The costs for these two tactics differ from those used in the final PAWN briefing of December 1979 because in this report (1) we used updated cost estimates provided in Ref. 10.2, and (2) 1979 guilders were converted into 1976 guilders to make the costs comparable with the costs of other tactics.

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Chapter 11

SCREENING OF NATIONAL TACTICS

11.1. OVERVIEW

In the previous six chapters we described the water management problems in the various regions of the country and the contributions toward their solution offered by a large number of tactics. The impact of these tactics was almost invariably limited to a single region. However, the regions are not fully independent from the point of view of water management. They are linked by the major waterways in the country (the "national distribution system"). The flows in these waterways can be controlled to some extent by man, so choices must be made about the distribution of these flows. Furthermore, facilities may be added to the national system that offer the Dutch water managers additional possibilities to distribute the available surface water in such a way that the total benefits from usage of the water increase.

The national tactics that we will discuss in this chapter all involve changes to the national water distribution system and affect more than one region. Although most of these tactics are designed to improve the supply of surface water to various regions, a few tactics are related to other water management issues. In the remainder of this section, we describe the nature and function of the national distribution system and the water management problems with which the national tactics deal.

Figure 11.1 is a map showing the lakes and waterways comprising the national distribution system, and Fig. 11.2 is the schematization of the system that was used in the Distribution Model. Included in the national system are, first of all, the principal natural waterways: the major rivers (Rijn, Waal, Neder-Rijn, IJssel, and Maas); the waterways in the Delta (the Rotterdamse Waterweg, the Haringvliet, the Zoommeer, and the various connecting waterways); and the lakes in the north-central part of the Netherlands (IJsselmeer, Markermeer, and border lakes). The Rijn, after entering the country from Germany, splits into three branches--the Waal, the Neder-Rijn, and the IJssel. The IJssel River, in turn, is the principal source of water for the north-central lakes. The distribution of the Rijn flow among the three branches is partly controlled by the weir in the Neder-Rijn at Driel; closure of the weir causes the Rijn flow to be divided between the Waal and the IJssel only, while an open weir results in the natural division among all three branches. The operating policy for the weir is described in Sec. 3.1.1. Here, it suffices to say that the weir is closed during periods of low Rijn flows in order to obtain the maximum flow possible on the IJssel to the IJsselmeer and the Markermeer.

The geographic placement of the major rivers and the north-central lakes leads to a division of the country into three parts for purposes of surface water supply (see Fig. 1.3):

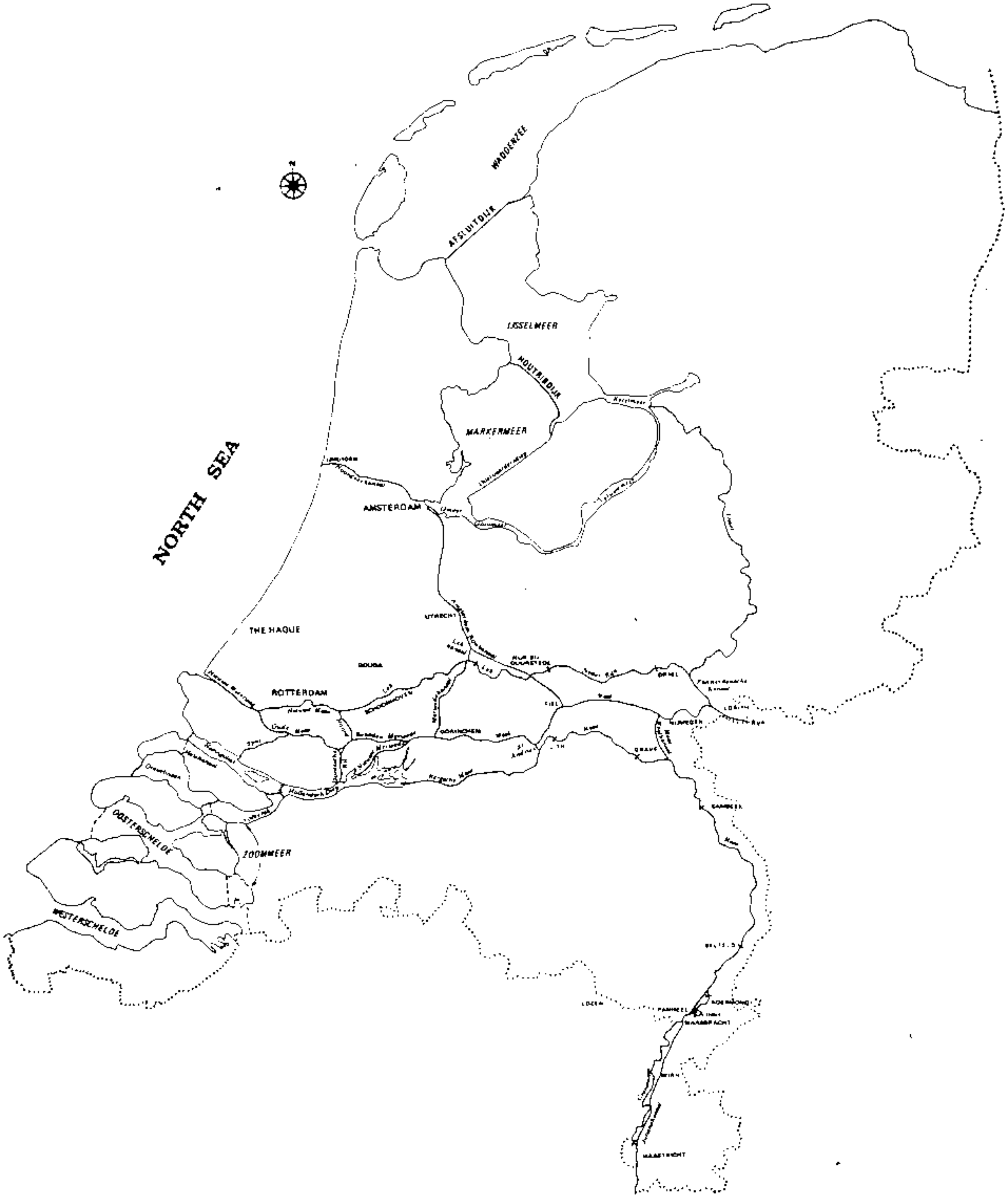

Fig. 11.1--Map showing national distribution system

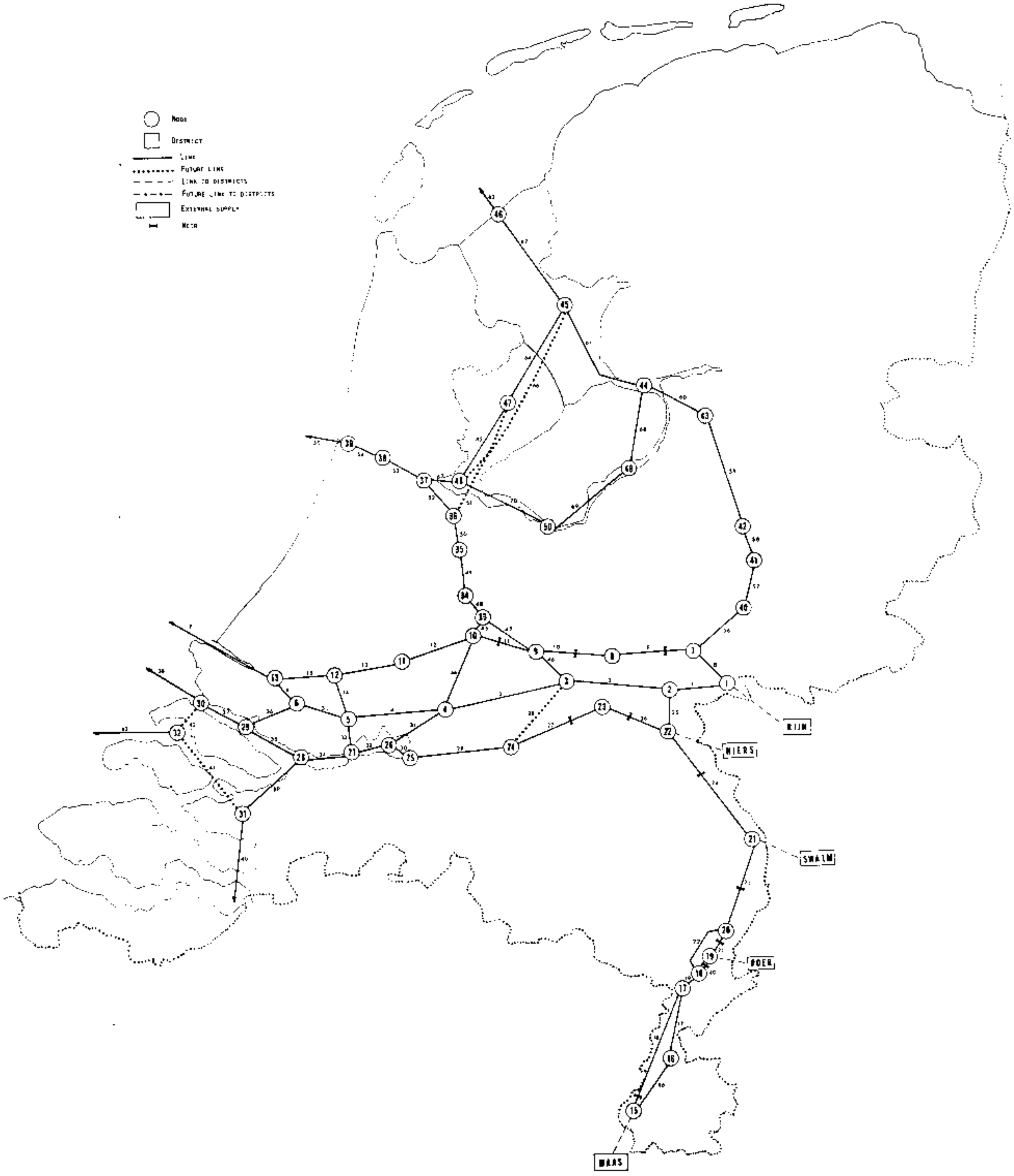

Fig. 11.2--National surface water distribution network

1. The area mainly dependent for its surface water supply on the lakes--Regions 1 (North), 2 (Northeast Highlands), 3 (Flevoland and Veluwe), and 4 (North Holland).
2. The area dependent on the Maas--Region 8 (Southeast Highands).
3. The area dependent on the Neder-Rijn, the Waal, and the Maas together--Regions 5 (Midwest and Utrecht), 6 (Large Rivers and Northern Delta), and 7 (West Brabant and Southern Delta).

In addition to the principal natural waterways, the national distribution system also includes a number of major canals: the Amsterdam-Rijnkanaal, the Noordzeekanaal, the Betuwe section of the Merwedekanaal, the Lekkanaal, the Julianakanaal, the Maas-Waalkanaal, and the St. Andries Connection. Of these, the Amsterdam-Rijnkanaal and the Merwedekanaal are important connections between the Waal and the Neder-Rijn; and the Maas-Waalkanaal and the St. Andries Connection link the Waal with the Maas.

Tables 11.1 through 11.3 indicate the total demands for extraction from the surface water distribution network for each of the three areas defined above, distinguished according to the various demand scenarios. The demands are given for the average and the driest decade for both 1943 and DEX river flows and rainfall; the average decade demands reflect averages over decades having a positive demand. A comparison of these tables shows that the demands in Area 1 overshadow the demands from the other two areas.

There are four water management problems in the Netherlands that are of national significance in that they affect several of the regions. First is the limited flexibility offered by the national distribution system for dividing the available water supply among the three aforementioned areas. There are two sides to this problem. The weir in the Neder-Rijn at Driel can be used to modify the division of the Rijn flow among its three branches to increase the flow to the IJsselmeer. However, it is currently not possible to reduce the flow to the IJsselmeer--for instance, in order to reduce shipping losses on the Waal. Furthermore, the only effective reservoir capacity in the Netherlands (the IJsselmeer and the Markermeer) is located in Area 1. (Area 3 will have some reservoir capacity in the Zoommeer, and possibly in the Grevelingen. However, this capacity will be only of local importance since it will serve Region 7 exclusively.) The IJsselmeer and the Markermeer cannot be used to alleviate shortages in the other two areas since water cannot currently be transported from these lakes to the western and southern portions of the country. The transport possibilities in the opposite direction (i.e., to the lakes) are very limited. It is possible, therefore, that agriculture shortage losses in the various areas could be decreased by improving the flexibility of the distribution system. Two tactics that would improve the system's flexibility have been investigated.

The second problem of national significance involves the storage capacity of the IJsselmeer and the Markermeer. If we accept the limited flexibility of the national distribution system--in particular,

Table 11.1

DEMANDS FOR EXTRACTIONS FROM NATIONAL SURFACE WATER DISTRIBUTION NETWORK, FROM AREA DEPENDENT ON IJSSELMEER AND MARKERMEER (m^3/s)

	Low Intensity		High Intensity	
Type of Decade	No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
1943: Average decade	42.8	45.0	59.1	66.2
Driest decade	129.3	145.8	212.2	241.5
DEX: Average decade	55.5	61.6	79.5	91.6
Driest decade	136.8	155.7	225.0	259.1
Flushing of waterways	27.1	27.1	27.1	27.1

Table 11.2

DEMANDS FOR EXTRACTIONS FROM NATIONAL SURFACE WATER DISTRIBUTION NETWORK, FROM AREA DEPENDENT ON MAAS (m^3/s)

	Low Intensity		High Intensity	
Type of Decade	No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
1943: Average decade	1.7	4.0	2.8	9.9
Driest decade	3.6	9.3	8.2	23.7
DEX: Average decade	2.9	7.0	4.2	11.8
Driest decade	4.9	14.1	11.7	34.0
Lock losses and seepage from canals	6.5	6.5	6.5	6.5

Table 11.3

DEMANDS FOR EXTRACTIONS FROM NATIONAL SURFACE WATER DISTRIBUTION NETWORK, FROM AREA DEPENDENT ON COMBINATION OF THE NEDER-RIJN, WAAL, AND MAAS (m^3/s)

	Low Intensity		High Intensity	
Type of Decade	No W/B Plans	With W/B Plans	No W/B Plans	With W/B Plans
1943: Average decade	20.4	29.3	22.8	34.1
Driest decade	54.3	70.3	70.0	93.6
DEX: Average decade	30.9	43.3	37.0	54.7
Driest decade	68.6	89.2	92.0	125.9
Flushing: Waterways in area	14.0	14.0	14.0	14.0
Zoommeer	50.0	50.0	50.0	50.0

the limited water transport possibilities toward the lakes, other than by means of the IJssel--then the storage capacity of the lakes is insufficient to prevent water shortages in very dry periods when the extraction demands are high, while the supply of water to the lakes is low (due to low inflows from the IJssel River and a high evaporation loss). Consequently, the lake levels drop and might reach their minimum levels before the dry period is over. The likelihood of shortages will increase if some of the promising tactics in the North and Northeast Highlands regions are implemented, all of which increase the extraction demands imposed on the IJsselmeer. There are various ways in which more water can be made available in the IJsselmeer and the Markermeer, other than by linking the lakes with the western and southern areas. Several such tactics have been evaluated.

The third national problem relates to extractions from the Waal that are sent into the Amsterdam-Rijnkanaal. These extractions cause losses to shipping because they result in a reduced depth below the extraction location. Various tactics have been investigated that would reduce or eliminate these shipping losses. Two such tactics involve the construction of works in the Waal itself. Another tactic would change the extraction location.

The final problem of national significance is not purely a water management problem. It involves the protection of the Flevoland polder against flooding. Some tactics currently under consideration to deal with this problem are, however, essentially water management tactics: they involve the construction of dike segments, pipelines, and/or syphons. Some of these tactics contribute to reducing agricultural losses due to both shortage and salinity in the regions bordering the IJsselmeer and the Markermeer. For this reason, we have dedicated a section of this chapter to a discussion of nine tactics that deal with this problem.

11.2. CHANGE POLICY FOR FLUSHING MARKERMEER

Typically, the IJsselmeer is less saline than the Markermeer, and the Markermeer is less saline than the Noordzeekanaal. Since a number of districts extract water for sprinkling crops from the Markermeer, the policy is to try to reduce its salinity by flushing it with large amounts of IJsselmeer water. Water from the Markermeer then passes through the IJmeer and the Noordzeekanaal. Thus, salinity is reduced all along the discharge route. The flow also provides water for flushing the canals in Amsterdam, and provides cooling water for the Hemweg power plant at Amsterdam and the Velsen power plant at IJmuiden along the Noordzeekanaal.

In Sec. 3.1.5, we described the current rules for flushing the Markermeer. Under these rules, a minimum of 10 m^3/s is extracted from the IJmeer by the Zeeburg pumping station to flush the canals of Amsterdam. In addition, whenever the IJsselmeer is less saline than the Markermeer and the lakes are above their emergency level for flushing, additional water is extracted from the IJsselmeer through the

Houtribsluizen and sent through the Oranjesluizen to the Noordzeekanaal in order to reduce the salinity of the Markermeer. The desired additional amount at the Oranjesluizen is 20 m^3/s in the winter half-year (October-March) and 60 m^3/s in the summer half-year. Less than the desired amount is flushed only if, by flushing more, the lakes would fall below their emergency level for flushing.

The problem with the current rules is that, in dry years, heavy flushing early in the summer during periods in which the inflow into the lakes is insufficient to retain the target level leads to cutbacks in extractions from the lakes later in the summer, thereby causing agriculture shortage losses. For example, when we consider the Distribution Model run with the current flushing rules for the DEX supply scenario and SPRHI-RALL demand scenario, 70 m^3/s are flushed through the Oranjesluizen during most of April and May, while the lake levels are above their emergency level for flushing. But the rainfall and river flows in May and June are insufficient to replenish the water flushed and meet the demand for extractions. As a result, although flushing is cut back to the minimum at the end of May and in June, the lakes never reach their target level; in fact, the highest level they can reach in the early summer is NAP - 0.22 m. If the flushing of the Markermeer had been decreased so as to allow the target lake levels to be reached, the additional 2 cm of stored water could have been used to reduce the cutbacks in sprinkling in July and August, which caused millions of guilders of shortage losses to agriculture.

As described in Sec. 3.1.5, we decided to evaluate a change in the flushing rules that would flush more than 10 m^3/s only when the lakes were at their target level. This change will decrease shortage losses in all areas extracting from the IJsselmeer and the Markermeer in any year that cutbacks in extractions from the lakes for the sprinkling of crops would have been instituted under the current flushing policy because the lake levels were too low (this happened in only one of our supply scenarios--DEX). The change will also increase the salinity losses in North Holland in such years (since the Markermeer will be flushed less) and will reduce the amount of electricity that is generated by the power plant on the Noordzeekanaal at Velsen (since less water is available for cooling the power plant). The question to be answered is whether or not the reduction in shortage losses outweighs the increase in salinity losses and losses due to decreased power generation.

The results from Distribution Model runs made to answer this question are presented in Table 11.4. The runs were made for the demand scenario with high sprinkler intensity and waterboard plans. The results show that the new flushing rules, which reduce the amount of flushing that takes place in very dry years, lead to only small increases in salinity and power generation losses, while reducing the shortage losses considerably. The net benefits are therefore positive. Since implementation of the new rules requires no new construction, there is no investment cost to consider. This managerial tactic was, thus, found to be promising. In the analysis of all other tactics, we assumed that this change had been implemented because it seemed to be such an attractive tactic (considerable benefits and no costs).

Table 11.4

BENEFITS (Dflm) FROM NEW RULES FOR FLUSHING THE MARKERMEER
(High Sprinkler Intensity, with Waterboard Plans)

	DEX	1959	1943	1967	Expected Annual Benefits UB	Expected Annual Benefits LB
Reduction in shortage losses	40.7	0	0	0		
Increase in salinity losses	2.5	0	0	0		
Increase in power generation costs	2.6	0	0	0		
Net benefits	35.6	0	0	0	2.5	0.7

11.3. IMPROVE FLEVOLAND'S SAFETY AND REDUCE MARKERMEER SALINITY

The present dike separating Flevoland from the Markermeer affords a relatively low level of protection because at the time it was designed it was expected that the Markerwaard would be built. With the Markerwaard in place, this dike would not have to face a major increase in the water levels due to wind effects under storm conditions. However, it is not certain that the Markerwaard will be built. Thus, it may be necessary to improve Flevoland's safety in some other way.

Apart from simply raising the Flevoland dike, we considered various water management tactics that would provide benefits in addition to improving the safety of Flevoland. Specifically, we examined some that were designed to reduce the salinity of the Markermeer. Currently, Flevoland discharges its drainage water into the Oostvaardersdiep (the shipping channel along the coast of Flevoland, from the southwest corner of the polder to Lelystad). The Oostvaardersdiep is part of the Markermeer. In an average year, about 11 percent of the salt that enters the IJsselmeer and Markermeer comes from Flevoland's discharges.[1] These discharges degrade the quality of the water in the lake, which is an important source of fresh water for agriculture in Noord-Holland and Flevoland. The current policy that attempts to alleviate this problem involves flushing of the Markermeer with water from the IJsselmeer. This policy was discussed in Sec. 11.2. A number of the tactics we examined would separate the Markermeer from the IJmeer (there is currently no physical separation between them), and would send Flevoland's discharges through the Oostvaardersdiep to the IJmeer. Others would leave an open connection between the Markermeer and IJmeer, but would transport Flevoland's discharges to the Noordzeekanaal (through a pipe or a drainage channel). The common element in all these tactics is that they would keep the discharges from Flevoland out of the Markermeer.

The design of some of the tactics to reduce the salinity of the Markermeer allows for the construction of a North-South Connection (a way of transporting water between the Markermeer and the large rivers, i.e., the Lek, the Waal, and the Maas). If a North-South Connection were to be built, there would have to be a way to transport fresh water between the Markermeer and the Amsterdam-Rijnkanaal without having it mix with the Flevoland discharges. The route between the Markermeer and the Amsterdam-Rijnkanaal would include the Diemen, a waterway connecting the canal with the IJmeer. Several of the tactics provide the necessary infrastructure. (The North-South Connection tactic is evaluated in Sec. 11.5.)

Most of the tactics considered in this section involve the construction of one or two dikes (separation dams) in the Markermeer and IJmeer. Since there is a large amount of ship traffic in the IJmeer, the tactics were designed to minimize the impact on shipping (particularly delays at locks); different tactics will have different impacts on shipping.

Almost all of the tactics considered in this section involve a number of changes to the current infrastructure. The tactics tend to overlap each other--i.e., some of the changes are part of more than one of the tactics. Therefore, as in the Southeast Highlands analysis, we have made a distinction between elementary tactics and aggregate tactics. The aggregate tactics, which we subject to analysis, are combinations of elementary tactics.

Table 11.5 contains a list of the nine elementary tactics together with their annualized fixed costs. The elementary tactics are described in the following subsection. In Sec. 11.3.2, we present the analysis of the aggregate tactics.

Table 11.5

ELEMENTARY TACTICS TO IMPROVE FLEVOLAND'S SAFETY AND REDUCE MARKERMEER SALINITY

Subsection Reference	Tactic Name	Capacity (m^3/s)	Annualized Fixed Cost (Dflm)
11.3.1.1	Raise Flevoland dike	--	5.3
11.3.1.2	Build short second Oostvaardersdijk to Marken	--	18.8
11.3.1.3	Build long second Oostvaardersdijk to Durgerdam	--	23.9
11.3.1.4	Pump Flevoland's discharges to IJsselmeer	35	3.0
11.3.1.5	Build drainage pipeline from Flevoland to Noordzeekanaal	52	40.7
11.3.1.6	Extend first Oostvaardersdijk through IJmeer to create drainage channel from Flevoland to Noordzeekanaal fully separating IJmeer from Markermeer	85	12.6

Table 11.5 (continued)

Subsection Reference	Tactic Name	Capacity (m^3/s)	Annualized Fixed Cost (Dflm)
11.3.1.7	Extend first Oostvaardersdijk through IJmeer to create drainage channel from Flevoland to Noordzeekanaal with open connection between Markermeer and IJmeer	85	12.1
11.3.1.8	Build freshwater syphon between Markermeer and IJmeer	100	1.5
11.3.1.9	Build freshwater channel through IJmeer to Diemen	100	1.0

11.3.1. Elementary Tactics To Improve Flevoland Safety and Reduce Markermeer Salinity

11.3.1.1. Raise Flevoland Dike. The purpose of this tactic is strictly to provide increased safety from flooding to the southern part of Flevoland (see Fig. 11.3). It would have no effect on shipping or on the quality of water in the Markermeer. It involves heightening a total of approximately 53 km of existing dikes around Flevoland. The annualized fixed cost of the tactic is 5.3 Dflm.

11.3.1.2. Build Short Second Oostvaardersdijk to Marken. The part of the Flevoland dike between the polder's southwest corner and Lelystad is known as the Oostvaardersdijk. This tactic is to build a second Oostvaardersdijk, continuing the Houtribdijk from the Houtribsluizen near Lelystad along the Oostvaardersdiep and then across the lake to the Noord-Holland coast in the vicinity of Marken (see Fig. 11.6). This new dike is called the "short" second Oostvaardersdijk to contrast it with another alternative, which involves a similar but longer dike to Durgerdam (see Sec. 11.3.1.3 below). It would be 28 km long.

Because of its proximity to the Flevoland coast, this new dike is likely to provide sufficient safety to Flevoland from flooding by reducing water level increases due to wind effects under storm conditions. The dike separates the Markermeer from the Oostvaardersdiep and the IJmeer and thus prevents the discharges from Flevoland from entering the Markermeer. This will reduce the salinity of the water in the Markermeer. However, the discharges are sent to the IJmeer, which increases the salinity of the water in that lake. There will be some cost to shipping, since ship traffic between Amsterdam and the Noord-Holland coast between Marken and Enkhuizen will need to pass through a lock in the new dike. The annualized fixed cost of the tactic is 18.8 Dflm.

11.3.1.3. Build Long Second Oostvaardersdijk to Durgerdam. This tactic has been under consideration by the Rijkswaterstaat for a number of years. The dike is 39 km long. Its first part, starting at the

Houtribsluizen and continuing along the Oostvaardersdiep, coincides with the location of the short second Oostvaardersdijk. It then turns west, intersecting the Noord-Holland coast at a more southerly location just north of the entrance to the Noordzeekanaal (see Fig. 11.10). As does the short Oostvaardersdijk, this dike provides adequate safety from flooding for Flevoland and separates the Markermeer from the Oostvaardersdiep and the IJmeer, thus preventing discharges from Flevoland from entering and contaminating the Markermeer. Again, these discharges are sent to the IJmeer, which increases the salinity of water in that lake. The impact of this tactic on shipping is the same as that of the short second Oostvaardersdijk. The annualized fixed cost of the tactic is 23.9 Dflm. The primary advantage of this tactic over the previous one (build short second Oostvaardersdijk to Marken) is that it makes it possible to construct a North-South Connection.

11.3.1.4. Pump Flevoland's Discharges to IJsselmeer. This tactic would reduce the salinity of the Markermeer by pumping some of Flevoland's discharges into the IJsselmeer rather than into the Markermeer. It was first suggested in an internal RWS memorandum [11.1]. Generally, discharges from Flevoland are pumped into the Oostvaardersdiep by two pumping stations: Wortman (capacity 35 m^3/s) and Blocq van Kuffeler (capacity 52 m^3/s). Under this tactic, a canal would be built from Wortman to the Houtribsluis (about 4 km to the north), and a pumping station would be built there to pump the water into the IJsselmeer (see Fig. 11.4). The canal and pumping station would each have a capacity of 35 m^3/s. With the new infrastructure, roughly 40 percent of Flevoland's discharges, which are currently pumped into the Markermeer, would be pumped into the IJsselmeer. The estimated annualized fixed cost of the tactic is 3.0 Dflm.

11.3.1.5. Build Drainage Pipeline from Flevoland to Noordzeekanaal. This tactic would send the Flevoland discharges that are normally pumped into the Oostvaardersdiep at Blocq van Kuffeler through a new pipeline to the Noordzeekanaal. We chose a route for the pipeline that runs on land from Blocq van Kuffeler southwest along the coast of Flevoland to the IJmeer, and then through the IJmeer to Amsterdam. The capacity of the pipeline was chosen to be 52 m^3/s, the same as that of Blocq van Kuffeler. With the pipeline, roughly 60 percent of Flevoland's discharges, which are currently pumped into the Oostvaardersdiep, would be transported directly to the Noordzeekanaal. The estimated annualized fixed cost of the tactic is 40.7 Dflm.

11.3.1.6. Extend First Oostvaardersdijk through IJmeer To Create Drainage Channel from Flevoland to Noordzeekanaal Fully Separating IJmeer from Markermeer. This tactic would provide another way of carrying discharges from Flevoland to the Noordzeekanaal without allowing them to contaminate either the Markermeer or the IJmeer. It assumes that a second Oostvaardersdijk would be built (either short or long) and uses that dike as one of two dikes that together form a drainage channel from Lelystad on Flevoland to the Noordzeekanaal at Amsterdam. The southern side of the channel is formed by extending the first Oostvaardersdijk through the IJmeer parallel to the second

Oostvaardersdijk to a location on the Noord-Holland coast, south of the Oranjesluizen, a distance of 19 km (see Fig. 11.7). There is a ship lock and a discharge sluice in this dike south of the ship lock in the second Oostvaardersdijk. The discharge sluice makes it possible to manage the water levels in the channel by permitting an exchange between the channel and the IJmeer. Under this tactic, all drainage from Flevoland would be pumped into the Oostvaardersdiep and sent to the Noordzeekanaal without contaminating either the Markermeer or the IJmeer. The capacity of the channel would be at least as large as the combined capacity of the Wortman and Blocq van Kuffeler pumping stations (85 m^3/s), and its annualized fixed cost is estimated to be 12.6 Dflm.

