A RAND NOTE

Policy Analysis of Water Management for the Netherlands

Vol. XI, Water Distribution Model

L. H. Wegner

October 1981

N-1500/11-NETH

Prepared for

The Netherlands Rijkswaterstaat

Rand
SANTA MONICA, CA. 90406

This note was prepared with the support of The Netherlands Rijkswaterstaat under Contract No. WW-256.

Published by The Rand Corporation

A RAND NOTE

Policy Analysis of Water Management for the Netherlands

Vol. XI, Water Distribution Model

L. H. Wegner

October 1981

N-1500/11-NETH

Prepared for

The Netherlands Rijkswaterstaat

Rand
SANTA MONICA, CA. 90406

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. XI in the PAWN series, describes the Water Distribution Model (DM), the central model in PAWN's analysis methodology. The DM is a computer simulation of the water distribution system in the Netherlands. It determines water demands over time, allocates water resources to help meet the demands, calculates the concentrations of several water pollutants throughout the distribution system, calculates losses to agriculture and shipping due to water shortages and water salinity, and provides output from which the costs of meeting water thermal standards can be determined for the electrical power industry (see Vol. XV).

The DM was used in the screening stage of the PAWN analysis to estimate the expected monetary benefits (or disbenefits) to agriculture and shipping from implementation of the technical and managerial tactics being evaluated. In the impact assessment stage of the analysis, the DM was used to determine the monetary benefits (or disbenefits) of promising water management policies to agriculture, shipping, and the electrical power generating industry, and to determine any effects of these policies on pollutant concentrations throughout the country.

This volume should be of interest to the users of the PAWN analysis who would like to know more about the details of the DM simulation, to readers of the other volumes who are interested in how the results presented in those volumes are used in the DM, and to research analysts concerned with water management analysis methodology. The volume also serves as an introduction to the water management system in the Netherlands, since the text provides an integrated description of the system infrastructure and the managerial rules used to control water distribution.

NOTES

1. Rand had had extensive experience with similar kinds of analysis and had been working with the Rijkswaterstaat for several years on other problems.
2. The Rand contract was officially with the Rijkswaterstaat, Directie Waterhuishouding en Waterbeweging (Directorate for Water Management and Water Movement), but numerous other parts of the Rijkswaterstaat contributed to the analysis.
3. Delft Hydraulics Laboratory research was performed under project number R1230, sponsored by the Netherlands Rijkswaterstaat.
4. Each water management policy involved a mix of tactics, each a particular action to affect water management, such as building a

particular canal or taxing a particular use. Four kinds of tactics were considered: building new water management facilities (infrastructure) or applying various treatments to the water (called _technical tactics_); using managerial measures (called _managerial tactics_) to change the distribution of water among competing regions and users; and imposing taxes or quotas to affect the quantity or quality of water extracted or discharged by different users (called _price and regulation tactics_, respectively). A mix of tactics of the same kind is called a _strategy_. Thus, the overall policy could be conceived as a combination of technical, managerial, pricing, and regulation strategies.

SUMMARY

The surface water management system in the Netherlands is a large system of many components. The system infrastructure consists of the rivers and canals that transport water, the lakes and reservoirs that store water, and the weirs, locks and lock bypasses, sluices, and pumping stations that are used to control the transport of water to and within the various regions of the country. The water distribution model (DM) described in this note simulates the major components of this system in detail and contains aggregated representations of the other components. For convenience, three categories of subsystems are distinguished in the overall water distribution system:

- The large rivers, canals, and lakes that comprise the national system (e.g., the Rijn River and its branches--the Waal, IJssel, and Neder-Rijn--the Maas River, the Amsterdam-Rijnkanaal, the Noordzeekanaal, the IJssel lakes, and the Zoommeer).
- The networks of waterways (small rivers, canals, boezems, and lakes) that transport water from the national system into the regions and comprise the regional systems.
- The networks of ditches that carry water from the regional systems to the individual farms and the inlet works and small waterways that connect the ditch network to the regional systems.

The national and regional systems are schematized in the DM as a single network (called the PAWN network) consisting of 92 nodes and 154 links. In general, the links represent sections of waterways, and the nodes represent locations where waterways join or places where water is stored. For the purpose of modeling drainage, groundwater, and the water demands of agriculture, the entire country is divided into 77 districts, and the networks of ditches are treated in an aggregated way within the districts.

A complete account is kept of all the water that enters the country and all the water that leaves (except that the southwestern corner of the country, the coastal dunes, and the islands in the North Sea are not included in the model). Each point in the country is assigned to one of 14 weather stations, and selected years of historical precipitation and evaporation patterns from these stations are used to determine precipitation on and evaporation from all bodies of water, and precipitation on and evapotranspiration from all croplands and nature preserves. The flows of the major rivers entering the country (the Rijn, Maas, Overijsselsche Vecht, Roer, Niers, and Swalm) are entered as discharges at the nodes where these rivers enter the network. Drainage from streams and small rivers and groundwater drainage into the large rivers, originating inside the country, are calculated as part of the discharges from the districts to the nodes

of the network. At nodes on the upper Maas, additional discharges are entered that represent drainage from highlands areas in Belgium and Germany to the Maas that is not included as part of the discharges of the major rivers.

The water demands of each of the water use categories is represented in detail in the DM. Agriculture is by far the largest user of water; croplands cover over 60 percent of the country and, during a dry period, evapotranspiration from croplands may be over 1000 m^3/s, most of which is provided by precipitation. (In contrast, the combined use of water by drinking-water companies and industry is about 30 m^3/s.) Agricultural demands are calculated by a submodel of the DM called DISTAG (for District Hydrologic and Agriculture Model) that performs detailed water balance calculations within each of the districts (including groundwater) and determines the water extraction and discharge demands from the distribution system for each of the districts as a whole.

Level control requires a large percentage of the water available during dry periods--evaporation from open water and leakage from canals and ditches can amount to as much as 300 m^3/s (approximately one-half of this is due to evaporation from the IJssel lakes). In the districts, constant water levels are maintained, and water required for level control is part of the water demand of the district. For links in the network, evaporation creates a diminished flow in the link, or, for links representing canals, a demand at the upstream end of the link to replace the water lost by evaporation. At nodes representing bodies of water used for storage, e.g., the IJssel lakes, evaporation from the storage area is treated as an irreducible water demand from the storage at the node.

Although shipping requirements for water are not represented as a direct demand, water shortages are reflected by increased shipping costs due to low flows in the major shipping arteries--the Rijn, Waal, IJssel, and Maas--and to shipping delays at locks when insufficient water is available for optimum locking operations.

Water demand for pollution control takes two forms: higher quality water is used to dilute polluted water by flushing, and water flows are used to push back salt intrusion from the North Sea or brackish bodies of water. These flushing water demands are represented as desired flushing flows through districts and desired minimum flows on specified links (for cooling water for electrical power plants, for combating salt intrusion at salt-fresh locks, for flushing the canals in cities, etc.). Management policies reduce lower priority demands for Rijn water during periods of low flows in order to increase the discharge in the Rotterdamse Waterweg and, thereby, decrease the inland penetration of the Rotterdam salt wedge.

The water demands of drinking-water companies and industry are input as groundwater extractions in the districts and surface water extractions at the nodes of the network.

A DM run simulates the water distribution for a calendar year (January 1 through December 31), using a decade as the computational time step. A decade is nominally a 10-day interval, but for convenience in aggregating results for monthly, seasonal, and yearly comparisons, a decade is defined as a variable-length interval dividing the year into 36 decades. Each month is divided into 3 decades with the first 2 decades being of 10 days' duration and the third decade filling out the remainder of the month.

Given input and calculated data by decade on how much water is available across the country (from precipitation, river discharges, groundwater flows, and storage), and how much water is desired by the various water users, the model determines the water flows in the sections of the major rivers and canals and the levels of the storage lakes. The distribution of water flows in the network is demand-driven and determined in several steps. All desired extractions and discharges (by districts, industry, etc.) are entered at the nodes, desired and minimum flows are specified for certain links, and target and emergency levels specified for the storage lakes (IJssel lakes, Zoommeer and Grevelingen when fresh, and the Maas weir ponds). A trial set of flows is obtained that meets the demands but may exceed flow capacities or the quantities of water available. When any of the constraints are violated, the DM evokes managerial rules that cut back demands for cooling water, flushing, and surface water sprinkling that affect the violated constraints until the constraints are met (or until the demands are reduced to their minimum values). In the event that any constraints are still violated, messages are printed notifying the user of the violations so that remedial action can be taken on subsequent runs (reducing the demands, changing managerial rule parameters, etc.).

After the water distribution has been determined for a decade, the DM determines pollutant concentrations at each node and in each district, for up to six pollutants: salt (chloride ion), heat, phosphate, BOD, nitrogen, and chromium. Salt concentrations are always calculated but the other pollutants are optional. Pollutant concentrations in the rivers when they enter the country are combined with pollutant discharges internal to the Netherlands, and changes in concentrations over time are modeled as exponential decay processes.

The model then calculates the monetary losses to agriculture and shipping when compared with the ideal situation in which neither of these users suffers any losses due to water shortage or salinity. The model also provides output from which costs of meeting thermal standards can be determined for the electrical power industry (Vol. XV). By comparing the output of the DM for runs with different tactics or policies, the model user can determine the relative monetary benefits of the different tactics or policies to agriculture, shipping, and the electrical power industry. The effects of different tactics or different policies on pollutant concentrations throughout the distribution system can then be compared.

ACKNOWLEDGMENTS

The Water Distribution Model described in this volume incorporates a number of components documented in other PAWN volumes. Although this volume has only a single author, it should be recognized that the work described herein has otherwise undocumented contributions from most of the members of the PAWN team.

Members of the Rijkswaterstaat contributed extensively to the formulation and input data preparation phases of the model development. In particular, J. W. Pulles, T. S. Sprong, M. A. Veen, and N. W. Zuiderveen-Borgesius, using their extensive knowledge of the water management infrastructure in the Netherlands, provided most of the water managerial rules that were included as part of the model structure. H. Groen helped design the PAWN network representation of the water distribution system in the Netherlands, and Directie Waterhuishouding en Waterbeweging districts Zuid-Oost, Zuid-West, and Noord provided most of the data required to define the water distribution system. J. Daamen provided assistance with the implementation at Rand of the IMPLIC model (developed in the Netherlands), and with the representation of the lower rivers portion of the PAWN network.

B. F. Goeller, Project Leader of PAWN at Rand, provided broad guidance throughout the project, as well as very helpful administrative support.

D. E. Emerson of the Rand staff made a variety of suggestions whose incorporation has considerably improved the readability of the final text.

Special thanks are given to E. T. Gernert, Managing Editor of PAWN at Rand, and her colleagues in the Publications Department for their care in guiding this volume to press; to N. C. Moll for her very careful editing of the original manuscript; to C. Dzitzer for preparation of the pollutant discharge tables; to L. J. Batchelder and D. Dong for preparing the many figures; and to M. P. Dobson for painstakingly incorporating changes and corrections.

CONTENTS

Appendix

FIGURES

TABLES

GLOSSARY

aquifer	A stratum of earth or porous rock that contains water.
BOD	The amount of oxygen consumed by the bacterial digestion of substances in water in a standard amount of time at a standard temperature (usually 5 days and 20 deg C).
boezem	The system of main rivers, lakes, and canals that serve as a water supply and drainage system for groups of polders in the lowlands of the Netherlands.
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.
Dfl	Dutch florin (guilder).
Dflm	Millions of Dutch florins.
DHL	Delft Hydraulics Laboratory.
DISTAG	District Hydrologic and Agriculture Model.
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 water management standpoint.
dm	Decimeter.
DM	Water Distribution Model.
drainage	The flow of groundwater to streams and rivers.
DW	Drinking water.
eutrophication	The condition in which a body of water is becoming rich in dissolved nutrients.
EPRAC	Electric Power Reallocation and Cost Model.
evapotranspiration	The combined loss of water from an area by direct evaporation and transpiration by plants.
groundwater	Water in the ground near the surface that fills

groundwater	Water in the ground near the surface that fills wells and in high ground drains to lower ground, streams, and rivers.
ha	Hectare.
highlands	That part of the Netherlands where the ground elevation is more than 2 m above mean sea level.
impact assessment	The final phase in the PAWN study. Promising water management policies were compared in terms of their many consequences (impacts) on the various sectors of the economy and the Dutch society in general.
kg/s	Kilogram per second.
km	Kilometer.
km^2	Square kilometer.
level control	The maintenance of the level of a body of water at a desired value.
lowlands	That part of the Netherlands where the ground elevation is less than 2 m above mean sea level.
m	Meter.
m^2	Square meter.
m/s	Meter per second.
m^3/s	Cubic meter per second.
mg/l	Milligram per liter.
managerial rule	A prescribed action or set of actions that controls water allocation or distribution, at least locally.
managerial tactic	A tactic that involves changing the way the water management infrastructure operates (i.e., a change in a managerial rule).
MAXTACS	The set of nine dominant promising technical and managerial tactics presented at the final PAWN briefing.
Mcal/s	Megacalorie per second.
MSDM	Managerial Strategy Design Model.

NAP	Normaal Amsterdams Peil, the mean sea level at Amsterdam. This is the reference for measuring elevations in the Netherlands.
national 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.
region	The basic geographic unit used in the screening analysis. The Netherlands was divided into eight regions, each of which is a combination of contiguous districts.
regional system	The rivers, canals, and lakes that transport water within a region and from the national system to the region.
RID	Rijksinstituut voor Drinkwatervoorziening, the Netherlands Institute for Drinking-Water Supply.
RIZA	Rijksinstituut voor Zuivering van Afvalwater, State Institute for Wastewater Treatment.
RWS	Rijkswaterstaat, the Dutch 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 could be examined in detail.
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.
water management policy	A combination of tactics--technical, managerial, pricing, and regulation--designed as a package to be an overall policy for the management of Dutch water resources.

waterway	A river, canal, or lake that is used to transport water.
waterwork	A pumping station, sluice, syphon, or lock that is used to transport water between adjacent bodies of water.
weir	A (movable) dam placed across a river to raise the level of the river behind the weir.
weir pond	The water behind a weir.
WW	Directie Waterhuishouding en Waterbeweging (The Directorate for Water Management and Water Movement). The directorate within the RWS for whom the PAWN study was done.
μg/l	Microgram per liter.

Chapter 1

INTRODUCTION

This note describes the Water Distribution Model (DM), a computer simulation of the surface water distribution system in the Netherlands. The model simulates not only the system as it currently exists but has provisions for modifying the system (by simple model inputs under control of the user) to include most of the large number of technical and managerial tactics considered in the PAWN study for improving the current system (see Vol. II).

Historically, the main water management problem in the Netherlands has been too much water. More than one-quarter of the country lies below mean sea level, and more than one-half of the low-lying portion of the country must be protected by dikes and artificially drained by use of electric and diesel pumps. Over the years continuous effort has been devoted to improving these protective measures. In recent years, increased attention has been given to the problem of too little water. As the country's population and industry have grown, the water needs of the various water user groups have grown in parallel. During dry periods the water resources are not sufficient to meet the demand. For the recent drought year 1976, it is estimated that the effects of the drought cost the economy over 6000 Dflm. In average years drought losses are on the order of 1000 Dflm (these losses are primarily to unirrigated crops). The primary effort in the PAWN study has been the evaluation of various proposed improvements to the water management system that ameliorate the effects of drought periods. The design of the DM reflects this emphasis on drought periods, and the model contains no representations of the effects of floods and storms.

1.1. SOME HYDROLOGICAL FEATURES OF THE NETHERLANDS

The Rijn River provides a major portion of the water supply of the Netherlands and is the most important shipping artery in Europe. In an average year the Rijn accounts for 63 percent of the Netherlands' water supply, precipitation 27 percent, and the Maas River 8 percent; the remaining 2 percent is from small rivers and groundwater drainage. Shortly after crossing the border from West Germany, the Rijn divides into three branches: the Waal, Neder-Rijn, and the IJssel rivers (see Fig. 1.1). The IJssel flows north into the IJsselmeer, forming with the storage in that lake the principal surface water supply for the northern portion of the country. The Waal and the Neder-Rijn continue westward to the North Sea and along with the Maas River provide the principal water supply for the southern part of the country (the Maas is the main supplier for the southeastern section).

The division of Rijn water among its three branches is controlled by means of a weir (barrier) at Driel on the Neder-Rijn. At low Rijn

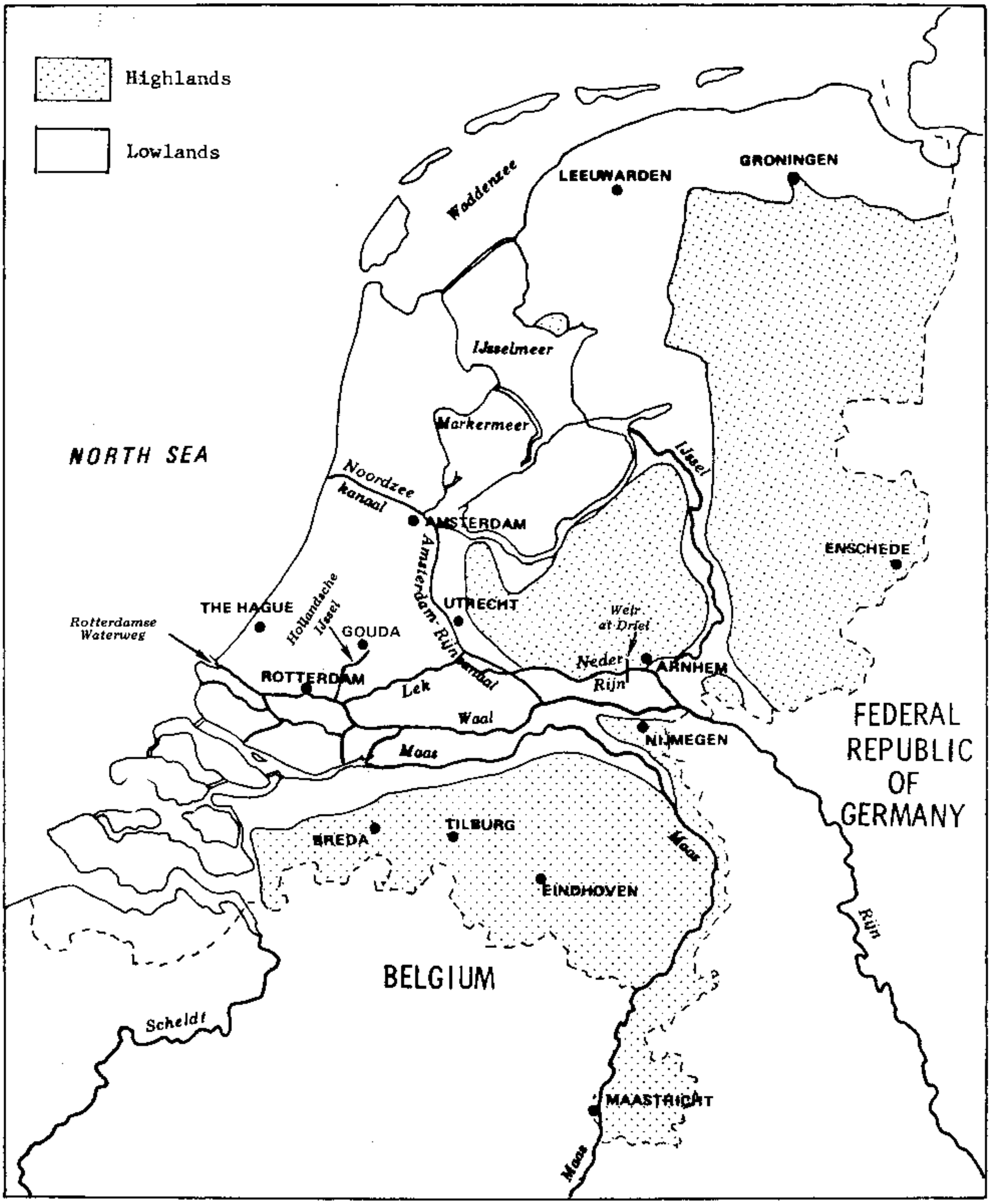


Fig. 1.1--Water system in the Netherlands: Major features

flows and with the weir completely open, the Waal carries 67 percent, the Neder-Rijn 20 percent, and the IJssel 13 percent of the Rijn flow. With the weir fully closed (or set so that there is a small flow in the Neder-Rijn), the Waal carries approximately 80 percent and the IJssel 20 percent of the total flow. Thus, the amount of Rijn water sent to the north can be substantially increased from the natural division, but at the expense of decreased supply to the southern (and midwest) sections of the country. (The two most important effects of lower flows on the Waal and Neder-Rijn are increased shipping costs on the Waal due to lower water levels and an increased penetration of the Rotterdam salt wedge, with a resultant increase in the salinity of the water supply to the salt-sensitive glasshouse crops in the midwest section of the country.)

In PAWN the lowlands are defined as that part of the Netherlands that lies below NAP + 2 m;[1] the remainder of the country is highlands. The lowlands are in the northwest, and a line drawn from the southwest corner of the country to the northeast corner approximates the division between lowlands and highlands (see Fig. 1.1).

Much of the lowlands is subdivided into polders, areas containing networks of ditches and enclosed by a system of raised canals called a boezem. Excess water from precipitation and seepage is artificially drained by pumping from the polders to the boezem systems and drained naturally or pumped from the boezem systems directly to the North Sea or to waterways that connect to the North Sea. The original low elevations of the empoldered areas have become even lower over time due to subsidence--the change in elevation amounting to 10 to 20 cm per century. Water in the ditches and boezems is maintained at high levels to prevent the soil from drying out and shrinking, and thereby further subsiding.

An extensive surface water distribution system exists in the lowlands, connecting the local boezem systems to the major distribution system. However, in dry periods parts of the lowlands distribution system have insufficient capacity to provide all the freshwater demands in the lowlands--for level control, crop irrigation, and salinity control.

A major water management problem in the lowlands is excess water salinity. The level differences between the low-lying polders and the North Sea force saline water from the North Sea and from deep brackish aquifers into the groundwater of the polders and subsequently into the surface water of the polders and the boezem canals. Saline water also enters some boezem systems as a result of locking operations at salt-fresh locks that connect canals in the lowlands to the North Sea or to brackish waterways (e.g., to the Noordzeekanaal or the Rotterdamse Waterweg).

Another important source of salt intrusion into lowlands is the Rotterdam salt wedge. The Rotterdamse Waterweg carries Rijn and Maas water into the North Sea. During periods of low discharges, tidal action forces the denser salt water of the North Sea under the lighter fresh water (in the form of a salt wedge) and the salt water may penetrate tens of kilometers inland. As the salt wedge penetrates farther upstream, mixing takes place, the vertical salinity profile becomes less pronounced, and water extracted at points in the Rijn delta under influence of the salt wedge will have an increased salt content. (The salinity of seawater is approximately 18000 mg/l. Since damage to salt-sensitive crops starts at salinities of 200 mg/l or so, it is easy to see the importance of keeping seawater away from intake points for agriculture.) The most important intake point influenced by the salt wedge is the inlet at Gouda on the Hollandsche IJssel. The Gouda inlet provides the water supply for the midwest section of the country, a section that contains a high percentage of the valuable, and salt-sensitive, glasshouse crops.

The increased salinity in the polders and boezems due to seepage and salt intrusion is diluted in wet periods by precipitation. But during dry periods surface water extractions are used to dilute and flush the saline water from the boezems. Most of the surface water supply in the lowlands is from the Rijn, and, since the salinity of the Rijn has been steadily increasing, the salinity-reducing effect of flushing is continually being diminished. (The average rate of increase per year in the salt load of the Rijn is about 6 kg/s, from 60 kg/s in 1930 to 350 kg/s in 1979; in periods of low Rijn flows, the salt concentration may exceed 400 mg/l.)

The situation in the highlands portion of the country is quite different from that in the lowlands. There are no polders and no serious salinity problems from seepage or salt intrusion. Excess water from precipitation drains from the land by ditches into streams or percolates into the groundwater from where it drains into streams and rivers. The surface water supply system in the highlands is much less developed than in the lowlands, and some areas have no access to surface water. Accordingly, there is a much higher use of groundwater for crop irrigation in the highlands than in the lowlands. Even though the supply needed in the highlands is small relative to that needed in the lowlands, the capacities of the supply routes to the highlands from the major distribution system generally are becoming inadequate to meet the increasing demands during dry periods.

In the Southeast Highlands (the highlands south of the Waal River) the principal source of surface water is the Maas River. The Maas has very low salinity (usually less than 100 mg/l) and generally adequate discharges, but during dry periods the Maas may provide as little as 10 m^3/s to the supply of the Southeast Highlands[2]--not nearly enough to meet the needs at Maastricht, where the Maas discharge is divided among several competing demands: a flow on the Zuid-Willemsvaart to supply water to a large portion of the Southeast Highlands and for shipping on the Zuid-Willemsvaart and the Wilhelminakanaal; extractions by industry of 1.7 m^3/s; a desired flow on the Julianakanaal of 16 m^3/s for shipping; and a desired flow on the Grensmaas (the section of the Maas that is part of the border with Belgium) of 10 m^3/s for pollution control. As the Maas flows farther north into the Netherlands, the flow is increased substantially by the discharges of small tributaries and groundwater drainage (e.g., between Maastricht and Panheel the Maas flow is increased by 6 to 8 m^3/s by groundwater drainage, and at Roermond the flow is increased by a minimum of 10 to 12 m^3/s by the discharge of the Roer River).

The Northeast Highlands (the highlands north of the Waal) are supplied from the east by the discharge of the Overijsselsche Vecht River, from the south by the IJssel River via the Twenthekanaal, and from the north by the Ketelmeer via the Zwartemeer, Meppelerdiep, and the Drentsche Hoofdvaart. The combined capacity of all of these routes is insufficient to meet the demands in dry periods (e.g., the discharge of the Overijsselsche Vecht can drop below 2 m^3/s). Furthermore, the source for the northern and southern supply routes is ultimately the Rijn, and the increasing Rijn salinity is increasing the salinity of the supply to the Northeast Highlands. Fortunately, the crops grown in the Northeast Highlands are not very salt-sensitive, and losses to crops due to salt damage are relatively small.

1.2. THE RELATIONSHIP OF THE DM TO WAMAMO

At the beginning of the PAWN project there was already in existence a computer model of the water distribution system in part of the Netherlands called WAMAMO (for Water Management Model). Although WAMAMO contained many of the components needed for PAWN, it was decided that a number of changes would be necessary and that it would be more efficient to design a new model incorporating many of the features of WAMAMO but tailored to the needs of the screening of technical and managerial tactics and impact assessment stages of the PAWN study. In particular, it was decided that a more realistic model of agricultural water demands and the costs of water shortage and water salinity to agriculture was necessary; that the various managerial and technical tactics to be evaluated be incorporated directly in the model; and that provision be made for including several pollutants. Since the new agriculture model envisioned would be expensive in computer running time, it was desired that the remainder of the DM model be as efficient as possible, and that the best way to achieve this goal was to develop a new model of the water distribution system in parallel with the development of the model for agriculture.

The WAMAMO and DM models are to a certain extent complementary. WAMAMO is best used to obtain estimates of frequencies of occurrence of various events of interest to water management based on historical time series on weather and water supply, e.g., the number of decades in which IJsselmeer levels drop below a specified level. The DM is more useful as an aid in estimating costs and benefits of proposed changes in water management infrastructure and policies.

1.3. THE RELATIONSHIP OF THE DM TO MSDM

A second model of the water distribution system in the Netherlands was developed in PAWN (Vol. V). The MSDM (for Managerial Strategy

Design Model) starts from the conceptual point of view that the water management problem is one of optimal allocation of scarce resources among competing demands. The problem is then formalized as a nonlinear program that distributes water to maximize the total monetary benefits. Within the model, for example, water quality standards may be placed as constraints and the costs of meeting these constraints measured by the loss in benefits under the (new) optimal allocation. The DM and MSDM models are complementary--the more detailed DM has no optimization procedure but can use optimal allocation rules developed by the MSDM, apply them throughout the year, and serve as a check on the MSDM optimization that uses aggregated versions of the PAWN network and districts.

1.4. THE USE OF THE DM IN SCREENING OF TECHNICAL AND MANAGERIAL TACTICS

A water managerial tactic is any proposed change in the water management system that is designed to solve some water management problem or help meet some water management objective. A technical tactic is one that modifies or adds to the existing water management infrastructure, e.g., the expansion or construction of canals, pumping stations, or weirs. A managerial tactic changes the operation of the water distribution system. Changes in weir control schedules, lake level control rules, and flushing rules for lakes and boezems are all examples of managerial tactics. Technical and managerial tactics influence the supply of water by physical controls and restrictions on water movement or lake levels. The demand for water can also be influenced--by pricing and regulation. Pricing and regulation tactics change the prices of water and the regulations on its use.

In the screening of technical and managerial tactics stage of the PAWN study, over 100 individual technical and managerial tactics and 65 waterboard plans were evaluated. (Waterboard plans are proposals by waterboards for improvements in the local infrastructure that provides water to the individual farms in the area under the waterboard's jurisdiction.) The purpose of the screening stage of the analysis was to eliminate from further consideration those tactics whose benefits were judged not to be worth their costs or which were dominated by some retained tactic designed to solve the same water management problem. The DM was used in the evaluation to estimate the expected monetary benefits (or disbenefits) to agriculture and shipping from implementation of the tactics.

The benefits from implementing a tactic will, in general, differ year by year, depending primarily upon the temporal pattern of river flows and the temporal and spatial patterns of precipitation and evaporation. In principle, the expected (or average) benefits of a tactic could be estimated by running the DM for a large number of years, using actual patterns of river flows, precipitation, and evaporation, or by using a time series of these random variables derived synthetically from Monte Carlo procedures using estimated probability distributions. Two such runs would be compared--one with the tactic and one without--to determine the benefits of the tactic.

However, this procedure would be prohibitively expensive for the many tactics to be evaluated and the many simulated years needed to obtain useful estimates of the expected benefits of each tactic--the DM costs approximately 250 Dfl per simulated year. Instead, formulas were developed that provide upper and lower bounds on the expected benefits of a tactic as weighted sums of the calculated benefits from runs of only four years (Vol. II). Three of these years were selected from among the years 1930-1976 on the basis of their ranking on various drought criteria: 1959 was selected as a "very dry" year; 1943 as a "moderately" dry year; and 1967 as an "average dry" year. The fourth year (called DEX), an "extremely dry" year, was constructed artificially using 1976 values except for Rijn flows, which were set equal to the minimum of the flows from the dry years 1976, 1949, and 1934 on a decade-by-decade basis. (A wetter than average year was selected but not used in screening since all the tactics evaluated were designed to help solve water shortage problems in drought periods and will have little or no benefits in wet years; and in the upper- and lower-bound formulas, wetter than average years are assumed to have zero benefits.) Special multiyear runs of the DM for the years 1930-1976 were used to estimate the probability distribution of losses due to water shortage and water salinity, and the exceedance probabilities for each of the "dry years" were estimated from the year's position in the estimated probability distributions. The weights attached to the years in the upper- and lower-bound formulas are functions of these exceedance probabilities (see Vol. II). Table 1.1 contains the estimated exceedance probabilities for each of the four years.

Table 1.1

ESTIMATED EXCEEDANCE PROBABILITIES
FOR THE FOUR SELECTED YEARS

Type	DEX	1959	1943	1967
Losses due to water shortage	0.02	0.07	0.21	0.63
Losses due to water salinity	0.02	0.09	0.13	0.57

NOTE: An exceedance probability is the probability that an annual loss will exceed that of the given year.

1.5. THE USE OF THE DM IN IMPACT ASSESSMENT

In PAWN, a water management policy is a combination of tactics--technical, managerial, pricing, and regulation--designed as a package to be an overall policy for the management of Dutch water resources. The objectives of the PAWN study were to formulate alternative water management policies, to develop appropriate tools and methodologies for evaluating and selecting promising policies, and to compare the promising policies in terms of their impacts on the various sectors of the economy and Dutch society in general. After the screening stage of the study, the surviving tactics were combined into promising policies, whose many consequences (impacts) were estimated in the impact assessment stage of the study.

For impact assessment, 38 cases were defined--a case consists of a water management policy and assumptions concerning scenario variables defining the future environment for the policy and perhaps affecting its impacts. Table 1.2 (see page 12) contains the values of the policy and scenario variables defining the 38 impact assessment cases. These cases differ in the values of the policy and scenario variables described below and summarized here:

1. External supply--DEX, 1943, or 1967.
2. Managerial strategy--RWS, MSDM, or VELSEN.
3. Implementation of the 46 waterboard plans, or no implementation.
4. MAXTACS or no MAXTACS.
5. Level of installed surface water sprinklers--low, medium, or high.
6. Level of installed groundwater sprinklers--low, medium, or high.
7. Groundwater quota--0.25, 1.0, or 1.5 times the extractable amount.
8. Groundwater extraction priority--agricultural or industry/drinking-water companies (for medium and high levels of installed groundwater sprinklers only).
9. Groundwater charge--0.0 or 0.20 Dfl/m^3.
10. Rijn salinity--reference value for the Rijn salt dump (311 kg/s) or the high value (365 kg/s).
11. Other pollutants--reference values (1976 measured concentrations) or low (1985 scenario) values.

A complete discussion of the policy and scenario variables is contained in Vol. I; here we shall describe in general terms those variables that affect the impact assessment cases. The external supply scenario was chosen as one of three "dry years" defined in Sec. 1.4--DEX, the extremely dry year; 1943, the moderately dry year; or 1967, the average dry year.

Technical tactics can be divided into two groups, network infrastructure tactics and waterboard plans, and they were evaluated separately in screening. Eight of the network tactics were considered dominant over the remainder for a future scenario that included implementation of promising waterboard plans and a high level of installed sprinklers (see below). These eight tactics were considered as a unit, called MAXTACS, in impact assessment. We assumed that either all or none were to be implemented. MAXTACS consists of the following:

1. Expansion of the throughput capacity of the Van Starkenborghkanaal at Gaarkeuken by 9 m^3/s.

2. Expansion of supply capacity of the Twenthekanaal by 15 m^3/s.
3. An increase in the combined supply capacity of the Zuid-Willemsvaart, Kanaal Wessem-Nederweert, Noordervaart, and Wilhelminakanaal (by pumping water south) by 15 m^3/s.
4. Maintenance of the portable pumping capacity of 5 m^3/s at the Maasbracht lock on the Julianakanaal.
5. A decrease in the minimum levels of the IJsselmeer and Markermeer in summer by 10 cm (to NAP - 50 cm).
6. Construction of a pipeline from the Maas to Delfland with a capacity of 8 m^3/s.
7. Construction of a groin in the Nieuwe Waterweg.
8. A fresh Grevelingen supplied from an inlet in the Grevelingendam.

Some 65 waterboard plans were evaluated in screening, and 46 of the plans were retained as promising; most of the retained plans are located in the Northeast Highlands, Southeast Highlands, and the Delta areas. The retained plans were treated as a unit in the impact assessment cases assuming that either all or none were to be implemented.

Three managerial strategies, i.e., combinations of managerial tactics, were retained for impact assessment--the RWS, VELSEN, and MSDM strategies (Sec. 5.4). The RWS and VELSEN strategies differ only in the managerial rule for flushing the Noordzeekanaal. Both strategies are designed to achieve a minimum flow of 40 m^3/s in the Noordzeekanaal for salinity control in the canal and to provide cooling water for the Hemweg power plant at Amsterdam and the Velsen power plant at IJmuiden. But the RWS strategy achieves these objectives by bringing 20 m^3/s up the Amsterdam-Rijnkanaal, while the VELSEN strategy brings sufficient water from the IJsselmeer to reach the desired minimum flow. The MSDM strategy starts with the flows (and flow constraints) of the VELSEN strategy and attempts to improve upon the strategy by finding new flows that meet the constraints and minimize a loss function--the sum of the low water shipping losses on the Waal and IJssel (Sec. 7.2.1), the dredging costs on the Waal due to extractions at Tiel (Sec. 7.2.3), a proxy for the salinity losses due to the Rotterdam salt wedge (Sec. 6.2.3), and the negative of the future value of water stored in the IJssel lakes (Vol. V).

Three different levels for the area of croplands irrigated by overhead sprinkling were used in impact assessment--low, medium, and high. The total sprinkled area for each level depends upon whether or not the retained waterboard plans are assumed to be implemented. Without implementation of the waterboard plans, the low level approximates the current sprinkled area for both surface water and groundwater sprinkling. When waterboard plans are implemented, additional croplands have access to surface water, and surface water sprinklers are assumed to be installed in this newly suppliable area to the same extent as in the original suppliable area on a crop-by-crop basis; croplands without access to surface water are assumed to have the same level of groundwater sprinkling as without implementation of waterboard plans. For the high level, sprinklers are assumed to be installed on all croplands for which it is cost-beneficial to do so, for both croplands with access to surface water and those without. (See Vol. XIV for precise definitions of both the low and high level cases.) For the medium level, the sprinkled areas are taken to be the average of the low and high levels for both surface water and groundwater sprinklers. The sprinkled agricultural area increases from 13 percent of the total agricultural area (10 percent from surface water and 3 percent from groundwater) for the low level case with no waterboard plans implemented to 47 percent (31 percent from surface water and 16 percent from groundwater) in the high level case with all retained waterboard plans implemented.

Groundwater quota represents the maximum amount of groundwater that can be extracted in each district, and is expressed as a fraction of RID's (the Rijksinstituut voor Drinkwatervoorziening) estimates of the extractable amounts. The quota values used in impact assessment were 0.25, 1.0, and 1.5 times the extractable amounts.

For cases with the low level of installed sprinklers (i.e., the current situation), agriculture is assumed to extract what it needs and industry and drinking-water companies what they need up to the quota values. For cases with medium and high levels of installed groundwater sprinklers, groundwater extraction priority may be given to either agriculture or to industry and drinking-water companies for the groundwater available over that used by currently installed sprinklers, up to the groundwater quota.

The groundwater charge is a use charge or tax to be paid by farmers, industry, and drinking-water companies for each cubic meter of groundwater extracted. The values used are either 0.0 or 0.20 Dfl/m^3; the latter value is an estimate of the maximum charge to industry in the proposed groundwater law (Vol. VII).

In the DM, the salt concentration of the Rijn discharge at the Dutch border may be generated for each decade from a model using a single input parameter, the Rijn salt dump, representing the annual amount of salt dumped into the Rijn by industry. The values used for impact assessment are the reference value, 311 kg/s, the trend-line value for 1976, and the high value, 365 kg/s, the trend-line value for 1985 (Sec. 6.2.1). The salinities of the discharges of the other major rivers are taken to be their 1976 values.

The concentrations of the other pollutants in the major rivers at the border are taken to be the reference values, the measured concentrations in 1976; or the low or 1985 scenario values, the minimum of the measured concentrations in 1976 and 0.3 mg/l for phosphate, 2 mg/l for BOD, and 10 μg/l for chromium. The low values represent a mid-1980s situation in which it is assumed that measures have been taken to limit the amount of pollutants in the rivers.

In Table 1.2, the "A" cases are considered to be the base cases--they approximate the current situation with respect to the policy and sprinkling variables. The costs and benefits of other cases are obtained by comparing them with the A cases having the same external supply. The "A" through "F" cases are considered primary cases and constitute the minimum set used in all of the impact assessment evaluations; they consist of the base case, promising policies, and variations of sprinkler scenario variables for both surface water and groundwater sprinkling. The remaining cases are designed to examine the impact sensitivities to important policy and scenario variables. The cases used in various sensitivity comparisons are given in Table 1.3.

DM runs were made for the 38 impact assessment cases to determine the monetary benefits (or disbenefits) to agriculture and shipping and the total costs (sprinkling and tactic costs). The DM output was also used as input for determining other impacts: the costs to electrical power companies of meeting the thermal standards on rivers and canals; the distribution of agricultural benefits among provinces and among crop types; the distribution of costs and benefits to different impact groups--producers, consumers, and government; and the division of benefits and costs between the Netherlands and foreign countries.

The DM output for pollutants provided data for assessing the degree to which pollutant standards were being met for salt, phosphate, BOD, and chromium. The measure used for each pollutant was the sum over all nodes of the number of decades for which the pollutant concentration standard (Sec. 6.4.6) was not met at the nodes. Separate totals were also calculated for national nodes (i.e., network nodes in the national system) and provincial nodes.

1.6. THE CONTENTS OF THIS VOLUME

Chapter 2 presents the PAWN network. It indicates the correspondence between the network links and nodes and the infrastructure of the actual distribution system and presents the values that were used for the parameters associated with the network links and nodes. As an aid in presenting and interpreting results from DM runs, the Netherlands was divided into eight regions. For modeling groundwater and the water demands of agriculture, the regions were subdivided into a total of 77 districts (districts were further subdivided into over 1200 smaller areas called plots). The regions and districts are also presented in Chap. 2.

All discharges (by the major rivers, districts, industry, and drinking-water companies) and extractions (by districts, Belgium, industry, and drinking-water companies) from the surface water distribution system are represented at the nodes of the network. Extractions from groundwater by industry and drinking-water companies are treated within the districts (part of these extractions are discharged back into the surface water of the districts). Chapter 3 describes how the various sources of water supply and the water demands of the various user groups are integrated into the model.

Table 1.2

IMPACT ASSESSMENT CASES

Case Name											Pollutants	
	Ext. Supply		Mana-gerial	Water-board	MAX-	Surface Water	Groundwater				Rijn Salt	
DEX	1943	1967	Strat.	Plans	TACS	Sprink.	Sprink.	Quota	Priority	Charge	Load	Other
A1	A2	A3	RWS	No	No	Low	Low	1.0	None	0	Ref	Ref
B1	B2	B3	MSDM	No	No	Low	Low	1.0	None	0	Ref	Ref
C1	C2	--	MSDM	Yes	No	Med	Low	1.0	None	0	Ref	Ref
D1	D2	--	MSDM	Yes	Yes	Med	Low	1.0	None	0	Ref	Ref
E1	E2	--	MSDM	Yes	Yes	Med	Med	1.0	I/D	0	Ref	Ref
F1	F2	F3	MSDM	Yes	Yes	High	High	1.0	I/D	0	Ref	Ref
G1	G2	G3	MSDM	Yes	Yes	High	Low	0.25	AGR	0	Ref	Ref
H1	H2	--	RWS	Yes	Yes	High	High	1.0	I/D	0	Ref	Ref
J1	J2	--	VEL	No	No	Low	Low	1.0	None	0	Ref	Ref
K1	K2	--	VEL	Yes	Yes	High	High	1.0	I/D	0	Ref	Ref
L1	--	--	MSDM	Yes	Yes	High	High	1.0	I/D	0.20	Ref	Ref
M1	--	--	MSDM	Yes	Yes	High	High	1.0	AGR	0.20	Ref	Ref
N1	--	--	MSDM	Yes	No	Low	Low	1.0	None	0	Ref	Ref
P1	P2	--	MSDM	Yes	Yes	High	High	1.0	AGR	0	Ref	Ref
Q1	--	--	MSDM	Yes	Yes	High	High	1.5	I/D	0	Ref	Ref
R1	R2	R3	MSDM	No	No	Low	Low	1.0	None	0	High	Ref
S1	S2	S3	MSDM	Yes	Yes	High	High	1.0	I/D	0	High	Ref
T1	--	T3	MSDM	Yes	Yes	High	High	1.0	I/D	0	Ref	Low

NOTES: Groundwater charge is in Dfl/m3. I/D indicates priority to industry and drinking-water companies. AGR indicates priority to agriculture.

Table 1.3

IMPACT ASSESSMENT CASES USED FOR VARIOUS COMPARISONS

	Case																	
Type of Comparison	A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q	R	S	T
Base Case	X																	
Primary cases	X		X	X	X	X	X											
Effect of different management strategies	X	X				X		X	X	X								
Effect of increasing surface water sprinkling		X	X	X			X						X					
Effect of increasing groundwater sprinkling		X			X	X					X			X	X			
Effect of groundwater quota, priority, and charges						X	X				X	X		X	X			
Effect of increasing Rijn salt load	X	X				X										X	X	
Effect of decreasing Rijn BOD load	X					X												X

In the DM, the PAWN network of nodes and links is divided into a national system and six regional systems. The national system represents the major rivers, canals, and lakes that transport water into and across the country--the Rijn branches (the IJssel, Neder-Rijn, and Maas rivers), the Rijn delta, the Maas River, the Amsterdam-Rijnkanaal, the Noordzeekanaal, and the IJssel lakes. The links and nodes of the regional systems represent the portions of the water distribution system infrastructure that connect the national system to the different regions and transport water within the regions. Each of the regional systems extracts and discharges water at a few nodes of the national system, but does not connect to any other regional system (with one minor exception).

This factoring of the network into smaller networks simplifies the problem of determining the overall water distribution in the DM since the water distribution in each regional system can be determined independently of the water distribution in the other regional systems. And the water distribution in the national system can be determined separately from that in the regional systems, knowing the regional system extractions at the nodes of the national system. Chapters 4 and 5 define the nodes and links of the regional systems and the national systems, respectively, and describe the managerial rules that are implemented to effect the water distribution within each of the systems.

Chapter 6 defines the submodels that calculate the pollutant concentrations at each node and district in the network, and describes how they were calibrated. Chapter 7 describes how the losses to shipping and agriculture are calculated and combined with the investment and operating costs of tactics to give the monetary benefits (or disbenefits) of the tactics when compared with DM runs without the tactics. In Chap. 8, a comparison is made between measured values of flows and pollutant concentrations and values calculated by the DM for the drought year 1976.

Several appendixes are included that support the main text. Appendix A contains equations that give the distribution of the Rijn discharge among the IJssel, Neder-Rijn, and Waal for both the existing situation and the situation if the IJssel is canalized. Appendix B presents equations that approximate the water distribution among the branches in the lower rivers portion of the combined delta of the Rijn and Maas as functions of the flows in the Lek, Waal, and Maas and extractions from the lower rivers branches. Appendix C presents the differential equation that is used for pollutant concentration decay at nodes with storage. The inputs and outputs of the DM are given in Appendix D. And Appendix E lists changes that were made in the DM between December 1979 and July 1980.

NOTES

1. NAP (Normaal Amsterdams Peil) is the reference water level in the Netherlands and corresponds approximately to mean sea level.
2. A proposed treaty between the Netherlands and Belgium, the Maas Treaty, would guarantee a minimum flow into the Netherlands of 50 m^3/s (through the use of new reservoirs in Belgium). The Netherlands would return 23 m^3/s to Belgium and keep 27 m^3/s for its own use.

Chapter 2

THE PAWN NETWORK, DISTRICTS, AND REGIONS

2.1. THE PAWN NETWORK

The major waterways of the surface water distribution system in the Netherlands are shown in Fig. 2.1. The main infrastructure of this system is schematized in PAWN as a single network consisting of 92 nodes and 154 links (see Fig. 2.2). The links and nodes both serve dual purposes. The majority of the links represent the major rivers that bring water into and across the country--the Rijn and its branches, the Maas, and the Overijsselsche Vecht--or the canals that supply the various sections of the country with water from these rivers or from the IJsselmeer. The majority of the nodes represent the locations where these rivers and canals meet. But nodes may also be storage nodes representing major bodies of water, and the links joining storage nodes may represent an open connection between the bodies of water or sluices, locks, and pumps that transport water between the bodies of water.

In Fig. 2.2 the circles (with enclosed numbers) represent the nodes, and the lines joining the circles are the links. The squares (with enclosed numbers) indicate the 77 districts into which the Netherlands has been divided for modeling agriculture and groundwater (see Fig. 2.3 and Sec. 2.2), and the dashed lines connecting the district squares to the nodes indicate the closest nodes on the waterways where the districts extract and discharge water.

2.1.1. Links

The links indicated by solid lines in Fig. 2.2 represent waterways in the current infrastructure. The links indicated by dotted lines represent waterways that do not currently exist; they are included in the network so that they may be evaluated as possible future additions. As part of the default parameters defining the network, these links are given flow capacities of zero and are not used unless nonzero capacities are supplied by the user as part of the inputs.

Each link is identified by both a number and an 8-character mnemonic name. Table 2.1 contains the link numbers, mnemonic names, full names of the waterways or waterworks that the links represent, the nodes that each link connects, and parameter values for the links (the values of the parameters reflect the current system [2.1, 2.2, 2.3]). The table is read from a dataset at the beginning of a run; however, at any decade of a run, the Cap.1, Cap.2, and FLCT entries may be changed by inputs. For example, the desired flow for flushing the Markermeer from the IJsselmeer is 30 m^3/s in winter (the FLCT entry for link 67, ORANJESL) and 70 m^3/s in summer; this desired flow change is effected by an input that changes the FLCT entry for ORANJESL from 30 to 70 m^3/s in the 13th decade and another changing it back to 30 m^3/s in the 28th decade.