11.3.1.7. Extend First Oostvaardersdijk through IJmeer To Create Drainage Channel from Flevoland to Noordzeekanaal with Open Connection between Markermeer and IJmeer. This tactic is a modified version of the one presented in the preceding subsection. Its purpose is identical--to provide increased safety from flooding for Flevoland and to channel Flevoland's discharges to the Noordzeekanaal without contaminating the Markermeer or the IJmeer. However, the previous tactic is modified to reduce the shipping delays that would be caused by its implementation.

In this case the drainage channel would be divided into two parts that would be connected by a syphon. The two parts would be separated by an open connection between the IJmeer and Markermeer, allowing for a free flow between these lakes (see Fig. 11.8). The syphon would carry the discharges from Flevoland underneath the open connection between the two lakes. It would be 150 m long and would have a capacity of 85 m^3/s (the combined capacity of the Wortman and Blocq van Kuffeler pumping stations).

Shipping would benefit from this design, since traffic between Amsterdam and most points around the Markermeer and IJmeer and beyond would not need to pass through any new locks. Only shipping between Amsterdam and Lelystad would have to pass through a new lock--a lock in the second Oostvaardersdijk near Lelystad. The tactic has the additional advantage of facilitating a North-South Connection (see Sec. 11.5), since fresh water can be transported between the Markermeer and the Amsterdam-Rijnkanaal through the IJmeer without being affected by the Flevoland discharges. The annualized fixed cost of this tactic is 12.1 Dflm.

11.3.1.8. Build Freshwater Syphon between Markermeer and IJmeer. If there is no open connection between the Markermeer and the IJmeer (e.g., in the tactic described in Sec. 11.3.1.3) and a North-South Connection is to be implemented, water must be transported under the second Oostvaardersdijk (or the saltwater channel). This tactic would accomplish that. The syphon would be 150 m long with a capacity of 100 m^3/s (the maximum capacity of a North-South Connection). The tactic's annualized fixed cost is 1.5 Dflm.

11.3.1.9. Build Freshwater Channel through IJmeer to Diemen. If only a second Oostvaardersdijk is constructed, the IJmeer would become more saline than it is currently. If a North-South Connection were to be constructed in this environment, fresh water would have to be transported between the Markermeer and the Diemen without having it be contaminated by IJmeer water. In addition to the syphon described in the preceding subsection, a freshwater channel through the IJmeer linking the syphon with Diemen would have to be built. The channel, which would be approximately 3 km long and would have a capacity of 100 m^3/s, would have an annualized fixed cost of 1 Dflm.

11.3.2. Definition of Aggregate Tactics

The nine elementary tactics described in Sec. 11.3.1 can be combined in a number of ways, each of which will produce different benefits with respect to the four factors that were considered in their design:

- Reducing the risk of flooding in Flevoland.
- Reducing the salinity of the Markermeer.
- Making a North-South Connection possible.
- Minimizing the impact on shipping.

We designed eight aggregate tactics, which were then subjected to analysis. All of them solve the primary problem of reducing the risk of flooding in Flevoland. The other factors are dealt with in varying degrees. The tactics are described below. Information on them is summarized in Table 11.6.

Table 11.6

AGGREGATE TACTICS TO IMPROVE FLEVOLAND'S SAFETY AND REDUCE MARKERMEER SALINITY

Aggregate Tactic No.	Elementary Tactics (Subsection Reference)	Safety Benefits	Salinity Benefits	Shipping Losses	N/S Conn. Possible	Annualized Fixed Cost (Dflm)
1	11.3.1.1	X				5.3
2	11.3.1.1,11.3.1.4	X	X		X	8.3
3	11.3.1.1,11.3.1.5	X	X		X	46.0
4	11.3.1.2	X	X	X		18.8
5	11.3.1.2,11.3.1.6	X	X	X		31.4
6	11.3.1.3,11.3.1.7	X	X	X	X	36.0
7	11.3.1.3,11.3.1.6, 11.3.1.8	X	X	X	X	38.0
8	11.3.1.3,11.3.1.8, 11.3.1.9	X	X	X	X	26.4

1. Raise Flevoland Dike. This tactic (which is the same as the elementary tactic described in Sec. 11.3.1.1) affects only the risk of flooding in Flevoland. Its annualized fixed cost is 5.3 Dflm. The location of the improved dikes is indicated in Fig. 11.3.
2. Raise Flevoland Dike and Pump Flevoland's Discharges to the IJsselmeer. This tactic would reduce the risk of flooding in Flevoland and reduce the salinity of the Markermeer. However, it would increase the salinity of the IJsselmeer. Its annualized fixed cost is 8.3 Dflm. The tactic is illustrated in Fig. 11.4.
3. Raise Flevoland Dike and Build a Drainage Pipeline from Flevoland to the Noordzeekanaal. This tactic would reduce the risk of flooding in Flevoland and reduce the salinity of the Markermeer. It would also make it possible to have a North-South Connection. Its annualized fixed cost is 46.0 Dflm. The tactic is illustrated in Fig. 11.5.
4. Build Short Second Oostvaardersdijk. This tactic (which is the same as the elementary tactic described in Sec. 11.3.1.2) would reduce the risk of flooding in Flevoland and reduce the salinity of the Markermeer. It would have a minor effect on shipping costs by requiring ships traveling to and from the Noord-Holland coast between Marken and Enkhuizen to pass through a lock in the new dike. Its annualized fixed cost is 18.8 Dflm. The tactic is illustrated in Fig. 11.6.
5. Build Drainage Channel to Amsterdam Fully Separating IJmeer from Markermeer. This tactic combines the elementary tactic to build a short second Oostvaardersdijk with one of the elementary tactics to extend the first Oostvaardersdijk through the IJmeer. Its benefits related to flooding and salinity are the same as those of Tactic 3. However, it would increase shipping costs by requiring ships traveling between Amsterdam and either the Marken-Enkhuizen section of the Noord-Holland coast or the IJmeer, Gooimeer, and eastern border lakes to pass through an additional lock. Its annualized fixed cost is 31.4 Dflm. The tactic is illustrated in Fig. 11.7.
6. Build Drainage Channel to Amsterdam with Open Connection between IJmeer and Markermeer. This tactic combines the elementary tactic to build a long second Oostvaardersdijk with one of the elementary tactics to extend the first Oostvaardersdijk through the IJmeer. It would provide the same benefits relative to flooding and salinity as Tactic 5 and would cause approximately the same losses to shipping by requiring ships traveling between Amsterdam and the Houtribsluizen to pass through an additional lock.[2] It would also make it possible to have a North-South Connection. Its annualized fixed cost is 36.0 Dflm. The tactic is illustrated in Fig. 11.8.
7. Build Drainage Channel to Amsterdam Fully Separating IJmeer from Markermeer with Syphon from Markermeer to IJmeer. This tactic combines the elementary tactic to build a long second

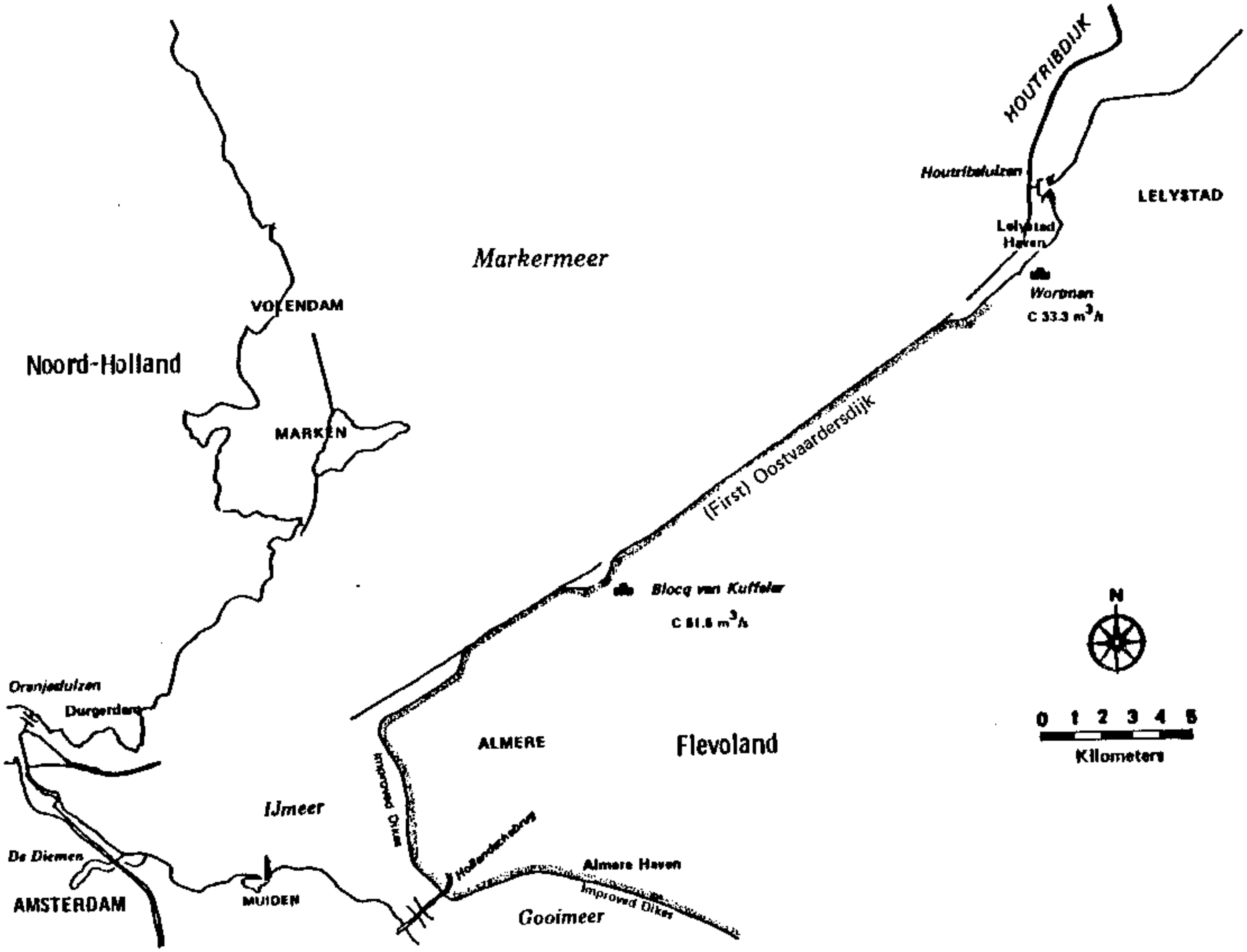

Fig. 11.3--Flevoland dike

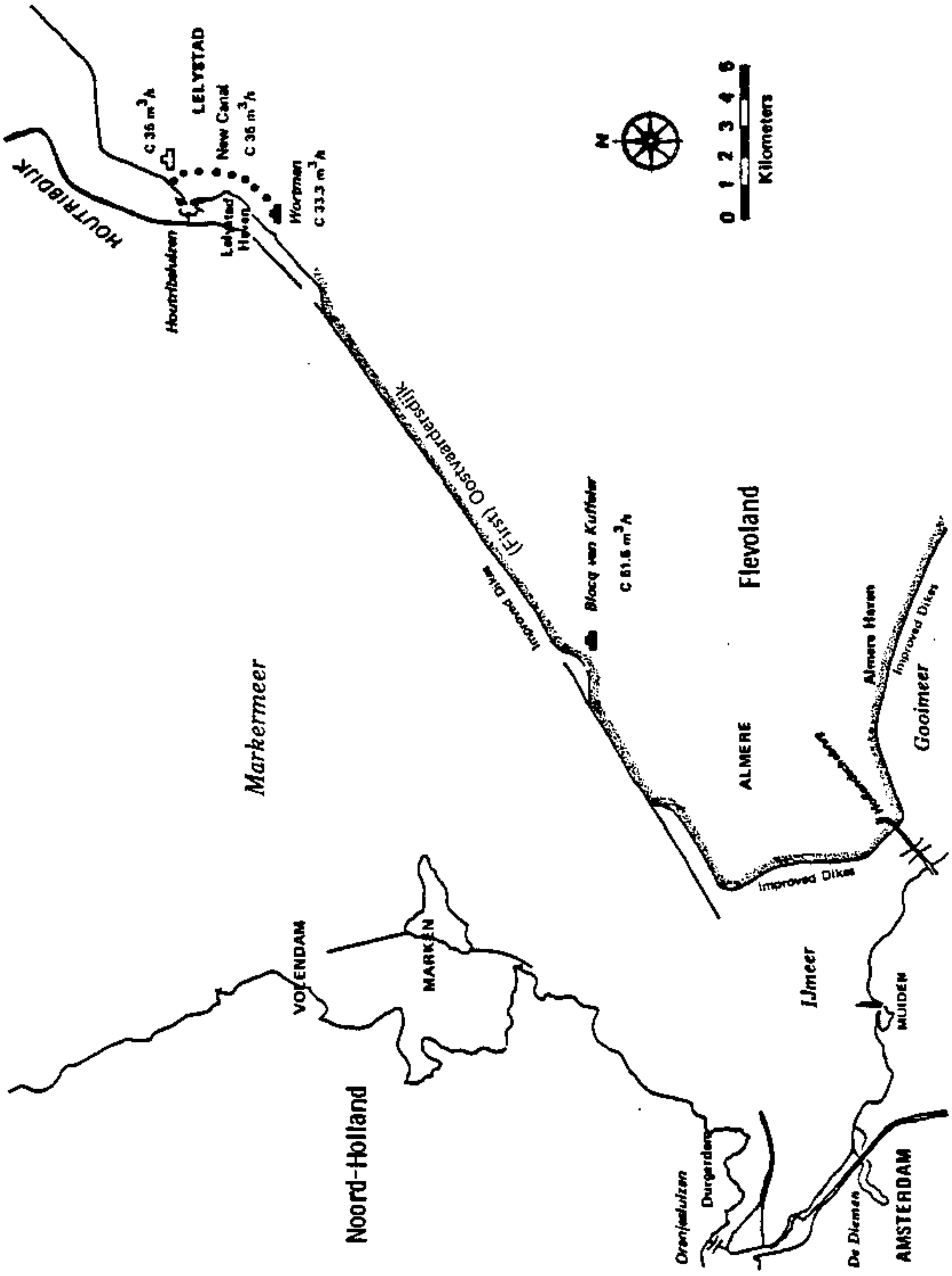

Fig. 11.4--Flevoland dike and drainage canal to IJsselmeer

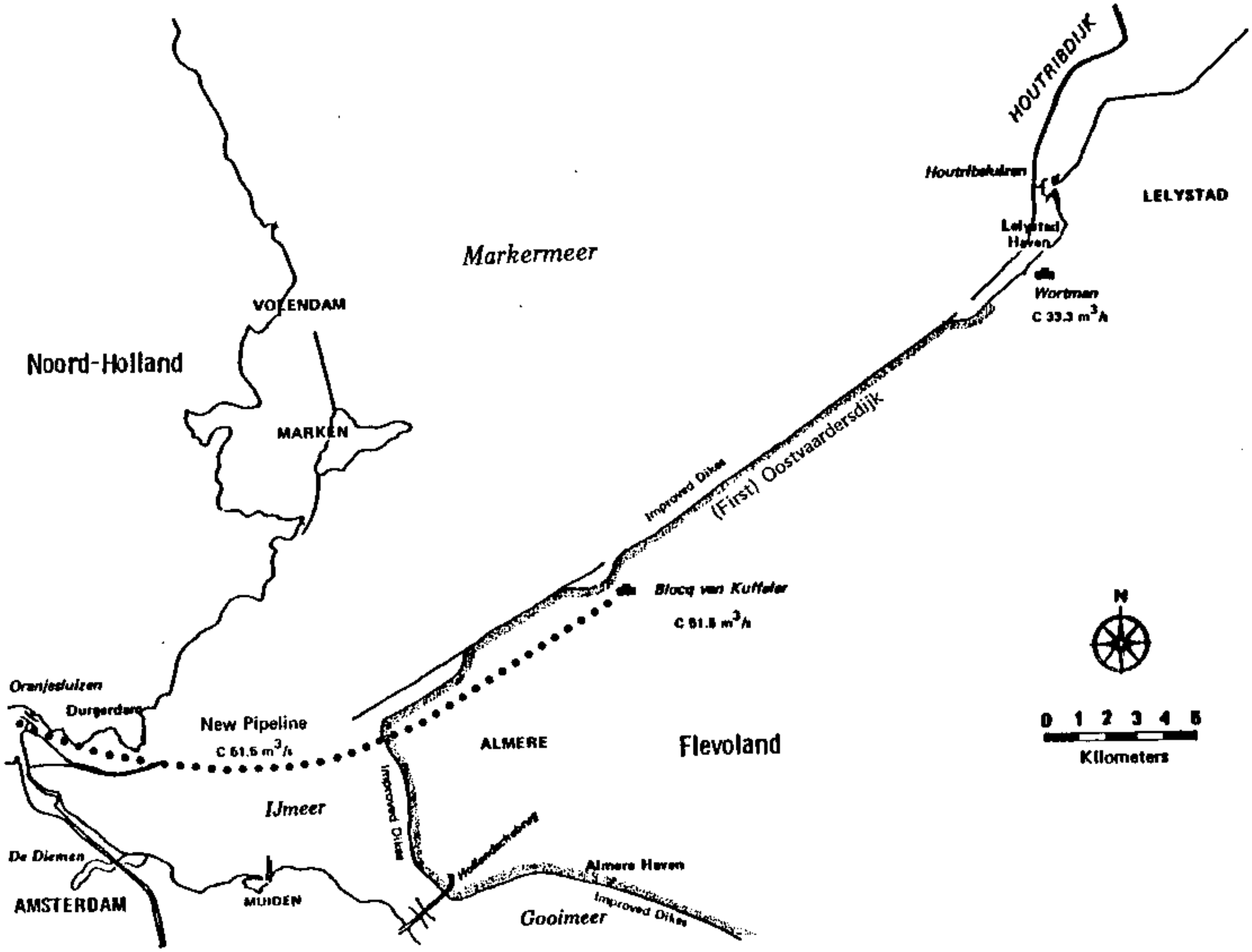

Fig. 11.5--Flevoland dike and drainage pipeline to Amsterdam

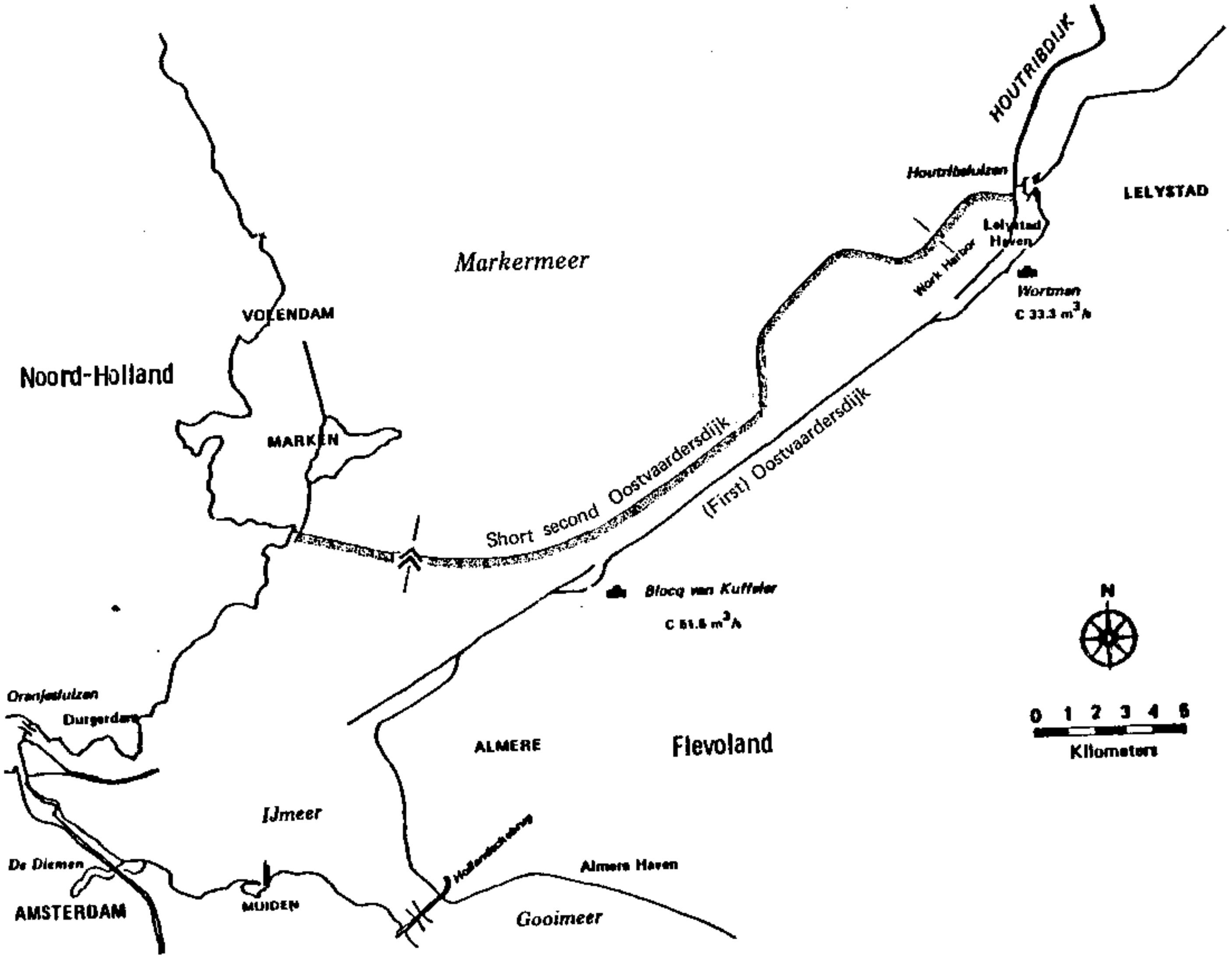

Fig. 11.6--Short second Oostvaardersdijk to Marken

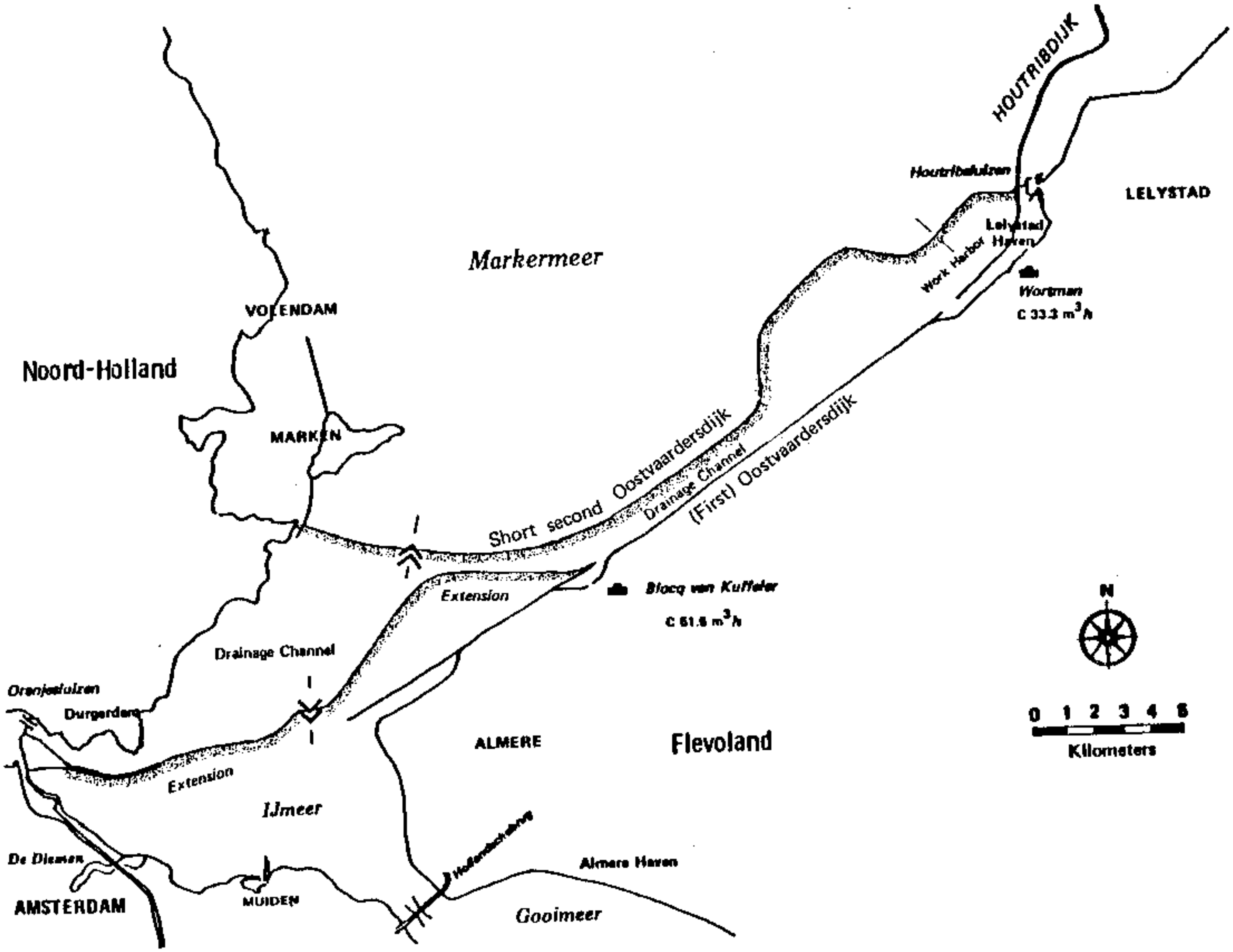

Fig. 11.7--Drainage channel from Flevoland to Amsterdam

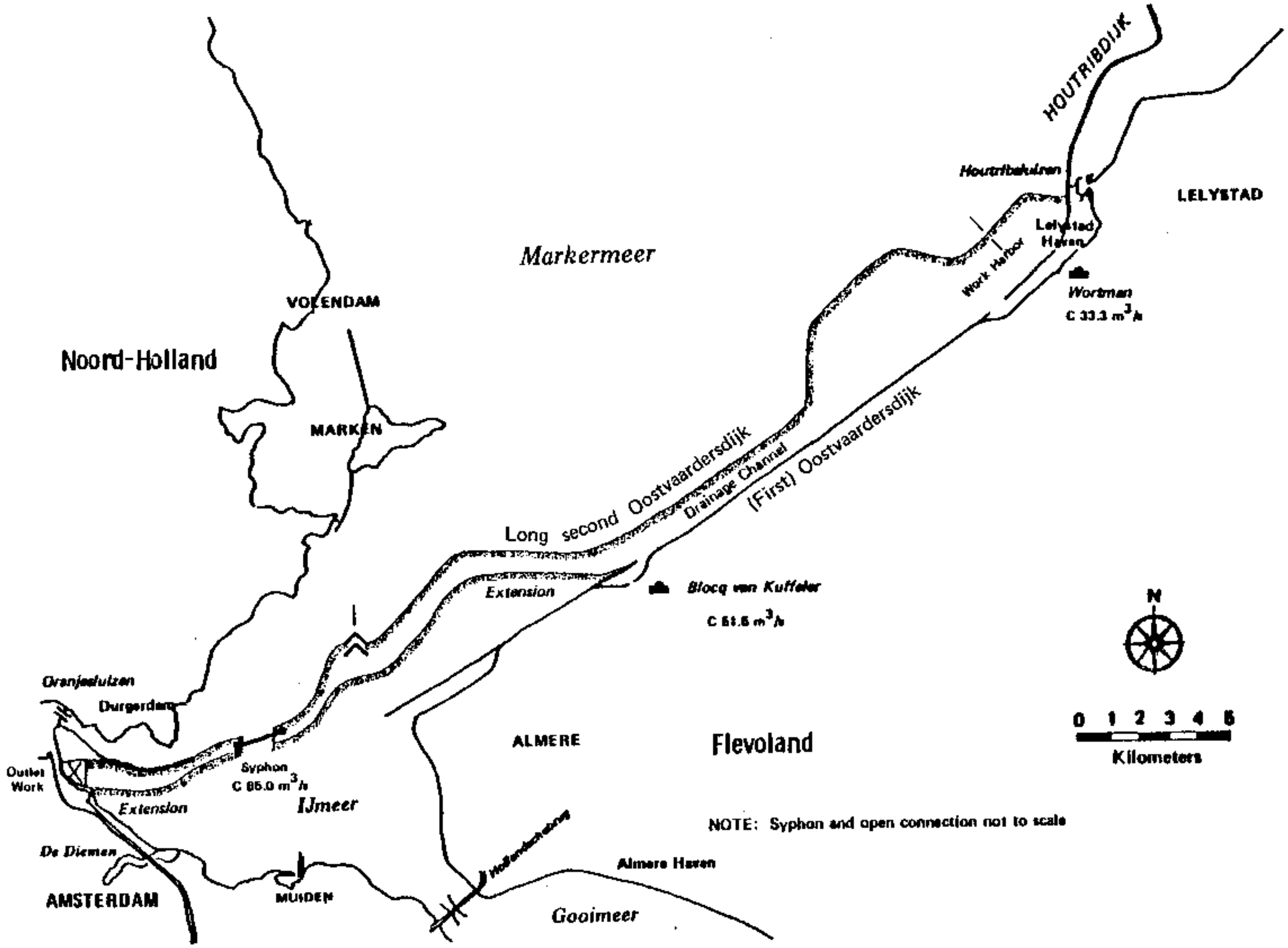

Fig. 11.8--Drainage channel from Flevoland to Amsterdam with syphon and open connection between Markermeer and IJmeer

Oostvaardersdijk with one of the elementary tactics to extend the first Oostvaardersdijk through the IJmeer and a syphon under the resulting drainage channel. The syphon is built so that water from the Markermeer can be let into the IJmeer for transport south via a North-South Connection. Its benefits related to flooding and salinity as well as its increased shipping losses are the same as those of Tactic 5. The annualized fixed cost of this tactic is 38.0 Dflm. It is illustrated in Fig. 11.9.

8. Build Long Second Oostvaardersdijk with Syphon and Freshwater Channel from Markermeer to Diemen. This tactic modifies Tactic 4 to make it possible to have a North-South Connection. There is a syphon under the dike, which empties into a channel that connects with the Diemen. The syphon is underwater, so there is no obstruction for ships traveling between Amsterdam and Lelystad. However, the tactic would have a minor effect on shipping costs by requiring ships traveling to and from the Noord-Holland coast between Amsterdam and Enkhuizen to pass through a lock in the new dike. The annualized fixed cost of this tactic is 26.4 Dflm. It is illustrated in Fig. 11.10.

11.3.3. Analysis of Aggregate Tactics

As shown in Table 11.6, all eight of the aggregate tactics reduce the risks of flooding in Flevoland. Raising the Flevoland dike (Tactic 1, not a water management tactic per se) is the least expensive way of providing this increase in protection. However, it provides no other benefits. All of the other (water management) tactics provide some reduction in the salinity of the lakes, and some of them make it possible to have a North-South Connection. In addition, five of the aggregate tactics would increase shipping delays by forcing ships to pass through additional locks. (This is clearly a negative benefit.)

Comparing Tactics 6, 7, and 8 with Tactic 4, we see that the former are more expensive, and their only additional benefit is that they offer infrastructure that makes a North-South Connection possible. Thus, Tactics 6, 7, and 8 can be promising only if a North-South Connection were to be constructed. In Sec. 11.5 we show that constructing a North-South Connection is not a promising tactic. Therefore we can screen out Tactics 6, 7, and 8.

This leaves us with Tactics 1-5 to analyze. Since the North-South Connection is not promising, the only advantage that Tactics 2-5 have compared with Tactic 1 is that they reduce the salinity of the Markermeer. Thus, for one of these tactics to be more attractive than Tactic 1, its increased cost would have to be offset by decreases in agriculture salinity losses. Tactics 3 and 5 would provide the greatest reduction in agriculture salinity losses, since they would transport all of Flevoland's discharges directly to the Noordzeekanaal. We therefore estimated the reduction in salinity losses that would occur if either tactic were implemented. The results, which are presented in Table 11.7, show that the upper bound on the expected

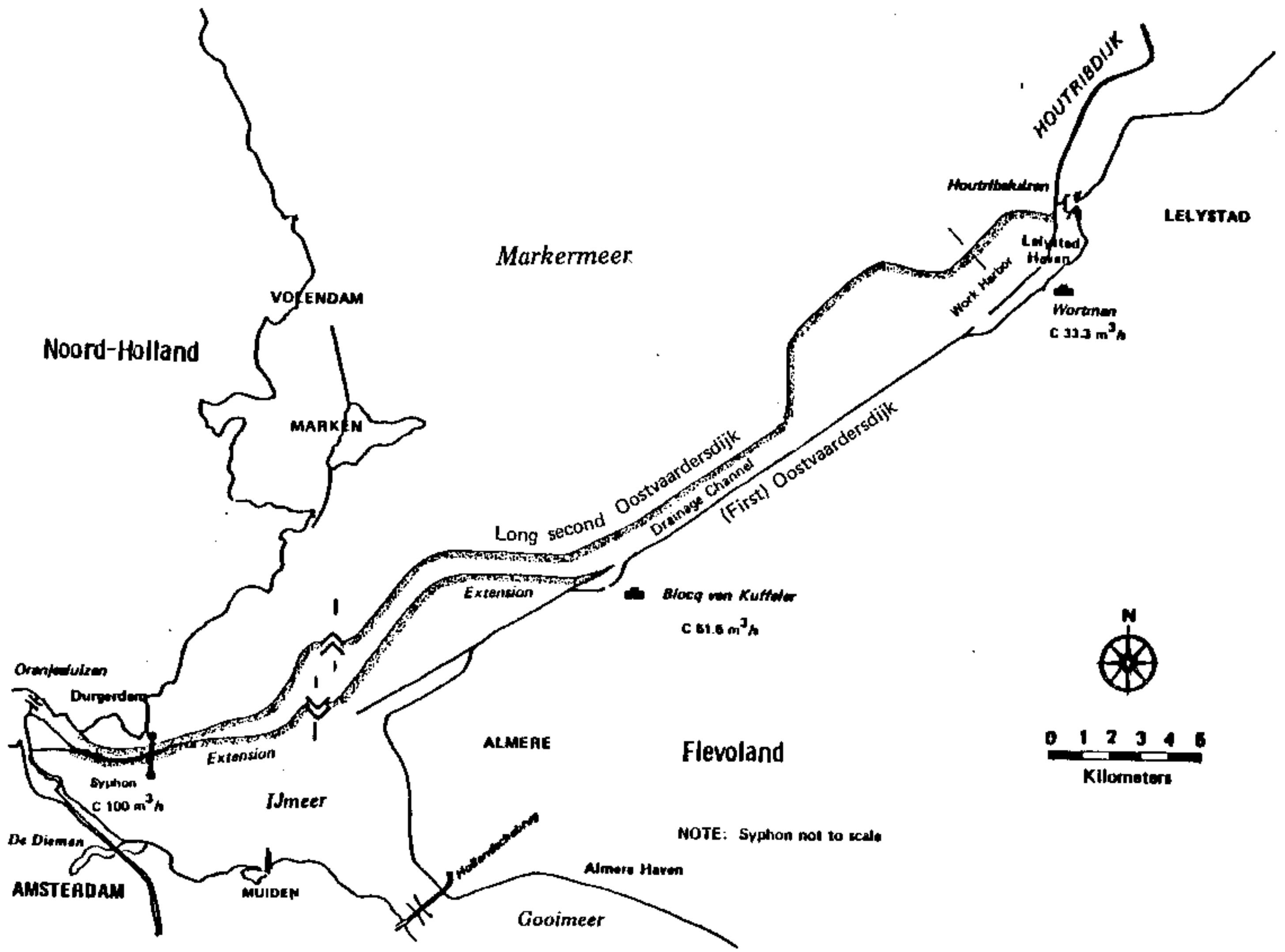

Fig. 11.9--Drainage channel from Flevoland to Amsterdam with syphon from Markermeer to IJmeer

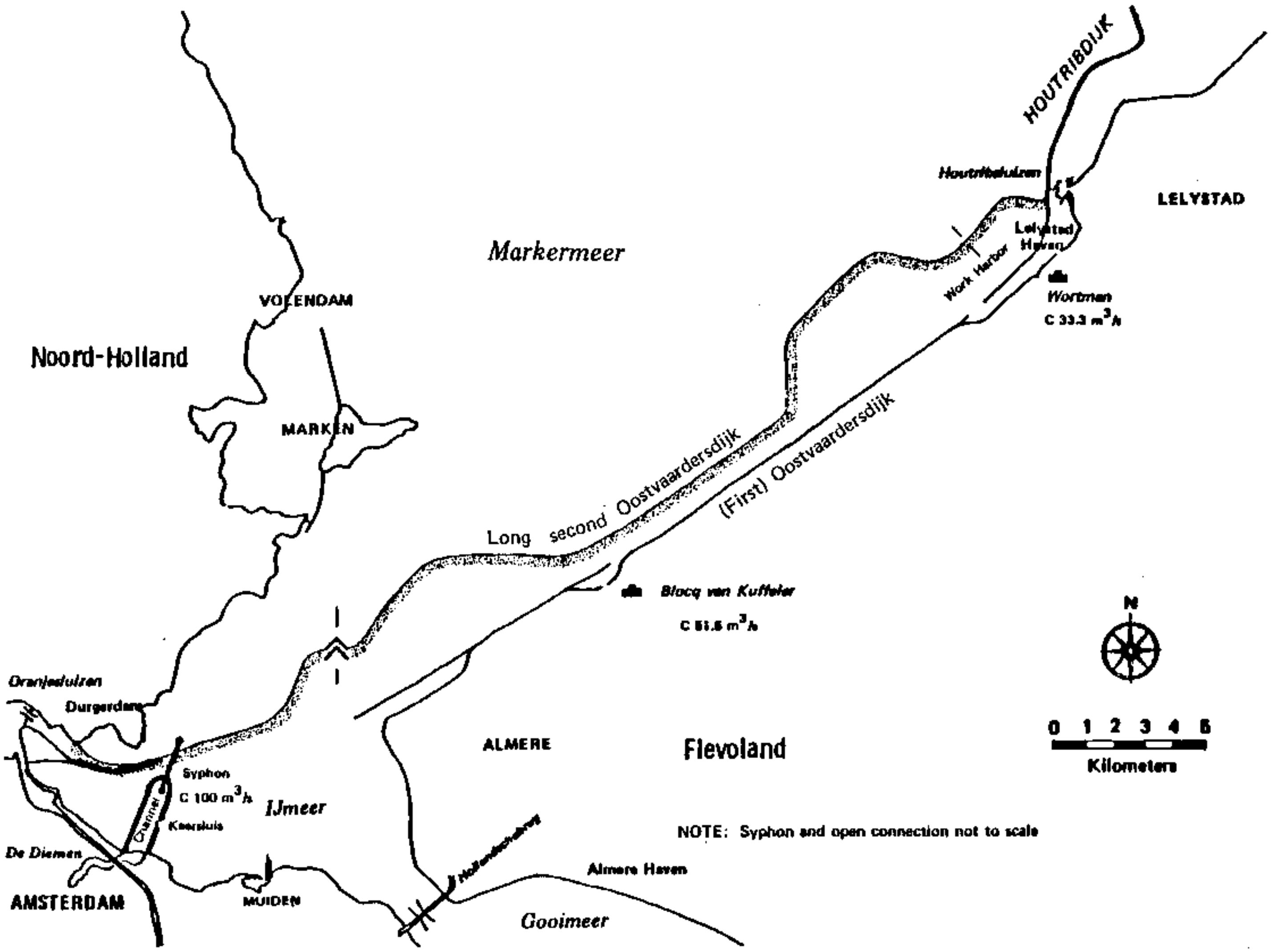

Fig. 11.10--Long second Oostvaardersdijk to Durgerdam with syphon and channel to De Diemen

annual reduction in salinity losses is less than 1 Dflm. This is not enough to justify the expenditures on Tactics 2-5. Tactic 1 (Raise Flevoland Dike) is, therefore, the only promising tactic.

Table 11.7

REDUCTION IN AGRICULTURE SALINITY LOSSES (Dflm) FROM TRANSPORTING FLEVOLAND DISCHARGES TO NOORDZEEKANAAL THROUGH CHANNEL OR PIPELINE
(High Sprinkler Intensity, with Waterboard Plans)

					Expected Annual Benefits	
	DEX	1959	1943	1967	UB	LB
Agriculture Salinity Losses						
With no tactic	501	352	310	274		
With tactic	494	351	310	274		
Reduction in losses	7	1	0	0	0.6	0.2

11.4. INCREASE STORAGE CAPACITY OF THE IJSSELMEER AND MARKERMEER

The IJsselmeer and Markermeer are practically the only freshwater reservoirs in the Netherlands. They supply fresh water to municipalities, industries, and agriculture in Noord-Holland, Flevoland, Friesland, Groningen, and Overijssel. In the summer, when the agricultural demand for water is highest, the storage capacity of the lakes under current policies is approximately 400 million m^3. However, in very dry summers there is a steady net outflow of water from the lakes, and this capacity is insufficient to satisfy all of the demands. We examined several tactics that would increase the storage capacity of the lakes.

The current storage capacity is achieved by allowing the level of the water in the lakes to vary between two limits during the summer half year. The upper limit (the summer target level) is NAP - 20 cm for the IJsselmeer and NAP - 25 cm for the Markermeer. The lower limit (the minimum level) is NAP - 40 cm for both lakes, which is also the winter target level for the lakes. Extractions from the lakes that exceed flows into the lakes are permitted without restriction until the lakes fall to their emergency level for flushing (in our analysis this level was set at NAP - 30 cm). At this point, flushing of the boezems in the surrounding areas with water from the lakes is cut back to its minimum. If the flushing cutbacks are not sufficient to maintain the levels of the lakes and the levels continue to fall, cutbacks in sprinkling are instituted when the lakes reach their emergency level for sprinkling (in our analysis this level was set at NAP - 38 cm). The cutback policies are described in more detail in Sec. 3.1.4.

In all of our analyses, the only combination of scenarios that caused the lake levels to fall enough to produce cutbacks in sprinkling was the DEX supply scenario with the SPRHI-RALL demand scenario. However, the resulting agriculture shortage losses in this case were extremely high in the area supplied by the lakes. And the losses would be even higher if some of the promising tactics were implemented (e.g., those that increase the supply capacity to the Northeast Highlands), since those tactics would produce even greater demands on the lakes for water.

Three tactics were examined that would increase the storage capacity of the lakes and thus permit extractions to continue during periods of protracted dryness. The first two expand the allowable range of variation in the lake levels, and the third constructs a new reservoir. The tactics are:

- Increase the summer target level of the IJsselmeer and Markermeer.
- Decrease the minimum level of the IJsselmeer and Markermeer.
- Build a freshwater reservoir in the Markermeer.

The analysis of the three tactics is described in the following two subsections. (The first two tactics are considered together.)

11.4.1. Increase Summer Target Level or Decrease Minimum Level of IJsselmeer and Markermeer

As noted above, increasing the amount of water available for extraction from the lakes increases the length of time extractions for sprinkling can continue during a prolonged drought before cutbacks become necessary. As a result, agriculture shortage losses are reduced.

Increasing the summer target level means that more water can be retained in the spring while inflows are still reasonably high and consumption is relatively low. Each centimeter of increase in the summer target level allows approximately 23 m^3/s of additional water to be extracted later in the season for an entire decade. Increasing the lake levels causes some problems in the areas around the lakes. Drainage from these areas is made more difficult, dikes and embankments around the lakes must be improved, and some valuable land on the lake side of the dikes (e.g., beaches and nature preserves) will be flooded. The cost of this tactic takes into account the required infrastructure changes and the amount and value of the flooded land.[3]

Decreasing the minimum level of the lakes means that they would be allowed to drop below NAP - 40 cm before sprinkling would be cut back. Each centimeter below NAP - 38 cm that the lakes were allowed to drop would provide about 23 m^3/s of additional water for sprinkling for a decade. However, lowering the lake levels beyond the present minimum would make it impossible to supply water to many boezems without pumping. (Supplying the boezems by gravity requires that the water levels in the boezem be substantially lower than the level of the lakes.) The cost of this tactic, therefore, includes the cost of building several pumping stations. It also includes costs for dredging the lakes in order to maintain a sufficient depth in the shipping lanes.[4]

The costs of both of these tactics depend on the amount by which the target level or minimum level is to be changed. We determined the changes that would be needed, and evaluated the resulting costs and benefits, for three different scenarios:

1. With the current water management infrastructure.
2. With implementation of those promising regional tactics that would increase the extractions from the IJsselmeer or its tributaries.
3. With the construction of a Markerwaard.

11.4.1.1. With Current Infrastructure. In all years for which we have data, the flow into the lakes in the spring exceeds the water that leaves the lakes through extractions and evaporation. In order to maintain the lakes at their summer target level, any excess water above the target level is discharged through the Afsluitdijk or the Oranjesluizen. If the target level were set higher, less water would be discharged, and, consequently, more would be available to satisfy demands for water later in the growing season.

In our driest supply scenario (DEX), with the highest sprinkler demands (SPRHI-RALL) it would have been possible to raise the lake levels to NAP - 9 cm (about 11 cm above the current summer target level). This increase in the summer target level would be more than enough to eliminate all of the agriculture shortage losses caused by cutbacks in sprinkling that were due to the low lake levels. (These losses totaled over 36 Dflm.) If flushing were to be cut back when the lakes reached an emergency flushing level of NAP - 25 cm,[5] then the summer target level would have to be increased to only NAP - 15 cm in order to avoid all of these losses. If it were considered desirable to avoid cutbacks in flushing as well, the lakes would have to be increased to NAP - 10 cm to avoid shortage losses due to cutbacks in extractions from the IJsselmeer.[6] The expected annual benefits and annualized fixed costs for both of these cases are shown in the first two lines of Table 11.8. (Note that we have not assigned a monetary benefit to increased flushing.) The cost of obtaining the equivalent amount of extra storage capacity by lowering the minimum level of the lakes (to NAP - 45 cm or NAP - 50 cm) is also shown in the table.

The results in Table 11.8 for the current infrastructure case show that lowering the minimum level of the lakes, although promising if flushing is cut back when the lakes get too low, is not as attractive as raising the summer target level. The upper bound on expected annual benefits from the tactic is 2.6 Dflm, while the

Table 11.8

COSTS AND BENEFITS (Dflm) OF RAISING THE SUMMER TARGET LEVEL OR LOWERING THE MINIMUM LEVEL OF THE MARKERMEER AND IJSSELMEER
(High Sprinkler Intensity, with Waterboard Plans)

	Change in Level	DEX	1959	1943	1967	Expected Benefits		Annualized Invest. Cost for	
						UB	LB	Raising	Lowering
Current Infrastructure									
With flushing cutbacks	5 cm	36.8	0	0	0	2.6	0.7	0.5	2.5
Without flushing cutbacks	10 cm	36.8	0	0	0	2.6	0.7	3.4	3.7
With Regional Tactics Implemented									
With flushing cutbacks	9 cm	121.5	0	0	0	8.5	2.4	2.8	3.4
With Markerwaard (and Flushing Cutbacks)									
Current infrastructure	6 cm	36.8	0	0	0	2.6	0.7	1.1	2.8
Regional tactics implemented	10 cm	121.5	0	0	0	8.5	2.4	3.5	3.9

annualized fixed cost of lowering the minimum level to NAP - 45 cm is 2.5 Dflm, and the annualized fixed cost of lowering the minimum level to NAP - 50 cm is 3.7 Dflm.

The results for increasing the summer target level of the lakes are more interesting. As mentioned above, if flushing were not to be cut back in DEX, the summer target level would have to be raised by about 10 cm to avoid sprinkling cutbacks due to low lake levels. However, the annualized fixed cost of raising the summer target level of the lakes by 10 cm is 3.4 Dflm, which exceeds the upper bound on the expected annual benefits. If flushing were cut back to the minimum allowable amounts whenever the lake levels fell below NAP - 25 cm (a reduction of about 10 m^3/s in extractions from the lakes), the summer target level would have to be raised by only 5 cm, which has an annualized fixed cost of only 0.5 Dflm. This tactic is clearly promising.

11.4.1.2. With Implementation of Promising Regional Tactics. Some of the promising tactics discussed in previous chapters would, if implemented, lead to increased extractions from the IJsselmeer and its primary tributary, the IJssel River. In discussing these tactics, we noted that they would be promising only if the summer target level of the IJsselmeer and Markermeer were to be raised (or the minimul level lowered). The reason for imposing this condition is that the additional extractions resulting from their implementation would lead to increased shortage losses in dry years in other areas that depend on the lakes for their fresh water. These increased shortage losses would be more than enough to make the expected annual benefits from the tactics negative (and therefore turn them into unpromising tactics).

Table 11.8 shows that if the promising regional tactics were implemented[7] without changing the summer target level or minimum level of the lakes, the agriculture shortage losses for the DEX SPRHI-RALL scenario would increase to 121.5 Dflm from 36.8 Dflm. We found that, even with the increased extractions resulting from implementation of these tactics, the lakes could be raised to a level of NAP - 10 cm by the end of May under this scenario. An increase in the summer target level of the lakes by 9 cm, to NAP - 11 cm, would be sufficient to eliminate the 121.5 Dflm in agriculture shortage losses caused by cutbacks in sprinkling that resulted from low lake levels.[8] (This assumes that flushing would be cut back to its minimum whenever the lake levels fell below NAP - 20 cm.[9] Cutbacks in sprinkling would be required if these cutbacks in flushing were not made.)

The results in Table 11.8 indicate that lowering the minimum level of the lakes by 9 cm (which would eliminate the 121.5 Dflm in agriculture shortage losses in the DEX SPRHI-RALL scenario) is also promising, but not as attractive as raising the summer target level. The annualized fixed cost of this tactic is 3.4 Dflm, while the upper bound on expected annual benefits is 8.5 Dflm. The annualized fixed cost of raising the summer target level of the lakes to NAP - 11 cm is estimated to be 2.8 Dflm.

11.4.1.3. With a Markerwaard. Plans to build a large new polder in the Markermeer have been under discussion for many years. A decision on whether or not to build the polder has not yet been made. The decision is likely to be made on the basis of economic, political, and social factors, with water management considerations playing a relatively minor role in the decisionmaking process. In our analysis of water management tactics, we assumed that a Markerwaard would not be built. In this section we discuss the water management implications of a Markerwaard.

Construction of a Markerwaard polder would convert approximately 410 km^2 of the Markermeer into dry land, leaving a lake approximately 200 km^2 in area. This would reduce the storage capacity of the remaining lakes considerably. However, since their surface area would also be significantly reduced, there would be less evaporation. Combining the two effects, we found that to produce the same agriculture shortage losses as would occur without a Markerwaard would require raising the summer target level of the remaining lakes by only 1 cm (or lowering the minimum level by 1 cm).

The implication of this finding is demonstrated in Table 11.8. If a Markerwaard were constructed and no other changes were made to the current infrastructure, increasing the summer target level of the lakes or decreasing the minimum level by 6 cm would be enough to eliminate agriculture shortage losses due to cutbacks in extractions from the lakes caused by low lake levels. (This assumes that flushing would be cut back to minimum levels whenever the lakes dropped below NAP - 25 cm.) The annualized fixed cost of lowering the minimum level to NAP - 46 cm is estimated to be 2.8 Dflm, which is more than the upper bound on expected annual benefits. The annualized fixed cost of raising the summer target level of the lakes to NAP - 14 cm is 1.1 Dflm, which is less than the upper bound on expected annual benefits. This tactic would, therefore, be promising if a Markerwaard were built.

If a Markerwaard were built and the promising regional tactics were implemented, a similar analysis shows that raising the summer target level of the remaining lakes to NAP - 10 cm or lowering their minimum level to NAP - 50 cm would eliminate shortage losses caused by cutbacks in sprinkling due to low lake levels and would be promising tactics. (In this case, elimination of the shortage losses requires that flushing be cut back to minimum levels whenever the lakes dropped below NAP - 20 cm.)[7]

11.4.2. Construct a "Wet Markerwaard"

The process of constructing a Markerwaard involves building a dike around the area of the Markermeer to be reclaimed, and then pumping the water out of the surrounded area. It has been suggested that the storage capacity of the lakes could be increased by building the dikes for a Markerwaard and then not draining it. With the dikes in place, an inlet facility and a pumping station on the Houtribdijk could be added and the area inside the dikes used to store water. We call this reservoir a "wet Markerwaard."

The minimum water level inside the reservoir could be much lower than in the surrounding lakes because the reservoir could be completely isolated from the lakes, so low inside water levels would not cause problems for inlet and other facilities around the lakes. When the water in the reservoir was needed, the pumping station would be used to pump water into the IJsselmeer. From the IJsselmeer, this water could be extracted by the surrounding polders and could also flow south through the Houtribsluizen and the Krabbegatsluizen to supply the polders around what used to be the Markermeer.

The wet Markerwaard would enable agriculture shortage losses caused by cutbacks due to low lake levels to be eliminated without raising the summer target level or lowering the minimum level of the lakes. Its expected annual benefits would therefore be 2.6 Dflm with the current water management infrastructure, and 8.5 Dflm if the promising regional tactics were implemented (see Table 11.8). However, its annualized fixed cost would be considerably higher than either of the benefit figures. If a second Oostvaardersdijk were already built (for some reason besides having a Markerwaard), the annualized fixed cost of constructing a wet Markerwaard would be 23 Dflm. If a second Oostvaardersdijk had to be built as part of this tactic, the annualized fixed cost would be 33 Dflm. In either case, a wet Markerwaard would not be a promising tactic.

11.5. CONSTRUCT A NORTH-SOUTH CONNECTION

With the current water management infrastructure, the water supply for the northern portion of the country is virtually separate from the water supply for the southern portion. The north is supplied with water that has been stored in the IJsselmeer and Markermeer. Water for the south comes directly from the major rivers, the Maas and the Rijn. The IJssel River brings Rijn water to the IJsselmeer. But there is no reasonable way to bring IJsselmeer water to the southern part of the country.

When water is plentiful, this situation causes no problems. However, when the river flows are low, it would be nice to be able to send water from the IJsselmeer and Markermeer south for use by agriculture in the Midwest or to push back the salt wedge, or even to augment the flow on the Maas. In addition, if a dry summer is anticipated or the lake levels are dropping, it would be nice to send extra water (in addition to IJssel River water) to the IJsselmeer and Markermeer to avoid later cutbacks in extractions.

One way of accomplishing these desirable objectives is to make changes to the Amsterdam-Rijnkanaal and adjoining waterways that enable them to carry water between the Waal and the Markermeer, between the Markermeer and the Lek, and/or between the Markermeer and the Maas. The relevant waterways are indicated on the map in Fig. 11.11. The set of changes required to accomplish one or more of these results is collectively called a North-South Connection. Various possible ways of achieving a North-South Connection have been discussed in the Netherlands since 1965. In that year an RWS working group suggested that a North-South Connection would be one good way of reducing the salinity losses in the Midwest caused by the salt wedge. The studies of the working group led to publication of a report in 1976 with the English title "Technical Aspects of the North-South Connection" [11.2], which discussed a number of alternative versions of the tactic, and developed costs for each.

We considered three alternatives for a North-South Connection. All three use all or part of the Amsterdam-Rijnkanaal for the major portion of their route and include a pumping station on the Diemen (at the northern end of the canal) to pump water to and from the Markermeer. All versions also require some modification of the current open connection between the IJmeer and Markermeer to avoid mixing North-South Connection water with IJmeer water. Possible modifications are discussed in Sec. 11.3. The annualized fixed cost of these modifications (which would be at least 8.7 Dflm) has not been included in the cost of the three North-South Connection tactics. The three tactics differ in (1) the starting point for the water being transported northward, and (2) the ending point for water being transported southward.

11.5.1. Alternative Paths

We considered two alternative paths for sending Waal water northward (they are identified by where the water would be extracted), and three

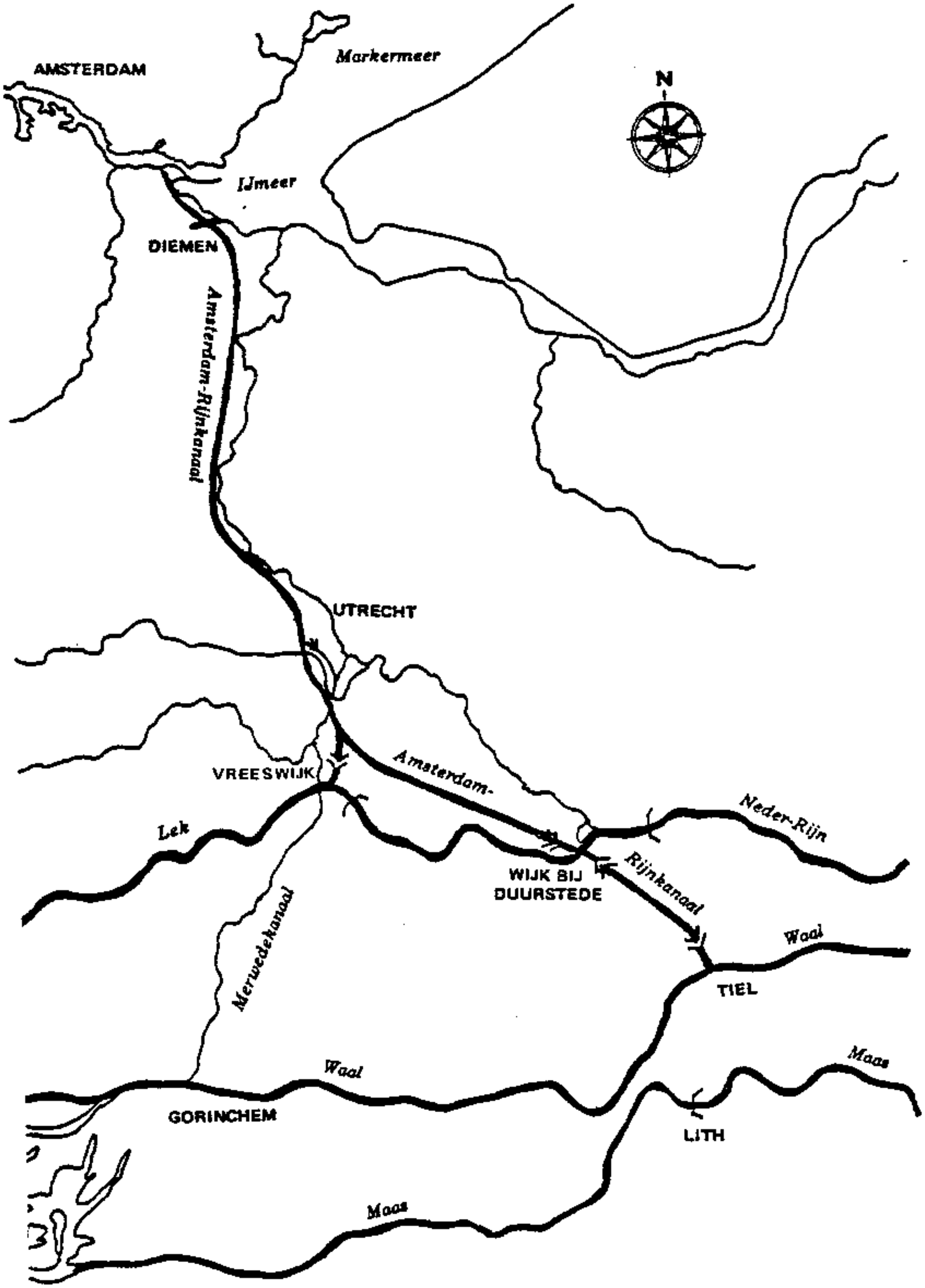

Fig. 11.11--Major waterways involved in North-South Connection tactics

paths for sending Markermeer water southward (identified by where the water would be deposited).