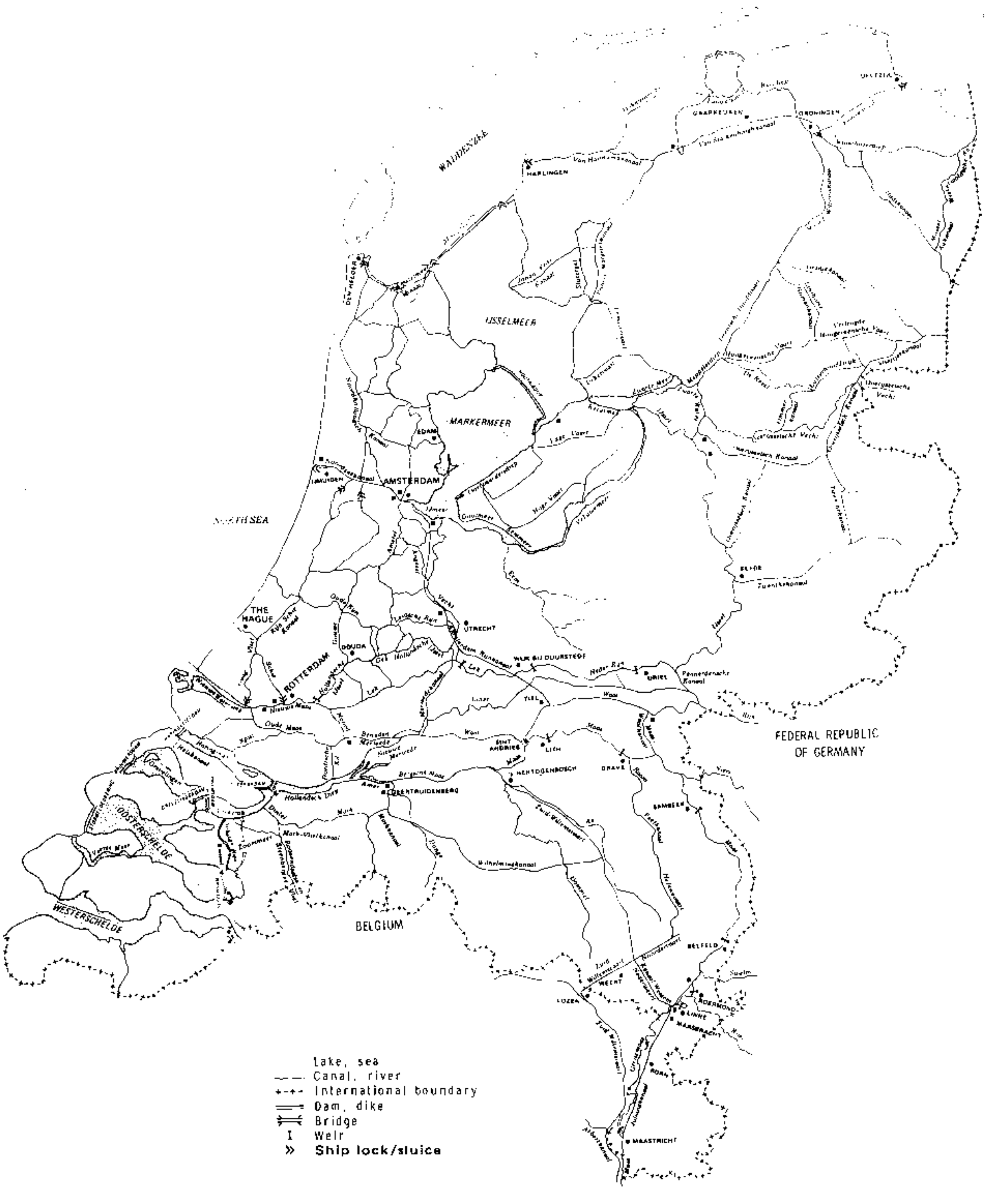


Fig. 2.1--Major waterways in the Netherlands

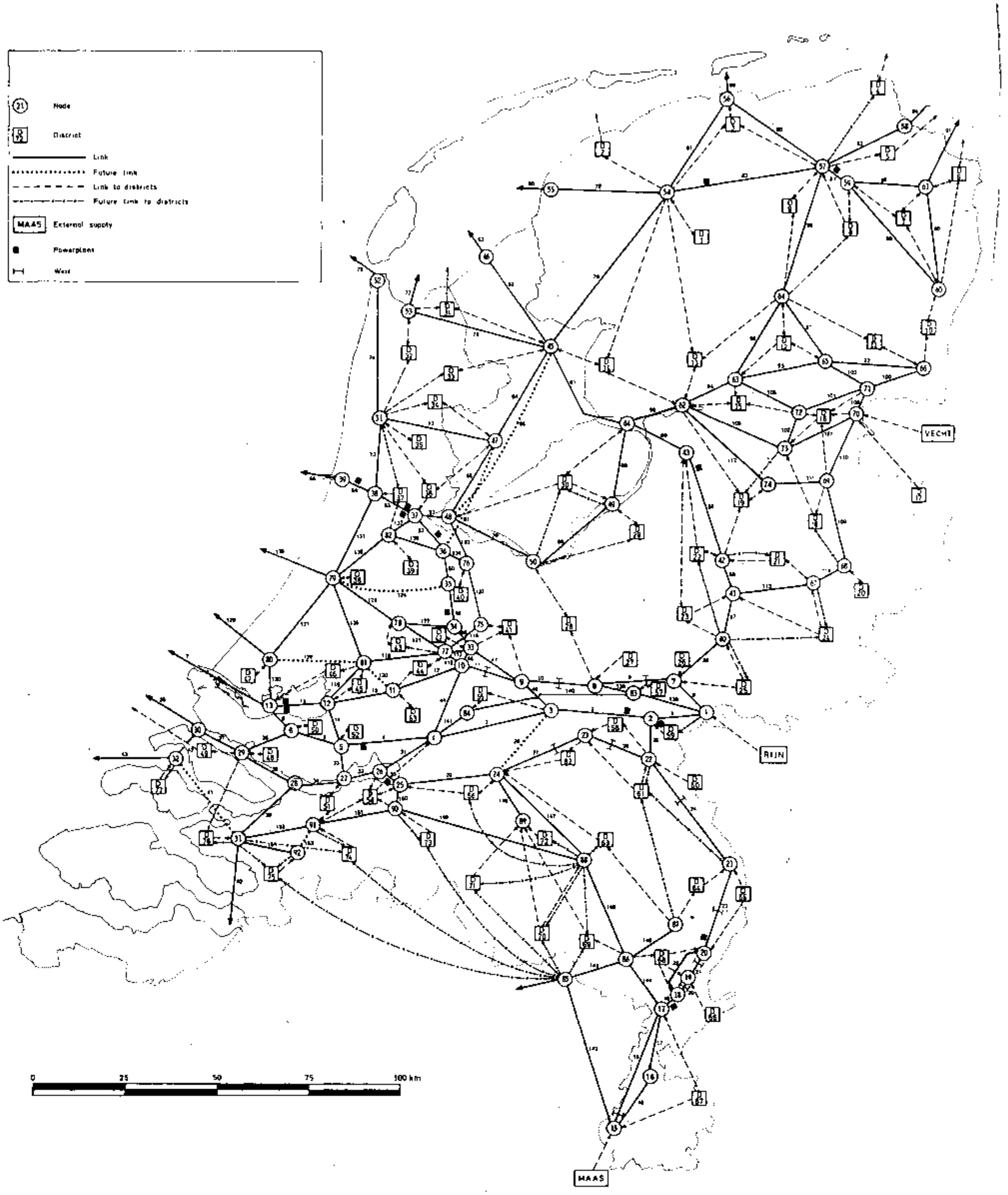


Fig. 2.2--The PAWN network

Table 2.1

LINK DATA

Link No.	Link Name	Waterway	From Node No.	From Node Name	To Node No.	To Node Name	Cap.1 (m3/s)	Cap.2 (m3/s)	FLCT (m3/s)	Surf. Area (km2)	Vol. (mil. m3)
1	WAAL1	Waal	1	PANDNKOP	2	NIJMEGEN	0.0		0.0	5.0	25.0
2	WAAL2	Waal	2	NIJMEGEN	3	TIEL	0.0		0.0	11.2	56.0
3	WAAL3	Waal	3	TIEL	4	GORINCHM	0.0		0.0	19.0	56.2
4	BENEMERW	Beneden Merwede	4	GORINCHM	5	DORDRECT	0.0		0.0	4.9	16.5
5	OUDEMAS1	Oude Maas	5	DORDRECT	6	OUDBIJER	0.0		0.0	11.9	65.8
6	OUDEMAS2	Oude Maas	6	OUDBIJER	13	SCHEUR	0.0		0.0	1.5	11.2
7	NEWATWEG	Nieuwe Waterweg	13	SCHEUR	14	NOORDZEE	0.0		1500.0T	13.2	142.0
8	PANDKAN	Pannerdensche Kanaal	1	PANDNKOP	7	IJSELKOP	0.0		0.0	1.6	4.8
9	NEDRIJN1	Neder-Rijn	7	IJSELKOP	8	WAGINGEN	0.0		0.0	2.7	8.1
10	NEDRIJN2	Neder-Rijn	8	WAGINGEN	9	DURSTEDE	0.0		0.0	2.1	6.3
11	LEK1	Lek	9	DURSTEDE	10	VIANEN	0.0		0.0	2.6	10.4
12	LEK2	Lek	10	VIANEN	11	SCONOVEN	0.0		0.0	4.5	15.6
13	LEK3	Lek	11	SCONOVEN	12	IJSLMOND	0.0		5.0T	5.5	22.8
14	NOORD	Noord	5	DORDRECT	12	IJSLMOND	0.0		0.0	2.2	10.1
15	NIEWMAAS	Nieuwe Maas	12	IJSLMOND	13	SCHEUR	0.0		0.0	10.9	67.5
16	JULKANL1	Julianakanaal	15	MASTRICT	16	BORN	4.0	23.0	22.0T	0.0	0.0
17	JULKANL2	Julianakanaal	16	BORN	17	PANHEEL	4.0	23.0	22.0T	0.0	0.0
18	MAAS1	Maas (Born lock)	15	MASTRICT	17	PANHEEL	1.0		10.0T	0.0	0.0
19	MAAS2	Maas (Linne weir and lock)	17	PANHEEL	18	LINNE	0.0		0.0	0.0	0.0
20	MAAS3	Maas (Roermond weir and lock)	18	LINNE	19	ROERMOND	0.0		0.0	0.0	0.0
21	MAAS4	Maas (Belfeld weir and lock)	19	ROERMOND	20	BELFELD	0.0		0.0	0.0	0.0
22	LATRAKAN	Lateraalkanaal	18	LINNE	20	BELFELD	0.0	9.5	9.5T	0.0	0.0
23	MAAS5	Maas (Sambeek weir and lock)	20	BELFELD	21	SAMBEEK	0.0		0.0	0.0	0.0
24	MAAS6	Maas (Grave weir and lock)	21	SAMBEEK	22	GRAVE	0.0		0.0	0.0	0.0
25	MAWAKAN	Maas-Waalkanaal	22	GRAVE	2	NIJMEGEN	0.0	1.0	1.0	0.0	0.0
26	MAAS7	Maas (Lith weir and lock)	22	GRAVE	23	LITH	0.0		0.0	0.0	0.0
27	MAAS8	Maas	23	LITH	24	DENBOSCH	0.0		0.0	5.3	12.7
28	SANDRIES	Sint Andries	3	TIEL	24	DENBOSCH	0.0	0.0	0.0	0.0	0.0
29	BERGMAAS	Bergsche Maas	24	DENBOSCH	25	GERTRUID	0.0		0.0	9.6	32.6
30	AMER1	Amer	25	GERTRUID	26	BIESBOSH	0.0		0.0	11.3	25.7
31	NIEWMERW	Nieuwe Merwede	4	GORINCHM	26	BIESBOSH	0.0		0.0	12.5	43.9
32	AMER2	Amer	26	BIESBOSH	27	MOERDIJK	0.0		0.0	7.6	37.7
33	DORDTKIL	Dordtsche Kil	27	MOERDIJK	5	DORDRECT			0.0	1.8	13.7
34	HOLLDIEP	Hollandsch Diep	27	MOERDIJK	28	WILEMSTD	0.0		0.0	38.0	266.9
35	HARINGV1	Haringvliet	28	WILEMSTD	29	HELVOETS	0.0		0.0	37.6	217.0
36	SPUI	Spui	29	HELVOETS	6	OUDBIJER			0.0	2.6	13.6
37	HARINGV2	Haringvliet	29	HELVOETS	30	STELNDAM	0.0		0.0	34.7	226.9
38	HARINGSL	Haringvlietsluizen	30	STELNDAM	14	NOORDZEE	0.0		10.0T	0.0	0.0
39	VOLKERAK	Volkerak	28	WILEMSTD	31	ZOOMMEER	0.0	25.0	25.0F	0.0	0.0
40	ZOOMERSL	Zoommeersluizen	31	ZOOMMEER	14	NOORDZEE		100.0	0.0	0.0	0.0
41	GREVDAM	Grevelingendam	32	GREVLING	31	ZOOMMEER	0.0	0.0	0.0	0.0	0.0
42	HALSKAN	Halskanaal	32	GREVLING	30	STELNDAM	0.0	0.0	0.0	0.0	0.0
43	BROUWDAM	Brouwersdam	32	GREVLING	14	NOORDZEE	0.0		0.0	0.0	0.0
44	MERWKAN1	Merwedekanaal	4	GORINCHM	10	VIANEN	0.0	0.0	0.0	0.8	2.8
45	LEKKANAL	Lekkanaal	10	VIANEN	33	JUTPHAAS	0.0	2.1	2.1L	0.6	2.4
46	ARKANAL1	Amsterdam-Rijnkanaal	3	TIEL	9	DURSTEDE	0.0	120.0	2.0L	1.42	6.62
47	ARKANAL2	Amsterdam-Rijnkanaal	9	DURSTEDE	33	JUTPHAAS	0.0	130.0	5.1L	1.9	7.6

Table 2.1 (continued)

Link No.	Link Name	Waterway	From Node No.	From Node Name	To Node No.	To Node Name	Cap.1 (m3/s)	Cap.2 (m3/s)	FLCT (m3/s)	Surf. Area (km2)	Vol. (mil. m3)
48	ARKANAL3	Amsterdam-Rijnkanaal	33	JUTPHAAS	34	UTRECHT			0.0	0.5	2.0
49	ARKANL4A	Amsterdam-Rijnkanaal	34	UTRECHT	35	MAARSSEN			0.0	0.95	4.4
50	ARKANL4B	Amsterdam-Rijnkanaal	35	MAARSSEN	36	DIEMEN			0.0	2.0	8.0
51	IJSYPHON	IJmeer Syphon	36	DIEMEN	47	MARKMEER	0.0	0.0	0.0	0.0	0.0
52	ARKANAL5	Amsterdam-Rijnkanaal	36	DIEMEN	37	AMSTEDAM	0.0		20.0T	4.86	20.0
53	NZKANAL1	Noordzeekanaal	37	AMSTEDAM	38	HALFWEG	0.0		0.0	2.0	21.0
54	NZKANAL2	Noordzeekanaal	38	HALFWEG	39	IJMUIDEN	0.0		0.0	2.55	40.8
55	NZKANLSL	Noordzeekanaalsluizen	39	IJMUIDEN	14	NOORDZEE	0.0	230.0	40.0F	0.0	0.0
56	IJSSEL1	IJssel	7	IJSELKOP	40	DIEREN	0.0		0.0	1.7	5.1
57	IJSSEL2	IJssel	40	DIEREN	41	ZUTPHEN	0.0		0.0	1.53	4.59
58	IJSSEL3	IJssel	41	ZUTPHEN	42	DEVENTER	0.0		0.0	1.62	4.86
59	IJSSEL4	IJssel	42	DEVENTER	43	ZWOLLE	0.0		0.0	4.5	15.75
60	IJSSEL5	IJssel	43	ZWOLLE	44	KETLMEER	0.0		0.0	3.13	10.96
61	KETLIJSL	Ketelmeer-IJsselmeer	44	KETLMEER	45	IJSLMEER			0.0	0.0	0.0
62	IJSLWADZ	IJsselmeer-Waddenzee	45	IJSLMEER	46	AFSLDIJK	0.0		0.0	0.0	0.0
63	AFSLUISL	Afsluitdijksluizen	46	AFSLDIJK	14	NOORDZEE	0.0		0.0	0.0	0.0
64	IJSLMARK	IJsselmeer-Markermeer	45	IJSLMEER	47	MARKMEER			0.0	0.0	0.0
65	MARKMIJM	Markermeer-IJmeer	47	MARKMEER	48	IJMEER			0.0	0.0	0.0
66	OSTVARDP	Oostvaardersdijk	45	IJSLMEER	48	IJMEER	0.0	0.0	0.0	0.0	0.0
67	ORANJESL	Oranjesluizen	48	IJMEER	37	AMSTEDAM	-169.5	136.0	30.0T	0.0	0.0
68	VELMKETM	Veluwemeer-Ketelmeer	49	VELUWMER	44	KETLMEER	-19.0	40.0	0.0	0.0	0.0
69	VELMGOIM	Veluwemeer-Gooimeer	49	VELUWMER	50	GOOIMEER	0.0	150.0	0.0	0.0	0.0
70	GOIMIJME	Gooimeer-IJmeer	50	GOOIMEER	48	IJMEER			0.0	0.0	0.0
71	NZDISCH	Noordzee Discharge	14	NOORDZEE	0		0.0		0.0	0.0	0.0
72	SCHERMIN	Schermer Inlet	47	MARKMEER	51	SCHERMER	0.0	30.0	0.0	0.0	0.0
73	ZAAN	Zaan	51	SCHERMER	38	HALFWEG	7.0	23.0	7.0F	1.0	3.0
74	NOHOLKAN	Noordhollandsch Kanaal	51	SCHERMER	52	DENHELDR	0.0		0.0	2.1	8.4
75	MARSDIEP	Marsdiep	52	DENHELDR	14	NOORDZEE	2.0	47.7	4.0F	0.0	0.0
76	STONTEL	Stontelerkeersluis	45	IJSLMEER	53	AMSTMEER	0.0	8.0	0.0	0.0	0.0
77	AMSTDIEP	Amsteldiep	53	AMSTMEER	14	NOORDZEE	2.0	45.0	2.0F	0.0	0.0
78	MARGKAN	Prinses Margrietkanaal	54	FRIELAND	45	IJSLMEER	-105.0	153.0	0.0	0.0	0.0
79	FRIEHARL	Van Harinxmakanaal	54	FRIELAND	55	HARLNGEN	0.0		0.0	2.8	9.8
80	HARLNGSL	Harlingensluis	55	HARLNGEN	14	NOORDZEE	2.0	12.4	8.0F	0.0	0.0
81	DOKKUMEE	Dokkumer-Ee	54	FRIELAND	56	LAUWMEER	0.0	62.8	4.5C	1.1	2.3
82	STABOKAN	Van Starkenborghkanaal	54	FRIELAND	57	GRONIGEN	0.0	16.0	0.0	11.9	35.8
83	EEMSKAN	Eemskanaal	57	GRONIGEN	58	DELFZIJL	0.0		0.0	1.58	8.71
84	DELFZISL	Delfzijlsluis	58	DELFZIJL	14	NOORDZEE	1.0	60.0	2.0F	0.0	0.0
85	REITDIEP	Reitdiep	57	GRONIGEN	56	LAUWMEER	0.0	83.3	0.0	1.4	4.2
86	LAUWSPUI	Lauwersmeer Spui	56	LAUWMEER	14	NOORDZEE	0.0	115.0	0.0	0.0	0.0
87	WINDIEP1	Winschoterdiep	57	GRONIGEN	59	HOGEZAND	2.0		10.0C	0.42	2.1
88	STADSKAN	Stadskanaal	60	TERAPEL	59	HOGEZAND	-5.0		0.3L	0.87	2.0
89	WINDIEP2	Winschoterdiep	59	HOGEZAND	61	WINSHOTN	0.0		0.0	0.77	2.7
90	WESTWOLA	Westerwoldsche Aa	60	TERAPEL	61	WINSHOTN	0.0	17.4	0.0	1.2	2.4
91	STATZIJL	Statenzijl	61	WINSHOTN	14	NOORDZEE	0.5	34.5	0.5F	0.0	0.0
92	VHOGVART	Verlengde Hoogeveensche Vaart	66	ERICASLU	65	HOGEVEEN	-18.3	18.3	0.0	0.46	0.87
93	HOGVART	Hoogeveensche Vaart	65	HOGEVEEN	63	MEPPEL	0.0	21.0	0.1L	0.8	1.69
94	MEPLDIEP	Meppelerdiep	63	MEPPEL	62	ZWARTMER			0.0	0.9	3.2

Table 2.1 (continued)

Link		Waterway	From Node		To Node		Cap.1 (m3/s)	Cap.2 (m3/s)	FLCT (m3/s)	Surf. Area (km2)	Vol. (mil. m3)
No.	Name		No.	Name	No.	Name					
95	RAMSDIEP	Ramsdiep	62	ZWARTMER	44	KETLMEER			0.0	0.0	0.0
96	ORANJKAN	Oranjekanaal	66	ERICASLU	64	SMILDE	0.0	0.0	0.0	0.77	1.18
97	LINHOKAN	Linthorst-Homankanaal	65	HOGEVEEN	64	SMILDE	-3.3	10.0	0.1L	0.43	0.78
98	NOWILKAN	Noord-Willemskanaal	64	SMILDE	57	GRONIGEN	0.0	40.0	0.2L	1.06	2.77
99	DRENTHOF	Drentsche Hoofdvaart	64	SMILDE	63	MEPPEL	-4.3	11.7	0.1L	0.79	1.59
100	STIELKAN	Stieltjeskanaal	66	ERICASLU	71	COVORDEN	0.0	26.0	0.1L	0.36	0.76
101	LUTHOFWK	Lutterhoofdwijk	71	COVORDEN	72	DEDEMSVA	0.0	15.0	0.1L	0.21	0.39
102	OMMERKAN	Ommerkanaal	72	DEDEMSVA	73	OMMEN	0.0	19.0	0.1L	0.47	1.22
103	KANCOZWI	Kanaal Coevorden-Zwinderen	65	HOGEVEEN	71	COVORDEN	0.0	10.0	0.1L	0.16	0.28
104	REEST1	De Reest	65	HOGEVEEN	72	DEDEMSVA	0.0		0.0	0.0	0.0
105	REEST2	De Reest	72	DEDEMSVA	63	MEPPEL	0.25	1.0	0.25F	0.0	0.0
106	COVORKAN	Coevorden-Vechtkanaal	71	COVORDEN	70	HAANDRIK	-44.0	44.0	0.0	0.12	0.23
107	OVIJVEC1	Overijsselsche Vecht	70	HAANDRIK	73	OMMEN	0.0		0.0	1.41	2.15
108	OVIJVEC2	Overijsselsche Vecht	73	OMMEN	62	ZWARTMER	0.0		0.0	1.18	2.76
109	OVIJKAN1	Overijsselsch Kanaal	68	DELDEN	69	VROMSHOP	0.0	5.0	0.0	0.28	0.63
110	OVIJKAN2	Overijsselsch Kanaal	69	VROMSHOP	70	HAANDRIK			0.0	0.57	1.37
111	OVIJKAN3	Overijsselsch Kanaal	69	VROMSHOP	74	SALLAND	0.0	11.5	0.1L	0.31	0.45
112	OVIJKAN4	Overijsselsch Kanaal	74	SALLAND	62	ZWARTMER	0.0	13.0	0.1L	0.32	0.47
113	TWENKAN1	Twenthekanaal	67	LOCHEM	41	ZUTPHEN	-11.0		1.75L	0.91	3.74
114	TWENKAN2	Twenthekanaal	68	DELDEN	67	LOCHEM			0.0	1.39	3.77
115	MERWKAN2	Merwedekanaal	10	VIANEN	77	LOPIKWAR	0.0	0.6	0.0	0.12	0.36
116	MERWKAN3	Merwedekanaal	77	LOPIKWAR	75	UTREVECH	2.0		2.0F	0.8	2.4
117	JUTGEMAL	Jutphaas gemaal	33	JUTPHAAS	77	LOPIKWAR	0.0	12.0	0.0	0.0	0.0
118	KANHOLIJ	Gekanaliseerde Hollandsche IJssel	77	LOPIKWAR	81	GOUDA	0.0		0.0	0.48	0.96
119	HOLIJSEL	Hollandsche IJssel	81	GOUDA	12	IJSLMOND			0.0	1.7	5.1
120	KRIMPKAN	Krimpenerwaardkanaal	11	SCONOVEN	81	GOUDA	0.0	6.0	0.0	0.0	0.0
121	WIERICKE	Wiericke	77	LOPIKWAR	78	WOERDEN	0.0	6.5	0.0	0.0	0.0
122	LEIDRIJN	Leidsche Rijn	34	UTRECHT	78	WOERDEN	0.0	3.5	0.0	0.3	0.75
123	OUDERIJN	Oude Rijn	78	WOERDEN	79	RIJNLAND	0.0	10.0	0.0	1.0	3.0
124	MARBOKAN	Kanaal Maarssen-Bodegraven	35	MAARSSEN	79	RIJNLAND	0.0	0.0	0.0	0.84	1.85
125	GOUWE	Gouwe	81	GOUDA	79	RIJNLAND		32.0	0.0	0.76	2.28
126	KATWIJK	Katwijk	79	RIJNLAND	14	NOORDZEE	1.0	54.0	3.0F	0.0	0.0
127	LEIDSDAM	Leidschendam	79	RIJNLAND	80	DELFLAND	0.0	8.0	0.0	1.5	4.5
128	SCHEVING	Scheveningen	80	DELFLAND	14	NOORDZEE	0.4	10.0	0.4F	0.0	0.0
129	KAWADVOR	Kanaal Waddinxveen-Voorburg	81	GOUDA	80	DELFLAND	0.0	0.0	0.0	0.76	1.54
130	VLIET	Vliet	80	DELFLAND	13	SCHEUR	4.0	37.0	5.6F	0.34	0.51
131	HARLMEER	Haarlemmermeer	79	RIJNLAND	38	HALFWEG	3.0	65.3	5.0F	0.0	0.0
132	VECHT1	Vecht	75	UTREVECH	76	NIGTVECH	0.0	20.0	0.0	0.0	0.0
133	VECHT2	Vecht	48	IJMEER	76	NIGTVECH	0.0	10.0	0.0	0.0	0.0
134	ARKVECHT	Amsterdam-Rijnkanaal/Vecht	76	NIGTVECH	36	DIEMEN	0.0		0.0	0.9	3.6
135	ANGSTEL	Angstel	82	AMSTLAND	36	DIEMEN	-7.0		0.0	0.6	1.2
136	TOLHUIS	Tolhuissluis	82	AMSTLAND	79	RIJNLAND	0.0	3.0	0.0	0.0	0.0
137	AMSTEL	Amstel	82	AMSTLAND	37	AMSTEDAM	0.0		0.0	0.48	1.2
138	LINGE1	Linge	1	PANDNKOP	83	BETUWE	0.0	7.3	0.0	0.32	0.42
139	LINGEKAN	Lingekanaal	83	BETUWE	8	WAGINGEN	-2.5	30.0	0.0	0.0	0.0
140	LINGE2	Linge	83	BETUWE	84	TIELWARD	0.0	15.0	0.0	1.23	2.39
141	LINGE3	Linge	84	TIELWARD	4	GORINCHM	0.0	60.0	0.0	1.19	2.49

Table 2.1 (continued)

Link			From Node		To Node		Cap.1	Cap.2	FLCT	Surf. Area	Vol. (mil.
No.	Name	Waterway	No.	Name	No.	Name	(m3/s)	(m3/s)	(m3/s)	(km2)	m3)
142	ZUIDWLM1	Zuid-Willemsvaart	15	MASTRICT	85	LOOZEN	13.0	20.0	16.0T	1.09	1.89
143	ZUIDWLM2	Zuid-Willemsvaart	85	LOOZEN	86	WEERT	0.0	7.0	1.0L	0.48	0.83
144	WESNWERT	Kanaal Wessem-Nederweert	86	WEERT	17	PANHEEL	-4.0	2.0	2.0L	0.47	0.86
145	NORDVART	Noordervaart	87	MEYEL	86	WEERT	-4.0	0.5	0.5L	0.27	0.52
146	ZUIDWLM3	Zuid-Willemsvaart	86	WEERT	88	HELMOND	0.0	5.0	1.0L	0.79	1.37
147	ZUIDWLM4	Zuid-Willemsvaart	88	HELMOND	24	DENBOSCH	0.3	7.0	1.0L	1.01	1.74
148	DOMMEL	Dommel	89	BOXTEL	24	DENBOSCH	0.0		0.0	0.0	0.0
149	WILHEKAN	Wilheminakanaal	88	HELMOND	90	OSTRHOUT	0.3	15.0	1.7L	2.18	4.23
150	DONGE	Donge	90	OSTRHOUT	25	GERTRUID			0.0	0.64	1.88
151	MARK1	Mark	90	OSTRHOUT	91	FIJNAART	0.0	8.0	0.0	1.45	3.74
152	MARK2	Mark	91	FIJNAART	31	ZOOMMEER	-50.0	150.0	0.0	0.32	1.18
153	VLIETKAN	Mark-Vlietkanaal	92	ROSENDAL	91	FIJNAART	0.0	0.0	0.0	0.16	0.38
154	ROSVLIET	Roosendaalsche-en Steenbergsche Vliet	92	ROSENDAL	31	ZOOMMEER	-100.0	100.0	0.0	0.66	1.23

NOTES: The positive flow direction on a link is from the first-named node to the second-named node. In PAWN we have adopted the convention that the positive direction be the usual discharge direction unless the link is not used for discharges, in which case it is the extraction direction. The Cap.1 entry serves several purposes: if blank, it indicates the capacity is large enough to be considered essentially unlimited in the negative direction; if 0.0 it indicates that the flow in the link is always in the positive direction; if negative and of the same magnitude as the Cap.2 value, it is the capacity of the canal or waterway; if negative and different in magnitude from the Cap.2 value it is a pumping or sluice capacity; if positive, it is the minimum flow in the discharge direction.

The Cap.2 value is the capacity of the link in the positive direction. If the value is blank, it indicates essentially unlimited capacity. The specified capacity may be the capacity of a lock, syphon, pump(s), sluice(s), canal, or the lock loss (if the waterway is not used to transport water otherwise).

The FLCT entry is a desired flow on the link. An entry marked with an F is a desired flushing flow; an entry marked with an L is a desired flow for locking operations; an entry marked with a C is a desired flow for cooling water for a power plant; an entry marked with a T is a desired or trigger flow for some management policy. The desired flows for the links marked with an F or a C will be met unless a management policy cuts back the flow to meet some capacity or water shortage constraint; in any event the minimum flow specified in the Cap.1 entry will be met. For entries marked with an L, the flows may be met by discharges from upstream links or by flows created by demands downstream; if not, the demand is met by pumping back from the downstream side of the link up to the Cap.1 entry that indicates the pumping capacity available. If the pumping capacity is not sufficient, the remaining flow needed for the lock will be met as a demand at the upstream node. An exception to this rule occurs for those links that have a positive value in the Cap.1 entry; this value is interpreted as the minimum flow on the link, and management policies may cut the actual flow to this minimum flow to meet upstream capacity or water shortage constraints. The usage of the entries marked with a T are discussed in various sections of the text: links 7 and 38, Sec. 5.3.3; link 13, Sec. 5.3.5; links 16, 17, 18, 22, and 142, Sec. 5.3.1; link 52, Sec. 5.3.4; and link 67, Sec. 5.3.11.

The indicated extraction capacities for links 72, 76, and 78 are the maximum capacities for the links. The actual capacity is a function of the level of the lake from which the link obtains its extraction and is read from input tables that are functions of the lake level (Secs. 4.3.2 and 4.3.3).

The actual pumping capacity at Panheel is 3.0 m3/s. However, whenever pumping is needed, the lock loss (given by the FLCT entry) is reduced from 2.0 m3/s to 1.0 m3/s by a water-saving feature. In the DM program this is equivalent to having a pumping capacity of 4.0 m3/s and no lock loss reduction.

2.1.2. Nodes

Each node is identified by a number and an 8-character mnemonic name. Table 2.2 contains the number, mnemonic name, and full name of each node.

The parameters input for each node consist of the storage area and volume for nodes with storage (and target, emergency, and minimum levels for storage volumes whose levels may change, Sec. 3.1.2.3); the values of any exogenously specified discharges and extractions at the node, e.g., by drinking-water companies or industry (these may be changed at any decade); the initial values for pollutant concentrations; and the rates at which pollutants are being discharged at the nodes (see Sec. 6.4).

2.2. PAWN DISTRICTS AND DISTRICT LINKS

2.2.1. PAWN Districts

For modeling drainage, groundwater, and the water demands of agriculture, the Netherlands was divided into 77 districts. However, the southeast corner of the country, in Zeeland, the dune area along the western coast, and the islands in the North Sea are not included in any district. When the Markerwaard is included, it forms a 78th district. The districts were formed on the basis of relevant existing partitions (e.g., among waterboards, drainage basins, etc.) and the relationship between areas and the water distribution system; e.g., areas that extract and discharge water to the same waterways were generally placed in the same district. A district consists of the land, urban area, and open water in its territory, except for the open water represented by the nodes and links of the network. Figure 2.3 contains a map of the Netherlands showing the areal extent of each district. Table 2.3 contains the number, mnemonic name, and full name of each district and the region containing the district (see Sec. 2.3). Volume XII contains detailed data on the physical characteristics of each district.

2.2.2. District Links

The districts are connected to the PAWN network by waterways or waterworks represented by the dotted lines in Fig. 2.2. A district link may be used to extract water from the network, discharge water to the network, or both. The water volumes of the district links are part of the water volumes of the districts.

2.3. PAWN REGIONS

As an aid in presenting and interpreting results from DM runs, the districts were aggregated into eight regions, using water supply

Table 2.2

NODE NUMBERS AND NAMES

No.	Name	Full Name	No.	Name	Full Name
1	PANDNKOP	Pannerdensche Kop	47	MARKMEER	Markermeer
2	NIJMEGEN	Nijmegen	48	IJMEER	IJmeer
3	TIEL	Tiel	49	VELUWMER	Veluwemeer
4	GORINCHM	Gorinchem	50	GOOIMEER	Gooimeer
5	DORDRECT	Dordrecht	51	SCHERMER	Schermer
6	OUDBIJER	Oud-Beijerland	52	DENHELDR	Den Helder
7	IJSELKOP	IJsselkop	53	AMSTMEER	Amstelmeer
8	WAGINGEN	Wageningen	54	FRIELAND	Friesland
9	DURSTEDE	Wijk bij Duurstede	55	HARLNGEN	Harlingen
10	VIANEN	Vianen	56	LAUWMEER	Lauwersmeer
11	SCONOVEN	Schoonhoven	57	GRONIGEN	Groningen
12	IJSLMOND	IJsselmonde	58	DELFZIJL	Delfzijl
13	SCHEUR	Scheur	59	HOGEZAND	Hoogezand
14	NOORDZEE	Noordzee	60	TERAPEL	Ter Apel
15	MASTRICT	Maastricht	61	WINSHOTN	Winschoten
16	BORN	Born	62	ZWARTMER	Zwartemeer
17	PANHEEL	Panheel	63	MEPPEL	Meppel
18	LINNE	Linne	64	SMILDE	Smilde
19	ROERMOND	Roermond	65	HOGEVEEN	Hoogeveen
20	BELFELD	Belfeld	66	ERICASLU	Ericasluis
21	SAMBEEK	Sambeek	67	LOCHEM	Lochem
22	GRAVE	Grave	68	DELDEN	Delden
23	LITH	Lith	69	VROMSHOP	Vroomshoop
24	DENBOSCH	's-Hertogenbosch	70	HAANDRIK	De Haandrik
25	GERTRUID	Geertruidenberg	71	COVORDEN	Coevorden
26	BIESBOSH	Biesbosch	72	DEDEMSVA	Dedemsvaart
27	MOERDIJK	Moerdijk	73	OMMEN	Ommen
28	WILEMSTD	Willemstad	74	SALLAND	Salland
29	HELVOETS	Hellevoetsluis	75	UTREVECH	Utrecht/Vecht
30	STELNDAM	Stellendam	76	NIGTVECH	Nigtevecht
31	ZOOMMEER	Zoommeer	77	LOPIKWAR	Lopikerwaard
32	GREVLING	Grevelingen	78	WOERDEN	Woerden
33	JUTPHAAS	Jutphaas	79	RIJNLAND	Rijnland
34	UTRECHT	Utrecht	80	DELFLAND	Delfland
35	MAARSSEN	Maarssen	81	GOUDA	Gouda
36	DIEMEN	Diemen	82	AMSTLAND	Amstelland
37	AMSTEDAM	Amsterdam	83	BETUWE	Betuwe
38	HALFWEG	Halfweg	84	TIELWARD	Tielerwaard
39	IJMUIDEN	IJmuiden	85	LOOZEN	Lozen
40	DIEREN	Dieren	86	WEERT	Weert
41	ZUTPHEN	Zutphen	87	MEYEL	Meijel
42	DEVENTER	Deventer	88	HELMOND	Helmond
43	ZWOLLE	Zwolle	89	BOXTEL	Boxtel
44	KETLMEER	Ketelmeer	90	OSTRHOUT	Oosterhout
45	IJSLMEER	IJsselmeer	91	FIJNAART	Fijnaart
46	AFSLDIJK	Afsluitdijk	92	ROSENDAL	Roosendaal

Fig. 2.3--PAWN districts

Table 2.3

PAWN DISTRICTS

District		Region		District		Region	
No.	Name	No.	Long Form of Name	No.	Name	No.	Long Form of Name
1	FRIELAND	1	Friesland	40	GOOI	5	Gooi
2	HETBILDT	1	Het Bildt	41	KROMRIJN	5	Area around Kromme Rijn
3	LAUWMEER	1	Area around Lauwersmeer	42	LEIDRIJN	5	Area around Leidsche Rijn
4	UITHUIZN	1	Uithuizen	43	WOERDEN	5	Woerden
5	EEMSKANN	1	Eemskanaalboezem--North	44	LOPIKWAR	5	Lopikerwaard
6	OLDAMBT	1	Oldambt	45	KRIMPWAR	5	Krimpenerwaard
7	WESTWOLD	1	Area around the Westerwoldsche Aa	46	SCIELAND	5	Schieland
8	NWDRENTE	1	Northwest Drenthe	47	DELFLAND	5	Delfland
9	WESKWART	1	Westerkwartier	48	VOORNE	6	Voorne-Putten + part of Hoeksche Waard
10	NEDRENTE	2	Northeast Drenthe	49	GOEREE	6	Northern part of Goeree-Overflakkee
11	SEDRENTE	2	Southeast Drenthe	50	IJSLMOND	6	IJsselmond
12	SWDRENTE	2	Southwest Drenthe	51	HOLNDIEP	8	Area around Hollandsch Diep
13	VOLENHOV	1	Land van Vollenhove	52	DORDRECT	6	Area around Dordrecht
14	NEPOLDER	1	Noordoostpolder	53	ABLASWAR	6	Alblasserwaard
15	MASTBROK	1	Mastenbroek	54	BIESBOSH	8	Biesbosch
16	OVIJVECT	2	Area around the Overijsselsche Vecht	55	TIELWARD	6	Tielerwaard
17	DINKEL	2	Area around the Dinkel	56	DENBOSCH	7	Area southwest of 's-Hertogenbosch
18	TWENTHE	2	Twenthe	57	BETUWE	6	Betuwe
19	SALLAND	2	Salland	58	MAASWAAL	7	Area between Maas and Waal
20	TWENTKAN	2	Area around Twenthekanaal	59	RECMAASN	6	Area on right bank of Maas--North
21	SHIPBEEK	2	Schipbeek	60	RECMAASM	7	Area on right bank of Maas--Middle
22	IJSELGEB	3	Area around the IJssel River	61	MASKANTE	7	Maaskant East
23	NEVELUWE	3	Northeast Veluwe	62	MASKANTW	7	Maaskant West
24	BERKEL	2	Berkel	63	AA	7	Area around the Aa
25	OUDEIJSL	2	Area around the Oude IJssel	64	DEPEEL	7	De Peel
26	ARNHEM	3	Area around Arnhem	65	RECMAASS	7	Area on right bank of Maas--South
27	SEVELUWE	3	Southeast Veluwe	66	ROERMOND	7	Area around Roermond
28	SWVELUWE	3	Southwest Veluwe	67	SLIMBURG	7	South Limburg
29	NWVELUWE	3	Northwest Veluwe	68	MLIMBURG	7	Middle Limburg
30	FLEVLAND	3	Flevoland	69	EDOMMEL	7	East Dommel
31	WIERGMER	4	Wieringermeerpolder	70	MDOMMEL	7	Middle Dommel
32	AMSTLMER	4	Amstelmeer	71	WDOMMEL	7	West Dommel
33	MEDMBLIK	4	Area of W.Friesland around Medemblik	72	NDOMMEL	7	North Dommel
34	HOORN	4	Area of W.Friesland around Hoorn	73	DONGE	7	Area around the Donge
35	SCHERMER	4	Schermerboezem	74	MARK	8	Area around the Mark
36	WATRLAND	4	Waterland	75	ROSENDAL	8	Steenbergse en Roosendaalse Vliet
37	NZKANGEB	4	Area around Noordzeekanaal	76	ZOOM	8	Area around the Zoommeer
38	RIJNLAND	5	Rijnland	77	SCHOUWEN	8	Schouwen
39	AMSTLAND	5	Amstelland	78	MARKWARD	3	Markerwaard

source and natural boundaries as criteria. A map of the PAWN regions is given in Fig. 2.4. The names of the regions and their primary sources of supply are given in Table 2.4.

Table 2.4

PAWN REGIONS

Region	Primary Supply Sources
1. North	IJsselmeer
2. Northeast Highlands	IJsselmeer
3. Flevoland and Veluwe	IJsselmeer/IJssel
4. North Holland	IJsselmeer/Markermeer
5. Midwest and Utrecht	Rijn
6. Large Rivers and Northern Delta	Rijn
7. West Brabant and Southern Delta	Rijn/Maas/Zoommeer
8. Southeast Highlands	Maas

REFERENCES

2.1. MW-154 (unpublished PAWN memorandum), "Distribution Network and Worksheets 1, 2, 3, RWS District South-East," February 1979.

2.2. Unpublished information from the Rijkswaterstaat, Directie Waterhuishouding en Waterbeweging, District Noord and District Zuidwest, concerning network distribution keys, July 1979.

2.3 MR-271 (unpublished PAWN memorandum), "Surface Areas and Water Volumes of PAWN Links and Nodes," April 1979.

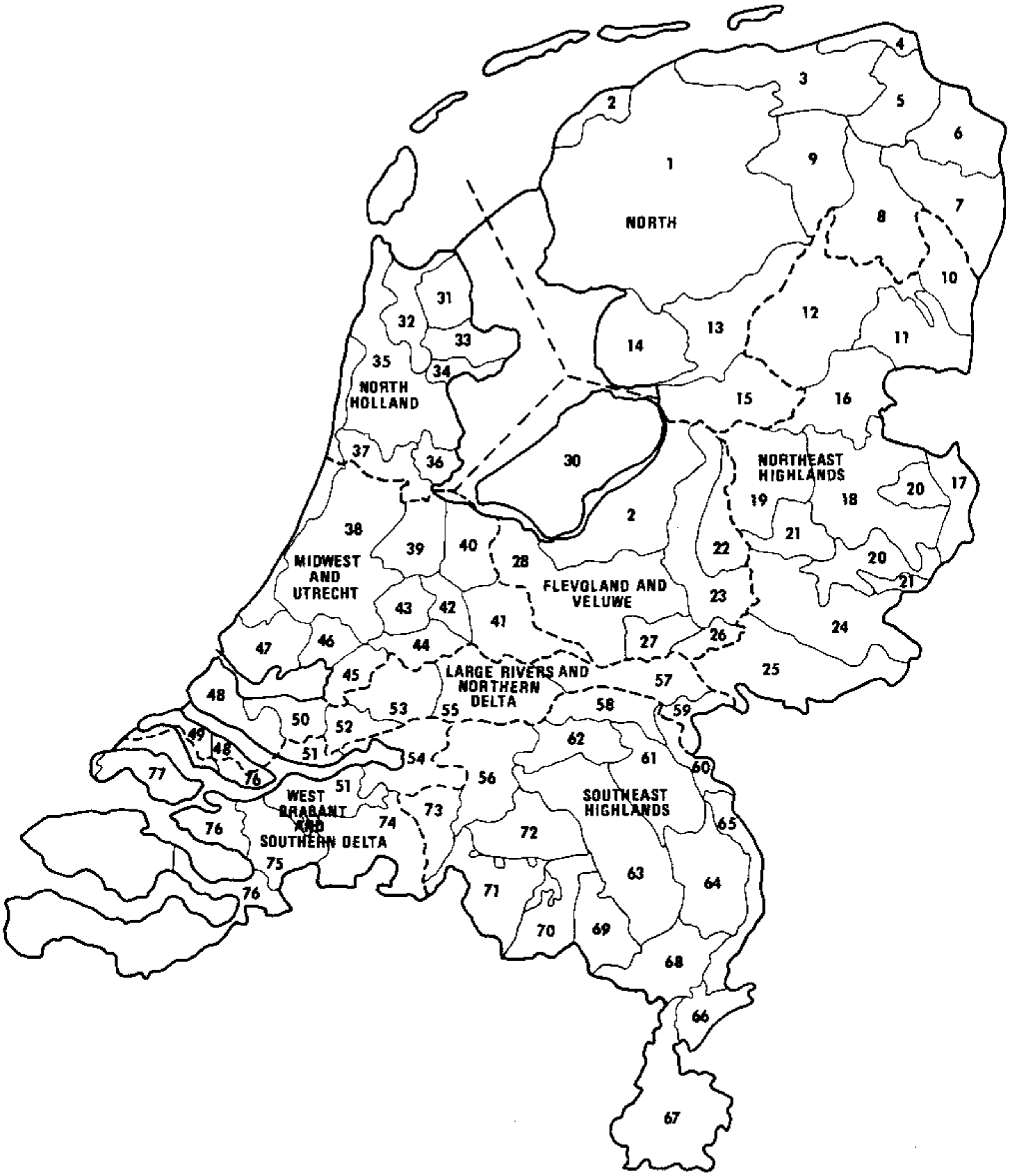


Fig. 2.4--PAWN regions

Chapter 3

WATER SUPPLY AND DEMAND

The DM contains representations for all sources of water supply and all demands on that supply. Since the calculation time step in the DM is a decade, the components of water supply and demand are input or calculated as averages over a decade. Any interactions between one decade and the next are conveyed as variables indicating the status of the distribution system and the districts at the end of a decade, e.g., the levels of storage lakes, the amount of water stored in the root zone of croplands, groundwater levels, and pollutant concentrations in the various volumes of water.

3.1. WATER SUPPLY

The country obtains most of its surface water supply from three sources: the Rijn River, the Maas River, and the IJssel lakes (the IJssel lakes serve as a large freshwater reservoir, receiving most of its water from the Rijn via the IJssel River and storing part of it for use during dry periods).

In the highlands these primary sources of supply are augmented by drainage and extractions from groundwater. Most of the precipitation in the highlands penetrates into the ground. Any excess water in the soil percolates into the groundwater from which it drains into lower-lying streams and rivers. This basic drainage process releases the groundwater at a relatively slow rate so that water accumulated in the ground during periods of excess precipitation is still draining during dry periods. Thus, groundwater serves as an underground reservoir, and basic drainage from the groundwater is a source of water throughout the year.

In PAWN the sources of water supply are placed into two categories: external supply is that portion of the supply that originates outside of the country--precipitation, the major rivers, and external drainage--and over which the country has little control; internal supply originates inside the country--small rivers and internal drainage, groundwater, and lake storage--and its use may be controlled, at least to a degree.

3.1.1. External Supply

3.1.1.1. Precipitation. The average annual precipitation in the Netherlands is about 750 mm. This precipitation is fairly uniform throughout the year, varying from 50 mm per month in winter and spring to 70 mm in summer and fall. Across the country the average annual precipitation varies from 650 mm to 800 mm per year. (The average annual open water evaporation is about 700 mm per year, varying from 5 mm per month in December to about 120 mm per month in June and July, and decreases from 750 mm in the coastal areas to 650 mm in the eastern parts of the country.) To reflect the geographical variation, precipitation and open water evaporation data from 15 weather stations located throughout the country are used in the DM (the names of the weather stations and the areas associated with each are given in Vol. XII). Each district and each node in the network are assigned to one of the weather stations. Precipitation on the area associated with a district is accounted for in the water balance calculation for the district (see Sec. 3.3), and precipitation on the waterways associated with the nodes and links is entered as discharges at the appropriate nodes.

3.1.1.2. Major Rivers. The decade flows of six rivers are read from input data files (along with the pollutant concentrations of the flows, discussed in Sec. 6.4) and entered as discharges at nodes in the network. Table 3.1 indicates the relative magnitudes of the discharges of the six rivers.

Table 3.1

MAJOR RIVERS INPUT TO THE DM

River	Discharge Node	Ave. Discharge (m^3/s)
Rijn	PANDNKOP	2200
Vecht	HAANDRIK	17
Maas	MASTRICT	260
Roer	ROERMOND	24
Swalm	SAMBEEK	2
Niers	GRAVE	9

The major portions of the drainage basins of these rivers lie outside of the Netherlands, and the river discharge data, except for the Maas, are taken from measuring stations in the vicinity of the border. The Maas flows are those at Maastricht immediately north of the point where the Jeker River joins the Maas, as we assume that the extractions by Belgium for use in the Albertkanaal are zero. The actual extraction for the Albertkanaal is then input as an extraction from the MAASTRICT node (in the PAWN study 10 m^3/s was used for this extraction as the best estimate for the actual 1976 situation, and 12 m^3/s for the 1985 scenario). The Maas discharges provided to PAWN by the Rijkswaterstaat, called the Monsin series, consisted of average decade discharges from 1911 to 1978. Prior to 1976, these discharges were based on measured discharges at Borgharen, and from 1976 through 1978 on measured discharges at Eijsden, with corrections for lock losses upstream to Monsin, but not for small river discharges. For PAWN, the Jeker River discharges were added to the Monsin series for the years 1976 to 1978 to provide a consistent series of Maas discharges for input to the DM.