11.5.1.1. Northward Paths.

Tiel. In this path, which involves very little change to the existing infrastructure, water is let into the Betuwe section of the Amsterdam-Rijnkanaal at Tiel. It flows north by gravity, crosses the Neder-Rijn (which is canalized) at Wijk bij Duurstede, and continues to flow north to the Diemen pumping station by gravity. This is the northward path shown in Fig. 11.12. At Wijk bij Duurstede, the water could be sent through one of the lock chambers in the Prinses Irenesluis. However, this ship lock is very busy, and its throughput capacity is only 30 m^3/s. Thus, a bypass around the lock would be constructed as part of this tactic.

Gorinchem. The only major problem with the Tiel path is that extracting water from the Waal at Tiel causes the water level in the river to drop downstream of the extraction point, and sedimentation builds up there. Both of these effects result in increased shipping losses. We, therefore, considered an alternative northward path that would avoid increases in the shipping losses. It would use the Merwedekanaal for bringing water from the Waal to the Lek, and the Lekkanaal for carrying the water from the Lek to the Amsterdam-Rijnkanaal. Once in the Amsterdam-Rijnkanaal, the water would follow the Tiel path to the Markermeer. This is the northward path shown in Fig. 11.13.

There is currently no water transported on the Merwedekanaal or Lekkanaal, both of which are primarily used for shipping. In order to extract water from the Waal and transport it north on the Merwedekanaal, pumping capacity would have to be installed at Gorinchem or slightly west of it. If a flow of more than 40 m^3/s on the canal were desired, some new canal construction would be required; if the desired flow were greater than 80 m^3/s, significant new canal construction would be required, together with relocation of utilities, modification of existing bridges, and construction of new bridges.

In order to use the Lekkanaal to transport water between the Lek and the Amsterdam-Rijnkanaal, a bypass and pumping station would be constructed at Vreeswijk to carry the water around the Prinses Beatrixsluis. The pumping station is required in order to transport water south on the Lekkanaal. When transporting water north, the pumping station ensures sufficient intake capacity into the bypass.

11.5.1.2. Southward Paths.

Wijk bij Duurstede. This southward path sends water from the Markermeer through a new pumping station on the Diemen, down the Amsterdam-Rijnkanaal, depositing the water into the Lek at Wijk bij Duurstede (where the Neder-Rijn becomes the Lek). This path is the opposite of the northward path from Tiel between Wijk bij Duurstede

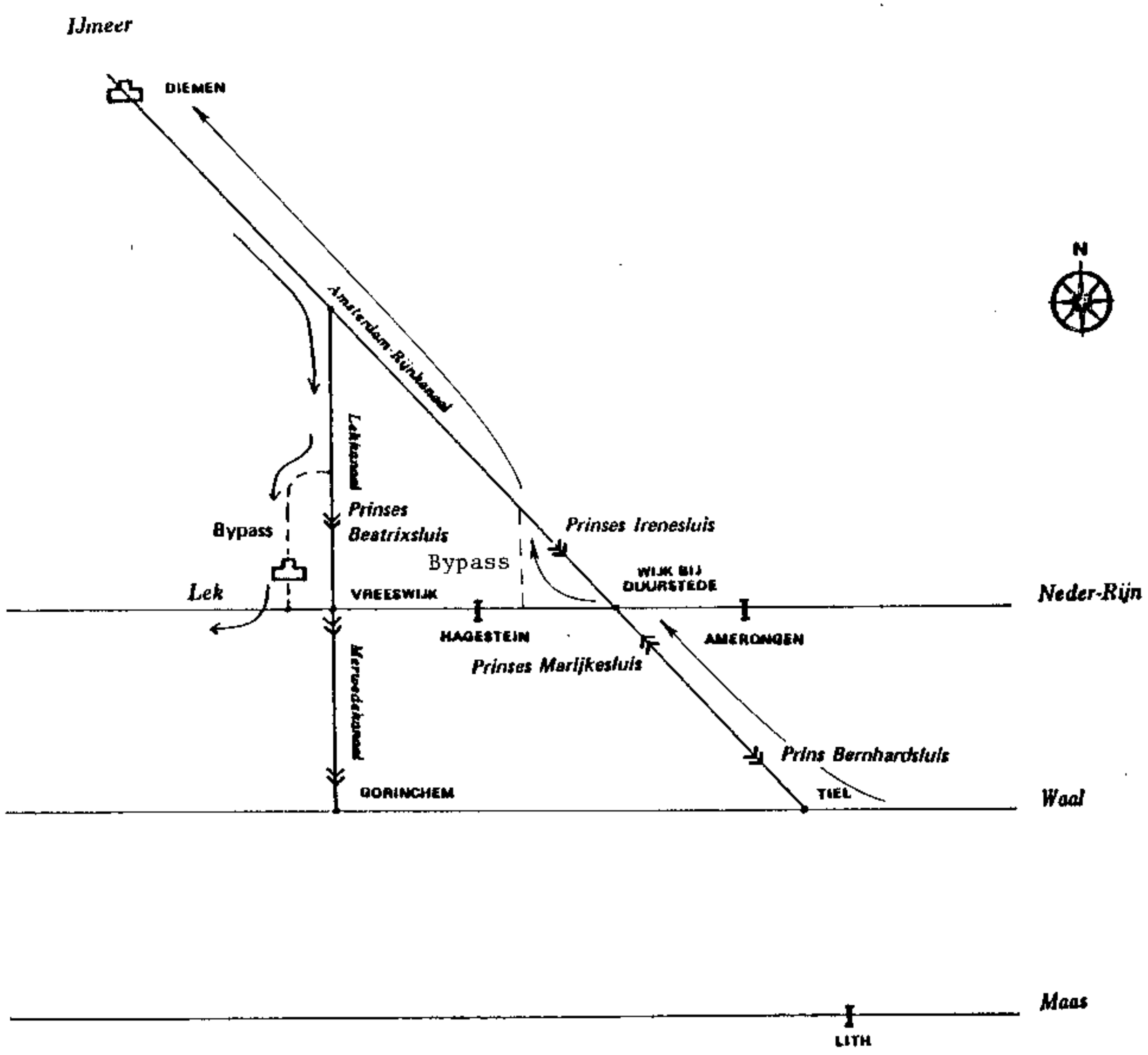

Fig. 11.12--North-South Connection: North to lakes via Tiel and Wijk bij Duurstede; south to Lek via Vreeswijk

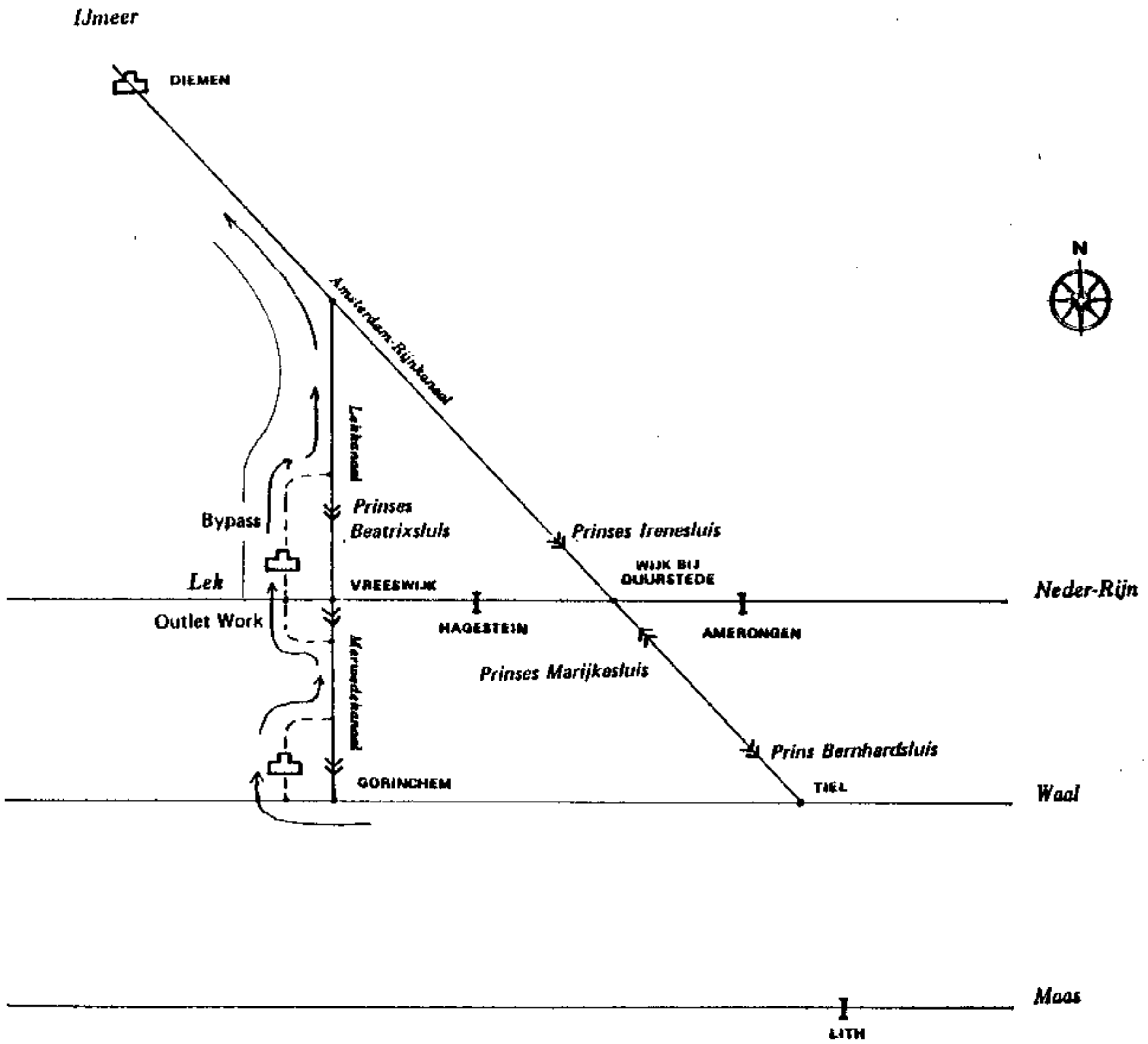

Fig. 11.13--North-South connection: North from Waal via Gorinchem and Vreeswijk; south to Lek via Vreeswijk

and the Markermeer. It is the portion of the southward path between Diemen and the Lek shown in Fig. 11.14. In addition to the bypass at the Prinses Irenesluis, a pumping station would have to be built there to pump water out of the canal and into the Lek.

Vreeswijk. This path sends water from the Markermeer through a new pumping station on the Diemen, down the Amsterdam-Rijnkanaal, depositing the water into the Lek at Vreeswijk. It is the opposite of the northward path from Gorinchem between Vreeswijk and the Markermeer, and is the southward path shown in Figs. 11.12 and 11.13. The path requires a pumping station at Vreeswijk. However, if the Merwedekanaal were to be used to transport water northward in a North-South Connection (the northward path from Gorinchem), then no additional pumping station would be required. This southward path is preferred to the previous one since it is shorter and requires pumping water into the Lek over a smaller head difference.

The Maas. Since the flow on the Maas is sometimes very low, Dutch water management experts have contemplated the possibility of bringing fresh water from the Markermeer to the Maas. This water might be used for sprinkling agricultural crops in the Southeast Highlands, or to flush a fresh Zoommeer. This southward path would bring water from the lakes to the Maas via Wijk bij Duurstede and Tiel. It follows the southward path between the lakes and Wijk bij Duurstede. It then flows through the Betuwe section of the Amsterdam-Rijnkanaal, through a new syphon under the Waal, and into a new canal between the Waal and the Maas. This is the southward path in Fig. 11.14.

11.5.2. Alternative Tactics

Using the above five paths as building blocks, we defined three alternative North-South Connections as tactics to be evaluated. They are each discussed briefly below. In order to assign concise names to the three alternatives, we adopted the following naming convention. We have used the label A-B, where A refers to the starting point for the northward path of the water and B refers to the ending point for water being transported southward. Their costs are summarized in Table 11.9.

11.5.2.1. Tiel-Vreeswijk. In this tactic water is extracted from the Waal at Tiel, is sent northward along the Amsterdam-Rijnkanaal, and passes through the new pumping station on the Diemen. When used in the southward direction, the water flows through the Amsterdam-Rijnkanaal and the Lekkanaal, depositing water into the Lek at Vreeswijk. The tactic is shown in Fig. 11.12. It requires building a pumping station on the Diemen, a bypass at the Prinses Irenesluis near Wijk bij Duurstede, and a bypass and pumping station at the Prinses Beatrixsluis near Vreeswijk. For purposes of our analysis we considered two capacities for this tactic--30 m^3/s and 100 m^3/s. The annualized fixed cost for a capacity of 30 m^3/s is 12.9 Dflm; for a capacity of 100 m^3/s, it is 23.9 Dflm.[10]

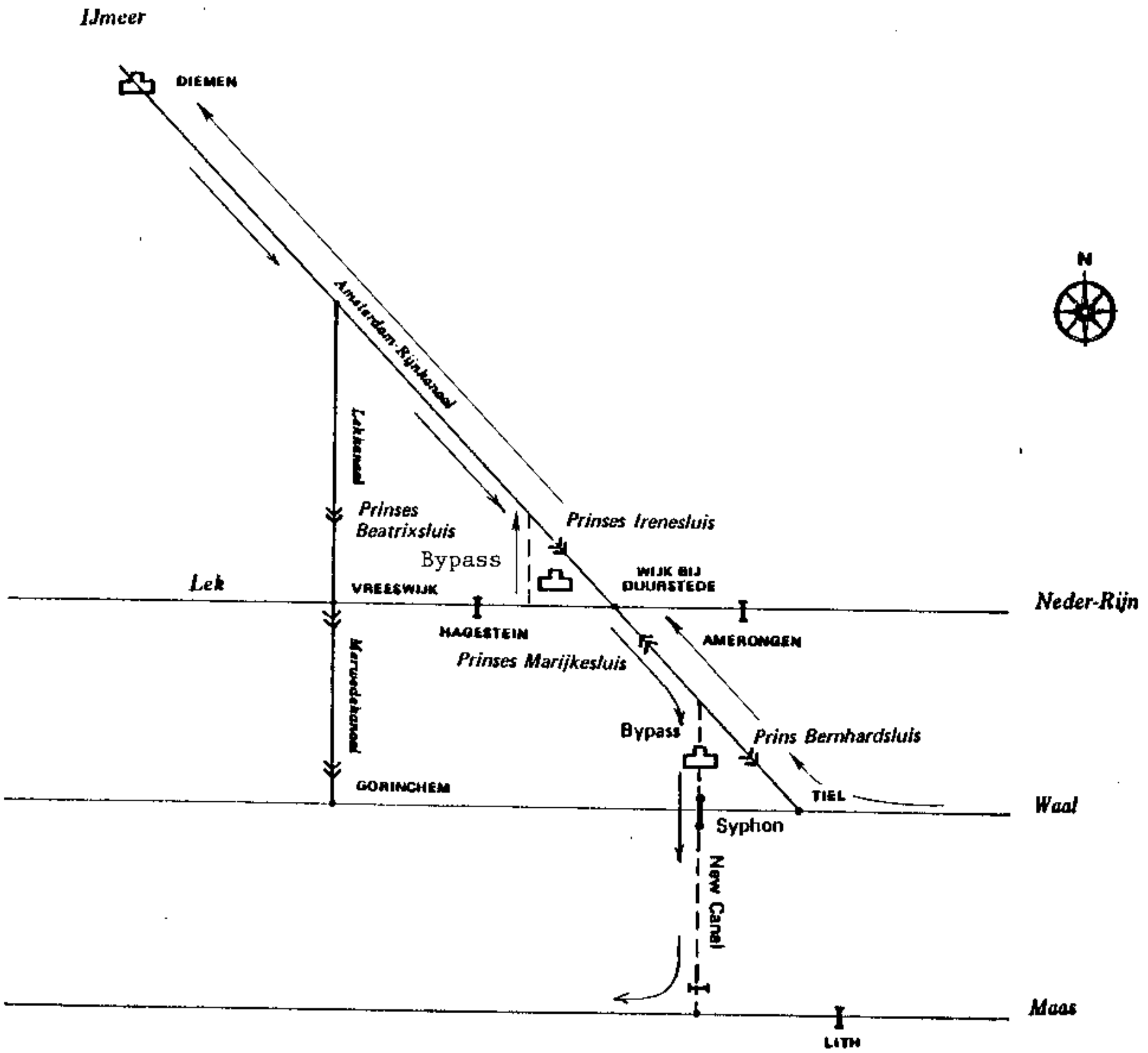

Fig. 11.14--North-South Connection: North to lakes via Tiel and Wijk bij Duurstede; south to Maas via Wijk bij Duurstede and Tiel

Table 11.9

ANNUALIZED FIXED COSTS (Dflm) FOR NORTH-SOUTH CONNECTION ALTERNATIVES

Alternative	Southern Extraction Location	Southern Discharge Location	Throughput Capacity (m^3/s)	Annualized Fixed Cost
1	Tiel	Vreeswijk	30	12.9
			100	23.9
2	Gorinchem	Vreeswijk	30	11.8
			100	51.8
3	Tiel	Maas	100	37.9

11.5.2.2. Gorinchem-Vreeswijk. This tactic avoids the increased low water shipping losses caused by extracting water from the Waal at Tiel. In this tactic, water is extracted from the Waal at Gorinchem and then flows north through the Merwedekanaal, the Lekkanaal, and the Amsterdam-Rijnkanaal. It follows the opposite path southward to the Lek at Vreeswijk. The tactic is shown in Fig. 11.13. It requires building a pumping station on the Diemen and a bypass and pumping station at the Prinses Beatrixsluis near Vreeswijk. For a northward throughput capacity of 30 m^3/s, six electrical underwater pumps would be needed to get Waal water into the Merwedekanaal. For a throughput capacity of 100 m^3/s, a pumping station would have to be built at Gorinchem, and major changes would have to be made to the Merwedekanaal to allow it to carry so much water. The annualized fixed cost of this tactic for a capacity of 30 m^3/s is 11.8 Dflm; for a capacity of 100 m^3/s, it is 51.8 Dflm.

11.5.2.3. Tiel-Maas. This version of the North-South Connection permits Markermeer water to be carried south to the Maas. Water traveling northward would be extracted from the Waal at Tiel. In addition to building a pumping station on the Diemen and a bypass of the ship locks at Wijk bij Duurstede, which are required for sending water northward, this tactic requires building a pumping station at Wijk bij Duurstede, a pumping station and a syphon under the Waal at Tiel, and a new 7-km canal between the Waal at Tiel and the Maas just west of Lith (see Fig. 11.14). We considered only a capacity of 100 m^3/s for this tactic. Its annualized fixed cost is 37.9 Dflm.

11.5.3. Analysis of Alternatives

There are three primary uses that a North-South Connection would serve:

1. Carry water northward to the lakes to reduce agriculture shortage losses in the north during dry summers.

2. Carry water southward from the lakes to reduce agriculture salinity losses in the Midwest during periods of low Rijn flows (and/or when the Rijn salinity is higher than the salinity of the Markermeer).
3. Carry water southward to the Maas to flush the (fresh) Zoommeer, and/or to provide water for reducing agriculture shortage losses in the Southeast Highlands.

For any of the alternative versions of the North-South Connection to be promising, the upper bound on the expected annual benefits from all three uses combined would have to exceed the annualized fixed cost. The minimum annualized fixed cost among the alternatives that bring water south to the Lek (excluding the costs for modifications of the IJmeer) is 11.8 Dflm, which is for the Gorinchem-Vreeswijk alternative with a throughput capacity of 30 m^3/s. We discuss the expected annual benefits from each of the three primary uses of a North-South Connection below, and compare them with these costs.

<u>11.5.3.1. Reduce Agriculture Shortage Losses in the North</u>. Currently, the only important source of water for the IJsselmeer and Markermeer is the IJssel River. The amount of water flowing in the IJssel can be varied by adjusting the weir on the Neder-Rijn that is located at Driel. However, even if the weir is fully closed, only about 20 percent of the Rijn water entering the country will flow up the IJssel. The remainder flows down the Waal.

The North-South Connection could be used to carry additional water to the lakes from the Waal during periods of high river flows in the spring and early summer, helping to raise their levels in anticipation of shortages later in the growing season. However, as shown in Sec. 11.4.1, the normal flow of water into the lakes is likely to be sufficient to raise lake levels high enough in the early summer to avoid all cutbacks in extractions later in the growing season. If it is decided not to raise the summer target level of the lakes (or lower their minimum level), the North-South Connection could be used to carry Waal water northward whenever cutbacks would be required because of low lake levels. However, its use in this way would lead to increased agriculture salinity losses in the Midwest (due to a reduction in the amount of water available for fighting the salt wedge), and to increased low water shipping losses for the two alternatives that extract water at Tiel. These increased losses are likely to outweigh the benefits from reducing the agriculture shortage losses in districts extracting water from the lakes. Thus, the net benefits from this use of the North-South Connection are likely to be negligible.

<u>11.5.3.2. Reduce Agriculture Salinity Losses in the Midwest</u>. There are two ways that a North-South Connection could be used during periods of low flows on the rivers to reduce agriculture salinity losses in the Midwest. First, water could be transported southward and then carried into the Midwest through a new canal, such as a Krimpenerwaard, Lopikerwaard, or Maarssen-Bodegravenkanaal (see Sec.

8.2). In fact, this is the only way that salinity losses in the Midwest could be substantially reduced if the capacity of the North-South Connection were only 30 m^3/s. Using the tactic in this way would require construction of one of these canals, which would have an annualized fixed cost of at least 2.3 Dflm (see Table 8.6). The second way of using the North-South Connection would be to send water southward to push back the salt wedge, allowing extractions of fresh water to continue at Gouda.

In either case, the reductions in salinity losses would be only slightly higher than those that would be achieved if a Krimpenerwaardkanaal were constructed (Markermeer water is slightly less saline than Rijn water when the Rijn flow is low), and increased shipping losses from extracting at Tiel for a Krimpenerwaardkanaal would be avoided. Using the reduction in salinity losses shown for Tactic 3 (the Krimpenerwaardkanaal) in Table 8.7, the upper bound on the expected annual benefits from this use of the North-South Connection would be 3.7 Dflm.[11]

11.5.3.3. Flush the Zoommeer and/or Reduce Agriculture Shortage Losses in Southeast Highlands. One version of the North-South Connection (which has an annualized fixed cost of 37.9 Dflm) would extend the Amsterdam-Rijnkanaal beyond the Waal to enable water from the Markermeer to be transported to the Maas. There are three primary purposes for doing this:

1. To increase the quantity of water available for extraction from the Bergsche Maas at Geertruidenberg.
2. To provide cooling water for the Amer power plant.
3. To improve the quality of the water available for flushing the Zoommeer (when it is turned into a freshwater lake).

As we discussed in Sec. 10.2.2, demands at the entrance to the Wilhelminakanaal that exceed the available flow on the Bergsche Maas above Geertruidenberg would occur very rarely. In addition, there are alternative, less expensive tactics for increasing the supply of water to the Southeast Highlands (see Chap. 10).

The benefits that could be obtained by providing extra cooling water for the power plant on the Amer are also quite small (see Sec. 9.4). The upper bound on expected annual benefits is less than 1 Dflm.

The salinity reductions in the Zoommeer (compared to flushing with Rijn water) are also likely to be small, and hence the reductions in agriculture salinity losses will be small. There are three reasons for this: First, most of the crops planted in areas near the Zoommeer are not very sensitive to salt. Even if all agriculture salinity losses in the districts extracting water from the fresh Zoommeer were eliminated, the upper bound on the expected annual reduction in salinity losses is only 4.3 Dflm. Second, the salinity of Markermeer water is normally not much lower than the salinity of the Rijn, so only a small proportion of this reduction in salinity losses is likely to be realized. Third, the lower salinity Markermeer/Maas water passes through the Hollandsch Diep before it gets to the Zoommeer. In order to retain its low salinity level, it must somehow be kept from mixing with the Waal water that also passes through the Hollandsch Diep. This is unlikely to occur without additional (costly) changes to the water management infrastructure.

11.5.3.4. Conclusion. We identified three alternative versions of a North-South Connection and a number of possible purposes that it could serve. For one of the versions to be promising, the sum of the benefits over all purposes would have to exceed its annualized fixed cost. We found that either the benefits to be gained from a purpose were negligible (e.g., from providing Markermeer water for flushing the Zoommeer), or that the purpose could be achieved in some other (less costly) way (e.g., reducing salinity losses in the Midwest and reducing shortage losses in the Southeast Highlands). We therefore concluded that none of the three versions of the North-South Connection was promising.

11.6. MINIMIZE COST OF TRANSPORTING WATER TO THE LEK

There are several reasons why water might have to be transported between the Waal and the Lek. One, as discussed in the previous section, is to serve as a link in a North-South Connection that would transport water from the Waal northward to the Markermeer. A second is to make a sufficient supply of fresh water available for transport to the Midwest through a new canal.

With the current infrastructure, the only way to transport water between the Waal and the Lek is to extract it at Tiel and let it flow to the Lek through the Betuwe section of the Amsterdam-Rijnkanaal. However, because less water remains in the Waal below Tiel, the water level drops. In addition, the sand-carrying capabilities of the river are diminished by the extractions, causing sediment to build up in the river downstream of Tiel. These two effects cause the river to become shallower, leading to increased low water shipping losses for ships using the Waal during periods of low river flows (see Vol. IX).

In this section we consider a number of tactics that are designed to reduce the low water shipping losses that result from extracting water from the Waal at Tiel.

11.6.1. Dredge in Waal below Tiel

This tactic deals only with the problem of sedimentation caused by extractions at Tiel, not the drop in water level. It would dredge away the sand that is precipitated during extraction, and dump it back into the river approximately 10 km downstream or upstream of Tiel. (This maintains an equilibrium between the sand-transporting capacity of the river and the available sediment, which prevents scour (erosion) of the river.)

We assumed that the dredge to be used was one with a capacity of 400 m^3 of sand, which would be able to make at least three trips per day (see Vol. XVIII). The tactics cost is dependent on the amount of sand that needs to be dredged (about 16 Dfl/m^3). The expected annual cost of the tactic is about 0.1 Dflm. The upper bound on expected annual benefits is 1.1 Dflm, which is the upper bound on the expected annual sedimentation losses caused by extractions at Tiel[12]. It is therefore a promising tactic.[13] Because it is so attractive, our analysis of all previous tactics (e.g., Midwest supply alternatives) that use the Amsterdam-Rijnkanaal to bring water from the Waal to the Lek assumed that this tactic was implemented.[14]

11.6.2. Modify Waal near Tiel

A system of groins that guide the flow of the Waal near Tiel currently exists. However, these groins are old, and not all of them are of the right lengths to narrow the river sufficiently. There are two possible ways of modifying them to increase the depth of the Waal below Tiel in order to compensate for the effect of the extractions there.

The first is to construct some new groins and repair some of the existing ones. It is estimated that these improvements would increase the depth of the Waal around Tiel by between 10 and 20 cm (see Vol. XVIII). The annualized fixed cost of this tactic is 1.2 Dflm. Implementation of this tactic is already under consideration as part of an overall plan for improvement of the Waal for shipping. Under this plan, the depth of the shipping route along the Waal would be increased by at least 10 cm.

The second approach involves narrowing of the Waal above and below Tiel. This tactic would require extensive construction. According to a study made in the early 1970s, the present groins along each side of the river would have to be lengthened by 5 to 20 m, depending on their location, for about 7 km upstream and 5 km downstream of Tiel. We assumed that the tactic would increase the depth of the Waal by 10 to 20 cm, although its actual impact is not known. Its annualized fixed cost is 2.3 Dflm.

There are several disadvantages associated with this tactic. One of the major ones is that these changes would be permanent. Thus, their effects are felt during periods when extractions at Tiel are not required, and the long-term effects on the river bottom are uncertain. In addition, changes in the river profile increase the resistance to high river flows, which lead to higher water levels. To compensate for this, additional changes in the infrastructure will be necessary, such as lowering the summer dikes to create less resistance. The costs of these changes are not included in the 2.3-Dflm annualized fixed cost of the tactic, since they are very difficult to estimate. There are also environmental impacts, which are not easily quantified.

Since this tactic is more expensive and has more disadvantages than the first one, but reduces the shipping losses due to extractions at Tiel to about the same extent, it is dominated by the first tactic for the situation with the current infrastructure. However, it may be worthwhile to consider it further in case the aforementioned Waal improvement plan is implemented. In this situation, boats with larger drafts would be using the Waal. This tactic would prevent Tiel from again becoming a critical point in the shipping route, enabling the boats with larger drafts to continue using the Waal in the face of extractions at Tiel.

We evaluated these two tactics by comparing the reductions in low water shipping losses that could be expected from their implementation with their annualized fixed cost.[13] The benefits were calculated separately for two assumptions about their effect: (1) that implementation of either tactic would increase the depth of the Waal below Tiel by 10 cm (the minimum expected improvement), and (2) that their implementation would increase the Waal's depth below Tiel by 15 cm. The results of the evaluation are presented in Table 11.10.