The three small rivers that flow into the Maas (the Roer, Swalm, and Niers) constitute a significant fraction of the Maas flow in dry periods, when the portion of the Maas discharge at Maastricht available to the Netherlands may drop to as low as 10 m^3/s. In particular, the Roer discharge has a minimum of 10 to 12 m^3/s (the discharge of the Roer is controlled by the release of water from a hydroelectric storage reservoir in West Germany).

3.1.1.3. External Drainage. In the Southeast Highlands there are a number of small rivers that flow into the Maas. The portions of the drainage basins of these rivers that lie in the Netherlands are treated in the DISTAG submodel of the DM (see Sec. 3.3). The portions of the drainage basins that lie in Belgium and West Germany are accounted for separately. The Roer, Swalm, and Niers discharges are input directly (see Sec. 3.1.1.2); but, as shown in the data on the maps of Ref. 3.1, there are three sections of the Maas that receive drainage from outside the country that are not accounted for in the Roer, Swalm, and Niers basins. These sections and the sizes of the additional drainage areas are: (1) between the weir at Maastricht and the weir at Linne (78700 ha); (2) between the weir at Roermond and the weir at Belfeld (10905 ha); and (3) between the weir at Belfeld and the weir at Sambeek (12450 ha). The drainage of each of these areas into the Netherlands is estimated in the DM by multiplying the basic drainage (in m^3/s) of the nearest district by the ratio of the given drainage area to the area of the district, i.e.,

$$EDp = (Ap/A67)BD67 = (78700/71345)BD67 = 1.10 \times BD67$$

$$EDb = (Ab/A68)BD68 = (10905/40516)BD68 = 0.27 \times BD68$$

$$EDs = (As/A65)BD65 = (12450/26087)BD65 = 0.48 \times BD65$$

where EDp, EDb, and EDs are the discharges (m^3/s) entered at the PANHEEL, BELFELD, and SAMBEEK nodes to represent the drainage from the three foreign areas (PANHEEL is used instead of LINNE since the sections of the Maas represented by each are in open connection and PANHEEL is farther upstream); Ap, Ab, and As are the sizes (ha) of the three foreign areas; A67, A68, and A65 are the areas (ha), and BD67, BD68, and BD65 the basic drainage (m^3/s) of districts 67, 68, and 65, respectively.

According to Dutch experts there is considerable groundwater discharge from the Niers drainage basin directly into the Maas (the Niers basin lies in West Germany and parallels the Maas). We estimated this groundwater discharge by estimating the basic drainage of the Niers basin as the district 60 basic drainage multiplied by the ratio of the area of the Niers basin to the area of district 60, i.e.,

$$BDn = (An/A60)BD60 = (135965/11861)BD60 = 11.4 \times BD60$$

where BDn is the basic drainage (m^3/s) and An the area (ha) of the Niers basin; and BD60 is the basic drainage (m^3/s) and A60 the area (ha) of district 60. The groundwater discharge of the Niers basin to the Maas, GDn (m^3/s), is then estimated as the basic drainage of the Niers basin that is unaccounted for in the Niers discharge, Qn (m^3/s),

$$\mathrm{GDn} = \mathrm{BDn} - \mathrm{Qn} = 11.4 \times \mathrm{BD60} - \mathrm{Qn}$$

GDn is entered as a discharge into the node GRAVE, where the discharge of the Niers is entered.

3.1.1.4. Seepage. Seepage from adjacent districts, groundwater aquifers, or the North Sea is entered into the groundwater of lowland districts (and into the Grevelingen when it is fresh) at fixed rates over the year. The seepage rates for the districts are part of the input to the DISTAG submodel (see Sec. 3.3). The seepage rates for some districts are negative, indicating that these districts are providing or replacing seepage into adjacent districts. The difference in the total positive and negative seepage over all districts is assumed to come from outside of the country, i.e., from the North Sea, Oosterschelde, etc., and is part of the external supply. To the extent that the actual seepage is supplied or replaced from internal water sources, e.g., the IJssel lakes replacing seepage into Flevoland, this assumption creates an error in the model.

3.1.2. Internal Supply

3.1.2.1. Small Rivers and Internal Drainage. There are a number of small rivers whose drainage area is entirely or predominantly in the Netherlands. The drainage of these rivers and the drainage from Netherlands' territory directly into the major rivers represented in the PAWN network are part of the DISTAG submodel (see Sec. 3.3).

3.1.2.2. Groundwater. Groundwater provides most of the water used by drinking-water companies and industry (Sec. 3.2.5). Approximately 90 percent of the water extracted by drinking-water companies is discharged into the surface water, usually in the vicinity of the withdrawal location. Thus, most of the groundwater used by drinking-water companies and industry ends up in the surface water system. The groundwater extractions and subsequent discharges into the surface water are part of the district inputs to the DISTAG submodel (see Sec. 3.3).

Currently, 4 percent of the croplands in the Netherlands are irrigated by overhead sprinkling from groundwater (mostly in the highlands, see Vol. XII). In districts where the groundwater levels are sufficiently high that capillary rise from the saturated zone reaches the root zone of the crops, a portion of the evapotranspiration of the crops is supplied from groundwater, thus reducing irrigation water needs (as much as 1 mm per day may reach the root zone of the crops by capillary rise). Groundwater levels in the districts are calculated in the DISTAG submodel (see Sec. 3.3).

3.1.2.3. Storage Nodes. In the DM any node may have a volume of water assigned to it, and a number of nodes represent bodies of water that provide water storage. Table 3.2 contains the nodes in the network with storage and the maximum amount of storage available at each under the current restrictions on storage levels. The managerial rules associated with those storage volumes whose levels are allowed to change are discussed in Chaps. 4 and 5.

Table 3.2

STORAGE AT NODES

Node No.	Node Name	Water Levels[1] Max. (NAP+cm)	Water Levels[1] Min. (NAP+cm)	Surface Area (km^2)	Max.Vol. (million m^3)	Max.Store (m^3/s/ decade)
15	MASTRICT	4400.0	4320.0	2.926	12.6	2.7
16	BORN	3265.0	3145.0	0.850	3.8	1.2
17	PANHEEL	2050.0	1960.0	1.152	3.9	1.3
18	LINNE	2050.0	1960.0	1.390	5.3	1.4
19	ROERMOND	1675.0	1625.0	1.336	5.5	0.8
20	BELFELD	1400.0	1350.0	2.941	12.4	1.7
21	SAMBEEK	1075.0	1005.0	6.235	24.0	5.1
22	GRAVE	750.0	680.0	4.287	19.0	3.5
23	LITH	460.0	380.0	3.650	17.1	3.4
31	ZOOMMEER	0.0	-100.0	64.4	250.5	74.5
32	GREVLING	-20.0	-20.0	109.52	568.0	0.0
45	IJSLMEER	-20.0	-40.0	1289.0	5413.8	298.4
47	MARKMEER	-25.0	-40.0	610.0	1799.5	105.9
48	IJMEER	-25.0	-40.0	89.4	391.5	15.5
49	VELUWMER	-10.0	-28.0	63.4	76.1	13.2
50	GOOIMEER	-25.0	-40.0	40.9	88.8	7.1
51	SCHERMER			16.7	37.1	
54	FRIELAND			140.0	180.0	
75	UTREVECH			1.5	3.0	
76	NIGTVECH			2.8	6.0	
77	LOPIKWAR			0.7	2.0	
78	WOERDEN			1.7	3.4	
79	RIJNLAND			39.0	90.0	
80	DELFLAND			6.7	13.4	
82	AMSTLAND			4.8	12.0	

SOURCE: Ref. 3.2.

[1] The maximum volume corresponds to the maximum level. When a level varies from the maximum, the volume varies in accordance with the implied depth change; i.e., we assume a constant surface area. The blank level entries are for nodes whose storage represents boezems, where no level changes are currently allowed in the DM program (see Sec. 3.3).

IJssel Lakes. The IJssel lakes are the freshwater lakes that remained after the Zuider Zee was closed off from the North Sea by the Afsluitdijk (or barrier dam) in 1932 and portions of the Zuider Zee reclaimed as the Wieringermeerpolder, Flevoland, and Noordoostpolder. In the PAWN network these lakes are represented as five nodes with storage: IJSLMEER (small IJsselmeer, Ketelmeer, and Zwartemeer), MARKMEER (Markermeer), IJMEER (IJmeer), GOOIMEER (Gooimeer and Eemmeer), and VELUWMER (Veluwemeer). The IJssel lakes are part of the water transportation system, carrying water from the IJssel River to the regions bordering the lakes, and they also provide freshwater storage for the northern portion of the country.

The total surface area of the lakes is 2093 km^2, so that 1 cm of storage in the lakes will provide for 24 m^3/s of extractions for a decade. As indicated in Table 3.2, the maximum storage currently available in the lakes is equivalent to 440 m^3/s for one decade. In Vol. II, tactics that increase the storage volume in the lakes by either lowering the minimum levels or raising the maximum levels are evaluated.

Zoommeer and Grevelingen. When the Zoommeer and Grevelingen are fresh, they are generally consumers of water; each requires flushing water to decrease the salinity caused by seepage and salt intrusion at salt-fresh locks (see Sec. 6.2.4) and, during dry periods, water to replace evaporation losses. However, under the managerial rules implemented in the DM (see Sec. 5.3.9), storage water from the Zoommeer and Grevelingen may be used during periods of water shortage.

If the Zoommeer is between its minimum and target levels (e.g., NAP - 100 cm and NAP, respectively), and there is a shortage of water in the Rotterdamse Waterweg (as measured by the salt wedge concentration at the Gouda inlet being above a specified input value), the flushing demand for the Zoommeer is first cut back to its minimum value; if there is still a salinity problem from the salt wedge, the flow to the Zoommeer for level control is cut back until the emergency level is reached or the extraction for level control has been reduced to zero. Under these conditions the storage in the Zoommeer is used to supply any extractions from the lakes (e.g., by districts 74, 75, and 76; see Fig. 2.2). From Table 3.2, the maximum storage available in the Zoommeer is equivalent to 75 m^3/s for one decade. The fresh Grevelingen is treated similarly except that the target and emergency levels generally used for the Grevelingen have been set equal (e.g, NAP - 20 cm), in which case no storage water is available.

When the Zoommeer and Grevelingen are brackish, they are considered as single nodes with storage. When either the Zoommeer or Grevelingen is fresh, it is treated in the DM as a freshwater lake with three sections. (These sections could have been handled automatically by the DM if three nodes had been defined for each of the Zoommeer and Grevelingen; but the decision to use three sections for each was made after the PAWN network was finalized, and it was inconvenient to redefine the network.) We denote these sections as Z1, Z2, and Z3 for the Zoommeer and G1, G2, and G3 for the Grevelingen (See Fig. 3.1).

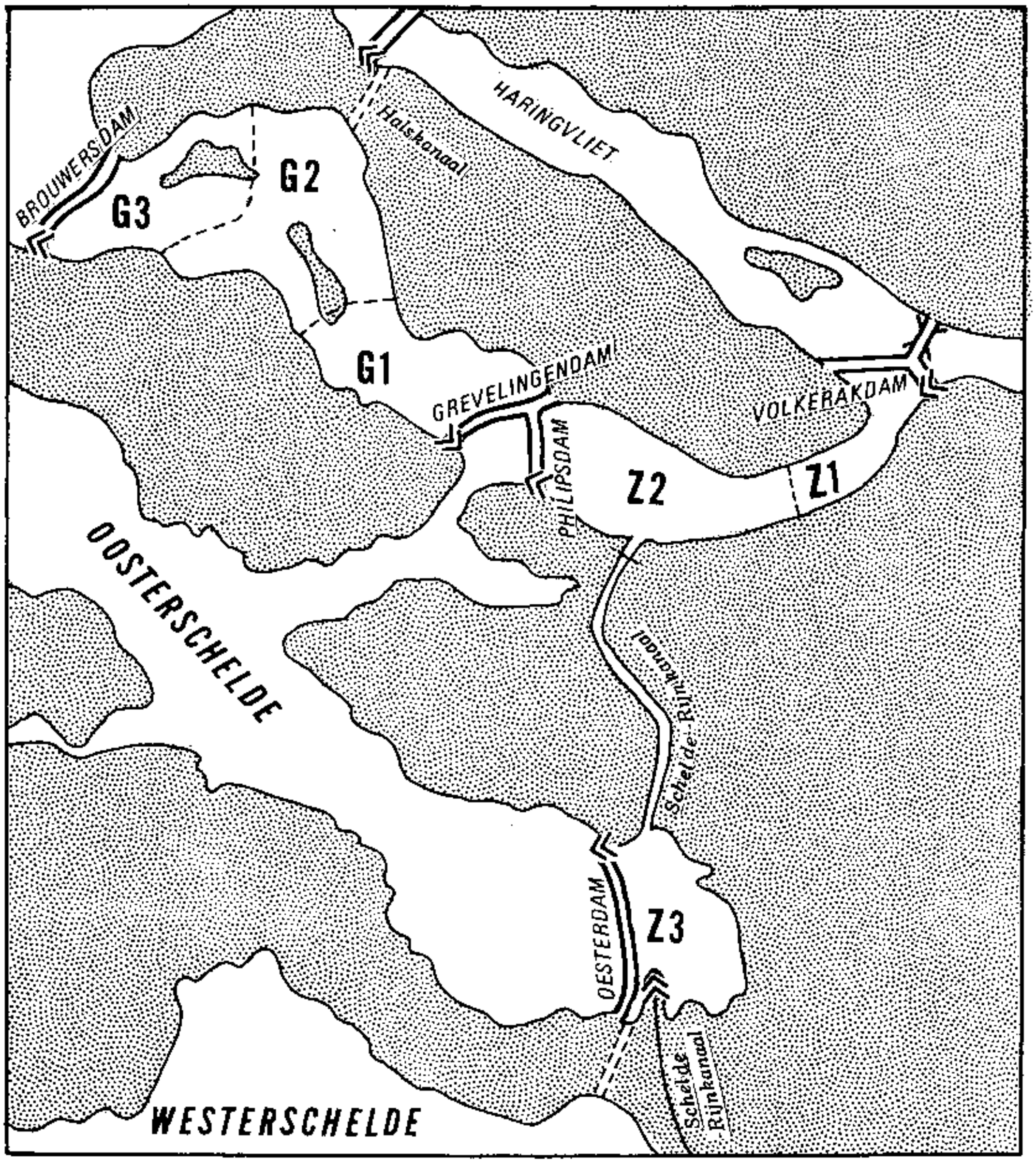


Fig. 3.1--Zoommeer and Grevelingen sections

Section Z1 is located directly behind the Volkerakdam, Z2 is the remainder of the Volkerak and the Krammer, and Z3 is the portion west of Bergen op Zoom and the canal to the Volkerak. Sections G1, G2, and G3 are the east, central, and west portions of the Grevelingen, respectively. Tables 3.3 and 3.4 show the areas and volumes of the sections of each of these lakes as a function of lake level.

Table 3.3

AREAS AND VOLUMES OF THE ZOOMMEER SECTIONS

	Area (km^2)					Volume (million m^3)				
	Level (cm above NAP)					Level (cm above NAP)				
Section	-100	-50	0	50	100	-100	-50	0	50	100
Z1	16.81	17.13	17.75	18.57	19.95	79	87	96	105	114
Z2	24.68	28.41	30.80	34.56	37.19	106	119	133	147	164
Z3			20.					27		

SOURCE: Ref. 3.3.

Table 3.4

AREAS AND VOLUMES OF THE GREVELINGEN SECTIONS

	Area (km^2)			Volume (million m^3)		
	Level (cm above NAP)			Level (cm above NAP)		
Section	-100	-20	0	-100	-20	0
G1	33.32	39.59	41.16	143	164	169
G2	26.42	38.63	41.69	123	153	160
G3	28.61	31.30	31.97	226	251	257

SOURCE: Ref. 3.4.

For flow and salinity calculations the three sections for each of the fresh Zoommeer and Grevelingen are treated as separate nodes with storage, with the three sections of each lake kept at the same level (they are in open connection). Water exchanges between the sections occur only from water flows for flushing and level control (the managerial rules for flushing and level control of the fresh Zoommeer and Grevelingen are given in Sec. 5.3.9). In the salinity calculations, salt is exchanged between the sections only through the water flows from section to section (see Sec. 6.2.6). For pollutants other than salt, the Zoommeer and Grevelingen are treated as single nodes with storage (see Sec. 6.4).

Maas Weir Ponds. During periods of low flows on the Maas, the weirs are raised from the river bottom at seven locations on the Maas--Borgharen (just north of Maastricht), Linne, Roermond, Belfeld, Sambeek, Grave, and Lith. Timbers are placed in the weir structures, cotton-wool wadding stuffed into the cracks between the timbers, and ashes or some similar substance placed in the river to filter into the cracks to reduce the leakage in the weirs to nearly zero. The raising of the weirs maintains the levels required for shipping (see Sec. 7.2.1), and the sections of the Maas between the weirs (called stuwpanden, or weir ponds) serve as water storage sections. The sections and their nodes are: (1) the Maas south of the weir at Borgharen and the Julianakanaal south of the lock at Born, MASTRICT; (2) the Julianakanaal between the locks at Born and Maasbracht, BORN; (3)

the Maas between the weirs at Maastricht and Linne is divided between the PANHEEL and LINNE nodes--the area above Panheel is assigned to PANHEEL; (4) the Maas between the weirs at Linne and Roermond, ROERMOND; (5) the Maas between the weirs at Roermond and Belfeld and the Lateraalkanaal, BELFELD; (6) the Maas between the weirs at Belfeld and Sambeek, SAMBEEK; (7) the Maas between the weirs at Sambeek and Grave, GRAVE; and (8) the Maas between the weirs at Grave and Lith, LITH.

In the DM the weirs are assumed to be raised whenever they are needed--the cost of raising the weirs must be added outside of the model (see Vol. II). The water stored in the weir ponds may then be used as a supplemental supply during decades with low Maas flows. The managerial rules for the control of the levels in the weir ponds are described in Sec. 5.3.1. From a water storage point of view, the most important of the weir ponds are the uppermost sections (the Maas south of the weir at Borgharen and the Julianakanaal south of the lock at Maasbracht), part of whose storage may be used to provide additional water for locking operations at the Born and Maasbracht locks. The maximum usable storage in these sections is equivalent to an additional flow of 4 m^3/s for one decade.

Boezems. In some districts in the lowlands, the water volumes of the boezems have been detached from the districts and attached to the nodes because these volumes are part of the waterways represented by the regional system, and because pollutants being transported by water passing through the node pass through the boezem (see Table 3.2).

3.2. WATER DEMAND

3.2.1. Agriculture

The water demands of agriculture are determined in a submodel of the DM called DISTAG that performs detailed water and salt balance calculations for each PAWN district (see Sec. 3.3). The district extraction demands include water for level control, crop irrigation, and flushing for salinity control (see Sec. 3.2.4.1).

Level Control. A large portion of the water demand in districts is for level control. Not only does water evaporate from the surface water of the district but a comparable amount of water also leaks from the ditches into the subsoil.

Crop Irrigation. Irrigation of crops by overhead sprinkling is the largest use of water supply in the districts and is becoming larger as the use of sprinkling equipment expands. Irrigation by flooding is small compared with sprinkling, and we include it as part of sprinkling. In 1976, 13 percent of the croplands were irrigated by sprinkling (9 percent from surface water and 4 percent from groundwater). In the most extreme case used in PAWN for projecting sprinkling demands into the future, the portion of croplands sprinkled rises to 40 percent in the 1985-1990 period (see Vol. XIV).

3.2.2. Level Control in the National and Regional Systems

Evaporation. There is a large total open water area associated with the links and storage nodes of the PAWN network, and a large amount of water can be lost to evaporation (over 200 m^3/s during the first two decades of 1976). Evaporation from the storage at nodes is calculated using the open water evaporation value for the weather station for the node and placed as a water extraction demand at the node. Similarly, the evaporation from the open water associated with a link is placed as an extraction demand at the node at the upstream end of the link. Decreased flows result from these demands for links representing rivers; increased demands are placed on the supply to the link for links representing canals since fixed levels are assumed for all canals.

Leakage. In some canals in the highlands, water leaks from the sides and bottoms of the canals into the ground. This leakage is placed as a fixed extraction at the node at the upstream end of the link representing the canal and also entered as part of the fixed input to DISTAG as water entering the groundwater of the appropriate district(s) (see Table 3.5).

Table 3.5

LEAKAGE FROM CANALS

Link	Extraction Node	Leakage (m^3/s)	Discharge Districts
ZUIDWLM1	MASTRICT	0.8	(Belgium)
ZUIDWLM2	LOOZEN	0.2	68
ZUIDWLM3	WEERT	0.3	63
WILHEKAN	HELMOND	1.0	70,71,72,73
DRENTHOF	MEPPEL	0.14	12
ORANJKAN	SMILDE	0.15	12
LINHOKAN	SMILDE	0.075	12
HOGVART	HOGEVEEN	0.075	12
VHOGVART	HOGEVEEN	0.075	11
TWENKAN1	LOCHEM	0.5	18,20,24
TWENKAN2	LOCHEM	0.5	18,20,24

SOURCE: Ref. 3.5.

3.2.3. Shipping

When the flows in the major shipping arteries--the Rijn, Waal, IJssel and Maas--are low, shipping costs increase because the river depths are not sufficient for the larger ships when they are fully loaded. More (and less efficient) ships must then be used or the cargoes stored until the river flows increase. These extra shipping costs are calculated in the DM by means of low water loss functions provided by the shipping analysis (Vol. IX) and are one of the primary outputs of a DM run (see Sec. 7.2).

A second water demand by shipping is the water needed for locking operations (i.e., lock losses). For salt-fresh locks, i.e., locks in the lowlands connecting freshwater canals to the North Sea or to brackish waterways, the water needed for locking operations is small compared to that needed for salinity control at the lock and is considered as part of the latter demand in the DM (see Sec. 3.2.4.1).

For locks in the Southeast Highlands, there may be insufficient flow in the Maas to provide the desired flow for locking operations (Sec. 4.3.7). When the water provided to the locks is less than that desired, ships are delayed and ship operating costs are increased. Curves for these shipping delay losses as functions of the available flows are derived in the shipping analysis (see Vol. IX and Sec. 7.2) and included in the DM for the Kanaal Wessem-Nederweert, Zuid-Willemsvaart, Wilhelminakanaal, Julianakanaal, and the Lateraalkanaal (Sec. 7.2.2).

The water demands for the locks are input as desired and minimum flows on the links representing the canals with locks (see Table 2.1). The desired flow is that needed to minimize shipping delay losses under optimal locking operations, and the desired flow will be met when water supplies are plentiful. The actual flows may be cut back to the specified minimum flows during periods of water shortage, and the minimum flows have generally been selected from the shipping delay loss versus flow curves (see Sec. 7.2.2) as the value of the flow where the losses start to increase dramatically.

For other locks, the water required for locking operations is represented as a desired flow in the link downstream of the lock (see Table 2.1). The water required for locking operations is then met by a water demand at the upstream node of the link, taking into account any other demands at the downstream end of the link and, for lock losses in excess of the downstream demands, any pumping capacity available at the lock to pump water back around the lock.

3.2.4. Pollution Control

The water demands for pollution control are represented in the DM as desired and minimum flows on links (Sec. 2.1.1) and as desired flows for flushing in districts (Sec. 3.3). In periods when water is plentiful the desired flows are met insofar as possible and as limited by other constraints, but in periods of water shortage the flows may be cut back to the minimum by managerial rules designed to match the demands with the available supply (see Chaps. 4 and 5).

3.2.4.1. Salinity Control

Flushing in Districts. Water from the surface water distribution system is used in the districts to dilute and replace saline water. A flushing demand for each district is part of the data input to DISTAG and is interpreted as the minimum desired discharge for the district;

i.e., the desired extraction demands for flushing are determined so that the minimum discharge is met.

Salinity Control at Salt-Fresh Locks. At locks in the lowlands that connect freshwater waterways to the North Sea or to brackish waterways (e.g., the Noordzeekanaal, Nieuwe Waterweg, Volkerak, and Oosterschelde), salt intrudes into the freshwater side during locking operations. The degree of salt intrusion can be reduced by flushing the waterway by means of discharge sluices alongside the locks. Salt intrusion at such salt-fresh locks as a function of the flushing rate is included in the DM at 13 nodes in the network (Sec. 6.2.4). When the fresh side is a body of water, the salt intrusion is represented as a salt dump into the storage volume at that node. When the fresh side is a canal, the saline water diffuses the canal and damages crops that use the canal water.

A separate salt damage calculation is made for each district containing such a salt-fresh lock (see Sec. 6.2.5). Flushing water for salinity control at salt-fresh locks is determined by entering desired and minimum flows on the links of the network that represent the fresh side of the waterway.

Markermeer Flushing. Discharges of saline water (due to brackish seepage) from Flevoland (district 30) increase the salinity of the Markermeer above that of the IJsselmeer during the winter and spring. To reduce the salinity of the Markermeer (and also the IJmeer), it is flushed with water from the IJsselmeer as long as the salinity of the IJsselmeer is lower than that of the Markermeer. (During years with low Rijn discharges, the salinity of the IJsselmeer will generally increase until the salinity of the IJsselmeer is above that of the Markermeer sometime during the summer.) In the DM this flushing flow is implemented by placing a desired flow (currently, 70 m^3/s in summer and 30 m^3/s in winter) on the ORANJESL link joining the IJmeer with the Noordzeekanaal at Amsterdam and subsequently to the North Sea at IJmuiden. This flow also serves to flush the city canals of Amsterdam, to lower the salinity of the Noordzeekanaal, and to provide cooling water for the Hemweg power plant at Amsterdam and the Velsen power plant at IJmuiden. The flushing flow is cut back to 10 m^3/s, the desired flow for flushing the canals of Amsterdam, whenever the salinity of the IJsselmeer is higher than that of the Markermeer or the level of the IJsselmeer is either below target level (for the RWS, Velsen, and MSDM strategies, see Sec. 5.4) or below its sprinkling emergency level (for the current strategy, see Sec. 5.4).

Zoommeer and Grevelingen Flushing. Flushing flows from the Haringvliet are used to control the salinity of the Zoommeer and Grevelingen when they are fresh. Saline discharges from districts, seepage, and salt intrusion at salt-fresh locks (see Sec. 6.2.4) can raise the salinity of the Zoommeer to as high as 1000 mg/l in the absence of flushing. Flushing flows for the Zoommeer are input as desired and minimum flows on the link ZOOMERSL (lock losses for the Philipsdam and Kreekrak locks are treated as part of the ZOOMERSL flow). For the Grevelingen, desired and minimum flows are placed on the GREVDAM, HALSKAN, or BROUWDAM links, depending upon which of these links is used for the flushing flows. The source of supply for both the Zoommeer and Grevelingen is the Haringvliet--via the VOLKERAK link for the Zoommeer, and via the HALSKAN or GREVDAM links for the Grevelingen. The target levels of the Zoommeer and Grevelingen and the desired flushing flows are met within the capacities of the supply and discharge links unless the Rotterdam salt wedge reaches the Gouda inlet (see Sec. 3.1.2.3).

Rotterdam Salt Wedge. No explicit flow requirements are set in the DM to combat the Rotterdam salt wedge. However, a managerial rule is brought into effect whenever the salinity at the Gouda inlet due to the salt wedge is above a specified input value (e.g., 50 mg/l). This policy (see Sec. 5.3.6) makes maximum use of the Midwest emergency supply system (and any new supply route through the Krimpenerwaard or Lopikerwaard, or the Maarssen-Bodegraven canal) to replace extractions at Gouda and, if necessary, cuts back certain lower priority extractions to increase the flow in the Rotterdamse Waterweg.

3.2.4.2. Urban, Nature, and Recreation Areas.

On several links desired flows are input to represent minimum water needs for flushing pollutants out of local areas. For flushing the city canals of Amsterdam and Utrecht, there are desired flows on the links ORANJESL (10 m^3/s, but see Markermeer Flushing above) and MERWKAN3 (2.0 m^3/s), respectively. On the link ZAAN, there is a desired flow of 7m^3/s from North Holland to the Noordzeekanaal at Zaandam to dilute industrial wastes. For freshening a nature area on the De Reest River, there is a desired flow of 0.25 m^3/s on REEST2. On the Grensmaas (link 81, MAAS1), there is a desired flow of 10 m^3/s to dilute pollutants (primarily discharges from the DSM chemical plant); however, this flow cannot be met when the Maas flow is low, and the actual flow is controlled by a managerial rule under control of the user (see Sec. 5.3.1).

3.2.4.3. Cooling Water for Electrical Power Plants.

There is currently a 3-deg-C standard in Dutch rivers for the allowable temperature increase due to heat discharged by electrical power plants (see Sec. 6.3). In the future, standards may be imposed on all waterways, and in PAWN scenarios future standards of 3 deg or 7 deg have been assumed for all other waterways.

Twenty-seven of the thirty-eight power plants in the Netherlands are located on waterways subject to the current or future standards. A number of these plants are located in close proximity to one another and may be combined as far as their heat discharge locations are concerned. There are fourteen such combined locations represented in the DM.

The average effective capacity of the power plants at these locations increases from 900 MW in 1976 to 1100 MW in 1985 (in 1985 the Diemen power plant has the lowest effective capacity, 351 MW, and the combined Amer and Donge power plants the highest, 1830 MW). A power plant generating 1000 MW will discharge approximately 300 Mcal/s of waste heat and require on the order of 90 m^3/s of water flow in the waterway supplying the cooling water to meet the 3-deg standard.

Many of the power plant locations are on the major rivers and lakes (at the modes ZWOLLE, NIJMEGEN, IJSLMEER, SCHEUR, DORDRECT, GERTRUID, BELFELD, and LINNE), and no flow demands specific to these power plants are input to the DM. For two locations--FRIELAND, representing the Bergum and Leeuwarden power plants, and GRONIGEN, representing the Helpman and Hunze power plants--desired and minimum flows are input on the links supplying the cooling water (DOKKUMEE for the FRIELAND location and WINDIEP1 for GRONIGEN). For the power plant locations on the Amsterdam-Rijnkanaal (the Lage Weide and Merwedekanaal power plants at UTRECHT and the Diemen power plant at DIEMEN), the cooling water flows are determined by the desired flow specified for the ARKANAL5 link that is used as a control to force the specified flow into the Noordzeekanaal from the Amsterdam-Rijnkanaal. Discharges from adjacent districts into the Amsterdam-Rijnkanaal may provide more than the specified flow during periods of heavy precipitation.

The flow in the Noordzeekanaal for cooling water for the Hemweg power plant at AMSTEDAM and the Velsen power plant at IJMUIDEN is determined by the desired flow specified for ARKANAL5, the flushing flow from the Markermeer (Sec. 5.3.11), and the flushing flows specified for the ZAAN and HARLMEER links (see Table 2.1).

3.2.5. Drinking-Water Companies and Industry

The demands of drinking-water companies and industry are represented as fixed demands in the districts (mostly from groundwater) and as extractions at nodes in the network. See Table 3.6. Only about 10 percent of the water used by drinking-water companies and industry is consumed. The remainder is discharged into the surface water of the district in which it is extracted or at nodes in the network.

3.2.6. Extractions by Belgium

By a treaty with Belgium in 1863, the Netherlands must send at least 10 m^3/s of the Maas discharge at Maastricht back into Belgium via the Zuid-Willemsvaart (link ZUIDWLM1). The Belgians then must return to the Netherlands at Lozen (link ZUIDWLM2) all but 8 m^3/s. In actuality, the flow measuring technique (specified in the treaty) that monitors the flow to Belgium is low by about 30 percent, and the amount sent to Belgium and not returned is closer to 11 m^3/s (including 0.8 m^3/s leakage from the Zuid-Willemsvaart; see Table 3.5), the value used in PAWN for the nominal amount extracted by Belgium at LOOZEN. The maximum amount of water sent along this route and returned to the Netherlands is limited by the capacities of the ZUIDWLM1 and ZUIDWLM2 links (20 m^3/s and 6 m^3/s, respectively).

Table 3.6

SURFACE WATER EXTRACTIONS BY DRINKING-WATER COMPANIES AND INDUSTRY

Extraction Node or District	Discharge[1] Node	DW/IND	Extractions (m^3/s) 1976	1990
DENBOSCH	NOORDZEE	DW	1.4	1.9
GERTRUID	SCHEUR	DW	4.1	4.4
IJSLMEER	HALFWEG	DW	0.6	1.5
JUTPHAAS	NOORDZEE	DW	2.5	2.2
RIJNLAND	NOORDZEE	DW	0.5	1.0
NIGTVECH	AMSTEDAM	DW	0.6	1.4
MASTRICT	(consumed)	IND	0.2	0.3
MASTRICT	PANHEEL[2]	IND	1.5	2.0
GERTRUID	ZOOMMEER	IND	---	1.0
IJSLMEER	NOORDZEE	IND	---	2.0
JUTPHAAS	HALFWEG	IND	1.1	0.3
GRONIGEN	NOORDZEE	IND	---	0.3

SOURCE: Ref. 3.6.

[1] In general, 90 percent of the extraction is discharged at the specified discharge node.

[2] Seventy-five percent of this extraction (for the DSM chemical plant) is discharged to the Grensmaas at the PANHEEL node.

3.2.7. Consumptive and Nonconsumptive Uses of Water

A consumptive use of water is one in which the water is taken from the surface water distribution system and not returned; other uses are nonconsumptive. Thus, water used to replace evaporation or evapotranspiration losses, (i.e., water for level control and crop irrigation), flushing water at salt-fresh locks that connect to the North Sea, and the flow in the Nieuwe Waterweg used to fight the Rotterdam salt wedge are consumptive uses. Cooling water for power plants, water flows in rivers to maintain shipping depths, water to compensate for lock losses in canals, and flushing water for districts are sometimes consumptive and sometimes nonconsumptive depending upon location and circumstance. For example, water flowing in the Waal is used for shipping but also is the major part of the flow in the Rotterdamse Waterweg. Another example is that the flow in the Noordzeekanaal serves a double purpose--flushing the canal and as cooling water for the Hemweg and Velsen power plants--but, depending upon the origin of the water, the flow may also serve to flush the Markermeer, flush the city canals of Amsterdam or Utrecht, be used as flushing water for Zaan or Spaarndam, and/or serve as cooling water for the power plants at Utrecht, Amsterdam, and Diemen.

Table 3.7 illustrates the consumptive and nonconsumptive usage of water for a dry decade. The data are from the A1 impact assessment run described in Sec. 1.5.

Table 3.7

ILLUSTRATIVE SURFACE WATER USAGE IN A VERY DRY DECADE (m^3/s)
(Run IMPA1: 19th Decade)

Supply: 1115 (Rivers = 907, IJsselmeer = 184, Drainage = 24)

		Consumptive	
Usage	Nonconsumptive	Item	Total
Nieuwe Waterweg[1]	0	582	582
OTHER SHIPPING			
IJssel	156	0	
Maas	11	0	
Lock losses at inland locks	13	0	0
EVAPORATION ON WATERWAYS			
IJssel lakes	0	160	
Zoommeer	0	5	
Other waterways	0	52	217
AGRICULTURE			
Sprinkling	0	93	
Level control in districts	0	101	
Flushing of districts	11	0.5	194.5
POWER PLANT COOLING			
DOKKUMEE (Bergum)	18	4	
Other power plants[2]	1400[4]	0	4
SALINITY CONTROL AT SALT-FRESH LOCKS			
STATZIJL+DELFZIJL+HARLNGSL	0	3.5	
MARSDIEP+AMSTDIEP	0	4	
HARLMEER	3	0	
NZKANLSL[2]	0	43	
VLIET	3	0	50.5
OTHER POLLUTION CONTROL			
REEST2	0.3	0	
ORANJESL (Markermeer flushing)	13	0	
KATWIJK+SCHEVING	0	1.5	
Amsterdam canals	10	0	
Utrecht canals	2	0	
ZAAN	7	0	
HARINGSL	0	5	
ZOOMERSL[3] (Zoommeer flushing)	0	25	31.5
MISC. EXTRACTIONS			
Belgium	0	22	
Industry and DW companies	15	10	
Leakage from canals	0	3.5	35.5

[1] The Nieuwe Waterweg discharge maintains shipping depths, keeps back the Rotterdam salt wedge, and provides cooling water for power plants on the Rotterdamse Waterweg.

[2] The Noordzeekanaal discharge also provides cooling water for the Hemweg and Velsen power plants.

[3] Flushing water for the Zoommeer includes lock losses at Philipsdam, Kreekrak, and Oesterdam locks (Fig. 3.1).

[4] Includes flows past all major power plants (Table 6.6). Nonconsumptive cooling water exclusive of power plants on the Waal, IJssel, IJsselmeer, and the Rotterdamse Waterweg is approximately 100 m^3/s.

3.3. THE DISTRICT HYDROLOGIC AND AGRICULTURE MODEL

The extraction demands and discharges from districts are determined by a submodel of the DM called DISTAG (for District Hydrologic and Agriculture Model). In this volume DISTAG will be considered as a component of the DM. However, DISTAG has a number of uses as a stand-alone model when a district (or districts) may be assumed to receive all the water that is needed from the surface water distribution system. It may be used, for example, to estimate district surface water requirements under various degrees of increased crop irrigation, or to evaluate the effect on groundwater levels in the districts of increased groundwater withdrawals. An existing stand-alone version of DISTAG is called DEMGEN (for DEMand GENerator). Detailed descriptions of both DISTAG and DEMGEN are contained in Vol. XII.

3.3.1. Some Features of DISTAG

In DISTAG the surface area of a district is subdivided into surface water area, urban area, and cropland. Croplands are further subdivided into constructs called plots, each of which consists of all the cropland in a district that has the same crop type, soil type, drainage parameters, and surface water irrigation type (surface water sprinkling, groundwater sprinkling, or no irrigation). The different crops grown in the Netherlands are aggregated into 13 crop types; since other vegetation-covered land (woodlands, parks, marshlands, etc.) is important for drainage and groundwater calculations, it is included as a 14th crop type called "nature." For the current situation, the total number of plots in all districts is over 1200; for some future scenarios used in PAWN, the number of plots increased to over 1400 as parts of currently unirrigated cropland were changed to irrigated cropland. For each decade time step, DISTAG models water and salt balances for each plot and each district.

The subsurface of each plot is divided into two layers: the root zone is the uppermost layer, from which 80 percent of the water withdrawn by plants is obtained (30 to 80 cm, depending upon crop type and soil type). The subsoil is the subsurface below the root zone. The moisture content of the subsoil generally increases with increasing depth until reaching the groundwater level, below which the moisture content is at a maximum, or saturation, capacity.

DISTAG calculates exchanges of water and salt between the root zone and the atmosphere by precipitation and evapotranspiration (the combined effect of evaporation from the surface and transpiration from plants), between the root zone and the subsoil (modeling the effects of gravity downward and capillary rise upward from the groundwater level), and between the district surface water and the subsoil. In lowlands plots the direction of flow depends upon the relative levels of the ditches in the plots--an input constant for each plot--and the groundwater level of the plot; for highlands plots where there are no systems of ditches, there is basic drainage from the plots to the surface water that is a function of the groundwater level.

Seepage from deep brackish aquifers or from the North Sea enters the groundwater of the plot at a fixed flow rate and salinity concentration. Any withdrawals from groundwater by drinking-water companies and industry, and for sprinkling of the plot, lower the groundwater level.

Water demands for surface water sprinkling are placed as demands on the surface water of the district. The amount of water needed for sprinkling during the decade is determined so that the moisture content of the plot lies between specified values needed to ensure minimum drought damage to the crop (see Vol. XIII for the precise specification of sprinkling water demands).

The surface water in the district is treated as a constant volume (i.e., there is assumed to be no level change) with extractions and discharges determined so as to maintain that constant volume. Flushing water for each district is part of the data input to DISTAG (see Vol. XII) and is interpreted as the minimum desired discharge for the district, i.e., the extraction demands for flushing are determined so that the minimum discharge is met. The net extraction or discharge from the district is determined from a water balance calculation that includes urban runoff (from precipitation), precipitation and evaporation from the surface water, water exchanges between the surface water and the subsoil of the plots (see above), extractions from the district surface water for surface water sprinkling, industrial and drinking-water company surface water extractions and discharges, and seepage directly into the surface water.

The salt concentration in the surface water (and consequently of the discharge from the district and in the surface water sprinkling) is determined under the assumption that the surface water volume is completely mixed at all times and takes into account the salinities of all water entering and leaving the surface water. DISTAG does not calculate the concentrations of pollutants in the districts other than salt; the other pollutant concentrations are calculated elsewhere in the DM (see Sec. 6.4).

3.3.2. Interactions of DISTAG with the Remainder of the DM

At the beginning of each decade time step, DISTAG is called from the DM in the <u>request mode</u> to establish the extractions requested by the districts and the quantity and salt concentration of any district discharges. The salinity of the extraction from the previous decade is passed to DISTAG for each district so that a preliminary salt balance calculation can be made and the salinity of any discharge estimated. The extraction demand from the district is passed to the DM from DISTAG as four component demands: extractions for level control, flushing, sprinkling for glasshouse crops (that cannot be reduced), and other sprinkling (that can be reduced). Both flushing and sprinkling may be cut back by the DM when water shortages occur, but flushing is cut back first.

The discharge from each district is given to the DM by DISTAG as two components--surface water discharge and outside drainage. During the testing of the discharges of districts calculated by DISTAG, it was determined that the discharges of the districts in the highlands were too high in the summer months when compared with the measured flows of small rivers in the highlands (see Vol. XII). One possibility is that deep groundwater flows remove water from the groundwater in the highlands to larger streams and rivers at some distance from the districts. A proposed representation of this phenomenon was to take a portion of the groundwater drainage of each highlands district (called outside drainage) and discharge it at nodes closer to the North Sea than the nodes to which the ordinary discharges of the district are discharged. Based on a comparison of calculated total discharges and measured flows, this outside drainage has been set to 60 mm/ha/year for all highlands districts (spread uniformly over the year).

However, in the DM the two discharge components--surface water discharge and outside drainage--are combined into a single discharge from the district unless an input parameter is specified (see Sec. D.1.2.2), in which case the outside drainage component is discarded. All DM runs for screening and impact assessment used the combined single discharge.

When the DM has determined the final water distribution for a decade time step, DISTAG is called again in the deliver mode. The fraction of the water requested by the district that is actually delivered to the district and the salinity of that water are passed to DISTAG so that the final water and salt balances in the plots and districts may be calculated. DISTAG then passes back to the DM, for each district, monetary values of the crop losses due to drought and salinity damage (for each crop type) and the labor and energy costs of sprinkling (by crop type and type of sprinkling--groundwater or surface water).

Groundwater levels are calculated separately for each plot in DISTAG. These groundwater levels interact with the surface water model in several ways: (1) in districts where the groundwater levels are sufficiently high that capillary rise from the saturated zone reaches the root zone of the crops, a portion of the evapotranspiration of the crops is supplied from the groundwater, thus reducing irrigation water needs; (2) groundwater levels determine the amount of water draining from the highlands portions of districts to the surface water. Drainage in the Southeast Highlands, for example, increases the flow in the Maas by a minimum of 20 m^3/s, representing a substantial portion of the flow in dry periods; (3) approximately 10 percent of the water used by drinking-water companies and industry is consumed and the remaining 90 percent is entered into the surface water, usually in the vicinity of the withdrawal location. Thus, most of the groundwater used by drinking-water companies and industry ends up in the surface water system; (4) leakage of surface water from the sides and bottoms of canals into the ground is entered into the DM as extractions from nodes (see Sec. 3.4) and entered into the groundwater of the district containing the canal as part of the input data to DISTAG.

3.4. WATER DEMANDS AT THE NETWORK NODES

All discharges and extractions from the network take place at the network nodes. At the beginning of the computation for each decade time step, river discharges are read from an external supply file (Sec. 3.1.1.2) and assigned to the appropriate nodes. Then discharges from external drainage are calculated (see Sec. 3.1.1.3) and assigned to nodes.

Next, the water demands at each node in the network are calculated. Input extractions and discharges by industry and drinking-water companies, leakage from canals, etc., are kept in a table and entered at the nodes. Each node has been assigned to a weather station, and precipitation and open water evaporation values for each weather station (mm/decade) are brought in from a data file so that the net rain, i.e., the difference between precipitation and evaporation, can be calculated for the storage areas at the nodes and for the areas of the links. Discharges and desired extractions for each district (for level control, flushing, and sprinkling) are calculated by the DISTAG submodel (Sec. 3.3.2). The district distribution keys (see below) are then used to assign the district discharges and extractions to the nodes. By summing all these demands, we find the total discharge and the desired extractions at each node (certain of the desired extractions may be cut back later due to capacity constraints), and consequently the total demand at each node.

District Distribution Keys. The district discharges and extractions are apportioned to the district links (and consequently to the network nodes) by means of extraction and discharge distribution keys. These keys are most easily defined by means of an example:

LAUWMEER EXT FRIELAND 8.9 0.30 LAUWMEER 1.4 0.03 GRONIGEN 5.2 0.67

The first name identifies the district of the key, and the abbreviation EXT (or DIS) identifies it as an extraction (or discharge) distribution key. A district distribution key contains up to four triples of parameters, each triple being a node name, a capacity (in m^3/s), and the fraction of the district extractions (or discharges) assigned to the district link connecting the district to the named node. In the above example, the LAUWMEER district apportions 0.30, 0.03, and 0.67 of its extractions to the FRIELAND, LAUWMEER, and GRONIGEN nodes, respectively. If an extraction exceeds the specified capacity for the link, the flushing and sprinkling components of the extraction are reduced until the capacity is met (flushing is reduced first and then sprinkling as needed). The level control component of the extraction demand is not reduced since the DISTAG submodel (Sec. 3.3) assumes that level control demands are always met, but a message is printed by the DM pointing out that the given capacity has been exceeded by extraction demands for level control. For discharge keys the capacity constraints for the district links are currently ignored by the DM.

Table 3.8 contains the district keys for the current situation [3.7, 3.8]. When waterboard plans are implemented, new district links may be added to those given in Table 3.8 and/or the capacities and fractions assigned to the district links may be modified (see Vol. XIV).

REFERENCES

3.1. Rijkswaterstaat, Directie Waterhuishouding en Waterbeweging, Afdeling Waterstaatkartografic, De Waterstaatkaart (Maps 46, 57, 59), various dates.
3.2. MR-271 (unpublished PAWN memorandum), "Surface Areas and Water Volumes of PAWN Links and Nodes," April 1979.
3.3. Rijkswaterstaat, Directie Waterhuishouding en Waterbeweging, District Zuidwest, Voorstudie Water-en Zoutbalans Oostmeer (Studies of the Water and Salt Balance of the East Lake), Notanummer 24.001.01, July 1975.
3.4. Unpublished information from the Rijkswaterstaat, Directie Waterhuishouding en Waterbeweging, District Zuidwest, concerning areas and volumes of Grevelingen sections, March 1979.
3.5. MW-177 (unpublished PAWN memorandum), "Losses from Canals in the Highlands," June 1979.
3.6. MR-282 (unpublished PAWN memorandum), "Industrial and Drinking-Water Company Demand Scenarios," July 1979.
3.7. MW-183 (unpublished PAWN memorandum), "Water Supply: Areas, Capacities, and Costs," July 1979.
3.8. Unpublished report containing the results of a waterboard inquiry on water supply conducted by the Union of Waterboards, February 1978 (PAWN file DW-470).