Table 11.10

COSTS AND BENEFITS (Dflm) OF MODIFYING GROINS OR NARROWING WAAL AROUND TIEL
(High Sprinkler Intensity, with Waterboard Plans)

					Expected Annual Benefits		Annualized Fixed Cost	
	DEX	1959	1943	1967	UB	LB	Modify Groins	Narrow Waal
Reduction in shipping losses from a 10-cm increase in depth of Waal	11.2	5.0	1.4	0.1	1.9	0.7	1.2	2.3
Reduction in shipping losses from a 15-cm increase in depth of Waal	14.3	6.2	1.9	0.1	2.4	0.8	1.2	2.3

The results indicate that modifying the groins around Tiel is a promising tactic, even if it leads to an increase in the depth of the Waal of only 10 cm. The narrowing of the Waal above and below Tiel is promising in neither case, because the annualized fixed cost of the additional changes to the infrastructure that are needed for implementation of this tactic will certainly exceed 0.1 Dflm.

11.6.3. Expand Supply Capacity of Merwedekanaal (Betuwe Section)

In our discussion of the North-South Connection (Sec. 11.5), we considered using the Betuwe section of the Merwedekanaal as an alternative to the Betuwe section of the Amsterdam-Rijnkanaal for transporting water between the Waal and the Lek. This possibility offers a big advantage over the Amsterdam-Rijnkanaal. Because of the depth of the Waal at Gorinchem (where the Merwedekanaal begins), extracting water there would not lead to increases in low water shipping losses.

The Merwedekanaal is currently used only as a shipping channel and to provide drainage for the surrounding area. There is no continuous flow of water in it. To use the canal for water transport would require adding pumping capacity. For throughput capacities above 30 m^3/s, some new canal construction would also be required, which increases the cost of the tactic substantially. In this section we assume that a throughput capacity of 30 m^3/s is all that is needed between the Waal and the Lek. (This is enough to meet the needs of a Lopikerwaardkanaal under most circumstances, for example.)

One possible use for the water brought to the Lek through the Merwedekanaal is to send it up the Lekkanaal and then into the Amsterdam-Rijnkanaal, thereby eliminating the need for extractions at Tiel. However, in addition to the cost of adding pumping capacity on the Merwedekanaal, a bypass of the Prinses Beatrixsluis on the Lekkanaal would have to be built. The bypass has an annualized fixed cost of over 2.5 Dflm. The upper bound on expected annual low water shipping losses due to extracting at Tiel is only 1.2 Dflm. Thus, we did not pursue this combination of tactics any further.

Another possibility is that water brought to the Lek through the Merwedekanaal can be extracted from that river farther downstream and be used to reduce agriculture salinity losses in the Midwest. This tactic would have an annualized fixed cost of only 0.9 Dflm for a throughput capacity of up to 30 m^3/s. However, the current infrastructure does not offer possibilities for major extractions from the Lek; the maximum extraction rate from the river lies between 10 and 15 m^3/s. Construction of a canal from the Lek through the Lopikerwaard or the Krimpenerwaard would change this: the maximum extraction rate might then increase to 30 m^3/s or more. In our discussion of Midwest supply alternatives in Sec. 8.2.1, we found that a canal through the Lopikerwaard would have been a promising tactic if it did not contribute to increasing low water shipping losses on the Waal. What if the Merwedekanaal were used instead of the Amsterdam-Rijnkanaal to transport water to the Lek for supply to the Lopikerwaardkanaal? Would the reduction in shipping losses be enough to offset the cost of adding pumping capacity to the Merwedekanaal? And how would the benefits from this combination of tactics compare with the tactic of constructing a groin in the Nieuwe Waterweg, which was found to be promising for reducing agriculture salinity losses in the Midwest (see Sec. 8.2.3)? We provide answers to these questions in the following subsections.

11.6.3.1. Expand Supply Capacity of Merwedekanaal and Build a Lopikerwaardkanaal.[13] This tactic combines the Midwest supply alternative that would extract water from the Lek, transport it across the Lopikerwaard, and discharge it into the Gekanaliseerde Hollandsche IJssel (see Sec. 8.2.1.1) with the first portion of the northward path of the North-South Connection that begins at Gorinchem (see Sec. 11.5.1.1).

Waal water would be pumped into the Kanaal van Steenenhoek just west of Gorinchem, and would then flow east to Gorinchem and north along the Merwedekanaal to the Lek (see Fig. 11.15). It would be extracted from the Lek at Wiel, flow through the new Lopikerwaardkanaal and be discharged into the Gekanaliseerde Hollandsche IJssel just east of Haastrecht (see Fig. 8.4). The portion of the route from the Waal to the Lek will require purchase and installation of six electrical underwater pumps at the mouth of the Kanaal van Steenenhoek. The remainder of the route requires digging a new canal, expanding some existing waterways, expanding the inlet work at Wiel, and expanding the pumping station at Haastrecht. The annualized fixed cost of the tactic is 3.2 Dflm.

In order to determine the benefits that could be derived from implementation of this tactic, we compared the agriculture salinity losses, low water shipping losses, and dredging costs with those that would occur with the current water management infrastructure. The results are presented in Table 11.11. The table also includes the corresponding changes in losses and costs for the tactic that would build a Lopikerwaardkanaal and extract water for it at Tiel (these are the same numbers as appear in Table 8.7). The results indicate that the use of the Merwedekanaal for bringing water from the Waal to the Lek would lead to a significant reduction in low water shipping losses. These reductions, compared to an increase in shipping losses when water for a Lopikerwaardkanaal is extracted at Tiel, are more than enough to make the combination of the Merwedekanaal and Lopikerwaardkanaal tactics promising.

11.6.3.2. A Comparison of the Merwedekanaal-Lopikerwaardkanaal Tactic with the Construction of a Groin in the Nieuwe Waterweg.[13] In the previous section we found that combining the addition of pumping capacity on the Merwedekanaal with the construction of a canal through the Lopikerwaard was a promising way of reducing agriculture salinity losses in the Midwest. In Sec. 8.2 we found that the construction of a groin in the Nieuwe Waterweg was also promising for this purpose. Would it be promising to do both? If not, which is the more promising approach? We examine these questions in this subsection.

The costs and benefits from implementing the Merwedekanaal-Lopikerwaardkanaal tactic are given in Table 11.11. The costs and benefits from constructing a groin in the Nieuwe Waterweg are given in Table 8.8. The additional costs and benefits of the former tactic are shown in Table 11.12. It shows that the Merwedekanaal-Lopikerwaardkanaal tactic provides some benefits not provided by the groin in the Nieuwe Waterweg, especially with respect to shipping. However, the upper bound on the expected additional benefits is only

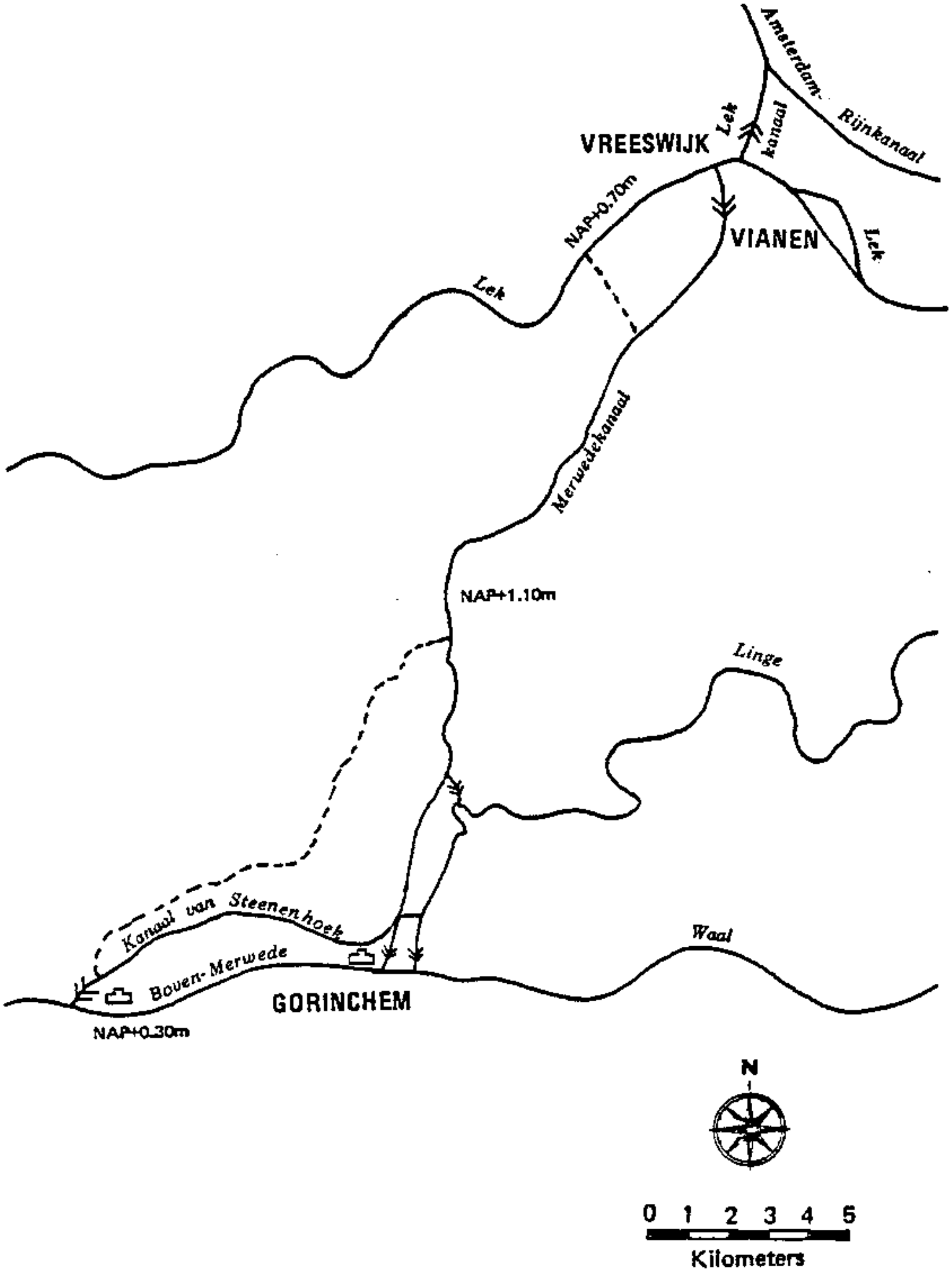

Fig. 11.15—Merwedekannal between Waal and Lek

Table 11.11

COMPARISON OF BENEFITS AND COSTS (Dflm) OF MERWEDEKANAAL AND AMSTERDAM-RIJNKANAAL COMBINED WITH A LOPIKERWAARDKANAAL
(High Sprinkler Intensity, with Waterboard Plans)

	External Supply Scenario				Expected Annual Benefits		Annualized Fixed
Type of Benefit	DEX	1959	1943	1967	UB	LB	Cost
Merwedekanaal							
Reduction in salinity losses	32.6	0.4	0.2	0.0			
Decrease in shipping losses	6.0	2.5	0.4	0.0			
Decrease in dredging costs	0.1	0.1	0.1	0.0			
Total	38.7	3.0	0.7	0.0	3.9	1.0	3.2
Amsterdam-Rijnkanaal							
Reduction in salinity losses	32.6	0.4	0.2	0.0			
Decrease in shipping losses	(3.9)	(1.7)	(1.0)	0.0			
Decrease in dredging costs	(0.1)	0.0	0.0	0.0			
Total	28.6	(1.3)	(0.8)	0.0	2.2	0.4	2.3

1.0 Dflm, while the additional annualized fixed cost is 2.5 Dflm. Thus, the higher benefits of the combination of the Merwedekanaal and Lopikerwaardkanaal are not sufficient to warrant the additional expenditures (i.e., it has a smaller benefit/cost ratio). The groin in the Nieuwe Waterweg remains the preferred alternative for reducing salinity losses in the Midwest.

However, the groin is able to prevent only about two-thirds of the salinity losses in the Midwest caused by the salt wedge. The Merwedekanaal-Lopikerwaardkanaal tactic would be able to eliminate the remaining one-third of the losses, and would also provide significant benefits to shipping. It is, therefore, conceivable that implementing the Merwedekanaal-Lopikerwaardkanaal tactic in addition to the groin would be promising. Our evaluation of this possibility led us to conclude that this was not the case. The upper bound on the additional expected annual benefits from reducing salinity losses was 1.0 Dflm, and the upper bound on additional expected annual benefits from reducing shipping losses was 0.8 Dflm. Thus, if a groin were constructed in the Nieuwe Waterweg, the upper bound on the additional expected annual benefits from adding pumping capacity on the Merwedekanaal and building a Lopikerwaardkanaal is 1.8 Dflm, and the additional annualized fixed cost is 3.2 Dflm. This means that the combination of all three tactics is not promising.

Table 11.12

ADDED COSTS AND BENEFITS (Dflm) OF COMBINATION
OF MERWEDEKANAAL AND LOPIKERWAARDKANAAL
COMPARED WITH GROIN IN NIEUWE WATERWEG
(High Sprinkler Intensity, with Waterboard Plans)

	DEX	1959	1943	1967	Expected Annual Additional Benefits		Additional Annualized Fixed Cost
					UB	LB	
Reduction in salinity losses	2.6	0.0	(0.2)	0.0			
Decrease in shipping losses	6.0	2.5	0.4	0.0			
Decrease in dredging costs	0.1	0.1	0.1	0.0			
Total	8.7	2.6	(0.3)	0.0	1.0	0.4	2.5

11.7. CANALIZE THE IJSSEL RIVER

Ever since the 1930s, Dutch shipping and water management experts have studied the benefits that might be derived from canalizing the IJssel River. Canalization involves building weirs and ship locks at a number of places along the river. The weirs could be closed when desired, thereby providing better control over the distribution of Rijn water and eliminating low water shipping losses on the IJssel.

In 1937 and 1938, one of the directorates of the RWS issued reports that examined the favorable and unfavorable outcomes from canalizing the IJssel [11.4,11.5]. The reports also described the weirs, their location, and the dimensions of the locks. In the 1950s it was decided that the Neder-Rijn, not the IJssel, should be canalized. The canalization of the Neder-Rijn was completed in 1970. After the decision to canalize the Neder-Rijn was made, there was little discussion of canalizing the IJssel until 1965, when the "Dienst der Zuiderzeewerken" noted that, even with the Neder-Rijn canalized, there would still be important benefits to be gained by canalizing the IJssel. The benefits pointed out by this and subsequent reports[15] fall into four categories:

1. Benefits to Shipping. Low water shipping losses on the IJssel would be eliminated. In addition, since additional water would flow down the Waal whenever the weirs on the IJssel were closed, low water shipping losses on the Waal would be reduced. Maintaining water levels in a canalized IJssel would also mean that extractions for agriculture could be made from the river during periods of low flows without affecting shipping at all.

2. Benefits to the Midwest. Closing the weirs on the IJssel sends more water down the Waal and the Lek, which can be used to push back the salt wedge, thereby reducing agriculture salinity losses in the Midwest.
3. Benefits to the Southern Delta. Increasing the flow along the Waal and the Lek makes it possible to flush the Zoommeer with fresh water without increasing agriculture salinity losses in the Midwest.
4. Benefits to areas surrounding the IJsselmeer and Markermeer. The weirs on the IJssel could be closed whenever accidents on the upper Rijn cause the water to become polluted, thus reducing the risk of contamination of the lakes.[16]

There are a number of disbenefits from canalizing the IJssel (in addition to its very high cost). First, since closing the weirs on the river reduces the amount of water flowing into the IJsselmeer, there will be an increase in the frequency and duration of cutbacks in extractions from the IJsselmeer and Markermeer during dry periods. This will lead to increases in agriculture shortage losses in the districts that extract from the lakes. Second, closure of the weirs on the IJssel leads to increased delays for shipping. Most importantly, implementation of the tactic will cause significant environmental damage to areas along the IJssel River.

The environmental damage occurs in two different ways:

- The IJssel has two channels--a "summer channel" and a wider "winter channel"--with dikes along each. During periods of high flow (which currently occur almost exclusively in the winter) the river overflows from the summer channel into the winter channel. When the winter channel is not flooded, the area between the two sets of dikes has valuable uses for recreation, agriculture, nature preserves, the ecology, etc. If the IJssel is canalized, it will overflow the summer channel more frequently, thus reducing the attractiveness of the area between the summer and winter dikes.
- Increasing the level of the river during the summer can have undesirable hydrological consequences. Groundwater levels in the polders adjoining the river would rise and perhaps even flood areas behind the dikes. Solving this problem would require additional pumping in the polders. The increased water levels would also disturb the existing ecosystem.

Aside from these disbenefits, the IJssel canalization is a very expensive tactic--the most costly of any that we have considered. Alternatives using three, four, and five weirs have been proposed [11.8]. The alternative with five weirs is generally favored, since it would minimize the impact on the environment. We, therefore, used the cost of this alternative in our analysis. Its annualized fixed cost is 60.2 Dflm (the alternative with three weirs would have an annualized fixed cost of about 40 Dflm).

Our analysis sought to determine an upper bound on the benefits that could be derived from an IJssel canalization. We therefore ignored all of the disbenefits listed above (e.g., the impact on agriculture shortage losses around the lakes and the impact on the environment).

We obtained quantitative measures (in terms of loss reductions) for the first three categories of benefits. Benefits to the areas surrounding the IJsselmeer and Markermeer (category 4) were not quantified, but are believed to be small [11.6]. Our analyses of the benefits in categories 1-3 are presented in the following subsections.

11.7.1. Benefits to Shipping

The shipping industry would be the major beneficiary of an IJssel canalization. Low water shipping losses on the IJssel would be eliminated (although there would be losses due to shipping delays at the locks on the river). In addition, low water shipping losses on the Waal would be reduced, since more water would be flowing on that river. In order to obtain an upper bound on the benefits that would accrue to shipping if the IJssel were canalized, we assumed that <u>all</u> shipping losses caused by low river depths on both the Waal and IJssel would be eliminated, and that there would be no additional shipping losses due to delays at the locks.

Using this definition, we show the shipping benefits from an IJssel canalization for the four external supply scenarios in Table 11.13. The upper bound on the expected annual benefits, although 16.6 Dflm, does not begin to match the annualized fixed cost of the tactic.

Table 11.13

BENEFITS AND COSTS (Dflm) OF CANALIZING THE IJSSEL RIVER
(High Sprinkler Intensity, with Waterboard Plans)

	External Supply Scenario				Expected Annual Benefits		Annualized Fixed Cost
Type of Benefit	DEX	1959	1943	1967	UB	LB	
Shipping	111.4	42.3	10.3	0.7	16.6	5.9	
Midwest	41.5	0.2	0.0	0.0	3.7	0.8	
Southern Delta	0.0	0.0	0.0	0.0	0.0	0.0	
Total	152.9	42.5	10.3	0.7	20.3	6.7	60.2

11.7.2. Benefits to the Midwest

In estimating the maximum benefits that an IJssel canalization would provide to agriculture in the Midwest, we assumed that the additional water flowing on the Waal would be sufficient to eliminate all agriculture salinity losses caused by the salt wedge. These benefits would be equivalent to those obtained from implementation of a Krimpenerwaardkanaal. They are shown in Table 11.13. The upper bound on the expected annual benefits is 3.7 Dflm.

11.7.3. Benefits to the Southern Delta

In order to maintain a fresh Zoommeer, extractions of water from the Haringvliet through the Volkerakdam will be necessary. The extractions are needed to provide fresh water for level control, sprinkling crops, and flushing the lake. During times of low flows on the Waal, the water needed for flushing the Zoommeer is also needed to fight the salt wedge. In most of our analysis, we used a policy for flushing the Zoommeer that reduced the amount flushed through the Volkerakdam whenever the salt wedge was approaching the inlet of the Hollandsche IJssel (see Sec. 3.6).

We assumed that with the IJssel canalized, no cutbacks in flushing of the Zoommeer would be required, and we used the Distribution Model to determine the reduction in salinity losses that would be obtained. It turned out that, even in DEX, the increases in Zoommeer salinity that resulted from the cutbacks in flushing were so small that agriculture salinity losses were not affected by the change in flushing policy. (The maximum difference in the average salinity of the lake in any decade was 9 ppm.) Therefore, the benefits to the Southern Delta from canalizing the IJssel River are negligible.

11.7.4. Conclusion

Table 11.13 contains estimates of the major benefits from an IJssel canalization that were derived under a set of very favorable assumptions (e.g., that all shipping losses caused by low depths on the Waal and IJssel would be eliminated). They overestimate the actual benefits that are likely to accrue from implementation of the tactic. There are also a number of disbenefits from implementation of the tactic (e.g., damage to the environment) that are not reflected in the table. Even so, the upper bound on expected annual benefits is considerably below the annualized fixed cost of an IJssel canalization with five weirs. (A canalization with three weirs would still have an annualized fixed cost that is about double the upper bound on expected annual benefits.) We, therefore, concluded that this is not a promising tactic.

11.8. SUMMARY OF CONCLUSIONS

In this chapter we evaluated tactics that affect the national distribution system. These include a number of ambitious and costly water management tactics that have been discussed in the Netherlands for many years. In general, we found the costly tactics to be unpromising, and found several relatively inexpensive tactics to be promising.

Specifically, we found that it would be worthwhile to change the rules for flushing the Markermeer. The new rules would cost nothing to implement, and would produce large benefits in very dry years. (In other years, they would produce the same amount of flushing as the current rules.) We also found that none of a large number of expensive proposed tactics for improving Flevoland's safety and reducing Markermeer salinity (including construction of a second Oostvaardersdijk) were promising from the water management point of view. There was no promising tactic for reducing the salinity of the Markermeer. Raising the Flevoland dikes was the only promising tactic for improving the safety of the polder, since it is the least expensive way of providing the required increase in protection.

In Sec. 11.4 we examined the need for increasing the storage capacity of the IJsselmeer and Markermeer, and evaluated a number of alternative ways of doing so. We showed that even in an extremely dry year cutbacks in flushing and open-air sprinkling could be avoided by increasing the usable depth of the lakes by 10 cm. If all of the regional tactics found to be promising in our screening analysis were implemented and flushing cutbacks were allowed, sprinkling cutbacks could be avoided by increasing the usable depth of the lakes by 9 cm (an additional 5 cm would be required to avoid flushing cutbacks). Construction of a Markerwaard reduces the storage capacity of the lakes somewhat, and requires that the usable depth of the remaining lakes be increased by an additional centimeter to achieve the same results possible with no Markerwaard.

The usable depth of the lakes can be increased by raising their summer target level, by decreasing their minimum level, and by constructing a reservoir within the Markermeer (we call the last possibility a "wet Markerwaard"). A comparison of the costs and benefits of the three alternatives shows that raising the summer target level of the lakes is promising and that the other two are not.

Given the fact that, even in the driest years, normal flows on the IJssel River should prove sufficient to allow the lakes to reach their increased target levels during the spring, we found that a North-South Connection used in the northward direction was unlikely to provide many additional benefits. The benefits of using the tactic in the southward direction, although somewhat higher than the northward benefits, fall far short of covering the costs of the tactic. A North-South Connection was, therefore, found to be unpromising.

Our consideration of alternative tactics for mitigating the problems associated with extracting water from the Waal at Tiel and transporting it to the Lek produced several promising tactics. The problem caused by the buildup of sedimentation in the Waal due to extractions could be solved by dredging away the sand that is precipitated during extraction. This is a very attractive tactic, since its cost is quite low and its benefits high.

The decrease in the depth of the Waal due to the extractions at Tiel could be solved by modifying the existing groins in the river around Tiel. This tactic would increase the depth of the Waal by between 10 and 20 cm. Its benefits in terms of reduced shipping losses are expected to outweigh its costs. It was therefore found to be promising.

We also found a promising combination of tactics that provide an alternative to extracting water at Tiel for use in the Midwest. If pumping capacity were added to the Merwedekanaal and a canal through the Lopikerwaard constructed, low water shipping losses on the Waal could be reduced and salinity losses due to the salt wedge practically eliminated. This combination of tactics, although promising, is dominated by a tactic that was discussed in Chap. 8: build a groin in the Nieuwe Waterweg.

Section 11.7 discusses one of the most costly of all the national tactics: canalization of the IJssel River. Although proposed many years ago and still under active consideration, we found that, even under optimistic assumptions, the benefits from this tactic do not come close to matching its cost. The tactic was therefore screened out.

NOTES

1. Sixty-five percent of the salt is brought in by the IJssel River, and 35 percent comes from other sources. Flevoland's discharges, therefore, account for about one-third of the salt not brought in by the IJssel.
2. We expect the losses to be of approximately equal magnitude because about half of the ships to or from Amsterdam pass through the Houtribsluizen. The ships affected by Tactic 6 are the ones that pass through the Houtribsluizen; the ones affected by Tactic 5 are the ones that do not.
3. The cost of raising the summer target level of the Markermeer that we used in our analysis assumes that a second Oostvaardersdijk has already been constructed (see Sec. 11.3). If this dike is not constructed, the cost of raising the summer target level of the Markermeer will be higher, because the levels of the IJmeer and the other border lakes would also be increased (there is currently an open connection between them and the Markermeer). An alternative to raising the summer target level of the Markermeer is to raise the summer target level of the IJsselmeer by enough to store the combined additional amount of water desired in the two lakes. This would increase the annualized investment

costs presented in Table 11.8 by about 1 Dflm. All tactics that we found to be promising would, therefore, remain promising. The costs presented in Table 11.8 for this tactic are somewhat less than those presented in the final PAWN briefing in December 1979 because more careful estimates of the costs were made subsequent to the briefing.

4. The costs for this tactic are different from those presented in the final PAWN briefing in December 1979 because more careful estimates of the costs were made subsequent to the briefing. The costs differ from those presented in Vol. XVI because we have omitted the cost of increasing the inlet capacity of the Margrietkanaal when the minimum level of the lakes is lowered. In the Distribution Model runs we made to analyze this tactic, surface water sprinkling never had to be cut back because of insufficient inlet capacity at the entrance to the Margrietkanaal.
5. The emergency level for flushing is increased from NAP - 30 cm in this case because we used Distribution Model runs that simulated a lowering of the minimum level of the lakes to estimate the benefits for both lowering the minimum level and raising the summer target level. For example, the results from a run that lowered the minimum level of the lakes to NAP - 45 cm with an emergency level for flushing of NAP - 30 cm were assumed to be the same as for raising the summer target level of the lakes to NAP - 15 cm with an emergency level for flushing of NAP - 25 cm. (See Table 3.1.)
6. We estimated the required increase in the summer target level by using Distribution Model runs in which no minimum level was placed on the lakes. The amount by which lake levels dropped below NAP - .40 m indicated the amount that the summer target level needed to be raised.
7. The promising regional tactics that have the greatest effect on the amount of water in the IJsselmeer and Markermeer are: (1) expand the throughput capacity of the Van Starkenborghkanaal (see Sec. 5.2.1), and (2) expand the supply capacity to the Northeast Highlands (see Sec. 6.2). The tactic that would redirect the discharges of the Wieringermeerpolder to the Waddenzee (see Sec. 7.3) would also reduce the amount of water in the lakes, but its effect would be minor, and it was not included in this analysis.
8. See Note No. 6.
9. See Note No. 5.
10. These estimates assume that the sedimentation that builds up in the Waal as a result of extracting at Tiel can be removed by dredging. If dredging at Tiel is not to be allowed, other measures will have to be taken to ameliorate the problem, which will increase the cost of the tactic (see Sec. 11.6).
11. This upper bound is found by subtracting the (negative) shipping and dredging benefits from the net benefits shown for Tactic 3 in Table 8.7.

12. This upper bound is conservative because it pertains to the SPRLO-RNONE demand scenario. The bound is higher in cases with SPRHI or RALL. These upper bounds are based on information contained in Ref. 11.3.
13. This analysis was not presented in the final PAWN briefing held in the Netherlands in December 1979.
14. This means, for example, that all of the increased shipping losses for the Midwest supply alternatives that are shown in Table 8.7 are caused by the drop in water level because of extracting at Tiel, and not by a buildup of sedimentation.
15. See Ref. 11.6 for a summary of the information contained in reports and notes on an IJssel canalization.
16. This aspect of the IJssel canalization is discussed in Ref. 11.7.

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Chapter 12

SUMMARY OF SCREENING RESULTS

12.1. PROMISING TACTICS

The previous eleven chapters of this volume have documented a methodology that was used to evaluate the potential usefulness of about 100 changes to the Dutch water management infrastructure and 65 plans for expanding the area eligible to be supplied with surface water. In this section we discuss those tactics that were found to be promising and draw some general conclusions. In the next section we discuss some changes in the models and assumptions that will cause some of our numbers to change and may cause some results to change.

As stated in Chap. 1 of this volume, our objective in the screening phase of the PAWN project was to identify a reasonably small number of tactics that seemed to be worthwhile to evaluate in greater detail out of the large number of potential tactics. We called these seemingly worthwhile tactics "promising."

In general, we found that there were relatively few tactics that were worth considering further under the low sprinkler intensity scenarios (SPRLO), which roughly correspond to the current pattern of sprinkling in the country. In addition, practically none were worth pursuing further unless the promising waterboard plans were also implemented. Thus, most of the tactics we identified as promising are promising only if the system is stressed by the high demands represented by the SPRHI-RALL demand scenario.

Included in our study were several large and very costly tactics, some of which had total investment costs of well over 200 Dflm (e.g., building a North-South Connection, canalizing the IJssel River, and constructing a second Oostvaardersdijk). We found only one such expensive tactic to be promising--construction of a pipeline from the Maas to Delfland, which had an investment cost of over 400 Dflm. All the other promising tactics had investment costs of less than 80 Dflm, and most were considerably below this amount.