Table 3.8

DISTRICT EXTRACTION AND DISCHARGE DISTRIBUTION KEYS

District		Key	Link 1			Link 2			Link 3			Link 4		
No.	Name	Type	Node	Cap.	Frac.	Node	Cap.	Frac.	Node	Cap.	Frac.	Node	Cap.	Frac.
1	FRIELAND	EXT	54 FRIELAND	86.10	1.000									
1	FRIELAND	DIS	54 FRIELAND	213.80	1.000									
2	HETBILDT	EXT	54 FRIELAND	6.00	1.000									
2	HETBILDT	DIS	14 NOORDZEE	19.40	1.000									
3	LAUWMEER	EXT	54 FRIELAND	8.90	0.300	56 LAUWMEER	1.40	0.030	57 GRONIGEN	5.20	0.670			
3	LAUWMEER	DIS	56 LAUWMEER	38.90	1.000									
4	UITHUIZN	EXT												
4	UITHUIZN	DIS	14 NOORDZEE	21.40	1.000									
5	EEMSKANN	EXT	57 GRONIGEN	7.10	1.000									
5	EEMSKANN	DIS	14 NOORDZEE	52.70	1.000									
6	OLDAMBT	EXT	60 TERAPEL	999.90	0.320	61 WINSHOTN	999.90	0.680						
6	OLDAMBT	DIS	14 NOORDZEE	38.20	1.000									
7	WESTWOLD	EXT	59 HOGEZAND	999.90	0.410	60 TERAPEL	2.50	0.590						
7	WESTWOLD	DIS	59 HOGEZAND	22.30	1.000	61 WINSHOTN	999.90	0.0						
8	NWDRENTE	EXT	59 HOGEZAND	1.07	0.810	64 SMILDE	999.90	0.190						
8	NWDRENTE	DIS	57 GRONIGEN	999.90	0.540	59 HOGEZAND	999.90	0.460						
9	WESKWART	EXT	57 GRONIGEN	3.03	0.870	64 SMILDE	0.90	0.130						
9	WESKWART	DIS	57 GRONIGEN	12.80	0.620	57 GRONIGEN	999.90	0.380						
10	NEDRENTE	EXT	66 ERICASLU	999.90	1.000									
10	NEDRENTE	DIS	60 TERAPEL	999.90	1.000									
11	SEDRENTE	EXT	64 SMILDE	999.90	0.220	66 ERICASLU	6.27	0.780						
11	SEDRENTE	DIS	66 ERICASLU	999.90	1.000									
12	SWDRENTE	EXT	64 SMILDE	999.90	0.580	65 HOGEVEEN	999.90	0.420						
12	SWDRENTE	DIS	63 MEPPEL	999.90	0.450	64 SMILDE	999.90	0.200	65 HOGEVEEN	999.90	0.350			
13	VOLENHOV	EXT	54 FRIELAND	15.70	0.760	62 ZWARTMER	999.90	0.080	64 SMILDE	999.90	0.160			
13	VOLENHOV	DIS	62 ZWARTMER	999.90	1.000									
14	NEPOLDER	EXT	45 IJSLMEER	999.90	0.310	54 FRIELAND	999.90	0.360	62 ZWARTMER	999.90	0.320			
14	NEPOLDER	DIS	45 IJSLMEER	57.90	0.760	62 ZWARTMER	22.30	0.240						
15	MASTBROK	EXT	62 ZWARTMER	16.20	0.920	63 MEPPEL	999.90	0.030	72 DEDEMSVA	0.60	0.050			
15	MASTBROK	DIS	62 ZWARTMER	59.80	1.000									
16	OVIJVECT	EXT	69 VROMSHOP	999.90	0.030	70 HAANDRIK	0.10	0.020	71 COVORDEN	999.90	0.850	72 DEDEMSVA	0.78	0.100
16	OVIJVECT	DIS	73 OMMEN	999.90	1.000									
17	DINKEL	EXT												
17	DINKEL	DIS	70 HAANDRIK	999.90	1.000									
18	TWENTHE	EXT												
18	TWENTHE	DIS	73 OMMEN	999.90	1.000									
19	SALLAND	EXT	42 DEVENTER	6.57	0.560	62 ZWARTMER	999.90	0.300	74 SALLAND	1.00	0.140			
19	SALLAND	DIS	74 SALLAND	999.90	1.000									
20	TWENTKAN	EXT	68 DELDEN	13.00	1.000									
20	TWENTKAN	DIS	68 DELDEN	999.90	1.000									

Table 3.8 (continued)

District		Key	Link 1			Link 2			Link 3			Link 4		
No.	Name	Type	Node	Cap.	Frac.	Node	Cap.	Frac.	Node	Cap.	Frac.	Node	Cap.	Frac.
21	SHIPBEEK	EXT	67 LOCHEM	999.90	1.000									
21	SHIPBEEK	DIS	42 DEVENTER	999.90	1.000									
22	IJSELGEB	EXT	42 DEVENTER	2.35	1.000									
22	IJSELGEB	DIS	42 DEVENTER	999.90	0.050	43 ZWOLLE	999.90	0.950						
23	NEVELUWE	EXT	40 DIEREN	999.90	0.290	43 ZWOLLE	999.90	0.710						
23	NEVELUWE	DIS	41 ZUTPHEN	999.90	0.330	43 ZWOLLE	999.90	0.670						
24	BERKEL	EXT												
24	BERKEL	DIS	41 ZUTPHEN	999.90	1.000									
25	OUDEIJSL	EXT												
25	OUDEIJSL	DIS	7 IJSELKOP	999.90	0.080	40 DIEREN	999.90	0.920						
26	ARNHEM	EXT												
26	ARNHEM	DIS	7 IJSELKOP	999.90	1.000									
27	SEVELUWE	EXT												
27	SEVELUWE	DIS	8 WAGINGEN	999.90	1.000									
28	SWVELUWE	EXT	8 WAGINGEN	999.90	0.320	50 GOOIMEER	999.90	0.680						
28	SWVELUWE	DIS	50 GOOIMEER	999.90	1.000									
29	NWVELUWE	EXT	49 VELUWMER	2.30	0.670	50 GOOIMEER	1.00	0.330						
29	NWVELUWE	DIS	49 VELUWMER	26.00	1.000									
30	FLEVLAND	EXT	44 KETLMEER	22.20	1.000									
30	FLEVLAND	DIS	48 IJMEER	99.10	0.720	44 KETLMEER	27.00	0.280						
31	WIERGMER	EXT	45 IJSLMEER	999.90	0.110	53 AMSTMEER	1.90	0.890						
31	WIERGMER	DIS	45 IJSLMEER	34.10	1.000									
32	AMSTLMER	EXT	51 SCHERMER	4.20	0.380	53 AMSTMEER	5.50	0.620						
32	AMSTLMER	DIS	53 AMSTMEER	33.70	1.000									
33	MEDMBLIK	EXT	45 IJSLMEER	12.30	0.800	51 SCHERMER	2.20	0.200						
33	MEDMBLIK	DIS	45 IJSLMEER	28.00	1.000									
34	HOORN	EXT	47 MARKMEER	999.90		51 SCHERMER	999.90	0.100						
34	HOORN	DIS	47 MARKMEER	11.10	1.000									
35	SCHERMER	EXT	51 SCHERMER	32.00	1.000									
35	SCHERMER	DIS	51 SCHERMER	88.00	1.000									
36	WATRLAND	EXT	47 MARKMEER	999.90	0.670	51 SCHERMER	999.90	0.330						
36	WATRLAND	DIS	47 MARKMEER	7.50	0.600	37 AMSTEDAM	5.00	0.400						
37	NZKANGEB	EXT	51 SCHERMER	999.90	0.870	82 AMSTLAND	999.90	0.130						
37	NZKANGEB	DIS	38 HALFWEG	999.90	0.940	51 SCHERMER	999.90	0.060						
38	RIJNLAND	EXT	79 RIJNLAND	35.00	1.000									
38	RIJNLAND	DIS	79 RIJNLAND	999.90	1.000									
39	AMSTLAND	EXT	82 AMSTLAND	15.00	1.000									
39	AMSTLAND	DIS	82 AMSTLAND	999.90	1.000									
40	GOOI	EXT	76 NIGTVECH	6.50	1.000									
40	GOOI	DIS	76 NIGTVECH	999.90	1.000									

Table 3.8 (continued)

District		Key	Link 1			Link 2			Link 3			Link 4		
No.	Name	Type	Node	Cap.	Frac.	Node	Cap.	Frac.	Node	Cap.	Frac.	Node	Cap.	Frac.
41	KROMRIJN	EXT	9 DURSTEDE	5.80	0.720	33 JUTPHAAS	1.50	0.180	75 UTREVECH	0.50	0.110			
41	KROMRIJN	DIS	75 UTREVECH	999.90	1.000									
42	LEIDRIJN	EXT	33 JUTPHAAS	3.70	1.000									
42	LEIDRIJN	DIS	33 JUTPHAAS	999.90	1.000									
43	WOERDEN	EXT	77 LOPIKWAR	1.70	0.200	78 WOERDEN	6.80	0.800						
43	WOERDEN	DIS	78 WOERDEN	999.90	1.000									
44	LOPIKWAR	EXT	11 SCONOVEN	6.02	0.700	77 LOPIKWAR	2.58	0.300						
44	LOPIKWAR	DIS	77 LOPIKWAR	999.90	1.000									
45	KRIMPWAR	EXT	81 GOUDA	2.22	0.400	12 IJSLMOND	3.33	0.600						
45	KRIMPWAR	DIS	12 IJSLMOND	999.90	1.000									
46	SCIELAND	EXT	81 GOUDA	999.90	1.000									
46	SCIELAND	DIS	13 SCHEUR	999.90	1.000									
47	DELFLAND	EXT	80 DELFLAND	11.00	1.000									
47	DELFLAND	DIS	80 DELFLAND	999.90	1.000									
48	VOORNE	EXT	29 HELVOETS	11.00	1.000									
48	VOORNE	DIS	29 HELVOETS	999.90	1.000									
49	GOEREE	EXT	29 HELVOETS	999.00	1.000									
49	GOEREE	DIS	14 NOORDZEE	999.90	1.000									
50	IJSLMOND	EXT	6 OUDBIJER	5.50	1.000									
50	IJSLMOND	DIS	6 OUDBIJER	999.90	1.000									
51	HOLNDIEP	EXT	27 MOERDIJK	999.90	0.480	91 FIJNAART	999.90	0.520						
51	HOLNDIEP	DIS	27 MOERDIJK	999.90	0.470	91 FIJNAART	999.90	0.530						
52	DORDRECT	EXT	5 DORDRECT	3.00	1.000									
52	DORDRECT	DIS	5 DORDRECT	999.90	1.000									
53	ABLASWAR	EXT	11 SCONOVEN	10.00	1.000									
53	ABLASWAR	DIS	11 SCONOVEN	999.90	1.000									
54	BIESBOSH	EXT	25 GERTRUID	6.10	0.760	26 BIESBOSH	0.80	0.090	90 OSTRHOUT	999.90	0.060	91 FIJNAART	0.80	0.090
54	BIESBOSH	DIS	4 GORINCHM	999.90	0.250	25 GERTRUID	999.90	0.750						
55	TIELWARD	EXT	84 TIELWARD	12.60	1.000									
55	TIELWARD	DIS	84 TIELWARD	999.90	1.000									
56	DENBOSCH	EXT	24 DENBOSCH	8.50	1.000									
56	DENBOSCH	DIS	24 DENBOSCH	999.90	0.430	25 GERTRUID	999.90	0.570						
57	BETUWE	EXT	83 BETUWE	12.00	1.000									
57	BETUWE	DIS	83 BETUWE	999.90	1.000									
58	MAASWAAL	EXT	22 GRAVE	999.90	1.000									
58	MAASWAAL	DIS	23 LITH	999.90	1.000									
59	RECMAASN	EXT												
59	RECMAASN	DIS	2 NIJMEGEN	999.90	1.000									
60	RECMAASM	EXT												
60	RECMAASM	DIS	22 GRAVE	999.90	1.000									

Table 3.8 (continued)

District		Key	Link 1			Link 2			Link 3			Link 4		
No.	Name	Type	Node	Cap.	Frac.	Node	Cap.	Frac.	Node	Cap.	Frac.	Node	Cap.	Frac.
61	MASKANTE	EXT												
61	MASKANTE	DIS	22 GRAVE	999.90	0.420	23 LITH	999.90	0.580						
62	MASKANTW	EXT	23 LITH	9.00	1.000									
62	MASKANTW	DIS	24 DENBOSCH	999.90	1.000									
63	AA	EXT	87 MEYEL	999.90	1.000									
63	AA	DIS	24 DENBOSCH	999.90	1.000									
64	DEPEEL	EXT	87 MEYEL	999.90	1.000									
64	DEPEEL	DIS	21 SAMBEEK	999.90	1.000									
65	RECMAASS	EXT												
65	RECMAASS	DIS	21 SAMBEEK	999.90	0.700	20 BELFELD	999.90	0.300						
66	ROERMOND	EXT												
66	ROERMOND	DIS	19 ROERMOND	999.90	1.000									
67	SLIMBURG	EXT												
67	SLIMBURG	DIS	15 MASTRICT	999.90	0.180	17 PANHEEL	999.90	0.820						
68	MLIMBURG	EXT	86 WEERT	999.90	1.000									
68	MLIMBURG	DIS	18 LINNE	999.90	0.130	19 ROERMOND	999.90	0.020	20 BELFELD	999.90	0.850			
69	EDOMMEL	EXT	86 WEERT	999.90	1.000									
69	EDOMMEL	DIS	89 BOXTEL	999.90	1.000									
70	MDOMMEL	EXT												
70	MDOMMEL	DIS	90 OSTRHOUT	999.90	0.630	89 BOXTEL	999.90	0.370						
71	WDOMMEL	EXT												
71	WDOMMEL	DIS	89 BOXTEL	999.90	1.000									
72	NDOMMEL	EXT												
72	NDOMMEL	DIS	89 BOXTEL	999.90	1.000									
73	DONGE	EXT												
73	DONGE	DIS	90 OSTRHOUT	999.90	1.000									
74	MARK	EXT												
74	MARK	DIS	91 FIJNAART	999.90	1.000									
75	ROSENDAL	EXT												
75	ROSENDAL	DIS	92 ROSENDAL	999.90	1.000									
76	ZOOM	EXT	29 HELVOETS	0.70	1.000									
76	ZOOM	DIS	31 ZOOMMEER	999.90	1.000									
77	SCHOUWEN	EXT												
77	SCHOUWEN	DIS	32 GREVLING	999.90	1.000									

Chapter 4

WATER DISTRIBUTION AND MANAGEMENT IN THE REGIONAL SYSTEMS

4.1. THE REGIONAL SYSTEMS

In Chap. 5, the national system is defined as those major waterways and their infrastructure represented by nodes 1 to 50 and links 1 to 71 of the PAWN network. It is possible to divide the remaining nodes and links into regional systems that are more or less self-contained; each extracts from and discharges to the national system, but has no or minimal connections to the other regional systems. The regional systems are defined in Table 4.1 and in Figs. 4.1 to 4.13.

Table 4.1

REGIONAL SYSTEMS

PAWN Region	Regional System	Links	Nodes
4	North Holland	72 to 77	51 to 53
1	North	78 to 91	54 to 61
2	Northeast Highlands	92 to 114	62 to 74
5	Midwest and Utrecht	115 to 137	75 to 82
Part of 6	Linge	138 to 141	83 to 84
7 and 8	South	142 to 154	85 to 91

With these definitions of the regional systems, there is only one link that connects one regional system to another--link 98 (NOWILKAN), representing the Noord-Willemskanaal, which connects the North and the Northeast Highlands regional systems. In the current infrastructure, this link has a fixed flow, a lock loss to the North of 0.2 m^3/s, so that the interaction between the two regional systems is minimal. However, one of the tactics uses the Noord-Willemskanaal to transport water from the North to the Northeast Highlands; for this reason, the DM treats the North and Northeast Highlands regional systems as one superregional system in certain places in the model structure.

4.2. GENERAL PROCEDURE FOR WATER DISTRIBUTION

Water distribution in a regional system is determined in the DM by the use of a general procedure, i.e., a computer program structure, that is controlled by parameters characterizing the regional system plus additions to the general procedure that are unique to the individual regional systems. In this section, we describe the general procedure, and in Sec. 4.3, the features that are unique to the regional systems and the managerial rules for the regional systems.

4.2.1. Water Demands at the Regional Nodes

At the beginning of the computation for each decade time step, discharges and desired extractions are established for every node in the network (see Sec. 3.4).

4.2.2. Flow Constraints on Regional Links

Each link in the PAWN network has two flow capacity constraints and a desired flow associated with it (Sec. 2.1.1); these may be changed at each decade by inputs. For regional links, the first flow constraint is interpreted as a minimum flow on the link if the constraint is a positive number, and as a pumping capacity if the constraint is a negative number; i.e., the absolute value of the flow constraint is the capacity to pump water from the downstream end of the link to the upstream end of the link. The second capacity constraint is the maximum capacity of the link in the positive flow direction. The desired flow is the minimum flow that will be maintained on the link whenever supply constraints will allow it; the desired flows represent demands for water to compensate for lock losses, flows needed for salinity control, flows to control the concentrations of other pollutants, and cooling water for electrical power plants.

4.2.3. Distribution Keys for the Regional System Nodes

Each node in a regional system has a discharge distribution key and an extraction distribution key. These keys are most easily defined by showing an example. The following is the discharge distribution key currently in use for node 54 (FRIELAND):

```
FRIELAND DIS MARGKAN 0.67 DOKKUMEE 0.33 FRIEHARL 0.0 STABOKAN 0.0
```

The node name identifies the node for the key, and the abbreviation DIS (or EXT) identifies it as a discharge (or extraction) distribution key. A distribution key contains up to four pairs of parameters, each pair being a link name and a fraction. The fraction member of the pair is the fraction of any discharge (or extraction) at the node to be discharged to (or extracted from) the link named in the pair after any desired flows in all the links named in the key have been fulfilled. In the example the entries for FRIEHARL and STABOKAN are included so that discharges to the FRIELAND node will automatically be used to fill any desired flows on those two links. In the procedure given in the next section for calculating the flows in the links of a regional system, the node distribution keys determine the fractional allocation of discharges and extractions from each node to the links. If the capacity of one of the nonzero fraction links is exceeded by an allocation, the excess flow is reassigned to the other named links with nonzero fractions according to the ratio of the fractions assigned to those links. If all the named links with nonzero fractions have their capacities reached, the named links with zero fractions are used in their order of appearance in the distribution key until their capacities are reached. Finally, if the capacities are reached for all the links given in the key, any remaining discharge (or extraction) is assigned to the first link appearing in the key. Table 4.2 contains the node distribution keys for the current situation [4.1, 4.2]; these keys may be changed by inputs at any decade.

4.2.4. The Iterative Procedure for Determining Link Flows

In the steps given below, both discharges and extractions are moved from node to node by the distribution keys described above until they reach a node outside the regional system. At each iteration of the procedure, each node is examined only once, and the net discharge or extraction at the node is moved to the appropriate next node(s). A status variable is kept for each node whose value is the sum of the discharges minus the extractions currently at the node. At the end of the iterations, all node status variables will be zero, and the final flows obtained for the links from the moving discharges and extractions will be the link flows necessary to meet the current discharge and extraction demands at the nodes.

Let Sj be the status variable at node j; i.e., at any point in the procedure, Sj is the sum of the discharges minus the extractions currently at the node. Initialize Sj as the difference of discharges minus desired extractions at node j, and initialize the flows in all links of the regional system equal to zero. The steps in the iterative procedure for determining the flows in a regional system are:

1. Examine all nodes with Sj > 0. If the discharge distribution key specifies a link with a nonzero desired flow in the direction of the specified discharge, say the link to node k, fulfill as much of the desired flow as possible, reduce Sj, increase Sk, and adjust the flow in the link from node j to node k, accordingly.
2. Examine all nodes with nonzero Sj. If Sj > 0, allocate Sj to the links specified by the discharge distribution key for node j (by the rules given in Sec. 4.2.3), adjust the flows on those links, and increase the values of the status variables at the nodes at the ends of those links, accordingly. Set Sj equal to zero. If Sj < 0, proceed similarly, using the extraction distribution keys.
3. Repeat Steps 1 and 2 until all status variables are equal to zero.
4. If the desired flows in all the links of the regional system are met, the procedure is finished. If the desired flow is not met for some link, say the link from node j to node k, set the value of Sk equal to the difference between the desired and current flow in that link, the value of Sj equal to minus Sk, and the flow in the link equal to the desired value; then repeat from Step 1.

Table 4.2

NODE EXTRACTION AND DISCHARGE DISTRIBUTION KEYS

Node		Key	Link 1			Link 2			Link 3			Link 4		
No.	Name	Type	No.	Name	Frac.	No.	Name	Frac.	No.	Name	Frac.	No.	Name	Frac.
51	SCHERMER	EXT	72	SCHERMIN	1.000									
51	SCHERMER	DIS	74	NOHOLKAN	0.500	73	ZAAN	0.500						
52	DENHELDR	EXT	74	NOHOLKAN	1.000									
52	DENHELDR	DIS	75	MARSDIEP	1.000									
53	AMSTMEER	EXT	76	STONTEL	1.000									
53	AMSTMEER	DIS	77	AMSTDIEP	1.000	76	STONTEL	0.0						
54	FRIELAND	EXT	78	MARGKAN	1.000									
54	FRIELAND	DIS	78	MARGKAN	0.670	81	DOKKUMEE	0.330	79	FRIEHARL	0.0	82	STABOKAN	0.0
55	HARLNGEN	EXT	79	FRIEHARL	1.000									
55	HARLNGEN	DIS	80	HARLNGSL	1.000									
56	LAUWMEER	EXT	81	DOKKUMEE	1.000									
56	LAUWMEER	DIS	86	LAUWSPUI	1.000									
57	GRONIGEN	EXT	82	STABOKAN	1.000									
57	GRONIGEN	DIS	83	EEMSKAN	1.000	85	REITDIEP	0.0	87	WINDIEP1	0.0			
58	DELFZIJL	EXT	83	EEMSKAN	1.000									
58	DELFZIJL	DIS	84	DELFZISL	1.000									
59	HOGEZAND	EXT	87	WINDIEP1	1.000									
59	HOGEZAND	DIS	89	WINDIEP2	1.000									
60	TERAPEL	EXT	88	STADSKAN	1.000									
60	TERAPEL	DIS	90	WESTWOLA	1.000	88	STADSKAN	0.0						
61	WINSHOTN	EXT	89	WINDIEP2	1.000									
61	WINSHOTN	DIS	91	STATZIJL	1.000									
62	ZWARTMER	EXT	95	RAMSDIEP	1.000									
62	ZWARTMER	DIS	95	RAMSDIEP	1.000									
63	MEPPEL	EXT	94	MEPLDIEP	1.000									
63	MEPPEL	DIS	94	MEPLDIEP	1.000									
64	SMILDE	EXT	99	DRENTHOF	1.000									
64	SMILDE	DIS	99	DRENTHOF	1.000									
65	HOGEVEEN	EXT	97	LINHOKAN	1.000									
65	HOGEVEEN	DIS	93	HOGVART	0.334	103	KANCOZWI	0.333	92	VHOGVART	0.333	97	LINHOKAN	0.0
66	ERICASLU	EXT	92	VHOGVART	1.000									
66	ERICASLU	DIS	100	STIELKAN	1.000									
67	LOCHEM	EXT	113	TWENKAN1	1.000									
67	LOCHEM	DIS	113	TWENKAN1	1.000									
68	DELDEN	EXT	114	TWENKAN2	1.000									
68	DELDEN	DIS	114	TWENKAN2	1.000									
69	VROMSHOP	EXT	109	OVIJKAN1	1.000									
69	VROMSHOP	DIS	110	OVIJKAN2	1.000	111	OVIJKAN3							
70	HAANDRIK	EXT	110	OVIJKAN2	1.000									
70	HAANDRIK	DIS	107	OVIJVEC1	1.000									
71	COVORDEN	EXT	106	COVORKAN	1.000									
71	COVORDEN	DIS	106	COVORKAN	1.000	101	LUTHOFWK	0.0						

Table 4.2 (continued)

Node		Key	Link 1			Link 2			Link 3			Link 4		
No.	Name	Type	No.	Name	Frac.	No.	Name	Frac.	No.	Name	Frac.	No.	Name	Frac.
72	DEDEMSVA	EXT	101	LUTHOFWK	1.000									
72	DEDEMSVA	DIS	102	OMMERKAN	1.000	105	REEST2	0.0						
73	OMMEN	EXT	107	OVIJVEC1	1.000	102	OMMERKAN	0.0						
73	OMMEN	DIS	108	OVIJVEC2	1.000									
74	SALLAND	EXT	111	OVIJKAN3	1.000									
74	SALLAND	DIS	112	OVIJKAN4	1.000									
75	UTREVECH	EXT	116	MERWKAN3	1.000									
75	UTREVECH	DIS	132	VECHT1	1.000									
76	NIGTVECH	EXT	132	VECHT1	1.000	133	VECHT2	0.0						
76	NIGTVECH	DIS	134	ARKVECHT	1.000									
77	LOPIKWAR	EXT	117	JUTGEMAL	0.0	115	MERWKAN2	1.000						
77	LOPIKWAR	DIS	118	KANHOLIJ	1.000	116	MERWKAN3	0.0						
78	WOERDEN	EXT	121	WIERICKE	1.000	122	LEIDRIJN	0.0						
78	WOERDEN	DIS	123	OUDERIJN	1.000									
79	RIJNLAND	EXT	125	GOUWE	1.000	124	MARBOKAN	0.0	123	OUDERIJN	0.0	136	TOLHUIS	0.0
79	RIJNLAND	DIS	131	HARLMEER	0.500	126	KATWIJK	0.500	127	LEIDSDAM	0.0			
80	DELFLAND	EXT	127	LEIDSDAM	0.0	129	KAWADVOR	1.000						
80	DELFLAND	DIS	130	VLIET	1.000	128	SCHEVING	0.0						
81	GOUDA	EXT	119	HOLIJSEL	1.000	120	KRIMPKAN	0.0	125	GOUWE	0.0			
81	GOUDA	DIS	119	HOLIJSEL	1.000									
82	AMSTLAND	EXT	135	ANGSTEL	1.000									
82	AMSTLAND	DIS	137	AMSTEL	0.670	135	ANGSTEL	0.330						
83	BETUWE	EXT	138	LINGE1	1.000	139	LINGEKAN	0.0						
83	BETUWE	DIS	140	LINGE2	1.000	139	LINGEKAN	0.0						
84	TIELWARD	EXT	140	LINGE2	1.000									
84	TIELWARD	DIS	141	LINGE3	1.000									
85	LOOZEN	EXT	142	ZUIDWLM1	1.000									
85	LOOZEN	DIS	143	ZUIDWLM2	1.000									
86	WEERT	EXT	144	WESNWERT	0.0	143	ZUIDWLM2	1.000						
86	WEERT	DIS	146	ZUIDWLM3	1.000	144	WESNWERT	0.0						
87	MEYEL	EXT	145	NORDVART	1.000									
87	MEYEL	DIS	145	NORDVART	1.000									
88	HELMOND	EXT	146	ZUIDWLM3	1.000									
88	HELMOND	DIS	147	ZUIDWLM4	0.500	149	WILHEKAN	0.500						
89	BOXTEL	EXT	148	DOMMEL	1.000									
89	BOXTEL	DIS	148	DOMMEL	1.000									
90	OSTRHOUT	EXT	150	DONGE	1.000									
90	OSTRHOUT	DIS	150	DONGE	1.000									
91	FIJNAART	EXT	151	MARK1	1.000									
91	FIJNAART	DIS	152	MARK2	1.000									
92	ROSENDAL	EXT	154	ROSVLIET	1.000	153	VLIETKAN	0.0						
92	ROSENDAL	DIS	154	ROSVLIET	1.000									

4.2.5. Demand Reductions

When the water distribution in a regional system is first determined by the procedure of Sec. 4.2.4, some of the links in the regional system may have their maximum capacity constraints violated. For each link for which corrective action is needed when the specified capacity constraint is exceeded, a section of computer program is written that represents the managerial rule for the corrective action (see Sec. 4.3). After the corrective action is taken for a link, a new water distribution is determined for the regional system by repeating the procedure of the preceding section.