The large and costly tactics were generally those that affect a number of regions (i.e., national tactics). Except for a few very inexpensive national tactics, most of the promising tactics primarily affect a single region. This suggests that the national water management infrastructure is functioning rather well, and that the attention of the RWS in the future should be focused more on regional water management problems.

In most instances there were several alternative ways of solving a given water management problem. For example, there were five alternatives evaluated for expanding the supply capacity to the Northeast Highlands. Sometimes more than one of these alternatives was found to be promising. However, in every case we were able to identify one of the alternatives as dominant--i.e., more attractive than the other promising alternatives for some reason (usually because it had a higher benefit/cost ratio). In the following subsections, we present the promising tactics for each of the demand scenarios.

12.1.1. Dominant Promising Tactics

12.1.1.1. Dominant Promising Tactics Independent of Demand Scenario. A few tactics are promising candidates no matter what the demand scenario. For example, it would clearly be worthwhile to follow up on the 46 waterboard plans that were identified as promising in the pre-screening analysis described in Sec. 4.1. We found that in both the low sprinkler intensity scenarios (SPRLO) and the high sprinkler intensity scenarios (SPRHI) implementation of the promising waterboard plans would produce significant net benefits, and that the benefits increase as the sprinkler intensity increases. We also showed in Sec. 9.2 that making the Zoommeer fresh is likely to lead to large agricultural benefits no matter what demand scenario is assumed.

Our analysis of technical and managerial tactics identified six that deserve to be explored in more detail no matter which of our four demand scenarios is assumed for the future. The six, which are listed in Table 12.1, are:

- Redirect Wieringermeerpolder discharges to the Waddenzee. This tactic would reduce the salinity of the surface water supplied to farmers in the Anna Paulowna polder (District 32) by between 350 and 600 ppm.
- Construct a groin in the Nieuwe Waterweg. This tactic would eliminate approximately 75 percent of the agriculture salinity losses in the Midwest that are caused by the salt wedge.
- Use portable pumps during periods of low flow on the Julianakanaal to recycle water at the Maasbracht lock. This tactic has already been implemented by the RWS.
- Change policy for flushing the Markermeer. The new policy will reduce spring flushing in very dry years, leading to only small increases in salinity losses while reducing shortage losses considerably.
- Raise Flevoland dike. This tactic was found to be the least expensive and most worthwhile way to provide Flevoland with adequate safety from flooding.
- Dredge in Waal below Tiel. This is a very low cost way to reduce low water shipping losses due to sedimentation in the Waal caused by extractions at Tiel.

These six tactics include two that are aimed at reducing agriculture salinity losses (redirect Wieringermeerpolder discharges and construct a groin in the Nieuwe Waterweg); one that will help reduce agriculture shortage losses (change the policy for flushing the Markermeer); two

Table 12.1

DOMINANT PROMISING TACTICS UNDER ANY DEMAND SCENARIO
(Costs in Dflm)

Region	Sec. Ref.	Description	Capacity (m^3/s)	Annualized Fixed Cost
4	7.3	Redirect Wieringermeerpolder discharges (a)	(b)	1.4
5	8.2	Groin in Nieuwe Waterweg (a)	(b)	0.7
8	10.3	Portable pumping at Maasbracht	5.0	0.1
Nat'l	11.2	Change policy for flushing Markermeer	(b)	0.0
Nat'l	11.3	Raise Flevoland dike	(b)	5.3
Nat'l	11.6	Dredge in Waal below Tiel	(b)	(b)

(a) Benefits from these tactics for SPRLO scenarios need further investigation, but the tactics are believed to be promising for these scenarios.

(b) Not applicable.

that will reduce low water shipping losses (maintain a portable pumping capacity at Maasbracht and dredge in the Waal below Tiel); and one that is designed to reduce the chance of flooding (raise the Flevoland dike). The last-mentioned tactic is the most costly of the six, having an annualized fixed cost of 5.3 Dflm. The annualized fixed cost of the other five combined is only 2.2 Dflm.

It should be pointed out that we analyzed the Wieringermeerpolder and Nieuwe Waterweg tactics only for the high sprinkler intensity scenarios. However, our analysis of other tactics under the low sprinkler intensity scenarios leads us to believe that these two tactics are promising for the low sprinkler intensity scenarios as well.

12.1.1.2. Dominant Promising Tactics for Scenario with Low Sprinkler Intensity and Promising Waterboard Plans. As shown in Sec. 4.2, the preventable shortage losses under the low sprinkler intensity demand scenarios are very small. Without implementation of the promising waterboard plans, we found no promising tactics (aside from those mentioned in the preceding subsection). Since the SPRLO-RNONE scenario was designed to be reasonably close to the current demand situation (or at least that existing in 1976), our analysis suggests that if only small increases in demand are expected in the future, only the tactics listed in Table 12.1 may be desirable.

Even if the promising waterboard plans are implemented, if the intensity of sprinkling in the areas that are able to be supplied with surface water remains low (an average of about 22 percent of the eligible area has sprinkler equipment installed in the SPRLO scenarios), the existing infrastructure should be able to satisfy most of the demands for water for surface water sprinkling (see Table 4.6).

There are two exceptions to this general conclusion. If the promising waterboard plans are implemented, the preventable shortage losses in the Southeast Highlands are high enough to justify a change in the infrastructure even with a low sprinkler intensity. In Sec. 10.2.3.2 we showed that the following tactic was promising for the SPRLO-RALL demand scenario: Increase the throughput capacity along the Zuid-Willemsvaart between Lozen and Nederweert to 9 m^3/s and expand the syphon capacity to the Noordervaart by 5 m^3/s. This tactic would increase the supply capacity to the Southeast Highlands by 5 m^3/s. It would primarily increase the water available to the farmers in the Peel area. Although it would eliminate only about 14 percent of the preventable losses in the region, its cost is low enough to make it worthwhile considering (see Table 12.2).

In addition, the annualized fixed cost of building an inlet in the Grevelingendam to make the Grevelingen fresh, and implementing a waterboard plan to enable the fresh water in the Grevelingen to be used by farmers, is less than the lower bound on expected annual benefits from the tactic.

Table 12.2

DOMINANT PROMISING TACTICS FOR SPRLO-RALL DEMAND SCENARIO
(Costs and Benefits in Dflm)

Region	Sec. Ref.	Description	Additional Capacity (m^3/s)	Annualized Fixed Cost	Expected Annual Benefits (UB)
7	9.3	Create fresh Grevelingen	(a)	0.7	3.2
8	10.2	Increase throughput capacity on Lozen-Nederweert section of Zuid-Willemsvaart and expand syphon capacity to Noordervaart	5	0.2	0.5

(a) Not applicable.

12.1.1.3. Dominant Promising Tactics for Scenario with High Sprinkler Intensity and No Waterboard Plans. If farmers expand their sprinkler capacity to enable them to sprinkle whenever the expected benefits outweigh the expected costs, the demand for surface water during dry periods will increase significantly. These increased demands will exceed the capacity of the existing water management infrastructure to a much greater extent than in the low sprinkler intensity situation, leading to high preventable shortage losses in some parts of the country. These high losses make the implementation of water management tactics more worthwhile than in the low sprinkler intensity case.

Even without the implementation of the promising waterboard plans, an increase in the sprinkler intensity in the areas currently eligible to receive surface water would add three tactics to the list in Table

12.1. All three tactics (which are listed in Table 12.3) would expand the capacity of the water distribution system to supply surface water to farmers in various regions of the country (primarily in the highlands). The three tactics are:

- Expand throughput capacity of Van Starkenborghkanaal at Gaarkeuken by 9 m^3/s. This tactic would primarily increase the water available to farmers in the province of Groningen, eliminating almost 80 percent of the preventable shortage losses they might experience in an extremely dry year.
- Expand the supply capacity to the Northeast Highlands by expanding the capacity of the Twenthekanaal route by 10 m^3/s. This tactic would primarily increase the water available to farmers in Drenthe. It would eliminate almost 80 percent of the preventable losses in the region in an extremely dry year.
- Increase the throughput capacity on the Lozen-Nederweert section of the Zuid-Willemsvaart to 9 m^3/s and expand the syphon capacity to the Noordervaart by 5 m^3/s. This tactic would increase the supply capacity to the Southeast Highlands by 5 m^3/s. It would primarily increase the water available to the farmers in the Peel area of the region.

The combined annualized fixed cost of the three tactics is 2.5 Dflm, while the upper bound on their expected annual benefits is 7.3 Dflm.

Table 12.3

DOMINANT PROMISING TACTICS FOR SPRHI-RNONE DEMAND SCENARIO
(Costs and Benefits in Dflm)

Region	Sec. Ref.	Description	Additional Capacity (m^3/s)	Annualized Fixed Cost	Expected Annual Benefits (UB)
1	5.2	Expand throughput capacity of Van Starkenborghkanaal	9	0.6	1.0
2	6.2	Expand supply capacity of Twenthekanaal route	10	1.7	6.0
8	10.2	Increase throughput capacity on Lozen-Nederweert section of Zuid-Willemsvaart and expand syphon capacity to Noordervaart	5	0.2	0.3

12.1.1.4. Dominant Promising Tactics for Scenario with High Sprinkler Intensity and Promising Waterboard Plans. The SPRHI-RALL scenario was used in our analysis to produce the highest demands for surface water that can reasonably be expected in the future. Nationwide, this scenario represents a tripling of the percentage of cultivated area that has sprinkling equipment compared with the SPRLO-RNONE scenario (from 9.8 percent to 31.1 percent--see Tables 2.5a and 2.5b), and a doubling of the demands for extractions from the national surface water distribution network in the driest decade of an extremely dry year (from 210.3 m^3/s to 419.0 m^3/s--see Tables 11.1-11.3).

The existing surface water distribution network--especially within the various regions--does not have adequate capacity to meet the high demands that would occur in dry periods. As a result, the preventable agriculture shortage losses are very high, and considerable benefits could be realized from implementation of tactics.

In particular, we identified eight dominant promising tactics for this scenario that merited further investigation and more detailed analysis. These tactics, which are listed in Table 12.4, are:

- Expand throughput capacity of Van Starkenborghkanaal by 9 m^3/s. This tactic would provide additional surface water to farmers in the province of Groningen, eliminating about 60 percent of their preventable losses in an extremely dry year.
- Expand the supply capacity to the Northeast Highlands by expanding the capacity of the Twenthekanaal route by 15 m^3/s. This tactic would primarily increase the water available to farmers in Drenthe. It would eliminate almost 80 percent of the preventable agriculture shortage losses in the region in an extremely dry year.
- Build a water supply pipeline from the Maas to Delfland. This tactic would enable up to 8 m^3/s of Maas-salinity water to be transported to Delfland, producing a significant decrease in agriculture salinity losses. The cost for the tactic shown in Table 12.4 is for the three-pipeline alternative, which is thought to be the more practical design.
- Expand throughput capacity of the Rijn-Schiekanaal at Leidschendam by 12 m^3/s. This tactic would practically eliminate the agriculture shortage losses in Delfland. If this tactic and the Delfland pipeline were both implemented, the capacity of this tactic might be able to be reduced somewhat.
- Create fresh Grevelingen. The benefits from this tactic are almost twice as great as they are under the SPRLO-RALL scenario. In this case, the lower bound on expected annual benefits is almost three times the annualized fixed cost of building an inlet in the Grevelingendam and implementing the waterboard plan that would enable farmers to use the water in the Grevelingen.
- Increase the throughput capacity on the Lozen-Nederweert section of the Zuid-Willemsvaart to 9 m^3/s, expand the syphon capacity to the Noordervaart by 5 m^3/s, and increase the pumping capacity at Panheel by 10 m^3/s. This tactic would

increase the supply capacity to the Southeast Highlands by 15 m³/s. It would reduce the preventable losses in the region in an extremely dry year by almost 75 percent.

- Increase the summer target level of the IJsselmeer and Markermeer to NAP - 0.10 m. This increase in the summer target level of the lakes is sufficient to avoid all cutbacks in open-air surface water sprinkling without cutbacks in flushing, even in an extremely dry year. If all promising tactics are implemented, this increase in the summer target level will be sufficient to avoid cutbacks in sprinkling if the emergency level for flushing is set at NAP - 0.20 m.[1]
- Modify groins around Tiel. Under the SPRHI-RALL scenario, large extractions into the Amsterdam-Rijnkanaal are made from the Waal at Tiel. This tactic would increase the depth of the Waal around Tiel by between 10 cm and 20 cm, thereby eliminating most of the low water shipping losses that would be caused by these extractions.

Table 12.4

DOMINANT PROMISING TACTICS FOR SPRHI-RALL DEMAND SCENARIO
(Costs and Benefits in Dflm)

Region	Sec. Ref.	Description	Additional Capacity (m^3/s)	Annualized Fixed Cost	Expected Annual Benefits (UB)
1	5.2	Expand throughput capacity of Van Starkenborghkanaal	9	0.6	2.0
2	6.2	Expand supply capacity of Twenthekanaal route	15	2.0	15.6
5	8.3	Build pipeline from Maas to Delfland	8	37.9(a)	48.8
5	8.3	Expand throughput capacity at Leidschendam	12	0.7	2.0
7	9.3	Create fresh Grevelingen	(b)	0.7	5.6
8	10.2	Increase throughput capacity on Lozen-Nederweert section of Zuid-Willemsvaart, expand syphon capacity to Noordervaart, and increase pumping capacity at Panheel	15(c)	2.1(d)	22.7
Nat'l	11.4	Increase summer target level of IJsselmeer and Markermeer	-0.10(e)	3.4	8.5(f)
Nat'l	11.6	Modify groins around Tiel	(b)	1.2	1.9(g)

(a) Cost for three-pipeline alternative, which includes expected annual pumping cost.

(b) Not applicable.

(c) Increase in supply capacity to the Southeast Highlands.

(d) Cost under the minimum shipping improvement scenario.

(e) Lake levels in meters relative to NAP. This increase assumes that promising regional tactics will be implemented. If not, levels need be raised only to NAP - 0.15 m.

(f) Benefits for situation with promising regional tactics implemented.

(g) Benefits assuming an increase of 10 cm in depth of Waal below Tiel.

These eight tactics include six that are aimed at reducing agriculture shortage losses, one that will help reduce agriculture salinity losses (the Delfland pipeline), and one that will reduce low water shipping losses (modify the groins around Tiel).

Of these eight tactics, seven are relatively inexpensive, having an annualized fixed cost of at most 3.5 Dflm. (The remaining tactic--the Delfland pipeline--has an annualized fixed cost of 37.9 Dflm, which includes the expected energy cost.) The combined annualized fixed cost of all eight tactics is 48.6 Dflm, while the upper bound on their expected annual benefits is 107.1 Dflm.

12.1.2. Additional Promising Tactics

Many of the Netherlands' water management problems have alternative solutions. Often, one of the alternative solutions is promising, and all others can be screened out because the costs of the alternatives outweigh the expected benefits. However, in a few instances--especially under the SPRHI-RALL scenario, in which the preventable losses are very high--several of the alternatives are promising. In each of these instances, we were able to identify one of the alternatives as the best choice. These "dominant" promising tactics were presented in Sec. 12.1.1 for each demand scenario. In this section we discuss the tactics that were found to be promising but are dominated by some other tactic or tactics.

There are no additional promising tactics for either of the demand scenarios with a low sprinkler intensity (SPRLO-RNONE or SPRLO-RALL). The following two subsections identify the additional promising tactics for the demand scenarios with a high sprinkler intensity.

12.1.2.1. Additional Promising Tactics for Scenario with High Sprinkler Intensity and No Waterboard Plans. Under the SPRHI-RNONE demand scenario there is only one water management problem that has more than one promising tactic as a possible solution. The problem is that there is insufficient supply capacity to the Northeast Highlands. In Sec. 6.2 we discussed five alternative routes for bringing more surface water to the region. The Twenthekanaal route (Route 1) was found to be the dominant promising alternative for this demand scenario. However, the other four alternative routes were also found to be promising (see Table 12.5).

The Twenthekanaal route was chosen over the other routes because it has the highest net expected annual benefits (upper bound on expected annual benefits less annualized fixed cost). However, it has several disadvantages. Its primary disadvantage is its length. Water destined for farms in Drenthe would have to travel through waterways under the authority of different jurisdictions before reaching Drenthe. (This is also true of the Van Starkenborghkanaal route.) It also extracts its water from the IJssel River, thereby increasing shipping losses during periods of low flow on the river.[2] Thus, when other considerations are taken into account, one of the four alternatives to the Twenthekanaal route (or some combination of two or more of the five alternative routes) might be found to be more attractive.

Table 12.5

ADDITIONAL PROMISING TACTICS FOR SPRHI-RNONE SCENARIO
(Costs and Benefits in Dflm)

Region	Sec. Ref.	Description	Increase in Supply Capacity to NE Highlands (m^3/s)	Annualized Fixed Cost	Expected Annual Benefits (UB)
2	6.2	Expand supply capacity of Hoogeveensche Vaart route	10	3.2	6.3
		Expand supply capacity of Van Starkenborghkanaal route	10	3.6	6.3(a)
		Expand supply capacity of Drentsche Hoofdvaart route	10	5.0	6.3(a)
		Expand supply capacity of Overijsselsche Vecht route	10	5.0	6.0(b)

(a) The expected annual benefits from this tactic are assumed to be approximately the same as for the Hoogeveensche Vaart route.

(b) The expected annual benefits from this tactic are assumed to be approximately the same as for the Twenthekanaal route.

12.1.2.2. Additional Promising Tactics for Scenario with High Sprinkler Intensity and Promising Waterboard Plans. The nationwide preventable losses expected under the SPRHI-RALL scenario are about 3 times as large as they are under the SPRHI-RNONE scenario, and about 20 times as large as they are under the SPRLO-RNONE scenario (see Table 4.6). As a result, we found a large number of promising tactics for this scenario. Some of them are alternatives to the dominant promising tactics discussed in Sec. 12.1.1.4. These tactics, which are listed in Table 12.6, are:

- The four alternatives to the Twenthekanaal route for expanding the supply capacity to the Northeast Highlands (see Sec. 12.1.2.1). For this demand scenario the supply capacity is increased by 15 m^3/s, instead of 10 m^3/s. Note that the annualized fixed cost for the Van Starkenborghkanaal route given in Table 12.6 is an underestimate, since it does not include the cost of expanding the throughput capacity of the Prinses Margrietkanaal.

- Close the Spui with a dam and ship lock. This tactic has a low annualized fixed cost. If it were reasonably successful in preventing the salt wedge from reaching the Gouda inlet (e.g., as successful as a groin in the Nieuwe Waterweg), it would be a promising tactic. We did not have enough time in our study to modify the Distribution Model so that it could be used to evaluate this tactic. Further investigation of the tactic appears to be warranted.
- Construct bubble screen in Nieuwe Waterweg. This tactic eliminates approximately 75 percent of the salinity losses in the Midwest due to the salt wedge, but is dominated by the construction of a groin in the Nieuwe Waterweg.
- Expand the supply capacity of the Merwedekanaal and build a Lopikerwaardkanaal. This tactic, although promising for this demand scenario, is dominated by the tactic to build a groin in the Nieuwe Waterweg.
- Three alternatives for expanding the supply capacity to the Southeast Highlands. These three tactics (numbered 5, 6, and 7 in Sec. 10.2.3.4), are dominated by the tactic that would increase the throughput capacity on the Lozen-Nederweert section of the Zuid-Willemsvaart, expand the syphon capacity to the Noordervaart, and increase the pumping capacity at Panheel (see Table 12.4).
- Increase the portable pumping capacity at Maasbracht to 10 m^3/s from the existing 5 m^3/s. This tactic was found to be promising only for the 1985 shipping fleet and goods scenario.
- Decrease the minimum level of the IJsselmmer and Markermeer to NAP - 0.50 m. This decrease in the minimum level of the lakes is sufficient to avoid all cutbacks in open-air surface water sprinkling without cutbacks in flushing, even in an extremely dry year. If all promising tactics are implemented, this decrease in minimum level will be sufficient to avoid cutbacks in sprinkling if the emergency level for flushing is set at NAP - 0.20 m.

12.1.2.3. MAXTACS. In summarizing the results of screening at the final PAWN briefing, we presented a list of 9 dominant promising tactics for the SPRHI-RALL demand scenario. These 9 "most promising tactics" were labeled MAXTACS. In the impact assessment stage of PAWN, these tactics were evaluated in terms of a large number of impact measures.

Information brought to our attention after the final briefing (such as updated cost estimates and more information regarding a tactic's specifications) produced changes in this set of tactics, resulting in the 14 dominant promising tactics for the SPRHI-RALL scenario presented in Secs. 12.1.1.1 and 12.1.1.4. For completeness in the reporting of screening results, and for consistency among the various volumes of PAWN documentation, the original set of MAXTACS are listed in Table 12.7.

Table 12.6

ADDITIONAL PROMISING TACTICS FOR SPRH1-RALL SCENARIO
(Costs and Benefits in Dflm)

Region	Sec. Ref.	Description	Additional Capacity (m^3/s)	Annualized Fixed Cost	Expected Annual Benefits (UB)
2	6.2	Expand supply capacity of Hoogeveensche Vaart route	15	4.4	16.7
		Expand supply capacity of Van Starkenborghkanaal route	15	5.1(a)	16.7(b)
		Expand supply capacity of Drentsche Hoofdvaart route	15	6.2	16.7(b)
		Expand supply capacity of Overijsselsche Vecht route	15	6.7	15.6(c)
5	8.2	Close Spui	(d)	2.0	(e)
	11.6	Expand supply capacity of Merwedekanaal and build a Lopikerwaardkanaal	20(f)	3.2	3.9
8	10.2	Increase throughput capacity on Lozen-Nederweert section of Zuid-Willemsvaart, expand syphon capacity to Noordervaart, increase pumping capacity at Panheel, and build pumping stations along Wilhelminakanaal	15(g)	7.1(h)	25.6
		Pump Roer water to Panheel, increase pumping capacity at Panheel, and build pumping station at Noordervaart	15(g)	4.8(h)	24.9
		Build pumping stations along Wilhelminakanaal	15(g)	5.8(h)	19.2
	10.3	Increase portable pumping capacity at Maasbracht	5	0.3	0.6(i)
	11.4	Decrease minimum level of IJsselmeer and Markermeer	-0.50(j)	3.7	8.5(k)

(a) This excludes the cost of expanding the carrying capacity of the Prinses Margrietkanaal. It therefore is an underestimate of the true cost of the tactic.

(b) The expected annual benefits from this tactic are assumed to be approximately the same as for the Hoogeveensche Vaart route.

(c) The expected annual benefits from this tactic are assumed to be approximately the same as for the Twenthekanaal route.

(d) Not applicable.

(e) We are not sure whether this tactic is indeed promising. Additional analysis is needed to determine its benefits.

(f) Increase in supply capacity to the Midwest.

(g) Increase in supply capacity to the Southeast Highlands.

(h) Cost under the minimum shipping improvement scenario.

(i) Under the 1985 shipping fleet and goods scenario.

(j) Lake levels in meters relative to NAP. Decreasing the lake levels to NAP - 0.50 m is needed only if the promising regional tactics are implemented. Otherwise, a decrease to NAP - 0.45 m is sufficient.

(k) Benefits for situation with promising regional tactics implemented.

Table 12.7

Tactics in MAXTACS

Region	Sec. Ref.	Description	Additional Capacity (m^3/s)
1	5.2	Expand throughput capacity of Van Starkenborghkanaal	9
2	6.2	Expand supply capacity of Twenthekanaal route	15
5	8.2	Construct groin in Nieuwe Waterweg	(a)
5	8.3	Build pipeline from Maas to Delfland	8
7	9.3	Create fresh Grevelingen	(a)
8	10.2	Increase throughput capacity on Lozen-Nederweert section of Zuid-Willemsvaart, expand syphon capacity to Noordervaart, increase pumping capacity at Panheel, and build pumping stations along Wilhelminakanaal	15(b)
8	10.3	Portable pumping at Maasbracht	5.0(c)
Nat'l	11.2	Change policy for flushing Markermeer	(a)
Nat'l	11.4	Decrease minimum level of IJsselmeer and Markermeer	-0.50(d)

(a) Not applicable.
(b) Increase in supply capacity to the Southeast Highlands.
(c) Current capacity.
(d) Lake levels in meters relative to NAP.

12.2. QUALIFICATIONS ON RESULTS

Thus far, this volume has described the results presented at the final PAWN briefing held in the Netherlands on December 11 and 12, 1979, except for a few changes explicitly noted. Here we shall discuss some qualifications on the results, and indicate the origin of these qualifications.

As the scheduled date for the final briefing on the project drew close, it became clear that the project could not accomplish everything desired in the time remaining. Facing this situation, Rand and the RWS jointly decided not to postpone the briefing. The main reason for this decision was their common view that they would face a similar situation even if they waited for six months, because as the understanding of the problem grew, so did the amount of analysis that seemed desirable. Another reason was that the RWS wished to keep their promised schedule for informing the interested organizations and institutions in the Netherlands about the PAWN methodology and the many significant, albeit tentative, results that had already been produced by the project.

Rand and the RWS recognized that this decision would create difficulties for the final briefing; for example, there would be insufficient time to perform all the desired analysis or to fully check the results for the analysis that had already been completed. However, it was anticipated that most of these difficulties would be remedied soon, i.e., when the RWS used the PAWN methodology, transferred from Rand after the ongoing analysis was concluded, to perform its own extensive analysis in support of the Nota Waterhuishouding, the national policy document on water management.

For Rand, the presentation of the final briefing in December 1979 marked the beginning of the documentation phase of the project and the end of the analysis phase. In the documentation phase, Rand's contractual obligation was to produce publications describing the methodology and the tentative results it had developed previously and had presented in the final briefing. This meant that the difficulties created by the decision not to postpone the briefing would be perpetuated in the Rand publications. Thus, the results presented in this volume are subject to a number of qualifications.

These qualifications arise from three kinds of conditions:

- Where we knew about the difficulty but we lacked sufficient time to do something about it.
- Where we did not learn about the difficulty until after the final briefing.
- Where we inadvertently made an error in data specification or modeling.

In the remainder of this section, we shall identify several significant difficulties that have been found in the data and models used in our analysis, and indicate what they seem to imply for our results.

12.2.1. Basic Drainage

Most of the rain falling on land in the highlands reaches the groundwater table, where it flows from places with higher groundwater levels to places with lower groundwater levels, and eventually ends in brooks or small rivers. We use the term basic drainage to refer to the phenomenon of water flowing out of the groundwater table and into waterways as a result of gravitational forces.

When we compared the flows predicted by our models with measured flows for a number of small rivers in the highlands, we found two serious discrepancies:

- The calculated annual flows were larger than the measured ones.
- The variation in the calculated discharges over the year was not as great as the variation in the measured ones--winter discharges were generally too low and summer discharges too high.

For example, for the current demand situation (SPRLO-RNONE) with no tactics implemented, our models showed a surplus of surface water in various areas of the highlands in DEX, while, in reality, deficits had occurred in 1976, and transport of water from outside these areas was needed to avoid large agriculture losses.

Changes were made to the models to try to correct these problems, but the versions of the models we used in screening still produced flows that were generally too high in the summer and too low in the winter. As a result, we have tended to underestimate the shortage losses that would occur in the highlands without implementation of tactics, which leads to underestimates of the potential benefits from tactics. (The estimated shortage losses with tactics implemented are approximately correct, however, since they generally eliminate almost all preventable losses in the area they affect.) This means that any tactics we found promising for reducing shortage losses in the highlands (e.g., the various tactics for increasing the supply of water to the Northeast Highlands) are likely to be even more worthwhile than we show; it also means that there may be other promising tactics that were not considered in our analysis or were screened out.

Another problem that results from overestimating basic drainage in the summer is that we overestimate the amount of water in the rivers that receive the drainage. This will generally have little or no effect on our results, because there would usually be more than enough water in these rivers to meet the desired extractions without the extra discharges. However, in Chap. 10, the most attractive tactic for increasing the supply of water to the Southeast Highlands under the SPRHI-RALL scenario includes the elementary tactic that would increase the throughput capacity at Panheel (see Sec. 10.2.1.5), but not the one that would bring Roer water to Panheel (see Sec. 10.2.2.1). Because of the drainage of water into the Maas above Panheel, there was generally sufficient water in the Maas at Panheel to meet the desired extractions into the Wessem-Nederweertkanaal. If the basic drainage were actually less, the Roer tactic might be needed to provide the desired water at Panheel. Thus, it might prove to be more attractive than we found.

12.2.2. Groundwater Scenarios

In order to minimize the sources of variation in benefits from tactics and to minimize the number of different scenarios that had to be considered, all of the screening analysis was performed using a single scenario for groundwater extractions by agriculture. The scenario used corresponds closely to the demands for groundwater currently experienced in the Netherlands.

The sensitivity of the results of the screening analysis to changes in the use of groundwater by agriculture was examined in the impact assessment stage of the PAWN study. In that stage three groundwater sprinkler scenarios were used:

- Low, which approximates the current amount of groundwater sprinkler equipment.
- High, which assumes that farmers purchase substantially more groundwater sprinkler equipment to maximize their expected net benefits. This is the assumption that was used in developing the SPRHI surface water sprinkler scenarios (see Sec. 2.2.1.2).
- Medium, which assumes that the amount of groundwater sprinkler equipment is midway between the low and high scenarios.

It might have been more realistic to perform the screening analysis using the low groundwater sprinkler scenario whenever SPRLO was used as the surface water sprinkler intensity (as was done), but using the high groundwater sprinkler scenario whenever SPRHI was used. This would have led to higher groundwater extractions, lower groundwater levels, and less basic drainage. As a result, we would have obtained higher shortage losses in situations with no tactics implemented, but little or no change in shortage losses for situations with tactics. Thus, one could argue that our use of a single groundwater scenario has caused us to underestimate the potential benefits of tactics in areas where groundwater extractions for agriculture take place. As pointed out in the preceding subsection, such underestimates of potential benefits from tactics make the tactics we found promising even more attractive.

12.2.3. Losses in Friesland and Groningen

Well after the final briefing, we were told that the inlet capacity from the IJsselmeer into the Margrietkanaal (which is the first part of the supply route for practically all of Region 1) was significantly smaller than what we had earlier been given by the Rijkswaterstaat for our analysis. The inlet capacity varies, depending on the level of the IJsselmeer. Table 12.8 presents both the inlet capacity function that we used in our analysis and the function that was given to us by the Rijkswaterstaat in August 1980.

Table 12.8

INLET CAPACITY OF MARGRIETKANAAL AS FUNCTION OF IJSSELMEER LEVEL (m^3/s)

Level of IJsselmeer (m relative to NAP)	Old Function	New Function
+0.10	0.0	69.0
0.0	69.0	93.0
-0.10	139.0	105.0
-0.20	129.0	97.0
-0.30	115.0	89.0
-0.40	98.0	53.0
-0.50	0.0	0.0

As the table shows, for IJsselmeer levels in the range of our interest (NAP - 0.10 m and below), significantly less water can be transported to Friesland and Groningen than we assumed in our analysis. Thus, we have underestimated the agriculture shortage losses in the North. The fact that, during dry periods, the inlet capacity may be much less than what is needed to supply the region's needs implies that a tactic to expand the capacity might prove to be promising. However, if such an expansion were not promising, less water would be extracted from the IJsselmeer than we projected. In this case, our estimate of the increase in the summer target level of the lakes that would be desirable (see Sec. 11.4) is higher than would be necessary. Our conclusion that some increase in the summer target level of the lakes is promising would probably not change, given the low costs of relatively small increases in the target level.

12.2.4. Sprinkling Cutbacks in Groningen

Agriculture Districts 6, 7, and 8 are in the southeastern part of Groningen. Most of the surface water used by these districts first passes by a complex of power plants on the Oude Winschoterdiep and serves to cool their discharges. The original version of the Distribution Model required a minimum flow of 10 m^3/s past these power plants. Since, in all our demand scenarios, this flow is greater than the maximum desired extractions of the districts that are located past the power plants, no provision was made in the model for cutting back on the extractions of those districts.

In an analysis of power plants and their need for cooling water that was carried out as part of the PAWN study (see Vol. XV), it was discovered that the power plants on the Oude Winschoterdiep (Hunze and Helpman) were relatively inefficient. A strategy for closing down inefficient power plants and transferring their loads to more efficient power plants during dry periods was developed. The strategy was designed to reduce demands for cooling water, thereby potentially making more water available for agriculture.

Implementation of the strategy in the Distribution Model involved, among other things, reducing the minimum flow of water past the Hunze and Helpman power plants to 2 m^3/s whenever the IJsselmeer reached its emergency level for flushing. However, no change was made in the cutback rules for Districts 6, 7, and 8. They would still receive their desired extractions, even when the IJsselmeer was below its emergency level for sprinkling and other districts using IJsselmeer water were receiving less than their desired amounts.

This error in the model means that we underestimated the agriculture shortage losses in Groningen. It also means that we underestimated the benefits from raising the summer target level of the lakes.

12.2.5. Analysis of Tactic To Expand the Throughput Capacity of the Van Starkenborghkanaal

Since each run of the Distribution Model cost over $100, we attempted to learn as much as possible from each run. The runs made with the throughput capacity of the Van Starkenborghkanaal expanded by 9 m^3/s (see Sec. 5.2.1) also had the capacity of the Twenthekanaal route expanded by 15 m^3/s (see Sec. 6.2). At the time, we felt that the benefits from each of the tactics could be easily identified, since we believed there were no districts that could obtain water from both sources.

In fact, our belief was correct. No farm in the North or the Northeast Highlands can currently obtain water that is transported along more than one of the two paths. However, portions of Districts 8 and 9 obtain their water via the Van Starkenborghkanaal, and other portions obtain their water via Smilde in the Northeast Highlands (see Fig. 5.2).

This situation is represented incorrectly in the Distribution Model, which allows water entering each district along either path to be used anywhere in the district. This modeling error by itself makes it difficult to assess the benefits from implementing any tactic that increases the supply capacity to Districts 8 or 9. Using a single Distribution Model run to accurately evaluate two such tactics is almost impossible.

Subsequent analysis of the Van Starkenborghkanaal tactic by the Rijkswaterstaat indicates that about half of the reduction in agriculture shortage losses in Districts 8 and 9 that we ascribed to the Van Starkenborghkanaal tactic was actually derived from the increased supply of water along the Twenthekanaal route. It still appears that the Van Starkenborghkanaal tactic is promising, but it is likely to be less attractive than our analysis would indicate.

12.2.6. Salinity of Midwest Boezems

Every run of the Distribution Model (DM) makes repeated use of the District Hydrologic and Agriculture Model (DISTAG) as a subroutine to compute water demands by agriculture and to calculate agriculture salinity and shortage losses.[3] Generally, the DM calculates the water flows and salinities in the lakes and waterways that comprise the national and regional distribution systems of the Netherlands, while the DISTAG calculates the salinities of the open water in the districts. A district's open water includes the water in its ditches and the water in its boezems.

In some lowlands districts, particularly in the Midwest, the water volumes of the boezems were attached to nodes in the DM network. This was done because these boezems were actually waterways in the regional distribution systems, so the salt being transported by water passing through the nodes was also passing through the boezems. When the water in these boezems was added to the DM, it should have been subtracted from the open water for the corresponding district in the DISTAG. However, this was not done.

As a result, the salinity of the water sprinkled on the crops in these districts is underestimated, producing agriculture salinity losses that are too low. This means that we have underestimated the benefits that can be derived from tactics designed to reduce the agriculture salinity losses in the Midwest (see Sec. 8.2). The tactics that we found to be promising should be even more attractive, and some of the tactics that were screened out may, in fact, be promising.

12.2.7 Estimating Expected Benefits from Tactics for Combatting Salt Wedge Salinity Losses

To estimate expected annual benefits from tactics, we calculated a weighted average of the benefits for several specific years (DEX, 1959, etc.). The agriculture losses in any given year were estimated using the Distribution Model. A dataset was used to define the salinities of the country's waterways and of the root zones of the plants in the various agricultural districts at the beginning of the year being simulated. The same "initial conditions" were used in every run. They approximate the salinities that would be found at the end of an "average" year.

An important question has been raised concerning this methodology: Are we not underestimating the expected annual benefits from tactics by considering only the salinity losses in the scenario years, and not the losses in future years caused by salt deposited in a scenario year? In particular, the salinity losses in the Midwest in the year following one in which the salt wedge reached the mouth of the Hollandsche IJssel are higher than they otherwise would be. Are these "carryover" losses reflected in our estimates of the expected benefits from tactics designed to reduce salt wedge salinity losses?

The answer to this question requires a thorough understanding of our methodology for estimating expected salinity losses. The agriculture salinity losses in any year depend both on the external supply (rainfall, river flows, and evapotranspiration) in that year, and on the external supply in preceding years. The salt that flows into the boezems and ditches in a dry year and enters the root zone of the plants in the districts takes a long time to leave, even if the following year is much wetter. The agriculture salinity losses, S, observed in any of our simulated years can, therefore, be viewed as dependent on two quantities: (1) the initial conditions, I, at the start of the year, and (2) the external supply patterns, P, experienced during the year.

Our analysis depends upon estimates of the expected salinity losses, E(S). The most straightforward way of estimating E(S) would be to average the estimates of S for a large number of years, using the conditions at the end of one year as the initial conditions for the start of the next. For reasons discussed in Chap. 2, we chose to estimate E(S) by taking a weighted average of the estimates of S (the salinity losses observed in an analysis year) for a small number of (nonconsecutive) analysis years. It would also be possible to estimate E(S) by considering losses in the analysis years as well as losses in subsequent years caused by the conditions carried over from the analysis years. However, when using this method, the losses in an analysis year should include only the losses caused by the external supply conditions during that year; i.e., the losses due to the salinity conditions at the beginning of the analysis year should be excluded. It can easily be demonstrated that both approaches produce unbiased estimates of E(S).[4]

The salinity losses in any year can be viewed as the sum of two quantities:

$$S = S1(I,P) + S2(I)$$

where S1 = the losses that would occur if the initial conditions reflected a situation with no salt from the salt wedge in the root zone of plants or in the surface water system, and

S2 = the additional losses due to the salinity associated with the salt wedge in the initial conditions.

Thus, $E(S) = E\{S1(I,P)\} + E\{S2(I)\}$.

In order to simplify the analysis, we used the same initial conditions, Io, for each of the analysis years. Io reflects our estimate of the actual conditions at the end of 1967 (a year of average dryness). There is little or no salt in the root zone of plants or in the surface water system at the end of 1967 that can be traced to the salt wedge.

Since, in estimating E(S), we varied only P, our estimator for E(S) can be written

$$E\{S1(Io,P)\} + E\{S2(Io)\}.$$

In calculating the expected benefits from a tactic, we subtract the expected losses for the situation with the tactic implemented from the expected losses without the tactic. For tactics designed to reduce salinity losses caused by the salt wedge, E{S1(Io,P)} will be about the same for both situations. Thus, the expected benefits from one of these tactics are approximately given by the difference in E{S2(Io)} for the two situations.

For any year that was preceded by a year in which the salt wedge did not intrude beyond the mouth of the Hollandsche IJssel, S2(Io) and S2(I) would be about the same (approximately zero) for situations both with and without the tactic; thus, using Io instead of I as the initial conditions causes no error in estimating benefits. However, in the year following a dry year, S2(Io) would be smaller than S2(I) in the situation without the tactic. As a result, we would tend to underestimate the benefits from the tactic in such a year.

The effect of this underestimation on our results is likely to be small. First, because S2(I) will be significantly different from zero in less than 5 percent of all years (e.g., in a year following one like DEX), the underestimation of the expected annual benefits from a tactic is unlikely to exceed 1 Dflm. Second, when the salinity in the root zone of glasshouse plants (the major cause of salinity losses) at the beginning of a year is very high, farmers flush the soil with low salinity water (which is abundantly available during the winter). This would tend to bring Io and I close together, which would reduce the already small amount by which salinity losses were being underestimated.

All in all, we believe that any error introduced into our analysis by our use of Io is likely to be small, and that our estimates of expected benefits from tactics for reducing salinity losses caused by the salt wedge are approximately correct. At most, one or two of the marginal tactics that we screened out (e.g., building a Lopikerwaardkanaal) would become promising (although they would still be dominated by other promising tactics).

12.2.8. Probabilities Associated with Shipping Losses

In Sec. 2.1.1 we discussed how probabilities were assigned to the four supply scenarios for use in calculating upper and lower bounds on expected annual agriculture shortage and salinity losses. At the time we were carrying out the screening analysis, we lacked information that would enable us to assign probabilities for use in calculating upper and lower bounds on expected annual low water shipping losses. In place of these probabilities, we used those associated with agriculture salinity losses.

Just prior to the final PAWN briefing, a set of probabilities for shipping losses was developed by constructing a cumulative distribution function for annual shipping losses using data on river flows from 1930 through 1976 (see App. C of Vol. IX). Table 12.9 presents the probabilities associated with shipping losses along with those for agriculture shortage and salinity losses.

Since the shipping loss probabilities assign lower weights to DEX and 1959 than do the salinity loss probabilities, our estimates of the benefits from tactics that reduce low water shipping losses are too high. The analysis of the tactics for installing pumping capacity at Maasbracht (see Sec. 10.3) is not affected by this change in probabilities, since the expected benefits from those tactics are based on the average of 66 years of benefits and not on the weighted average of 4 years of benefits. However, several of the other tactics we evaluated are affected.

In Chap. 8, we showed that a Lopikerwaardkanaal would be a promising tactic for reducing salinity losses in the Midwest if the increased shipping losses it would cause could be reduced. Applying the probabilities for shipping losses shown in Table 12.9 to the shipping losses shown for Tactic 1 (the Lopikerwaardkanaal) in Table 8.7 reduces the upper bound on the expected shipping losses by 0.2 Dflm, which increases the upper bound on the expected annual benefits from the tactic from 2.2 Dflm to 2.4 Dflm. The canal's annualized fixed cost is 2.3 Dflm. Thus, the tactic appears to be promising. (In Chap. 11, we found that the Lopikerwaardkanaal tactic would be promising if the Merwedekanaal were used to bring water from the Waal to the Lek. This conclusion remains unchanged, although the benefits to be derived from the combination of tactics is slightly lower than those shown in Table 11.11.)

Table 12.9

PROBABILITIES OF ANNUAL LOSSES EXCEEDING THOSE
OF FOUR CHOSEN YEARS

Type of Loss	DEX	1959	1943	1967
Agriculture shortage losses	.02	.07	.21	.73
Agriculture salinity losses	.02	.09	.13	.57
Low water shipping losses	.01	.06	.17	.89

The use of the probabilities shown in Table 12.9 for estimating expected shipping losses produces small changes in the estimated benefits from a number of other tactics. However, it does not change any other conclusion.

12.2.9. Benefits from Adding Pumping Capacity to Wilhelminakanaal

One of the elementary tactics for reducing agriculture shortage losses in the Southeast Highlands is to install pumping capacity along the Wilhelminakanaal (see Sec. 10.2.1.6). This tactic was included in two of the aggregate tactics that were evaluated for the SPRHI-RALL scenario (see Sec. 10.2.3.4). The Wilhelminakanaal tactic was incorrectly implemented in the Distribution Model. In the runs we made, the canal was never able to transport water up to its supposed capacity.

As a result, the benefits shown in Table 10.11 for Tactics 5 and 7 are somewhat lower than they ought to be. The benefits for Tactic 5 should be slightly higher. The benefits for Tactic 7 should be about the same as those shown for Tactics 4 and 6. These changes in the expected benefits from Tactics 5 and 7 are not likely to be large enough to affect the conclusions of our analysis.

12.2.10. Overall Perspective on Qualifications

In this section we have discussed several qualifications on the results due to difficulties that were found in the data and models used in the screening analysis, most of which were discovered after the final PAWN briefing. Generally, the qualifications suggest that benefits may have been underestimated for certain of the tactics. This implies that some tactics that we found to be promising are likely to be even more worthwhile than we show. It also means that there may be other promising tactics that were screened out in our analysis. In addition, since we underestimated the preventable losses in the various regions, it is possible that our pre-screening process led us to not even consider some tactics that would have turned out to be promising. We should point out, however, that we used a very conservative standard for identifying promising tactics: the upper bound on expected annual benefits. Taking into account all of the qualifications on the results, it is likely that all tactics whose expected annual benefits are greater than their annualized fixed costs are included in the set of tactics that we identified as promising.

NOTES

1. If the summer target level of the Markermeer cannot be raised (due to problems in the IJmeer and the border lakes), then equivalent benefits can be obtained by raising the summer target level of the IJsselmeer to NAP - 0.05 m.
2. Although these losses were taken into account in the analysis, their very occurrence may be a reason to prefer one of the alternative tactics.
3. The Distribution Model is documented in Vol. XI. The District Hydrologic and Agriculture Model is documented in Vol. XII.
4. Let L_{nm} represent the agriculture salinity losses experienced in year m that were caused by external supply conditions occurring in year $n < m$. Then, the total salinity losses caused by events in year n are given by

$$C_n = L_{nn} + L_{n\ n+1} + L_{n\ n+2} + \ldots.$$

The total agriculture salinity losses experienced in year n are given by

$$S_n = L_{nn} + L_{n-1\ n} + L_{n-2\ n} + \ldots.$$

We assume that the L_{nm} are stationary, since there is no reason to believe otherwise. This means that

$$E(L_{nm}) = E(L_{n+k\ m+k}) = u_{m-n}.$$

Hence,

$$E(C_n) = u_o + u_1 + u_2 + \ldots$$

$$E(S_n) = u_o + u_1 + u_2 + \ldots,$$

and the expected salinity losses caused by external supply conditions in a given year are the same as the expected salinity losses experienced in a year.

Appendix A

ANNUALIZED FIXED COSTS OF TACTICS

The cost estimates that were used in the screening analysis were obtained from many sources. A great deal of effort was required to put the estimates into a form in which the costs of alternative tactics could be compared and the cost of an individual tactic could be compared with its expected benefits. This effort is described in detail in Vol. XVI, which identifies the specific changes to the infrastructure that are needed in order to implement each tactic, and provides tables that enable the total investment cost, annual operating cost, annualized fixed cost, and daily energy cost of each tactic to be estimated. (The costs are usually expressed as functions of the tactic's capacity.)

We used the annualized fixed costs from Vol. XVI in our screening analysis. The calculation of annualized fixed cost assumed a useful life of 50 years for the tactic, and used an interest rate of 10 percent. In order to make the costs of all tactics comparable, we estimated their costs in 1976 guilders, exclusive of BTW (value-added tax).

The tables in this appendix list, for each region, all of the tactics examined in our screening analysis, together with the capacities that we considered and the annualized fixed cost of the tactic for these capacities. For those readers who would like to track down the source of any of the costs, a cross-reference to the appropriate table in Vol. XVI is provided.

Table A.1

ANNUALIZED FIXED COSTS FOR TACTICS: NORTH
(1976 Dflm, excluding BTW)

Table No. in Vol. XVI	Description	Capacity (m^3/s)	Annualized Fixed Cost
4.2	Expand throughput capacity of Van Starkenborghkanaal	25.0	0.60
4.1	Drainage pipeline from Noordoostpolder to Flevoland	15.0	4.20

Table A.2

ANNUALIZED FIXED COSTS FOR TACTICS: NORTHEAST HIGHLANDS
(1976 Dflm, excluding BTW)

Table No. in Vol. XVI	Description	Capacity (m^3/s)	Annualized Fixed Cost
	Route 1: Twenthekanaal		
5.1	Twenthekanaal: Pumping at Eefde	19.3	0.31
5.10	Oranjekanaal West: 3 pumping stations	2.0	0.24
5.11	Oranjesluis: Pumping	5.0	0.24
5.12	Ericasluis: Pumping	7.0	0.31
5.2	Almelo lock: Bypass	15.0	0.06
5.3	Stieltjeskanaal: Pumping	5.0	0.30
	Total Cost		1.46
5.1	Twenthekanaal: Pumping at Eefde	24.3	0.61
5.10	Oranjekanaal West: 3 pumping stations	2.0	0.24
5.11	Oranjesluis: Pumping	5.0	0.24
5.12	Ericasluis: Pumping	7.0	0.31
5.2	Almelo lock: Bypass	20.0	0.06
5.3	Stieltjeskanaal: Pumping	10.0	0.59
	Total Cost		2.05
	Route 2: Hoogeveensche Vaart		
5.4	Hoogeveensche Vaart: Pumping	10.0	2.38
5.10	Oranjekanaal West: 3 pumping stations	2.0	0.24
5.11	Oranjesluis: Pumping	5.0	0.24
5.12	Ericasluis: Pumping	7.0	0.31
	Total Cost		3.17
5.4	Hoogeveensche Vaart: Pumping	15.0	3.57
5.10	Oranjekanaal West: 3 pumping stations	2.0	0.24
5.11	Oranjesluis: Pumping	5.0	0.24
5.12	Ericasluis: Pumping	7.0	0.31
	Total Cost		4.36
	Route 3: Van Starkenborghkanaal		
4.2	Van Starkenborghkanaal: Pumping, bypass	25.0	0.60
5.5	Noord-Willemskanaal: Pumping	10.0	1.78
5.6	Linthorst-Homankanaal: Pumping	10.0	0.39
5.10	Oranjekanaal West: 3 pumping stations	2.0	0.24
5.11	Oranjesluis: Pumping	5.0	0.24
5.12	Ericasluis: Pumping	7.0	0.31
	Total Cost		3.57

Table A.2 (continued)

Table No. in Vol. XVI	Description	Capacity (m^3/s)	Annualized Fixed Cost
4.2	Van Starkenborghkanaal: Pumping, bypass	30.0	1.21
5.5	Noord-Willemskanaal: Pumping	15.0	2.67
5.6	Linthorst-Homankanaal: Pumping	10.0	0.39
5.10	Oranjekanaal West: 3 pumping stations	2.0	0.24
5.11	Oranjesluis: Pumping	5.0	0.24
5.12	Ericasluis: Pumping	7.0	0.31
	Total Cost		5.06
	Route 4: Drentsche Hoofdvaart		
5.7	Drentsche Hoofdvaart: Pumping	14.3	3.56
5.6	Linthorst-Homankanaal: Pumping	10.0	0.39
5.10	Oranjekanaal West: 3 pumping stations	2.0	0.24
5.11	Oranjesluis: Pumping	5.0	0.24
5.12	Ericasluis: Pumping	7.0	0.31
	Total Cost		4.74
5.7	Drentsche Hoofdvaart: Pumping	19.3	5.35
5.6	Linthorst-Homankanaal: Pumping	10.0	0.39
5.10	Oranjekanaal West: 3 pumping stations	2.0	0.24
5.11	Oranjesluis: Pumping	5.0	0.24
5.12	Ericasluis: Pumping	7.0	0.31
	Total Cost		6.53
	Route 5: Overijsselsche Vecht		
5.9	Overijsselsche Vecht (upper): Pumping	10.0	2.38
5.8	Overijsselsche Vecht (lower): Pumping	10.0	1.19
5.3	Stieltjeskanaal: Pumping	5.0	0.30
5.10	Oranjekanaal West: 3 pumping stations	2.0	0.24
5.11	Oranjesluis: Pumping	5.0	0.24
5.12	Ericasluis: Pumping	7.0	0.31
	Total Cost		4.66
5.9	Overijsselsche Vecht (upper): Pumping	15.0	3.57
5.8	Overijsselsche Vecht (lower): Pumping	15.0	1.78
5.3	Stieltjeskanaal: Pumping	10.0	0.59
5.10	Oranjekanaal West: 3 pumping stations	2.0	0.24
5.11	Oranjesluis: Pumping	5.0	0.24
5.12	Ericasluis: Pumping	7.0	0.31
	Total Cost		6.73

Table A.3

ANNUALIZED FIXED COSTS FOR TACTICS: NORTH HOLLAND
(1976 Dflm, excluding BTW)

Table No. in Vol. XVI	Description	Capacity (m^3/s)	Annualized Fixed Cost
6.1	Redirect Wieringermeerpolder Discharges	(a)	1.38

(a) Not applicable.

Table A.4

ANNUALIZED FIXED COSTS FOR TACTICS: MIDWEST AND UTRECHT
(1976 Dflm, excluding BTW)

Table No. in Vol. XVI	Description	Capacity (m^3/s)	Annualized Fixed Cost
7.2	Lopikerwaardkanaal	20.0(a)	2.29
7.3	Lopikerwaardkanaal plus Leidsche Rijn	30.0(a)	3.93
7.1	Krimpenerwaardkanaal	40.0(a)	5.68
7.4	Maarssen-Bodegravenkanaal	40.0(a)	12.79
7.11	Close Spui: dam & ship lock (permanent)	(b)	2.03
7.12	Close Oude Maas: caissons (temporary)	(b)	19.60
7.13	Close Nieuwe Maas: caissons (temporary)	(b)	26.30
7.9	Groin in Nieuwe Waterweg	(b)	0.68
7.10	Bubble screen in Nieuwe Waterweg	(b)	1.24
7.6	Pipeline from Maas to Delfland (3 pipes)	8.0	37.90(c)
7.7	Pipeline from Maas to Delfland (1 pipe)	8.0	29.50(c)
7.8	Leidschendam: Pumping	20.0	0.72
7.5	Waddinxveen-Voorburgkanaal	15.0	12.75

(a) Throughput capacity to Rijnland.

(b) Not applicable.

(c) Includes expected annual pumping cost.

Table A.5

ANNUALIZED FIXED COSTS FOR TACTICS: WEST BRABANT AND SOUTHERN DELTA
(1976 Dflm, excluding BTW)

Table No. in Vol. XVI	Description	Capacity (m^3/s)	Annualized Fixed Cost
8.1	Inlet in Grevelingendam	(a)	0.39
8.2	St. Andries: bypass	17.0	0.66

(a) Not applicable.

Table A.6

ANNUALIZED FIXED COSTS FOR TACTICS: SOUTHEAST HIGHLANDS
(1976 Dflm, excluding BTW)

Table No. in Vol. XVI	Description	Shipping Improvement Scenario	Capacity (m^3/s)	Annualized Fixed Cost
	Tactics To Expand the Supply Capacity to the Region			
Dominance Set 1(a)				
9.14	Install pumping on Wilhelminakanaal	min	5.0	5.44
9.5	Zuid-Willemsvaart (Denbosch-Helmond)	min	5.0	9.48
9.15	Install pumping on Wilhelminakanaal	max	5.0	4.11
9.6	Zuid-Willemsvaart (Denbosch-Helmond)	max	5.0	4.99
Dominance Set 2(a)				
9.11	Increase throughput at Panheel	min	6.2	1.55
9.12	Increase throughput at Panheel	max	6.2	1.05
9.16	Pipeline from Maasbracht to Panheel		4.2	2.50
Dominance Set 3(a)				
9.17	Pump Roer water to Panheel		10.0	1.17
9.18	Pump Waal water from St. Andries to Panheel		10.0	6.81
Tactic 1a				
9.2	Zuid-Willemsvaart (Lozen-Nederweert)	min	9.0	0.18
9.7	Expand syphon to Noordervaart		9.0	0.06
	Total cost			0.24
Tactic 1b				
9.3	Zuid-Willemsvaart (Lozen-Nederweert)	max	9.0	0.16
9.7	Expand syphon to Noordervaart		9.0	0.06
	Total cost			0.22
Tactic 2a				
9.17	Pump Roer water to Panheel		5.0	1.13
9.11	Increase throughput at Panheel	min	7.0	1.62
9.9	Build pumping station at Noordervaart		5.0	1.34
	Total cost			4.09

Table A.6 (continued)

Table No. in Vol. XVI	Description	Shipping Improvement Scenario	Capacity (m^3/s)	Annualized Fixed Cost
Tactic 2b				
9.17	Pump Roer water to Panheel		5.0	1.13
9.12	Increase throughput at Panheel	max	7.0	1.09
9.9	Build pumping station at Noordervaart		5.0	1.34
	Total cost			3.56
Tactic 3a				
9.11	Increase throughput at Panheel	min	7.0	1.62
9.9	Build pumping station at Noordervaart		5.0	1.34
	Total cost			2.96
Tactic 3b				
9.12	Increase throughput at Panheel	max	7.0	1.09
9.9	Build pumping station at Noordervaart		5.0	1.34
	Total cost			2.43
Tactic 4a				
9.2	Zuid-Willemsvaart (Lozen-Nederweert)	min	9.0	0.18
9.7	Expand syphon to Noordervaart		9.0	0.06
9.11	Increase throughput at Panheel	min	12.0	2.01
	Total cost			2.25
Tactic 4b				
9.3	Zuid-Willemsvaart (Lozen-Nederweert)	max	9.0	0.16
9.7	Expand syphon to Noordervaart		9.0	0.06
9.12	Increase throughput at Panheel	max	12.0	1.35
	Total cost			1.57
Tactic 5a				
9.2	Zuid-Willemsvaart (Lozen-Nederweert)	min	9.0	0.18
9.7	Expand syphon to Noordervaart		9.0	0.06
9.11	Increase throughput at Panheel	min	7.0	1.62
9.14	Install pumping on Wilhelminakanaal	min	5.0	5.44
	Total cost			7.30

Table A.6 (continued)

Table No. in Vol. XVI	Description	Shipping Improvement Scenario	Capacity (m^3/s)	Annualized Fixed Cost
Tactic 5b				
9.3	Zuid-Willemsvaart (Lozen-Nederweert)	max	9.0	0.16
9.7	Expand syphon to Noordervaart		9.0	0.06
9.12	Increase throughput at Panheel	max	7.0	1.09
9.15	Install pumping on Wilhelminakanaal	max	5.0	4.11
	Total cost			5.42
Tactic 6a				
9.17	Pump Roer water to Panheel		10.0	1.17
9.11	Increase throughput at Panheel	min	17.0	2.41
9.9	Build pumping station at Noordervaart		5.0	1.34
	Total cost			4.92
Tactic 6b				
9.17	Pump Roer water to Panheel		10.0	1.17
9.12	Increase throughput at Panheel	max	17.0	1.61
9.9	Build pumping station at Noordervaart		5.0	1.34
	Total cost			4.12
Tactic 7a				
9.14	Install pumping on Wilhelminakanaal	min	15.0	5.76
Tactic 7b				
9.15	Install pumping on Wilhelminakanaal	max	15.0	4.36
	Tactics To Reduce Shipping Losses on the Julianakanaal			
9.19	Use portable pumps at Maasbracht		5.0	0.13(b)
9.19	Use portable pumps at Maasbracht		10.0	0.39(b)
9.20	Build pumping station at Maasbracht		5.0	0.81
9.20	Build pumping station at Maasbracht		10.0	1.07

(a) Consideration of the relative merits of the tactics in this dominance set leads to the screening out of one of the tactics by dominance.

(b) In addition to this annualized fixed cost, both setup cost and operating cost were used in the screening analysis.

Table A.7

ANNUALIZED FIXED COSTS FOR TACTICS: NATIONAL
(1976 Dflm, excluding BTW)

Table No. in Vol. XVI	Description	Capacity (m^3/s)	Annualized Fixed Cost
	IJmeer		
10.1	Raise Flevoland dike	(a)	5.32
10.2	Flevoland dike and discharges to IJsselmeer	35.0	8.32
10.3	Flevoland dike and pipeline to Noordzeekanaal	51.5	46.02
10.4	Short 2d Oostvaardersdijk	(a)	18.77
10.6	Drainage channel to Amsterdam; full separation	85.0	31.41
10.8	Drainage channel to Amsterdam; open connection	85.0	35.97
10.7	Drainage channel to Amsterdam; full separation; and syphon under channel	100.0	38.04
10.5	Long 2d Oostvaardersdijk; syphon and freshwater channel to Diemen	100.0	26.42
	IJsselmeer and Markermeer		
Raise Summer Target Level of Lakes			
10.11	Raise summer target level of IJsselmeer	-0.15(b)	0.28
10.12	Raise summer target level of Markermeer	-0.15(b)	0.19
	Total cost		0.47
10.11	Raise summer target level of IJsselmeer	-0.10(b)	2.91
10.12	Raise summer target level of Markermeer	-0.10(b)	0.50
	Total cost		3.41
Decrease Minimum Level of Lakes			
10.15	Decrease minimum level of IJsselmeer	-0.45(b)	0.61(c)
10.16	Decrease minimum level of Markermeer	-0.45(b)	1.93(c)
	Total cost		2.54
10.15	Decrease minimum level of IJsselmeer	-0.50(b)	0.74(c)
10.16	Decrease minimum level of Markermeer	-0.50(b)	2.91(c)
	Total cost		3.65
10.17	Construct "wet Markerwaard"	33.0(d)	32.70

Table A.7 (continued)

Table No. in Vol. XVI	Description	Capacity (m^3/s)	Annualized Fixed Cost
	North-South Connection		
Alternative 1 (Tiel-Vreeswijk)			
10.18	Pumping station on the Diemen	30.0	6.59
10.19	Bypass at Wijk bij Duurstede	30.0	1.99
10.20	Bypass and pumping station at Vreeswijk	30.0	4.30
	Total cost		12.88
10.18	Pumping station on the Diemen	100.0	8.26
10.19	Bypass at Wijk bij Duurstede	100.0	2.90
10.20	Bypass and pumping station at Vreeswijk	100.0	12.77
	Total cost		23.93
Alternative 2 (Gorinchem-Vreeswijk)			
10.18	Pumping station on the Diemen	30.0	6.59
10.20	Bypass and pumping station at Vreeswijk	30.0	4.30
10.21	Merwedekanaal, Betuwe section	40.0(e)	0.92
	Total cost		11.81
10.18	Pumping station on the Diemen	100.0	8.26
10.20	Bypass and pumping station at Vreeswijk	100.0	12.77
10.21	Merwedekanaal, Betuwe section	110.0(e)	30.73
	Total cost		51.76
Alternative 3 (Tiel-Maas)			
10.18	Pumping station on the Diemen	100.0	8.26
10.19	Bypass at Wijk bij Duurstede	100.0	2.90
10.22	Extend Amsterdam-Rijnkanaal to Maas	100.0	26.74
	Total cost		37.90
	Bring Waal Water to Lek		
10.23	Dredging in Waal below Tiel	(a)	(f)
10.24	Modify groins in Waal around Tiel	(a)	1.16
10.25	Narrow Waal around Tiel	(a)	2.30
10.21	Merwedekanaal, Betuwe section	40.0(e)	0.92
	IJssel Canalization		
10.26	Canalize IJssel River	(a)	60.20

NOTES TO TABLE A.7

(a) Not applicable.

(b) Lake level, in meters relative to NAP.

(c) This cost excludes the cost of building pumping stations at the inlets to the Friesland boezem. Our analysis indicated that new pumping stations were not needed to supply the required water to Friesland for any of the demand scenarios.

(d) Capacity of pumping station between Markerwaard and IJsselmeer.

(e) Throughput capacity to the Lek is 10 m^3/s less because of extractions by the Lingeboezem.

(f) There is only a variable cost associated with this tactic.

Appendix B

COLLECTION AND PROCESSING OF WATERBOARD PLAN DATA

by G. Baarse

B.1. INTRODUCTION

For purposes of water management, the Netherlands is divided into about two hundred jurisdictions, each one supervised by a waterboard. A waterboard is a governmental body that is responsible for water management within its boundaries. The boundaries of a waterboard are determined by local geohydrological and infrastructural conditions and by historical factors.

A waterboard controls a number of water intake and discharge facilities that connect it to the regional or national water management system. In the low parts of the country, most of the agricultural land can be supplied with surface water, i.e., there is a network of ditches from which the agricultural land can be sprinkled. This is not true in the higher parts of the country, where only certain areas can be supplied with surface water. For that reason, many waterboards in the highlands have made plans to expand or improve the water supply possibilities within their jurisdictions.

As part of the screening analysis, we performed a rough cost/benefit analysis of each of these plans (see Sec. 4.1). This analysis required a great deal of data. We obtained these data from a survey of the waterboards that was carried out by the Union of Waterboards and employees of WW during 1978. In order to provide a sufficient and appropriate set of data for our analysis, the rough information from the survey had to be processed and supplemented. This appendix describes the information that was obtained from the survey and the steps we took to create the final data base used in our analysis.

B.2. INFORMATION FROM WATERBOARD SURVEY

In 1978 the Union of Waterboards, in cooperation with employees of WW, conducted a survey of all waterboards to learn about their current and future water supply situation. Specifically, each waterboard was asked about:

- Capacities of existing intake and discharge facilities.
- Areas that are currently able to be supplied with surface water.
- Areas that could be supplied in the future if specific waterboard plans were implemented.
- Investment costs for the waterboard plans.

In addition, most waterboards provided estimates of the area that was currently sprinkled and the area that could be sprinkled if the waterboard plans were implemented. Some waterboards also specified a desired flushing rate.

A number of qualifications should be made about these data that are important for the interpretation of the final results and for understanding certain steps in the processing of the data.

First, there is the question of what is meant by the area able to be supplied with surface water (we have called this the eligible area). Our definition of eligible area is the farmland that the local surface water system can supply with water for sprinkling. The waterboards generally consider an area suppliable if it has a network of ditches. In the latter case, however, not all the agricultural land can necessarily be sprinkled. There may be two reasons for this:

- The network is not dense enough.
- There are capacity constraints, either in the inlet facilities of the waterboard or in the internal ditch system.

From the survey we were able to obtain only a vague notion of whether certain limitations existed in an area, but hardly ever in quantitative terms. In our analysis we assumed that the areas indicated as suppliable by the waterboards could in fact be sprinkled. Our eligible areas are therefore generally overestimated (and, therefore, the amount of sprinkling in the RALL demand scenarios are likely to be too high).

Related to this is the problem of improvement versus expansion. In some plan descriptions it was indicated that certain areas would now become suppliable that could not be supplied before, whereas the suppliability of other areas would be "improved." The extent of the improvement was not further described. We dealt with this uncertainty by using two different interpretations of these plans--one pessimistic and the other optimistic. (See Sec. B.3 for further discussion.)

Apart from the uncertainties with respect to suppliability, we were unsure what the plan areas actually represented. In principle there are three possibilities for the area made suppliable by a waterboard plan:

- Net cultivated area (area actually planted with cash crops).
- Gross cultivated area.
- Total area.

In our analysis we are primarily concerned with the net cultivated area. The gross cultivated area consists of the net cultivated area plus the areas occupied by ditches, paths, roads, and scattered buildings in between the crop fields. Total area simply means the sum of all cultivated, urban, nature, and open water areas. Most plan specifications do not include a clear statement of what is actually included in the plan area. In many cases the plan area seems to be the gross cultivated area, but there are clearly cases where the total area is used and a few instances in which the net cultivated area is used.

There are additional uncertainties associated with the plan specifications. It should be borne in mind that the term plan in this context is not defined very strictly. In a number of waterboards, plans existed that were well thought-out and were worked out to a high level of detail. In others, only vague plans existed and few details were available. A few waterboards did not even have vague plans, but came up with some ideas in the course of the interview made for the survey. We therefore warn the reader that the estimates presented below for plan areas are often quite crude. This is even more true for the cost estimates. Given the many questions and uncertainties related to cost calculation and the fact that most plans were not worked out well, the cost estimates are probably not very reliable. They seem rather low to us, which might indicate that some necessary investments are not included. Also, the estimates cover only investment costs. Operating costs are not included, although these are likely to be small compared to the investment costs.

The survey of waterboards yielded the following information for each plan:

- Area affected by plan.
- Waterboard responsible for plan, usually accompanied by some indication of the location of the plan area within the waterboard.
- Total investment cost of plan.

These data are subject to the qualifications given above. Based on this information, we produced the list of plans given in Table B.1.

Table B.1

DATA FROM WATERBOARD PLAN SURVEY

Plan ID	Name of Waterboard	Plan Area (ha)	Investment Cost (1000s of Dfl)
1	Tusken Mar en Klif	2300	2000
2	De Stellingwerven	8650	8000
3	Tjonger Compagnonsv.	550	165
4	Lits en Lauwers	300	300
5	Reiderzijlvest	28500	14000

Table B.1 (continued)

Plan ID	Name of Waterboard	Plan Area (ha)	Investment Cost (1000s of Dfl)
6	Duurswold	3800	1900
7	Oldambt	4500	900
8	Westerkwartier	3000	10000
9(a)	Westerkwartier	26000	10000
10	Westerkwartier	1500	5000
11(a)	Westerkwartier	7000	5000
12	Hunsingo	23920	30000
13	Hesselte	230	115
14	De Oude Vaart	4440	1554
15	De Wold Aa	3015	1508
16	De Wold Aa	2365	1183
17	De Vledder en Wasp. A	1120	560
18	Smilde	3380	1690
19	Noordenveld	3830	1915
20	Drentse Aa	5685	5685
21	Riegmeer	1755	878
22	Middenveld	1975	1750
23(a)	Middenveld	3650	1750
24	Middenveld	5870	3500
25	Loo- en Drostendiep	2655	5000
26	Bargerbeek	1880	1880
27	De Veenmarken	20845	25000
28	De Oostermoerse vaart	12735	4775
29	Vollenhoven	1400	500
30	Benoorden de Dedemsv.	800	800
31	De Noordervechtdijken	2900	5000
32	De Bovenvecht	9395	3400
33	Bezuiden de Vecht	7500	5000
34(a)	Bezuiden de Vecht	9000	5000
35	Salland	12200	16600
36	Regge en Dinkel	4500	300
37	Berkel	6800	1100
38	Berkel	10000	25000
39	Baakse Beek	12500	27500
40	IJsselland	5000	12500
41	NW-Veluwe	950	475
42	Veluwe	23000	20000
43	Barneveldse Beek	500	25
44	Barneveldse Beek	1230	2460
45	Heiligenbergerbeek	1000	50
46	Wieringermeer	18000	1800
47	De Kromme Rijn	2900	750
48	Maas en Waal	6900	2500
49	Schouwen-Duiveland	15000	3000
50	Tholen	9000	4000
51	Brede Wat. v. Z-Bevel	6200	6000
52	Brede Wat. v. Z-Bevel	21100	29000

Table B.1 (continued)

Plan ID	Name of Waterboard	Plan Area (ha)	Investment Cost (1000s of Dfl)
53	Donge	5400	1675
54	West Brabant	33600	30000
55(a)	West Brabant	33600	18000
56	West Brabant	7200	3240
57	West Brabant	7400	3330
58	Maaskant	12000	6480
59	Maaskant	8000	5600
60	Dommel	14000	9800
61(a)	Dommel	14000	15400
62	Dommel	16220	11354
63(a)	Dommel	16220	17842
64	Dommel	18500	5735
65	Dommel	6700	3618
66	Midden-Limburg	14100	9870
67	Noord-Limburg	24600	5000
68(a)	Noord-Limburg	7380	5000
69	Aa	17000	4250
70	Oude IJssel	1000	200
71	Diverse (Groningen)	15000	4500
72	Noordoostpolder	37000	3700
73	Flevoland	24700	2470
74	Tjonger-Compagnonsv.	1400	420

(a) These are alternatives to the plans listed just above them.

Although the plans are numbered from 1 to 74, there are only 65 individual plans in the list, i.e., plans that affect separate areas in the waterboards and hence do not overlap or exclude other plans. Some plans were put in the list twice to reflect different interpretations of the same plan. (The duplicate plans are indicated with a footnote.) There are two reasons why this was done. The first has to do with the confusion between "newly suppliable" and "improved suppliability." Whenever the description of a plan indicated that it would improve the suppliability of an area (indicating that some supply possibilities already existed in the current situation), we considered two extreme cases for the current situation in that area:

1. The area to be improved is not suppliable in the current situation.
2. The area to be improved is fully suppliable in the current situation.[1]

In the first case, we can obtain an upper bound on the potential plan benefits. The latter case provides a lower bound. The notion is that a waterboard plan should not be rejected as long as the upper bound of potential benefits exceeds the costs. The lower bound yields some information about the sensitivity of the plan's evaluation to the assumptions about the ambiguous area.

The second reason for including a plan in the list twice has to do with differences in investment costs because of different ways of implementing the plan. For a number of plans in Noord-Brabant, there is the technical possibility to supply water from either the Dutch or the Belgian canal system. The investment costs for the latter are substantially lower than for the former, because supply can take place from higher elevations using a shorter route. However, the political realities are such that the less costly solution is unlikely to be implemented. For completeness these plans were included twice, i.e., with the two different cost estimates. A more complete description of each of the duplicated plans is given below.

- Plans 8 and 9 represent alternative interpretations of the same plan. The survey of waterboards showed that for a one-time investment cost of 10 Dflm, 3000 ha will be newly supplied and the supply to 23,000 ha will be improved. Thus, Plan 8 represents the case in which 3000 ha are newly suppliable, and Plan 9 is the case in which all 26,000 ha are newly suppliable. The investment cost for both cases is 10 Dflm.
- Plans 10 and 11. According to the survey of waterboards, for 5 Dflm, 1500 ha will be newly supplied and 5500 ha will be improved. Plan 10 represents the case in which 1500 ha are newly suppliable; Plan 11 is the case in which all 7000 ha are newly suppliable.
- Plans 22 and 23. According to the survey, for 1.75 Dflm, 1975 ha will be newly supplied and 1675 ha will be improved. Plan 22 represents the case in which 1975 ha are newly suppliable; Plan 23 is the case in which all 3650 ha are newly suppliable.
- Plans 33 and 34. According to the survey, for 5 Dflm, 7500 ha will be newly suppliable and 1500 ha will be improved. Plan 33 represents the case in which 7500 ha are newly suppliable; Plan 34 is the case in which all 9000 ha are newly suppliable.
- Plans 54 and 55. Two alternative plans were created because of different options for implementation. If the plan is supplied from the Dutch canal system, the investment is 30 Dflm. If the area is supplied from the Belgian canal system, the investment is only 18 Dflm.
- Plans 60, 61, 62, and 63. These four plans refer to a single plan from the survey of waterboards. The total area of the plan is 30,220 ha. It was split into two parts because we had a data-handling problem (the plan involved too many subdistricts to fit into our plan data file). Since the plan area could be supplied from either the Dutch or Belgian canal system, each of the two parts has two alternatives with respect to investment costs.

- Plans 67 and 68. The waterboard survey implied that this plan would make 24,600 ha eligible for sprinkling. We added Plan 68, which assumes that only 30 percent of the plan area would be eligible for sprinkling. The latter assumption seems far more realistic.

B.3. DETERMINING ELIG.FRAC

The pre-screening of waterboard plans (described in Sec. 4.1) is based on a computation of the net benefits of a plan, which is the difference between the expected annual net benefits from sprinkling in the plan area and the annualized investment cost of the plan. The sprinkling benefits are the sum of the expected benefits for each crop in each subdistrict that is affected by the plan. These benefits are computed using the expression:

$$\text{CROP.BEN} = \text{PERHA.BEN} * \text{ELIG.FRAC} * \text{CROP.AREA} * \text{SPR.INTENS},$$

where CROP.BEN = the expected annual net benefits from sprinkling the crop in the subdistrict, made possible by the plan,
PERHA.BEN = the expected annual net benefits from sprinkling one hectare of the crop in the subdistrict,
ELIG.FRAC = the fraction of the crop area in the subdistrict made eligible by the plan,
CROP.AREA = total crop area within subdistrict,
SPR.INTENS = the sprinkler intensity for the crop in the subdistrict (i.e., the fraction of the eligible area on which sprinkling equipment is actually installed).

The total area of each crop in each subdistrict is a data element in the data base for our agricultural models. The determination of PERHA.BEN and SPR.INTENS is described in Vol. XIV. The critical element to be explained here is ELIG.FRAC, which is a direct translation of the effect of the plan in terms of the eligibility for sprinkling of individual crops. The remainder of this chapter will deal with the way we determined ELIG.FRAC.

The equation given above is used for each crop in each subdistrict. We carried out the calculation this way because all of the relevant data (PERHA.BEN, SPR.INTENS, and CROP.AREA) are given by crop and subdistrict. But this meant that we needed to determine ELIG.FRAC by crop and subdistrict as well. This presented a number of problems. First, we had to locate the plan areas on a map and allocate them to subdistricts. This is not a straightforward procedure, because not all subdistricts are geographically determined. In addition, our data files on crop areas within subdistricts reflect hectares that are actually planted with cash crops (net cultivated area). As was explained in Sec. B.2, the plan areas may reflect either total area, gross cultivated area, or net cultivated area. This means that in most cases some adjustment is required to express plan areas in terms of crop areas within subdistricts.

We used the following procedure for determining ELIG.FRAC by crop and subdistrict. First, we decided for each plan what type of area it referred to. In most cases, this could be inferred from a comparison of areas given in the waterboard survey and net cultivated areas given by CBS[2] statistics [B.1] for the same region. In cases of doubt, it was assumed that the plan areas reflected gross cultivated areas. Next, we had to adjust the plan areas so that they all referred to net cultivated areas. To do this, we determined for each of eleven provinces in the Netherlands, based on statistical information of CBS [B.1, B.2], (1) the ratio between gross cultivated area and total area, and (2) the ratio between net cultivated area and gross cultivated area. As it turned out, the ratio of net cultivated area to gross cultivated area is relatively constant over the provinces, varying from 0.86 to 0.78 with an average of 0.83, so we used the average in all of our calculations. In computing the ratios of gross cultivated areas to total areas, we corrected the total areas for open water areas wider than 6 m, since it was clear that large water bodies were not included in the survey's estimates of plan areas. Because there is a fair amount of variation in these ratios over the provinces (from 0.66 to 0.89), it seemed appropriate to maintain these differences by province.

Given the different possibilities with respect to the meaning of the plan areas, we determined the adjustment factors in the following way:

- If the plan area is net cultivated area, the adjustment factor is 1.00.
- If the plan area is gross cultivated area, the adjustment factor is 0.83.
- If the plan area is total area, the adjustment factor is set equal to 0.83 times the province's ratio of gross cultivated area to total area. (The factor 0.83 converts gross cultivated area into net cultivated area.)

Table B.2 shows the adjustment factors by province that were used in our calculations. In principle, there should be an adjustment factor for each plan. However, we found that within provinces the estimates of waterboard plan areas appeared to be consistent. So we applied the same adjustment factor to all plan areas within each province.

By multiplying the plan area that was allocated to a subdistrict by the appropriate adjustment factor, we obtain the net cultivated area within the subdistrict that becomes eligible because of the plan under consideration.

Table B.2

ADJUSTMENT FACTORS FOR WATERBOARD PLAN AREAS BY PROVINCE

Province	Adjustment Factors
Friesland	.83
Groningen	.83
Drenthe	.83
Overijssel	.65
Gelderland	.83
Utrecht	.83
Noord-Holland	.83
Zuid-Holland	.83
Zeeland	1.00
Noord-Brabant	.58
Limburg	.57

The final step is then to determine the crop areas within a subdistrict that become eligible because of the plan. In our agricultural data bases there is no information about the location of crops within subdistricts. The only assumption that can be made therefore is that all crops are homogeneously distributed over a subdistrict. It should be realized that this is an important assumption that may cause substantial errors in the benefit computation, especially for small plans. This assumption makes the calculation of ELIG.FRAC quite simple. If the net cultivated area within a subdistrict that is made eligible by a plan is expressed as a fraction of the total net cultivated area in the subdistrict, this fraction indicates for each individual crop within the subdistrict what part of the total crop area is made eligible by the plan. This fraction is the variable ELIG.FRAC that we are looking for.

The following steps summarize the procedure to determine ELIG.FRAC:

- Allocate the plan area to subdistricts.
- Convert the plan area of each subdistrict to a net cultivated area.
- Express the plan area of each subdistrict as a fraction of the total net cultivated area of the subdistrict.

Assuming that crops are homogeneously distributed over the subdistricts, these fractions are the required ELIG.FRAC variables. Note that, associated with each plan, for each of the affected subdistricts there is a single ELIG.FRAC, which is valid for all crops within the subdistrict. Table B.3 presents the values of ELIG.FRAC by subdistrict for each of the plans given in Table B.1.

Table B.3

VALUES OF ELIG.FRAC FOR WATERBOARD PLANS

Plan ID	Sub-dist.	ELIG. FRAC	Sub-dist.	ELIG. FRAC	Sub-dist.	ELIG. FRAC	Sub-dist.	ELIG. FRAC
1	1	.029						
2	1	.110						
3	1	.007						
4	1	.004						
5	12	.257	13	.442	14	.241		
6	10	.090	11	.136				
7	12	.107	13	.166				
8	1	.013	17	.075				
9	1	.013	17	.687	8	.114		
10	1	.019						
11	1	.089						
12	8	.205	9	1.000				
13	22	.007						
14	23	.095						
15	23	.064						
16	23	.050						
17	25	.206						
18	1	.011	17	.042	23	.030		
19	17	.075	18	.206				
20	15	.240						
21	23	.037						
22	23	.042						
23	23	.078						
24	23	.125						
25	21	.114						
26	21	.080						
27	19	.878						
28	14	.034	15	.275	19	.072		
29	24	.056						
30	28	.051						
31	28	.135						
32	32	.359						
33	37	.113	38	.211				
34	37	.158	38	.211				
35	38	.545	42	.271				
36	35	.230						
37	47	.213	48	.070				
38	47	.314	48	.103				
39	47	.392	48	.129				
40	50	.134						
41	56	.058						
42	43	.714	44	.814				
43	54	.020						
44	54	.050						
45	54	.041						
46	59	.900						

Table B.3 (continued)

Plan ID	Sub-dist.	ELIG. FRAC	Sub-dist.	ELIG. FRAC	Sub-dist.	ELIG. FRAC	Sub-dist.	ELIG. FRAC
47	77	.286						
48	112	.290	113	.071	109	.562	110	.402
49	143	.806						
50	141	.214						
51	141	.148						
52	141	.502						
53	100	.269	135	.353	136	.119		
54	137	.706	138	.587	140	.741		
55	137	.706	138	.587	140	.741		
56	139	.552	140	.069				
57	139	.196	141	.124				
58	112	.628	113	.307				
59	113	.307						
60	128	.283	129	.120	130	.323	131	.306
61	128	.283	129	.120	130	.323	131	.306
62	132	.392	135	.205	136	.104		
63	132	.392	135	.205	136	.104		
64	106	.147	118	.058	133	.598	134	.392
65	133	.380	134	.196				
66	118	.027	126	.299	127	.329		
67	126	.091	119	.283	120	.544		
68	126	.048	119	.149	120	.286		
69	117	.101	118	.255				
70	50	.027						
71	14	.209						
72	27	.830						
73	58	.250						
74	1	.018						

B.4. SUMMARY OF RESULTS

The data described in Secs. B.2 and B.3 were used by a computer program that calculates the net benefits for each waterboard plan. The program sums potential benefits for each crop in the subdistrict(s) affected by a plan, and then subtracts the annualized waterboard plan costs, according to the procedure described in Sec. 4.1. Annualized plan costs were taken to be 10 percent of the total investment cost. This amount was meant to include both fixed and variable costs. Given the uncertainties about the investment cost estimates and the lack of data about the (presumably small) variable costs, we felt that there was no point in using more sophisticated methods to determine the annualized costs.

For 19 of the 65 individual waterboard plans, the net benefits were negative, so they were screened out (see Table 4.1). This left 46 plans screened in (see Table 4.2). The plans that have alternative interpretations were considered to be screened in as long as at least one of the alternatives had positive net benefits.

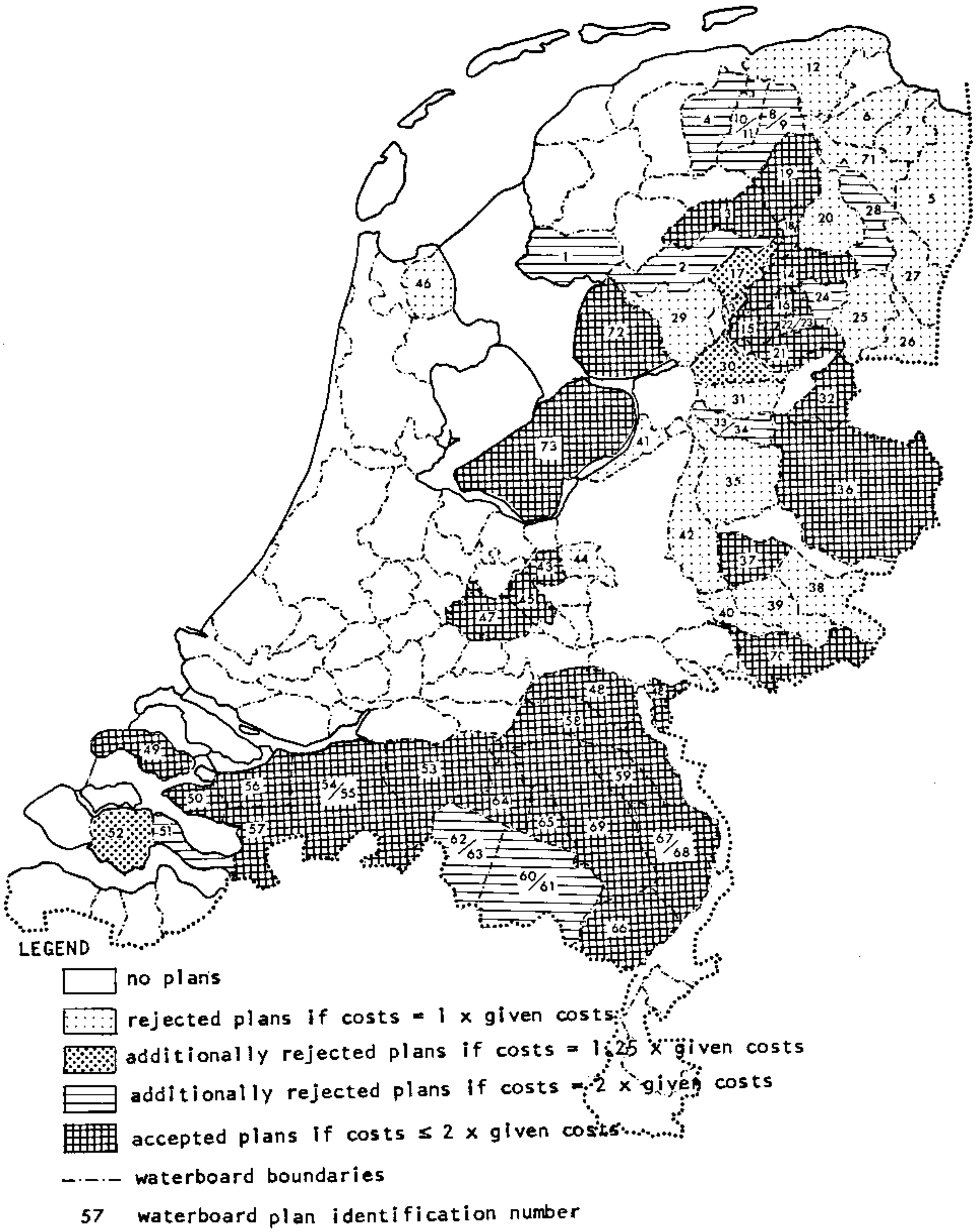

Fig. B.1--Approximate location of waterboard plans and results of their pre-screening

Because of the uncertainties with respect to plan costs, we carried out some sensitivity analysis. The calculation of net plan benefits was repeated with costs that were inflated by a factor of 1.25 and 2, respectively. Increasing the costs by 25 percent caused an additional 4 plans to be screened out, leaving 42 in. If the investment costs were doubled, 10 more plans dropped out (i.e., 14 more plans compared to the base case), leaving 32 promising plans. This information is summarized in Fig. B.1, which shows the status and approximate location of the waterboard plans. The plans are associated with the waterboards in which they are located and are identified by their plan number (see Table B.1). Furthermore, the different shadings indicate if plans are accepted or rejected, depending on the assumptions about plan costs. Note that the map shows waterboard areas, not actual plan areas. The plan areas comprise only a small part of the waterboards. The map shows the status of each plan by shading the entire waterboard in which the plan is located. No attempt was made to locate the plan areas within the waterboards.

NOTES

1. This is the assumption that is made in the demand scenarios with no waterboard plans implemented (RNONE).
2. CBS stands for the Centraal Bureau voor de Statistiek (Central Bureau of Statistics).

REFERENCES

B.1. Centraal Bureau voor de Statistiek, Landbouwtelling Mei 1976, Tabel 1: Oppervlakte en indeling van de kultuurgrond (Agriculture Survey May 1976, Table 1: Area and Classification of Cultivated Area), Voorburg, May 1976.

B.2. Centraal Bureau voor de Statistiek, Bodemstatistiek (Land Use Statistics), Voorburg, January 1975.

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