4.3. WATER MANAGEMENT IN THE REGIONAL SYSTEMS

The water managerial rules contained in the DM for the regional systems are concerned with actions taken to meet capacity constraints on the links of the regional systems. These actions reduce the water demands downstream from the links whose capacities would otherwise be exceeded. They may reduce the desired flows on the regional links needed for power plant cooling water, lock losses, and salinity control at salt-fresh locks (an input vector identifies each link whose desired flow may be decreased to the minimum flow for that link by a nonzero entry in the vector position corresponding to the link number). They may also cut back those portions of the desired extractions by districts that will be used for flushing and sprinkling.

4.3.1. A General Purpose Demand Reduction Subroutine

The reductions in desired flows and the cutbacks in district extractions are controlled by calls to a general purpose demand reduction subroutine as

```
CALL REDUCE(IND,CUTBACK,L1,L2,ID1,ID2,N1,N2,N3,N4)
```

where IND is a control variable with possible values 0, 1, -1, or -2; CUTBACK is the amount (m^3/s) by which the desired flows are to be decreased and/or flushing and/or sprinkling in districts are to be cut back; L1 and L2 are link numbers; ID1 and ID2 are district numbers; and N1 N2, N3, and N4 are node numbers.

The control variable IND is interpreted as follows:

1. IND = 0. For those districts whose district number is between ID1 and ID2, reduce extractions by the amount used for flushing from extractions at nodes whose node numbers are between N3 and N4 or are equal to N1 or N2.
2. IND = -1. For those links whose link numbers lie between L1 and L2 and for which reductions are possible, reduce the desired flows in proportion to the difference between the desired flows and the absolute minimum flows for those links

until a total reduction is reached that is equal to the value of CUTBACK or to the maximum possible reduction.

3. IND = -2. For those districts whose district number is between ID1 and ID2, reduce extractions in proportion to the amount used for sprinkling from extractions at nodes whose numbers are between N1 and N2 or are equal to N3 or N4 in proportion to the amount of such sprinkling until a total reduction is reached that is equal to the value of CUTBACK or to the maximum possible reduction.
4. IND = 1. Reduce flushing on links as when IND = -1; reduce CUTBACK accordingly; then reduce sprinkling as when IND = -2.

The standard usage of the subroutine REDUCE when a flow capacity constraint is violated is to first reduce flushing in those districts where extraction reductions will ease the violation; to solve for new flows in the regional links; then, if the flow constraint is still violated, to reduce desired flows on links contributing to the problem; and, finally, if further reductions are necessary, to reduce sprinkling in the same districts where flushing was reduced. The following sections describe how this subroutine is used to implement managerial rules in each of the regional systems.

4.3.2. Managerial Rules for the North Holland Regional System

Figure 4.1 contains a map of the North Holland Region and includes the waterways represented by the North Holland regional system. Figure 4.2 contains the links and nodes of the North Holland regional system and the districts that have at least a portion of their demands at the nodes of that system.

The North Holland Region is supplied from the Markermeer and IJsselmeer. Link 72 (SCHERMIN) connects the regional system to the Markermeer and represents inlet works to the Schermerboezem at Schardam, Monnickendam, and Edam. From the Schermerboezem (node 51, SCHERMER), various waterways supply parts of districts 32 through 37. The Noordhollandsch Kanaal (link 74, NOHOLKAN) serves as a shipping route connecting the Noordzeekanaal to the Waddenzee at Den Helder. A second supply route, in the north, is from the IJsselmeer to the Amstelmeerboezem via the Stontelerkeersluis (near Den Oever just south of the Afsluitdijk) and the Amstelmeerkanaal (link 76, STONTEL). This supply route provides a portion of the extraction demands of districts 31 and 32, and the portion of the desired flow for salinity control in link 77, AMSTDIEP, that is not met by discharges from district 32.

There are demands[1] for flushing water for salinity control at salt-fresh locks at Den Helder (link 75, MARSDIEP, desired flow = 4.0 m^3/s, minimum flow = 2.0 m^3/s), and at Oostoever (link 77, AMSTDIEP, desired flow = 2.0 m^3/s, minimum flow = 2.0 m^3/s), and a desired flow to dilute industrial wastes on the Zaan (link 73, ZAAN, desired flow = 7.0 m^3/s, minimum flow = 7.0 m^3/s).

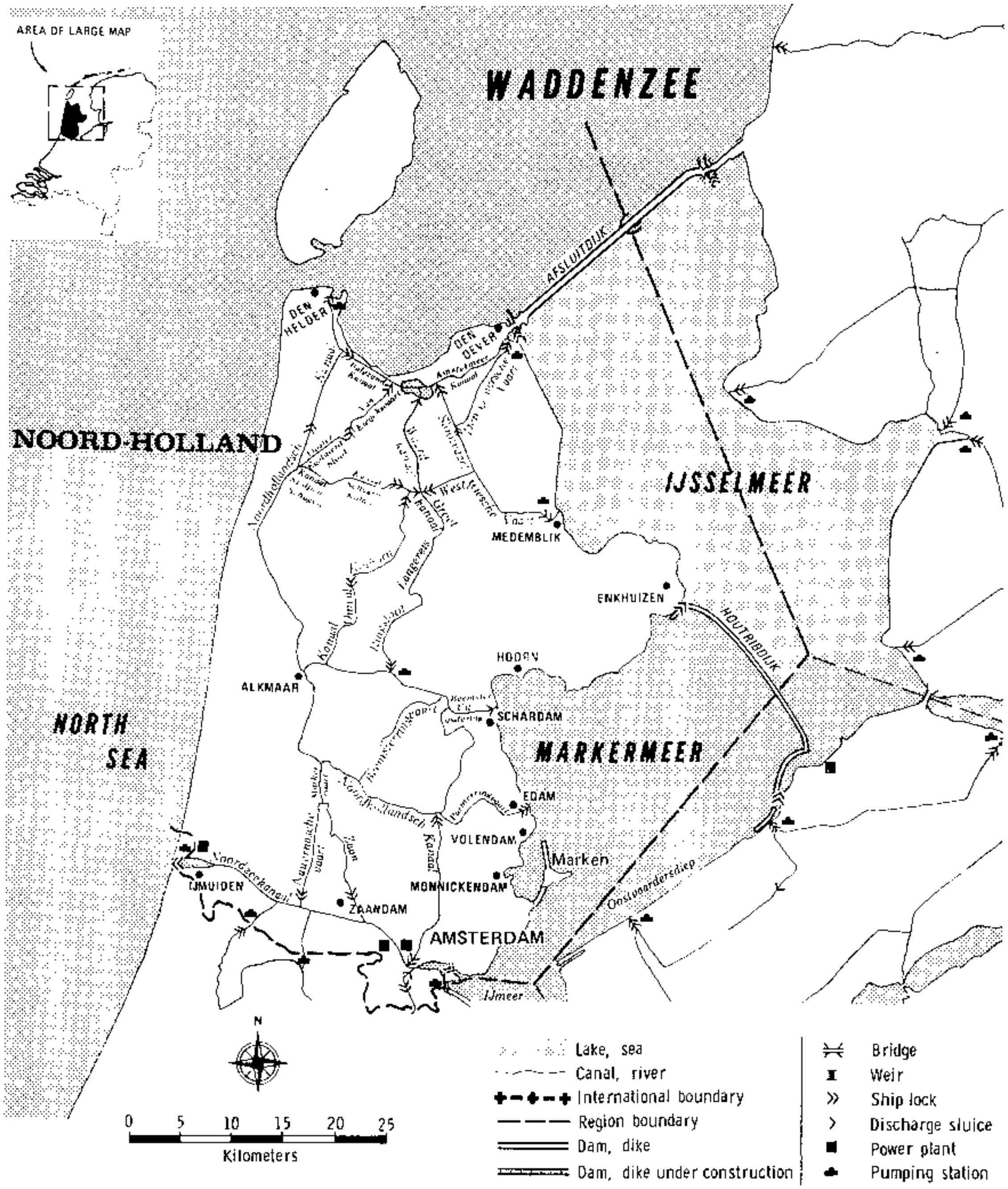


Fig. 4.1--Region 4: North Holland

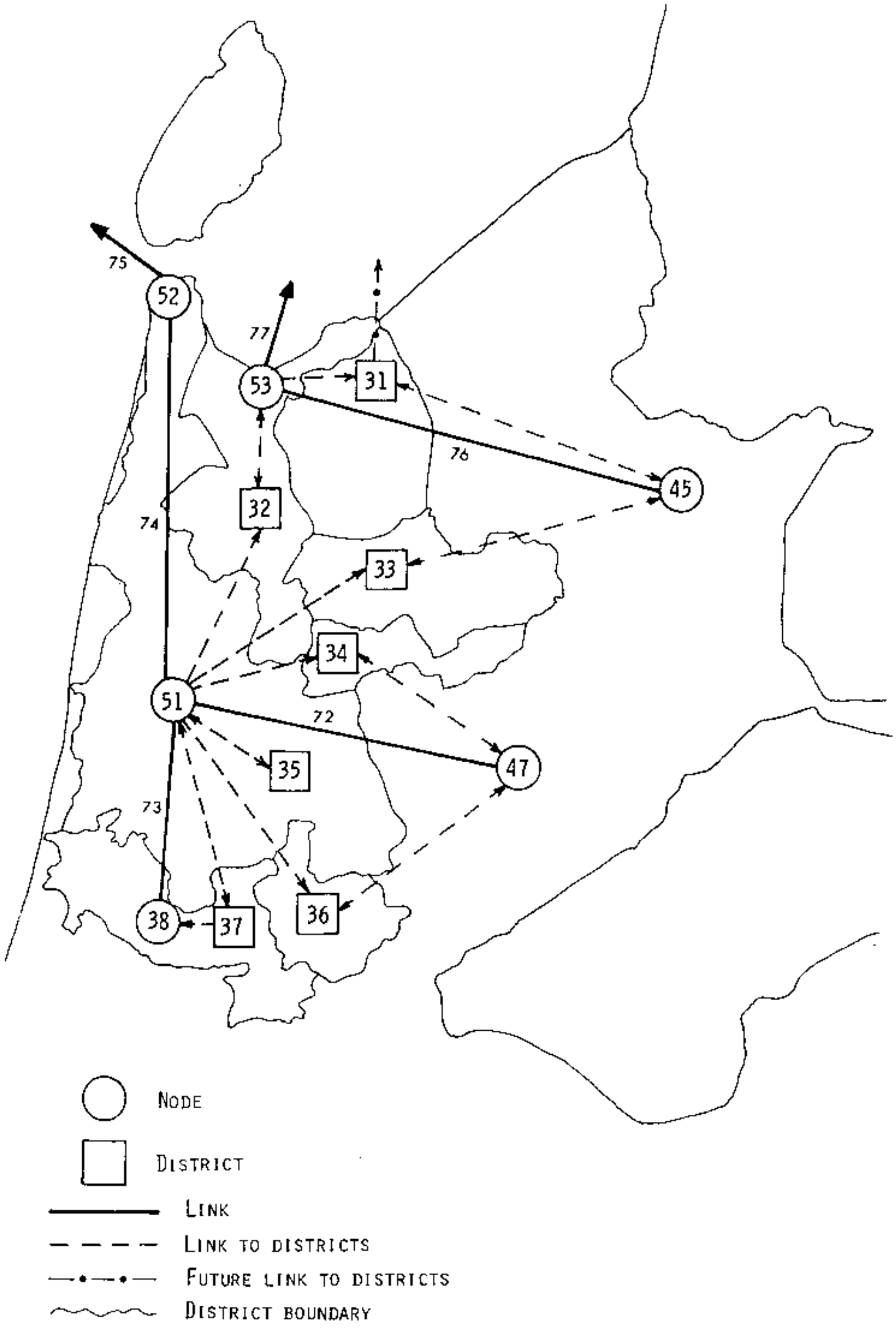


Fig. 4.2--The North Holland regional system

Both the STONTEL and SCHERMIN links have capacity constraints that depend upon the levels of the lakes from which they extract water. The capacities of SCHERMIN and STONTEL are obtained by linear interpolation in Table 4.3 using the levels of the Markermeer and IJsselmeer, respectively.

Table 4.3

EXTRACTION CAPACITIES OF SCHERMIN AND STONTEL
(m^3/s)

	Lake Levels (cm above NAP)		
Link	<-50	-40	>-30
SCHERMIN	0.0	23.9	30.0
STONTEL	0.0	0.0	8.0

If the capacity of STONTEL is exceeded by the extraction demands, the flushing extraction demands of districts 31 and 32 are reduced to zero; if the capacity is still exceeded, the flushing of AMSTDIEP is reduced from the desired value to the minimum value (in this case from 2.0 m^3/s to 2.0 m^3/s so that no actual reduction takes place); and finally the sprinkling in districts 31 and 32 is reduced as needed to meet the STONTEL capacity. If the capacity of SCHERMIN is exceeded, that part of the flushing in districts 32 to 37 that comes from SCHERMER (node 51) is reduced to zero; if necessary, flushing is reduced to the minimum values on MARSDIEP and ZAAN; and, finally, the portions of the sprinkling extractions for districts 32 to 37 that come from node 51 are reduced as needed to meet the capacity constraint.

The supply capacity to the area served by the inlets to the Schermerboezem is sufficient under current demands. However, for the increased sprinkling scenarios considered in screening, the capacity is insufficient in extremely dry decades. Tactics for increasing the capacity by either constructing a new canal from Schardam to Alkmaar, expanding one or more of the inlet works, or building a new pumping station at one of the inlets were evaluated in screening (Vol. II). These tactics are represented in the DM by inputs that change the capacities given in Table 4.3 for SCHERMIN.

4.3.3. Managerial Rules for the North Regional System

Figure 4.3 contains a map of the North Region and includes the waterways represented by the North regional system. Figure 4.4 contains the links and nodes of the North regional system and the districts that have at least a portion of their demands at the nodes of that system.

The North regional system is supplied by several inlet works (at Staveren, Tacozijl, and Teroelsterkolk) connecting the IJsselmeer to

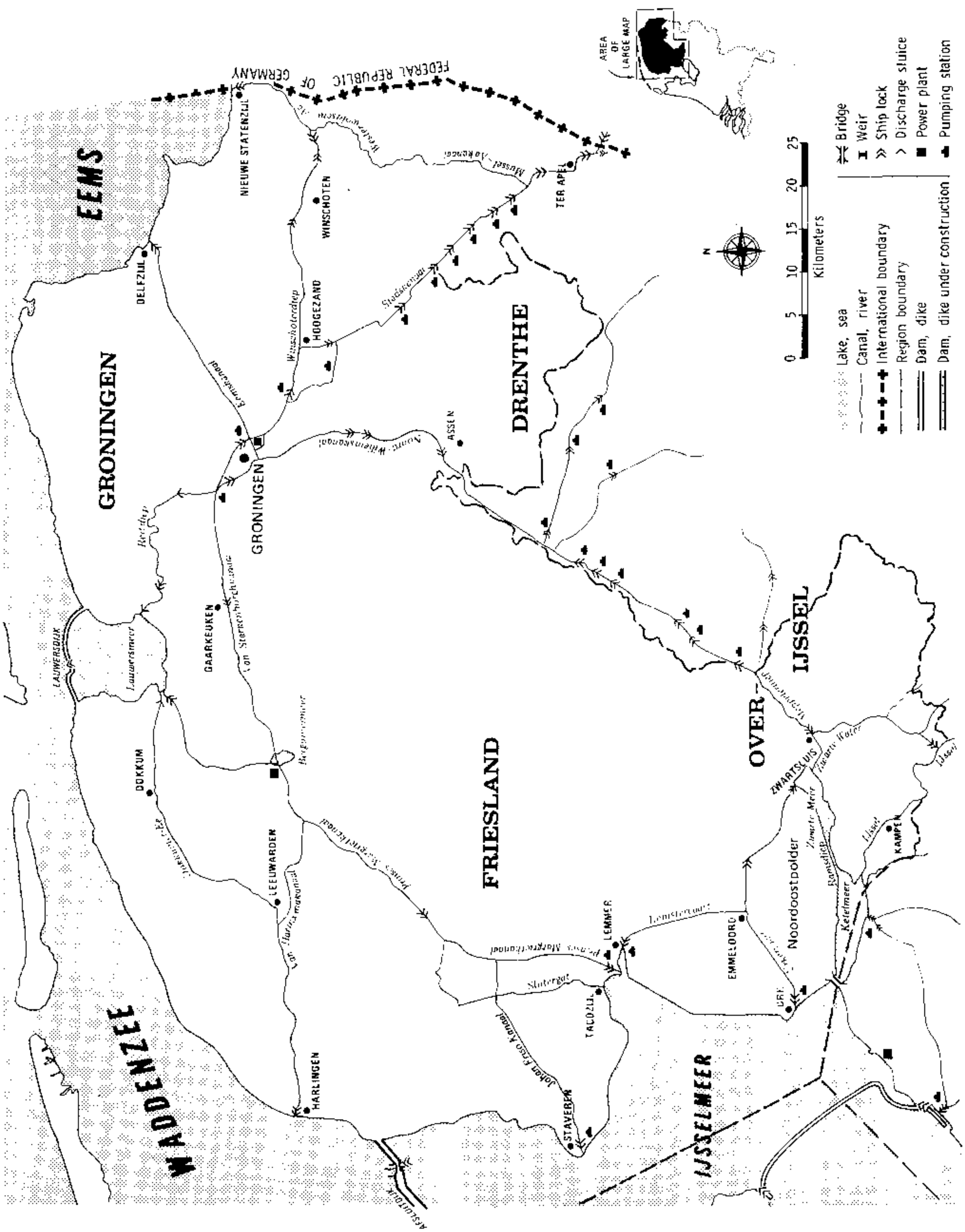


Fig. 4.3--Region 1: North

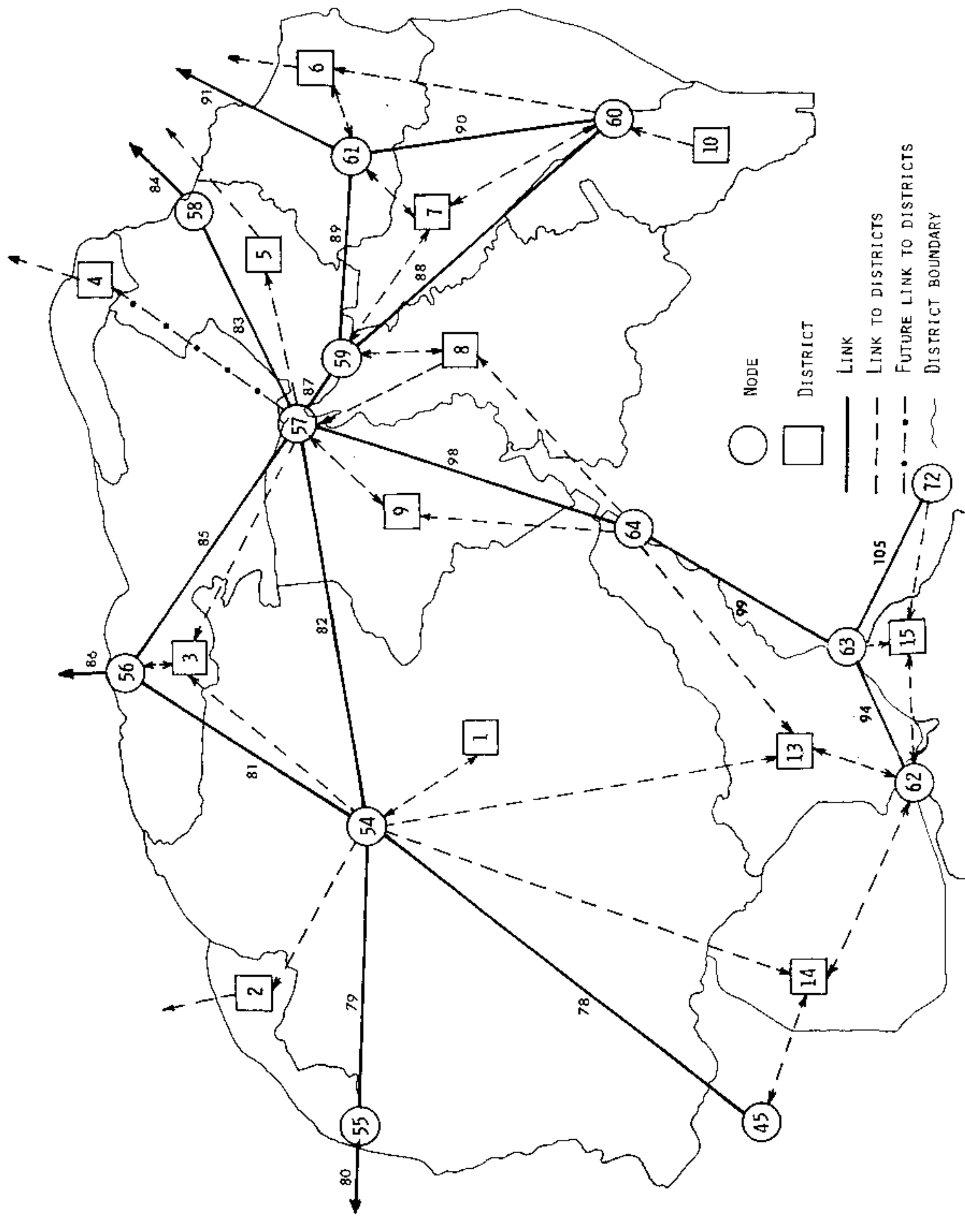


Fig. 4.4--The North regional system

the Friesland boezem system. The major waterway transporting water across Friesland is the Prinses Margrietkanaal (link 78, MARGKAN) that joins with the Van Starkenborghkanaal (link 82, STABOKAN) to provide the major supply for the districts in the province of Groningen. In Groningen the Winschoterdiep (links 87 and 89, WINDIEP1 and WINDIEP2) transports water from the Van Starkenborghkanaal to the east, and the Stadskanaal (link 88, STADSKAN) supplies water from the Winschoterdiep to the highlands in the southeast portion of the province.

There are demands for flushing water for salinity control at salt-fresh locks at Harlingen (link 80, HARLNGSL, desired flow = 8.0 m^3/s, minimum flow = 2.0 m^3/s), Delfzijl (link 84, DELFZISL, desired flow = 2.0 m^3/s, minimum flow = 1.0 m^3/s), and Nieuwe Statenzijl (link 91, STATZIJL, desired flow = 0.5 m^3/s, minimum flow = 0.5 m^3/s). For cooling water for the Hunze and Helpman power plants at Groningen, there is a demand on the Winschoterdiep (link 87, WINDIEP1, desired flow = 10.0 m^3/s, minimum flow = 2.0 m^3/s), and for cooling water for the Bergum power plant a demand on Nieuwe Vaart (link 81, DOKKUMEE, desired flow = 4.5 m^3/s, minimum flow = 0.0)--the Van Starkenborghkanaal is part of the cooling circuit for the Bergum power plant, and its flow provides most of the cooling capacity (Sec. 6.3.4).

STABOKAN (link 82) has a maximum flow of 16.0 m^3/s due to the lock bypass capacity at Garkeuken on the Van Starkenborghkanaal. If the maximum capacity of STABOKAN is exceeded, the portions of flushing water demands for districts 3 to 9 that come from STABOKAN are reduced to zero. The flows in the North regional system are then recalculated, and if the maximum capacity of STABOKAN is still exceeded, the desired flow on WINDIEP1 (link 87) is reduced as needed. The link flows in the North are recalculated again (a complication here is that the reduction on WINDIEP1 may not be effective because sprinkling and level control demands for districts 6, 7, and 8 may force a higher flow on that link). Then the portions of sprinkling demands for districts 3 to 9 that come from STABOKAN are reduced as needed to meet the capacity constraint.

The inlet works from the IJsselmeer that determine the capacity of MARGKAN (link 78) have a combined extraction capacity that depends on the level of the IJsselmeer according to Table 4.4.

Table 4.4

EXTRACTION CAPACITY OF MARGKAN
(m^3/s)

	IJsselmeer Level (cm above NAP)						
Link	<-50	-40	-30	-20	-10	0	>10
MARGKAN	0	53	89	97	105	93	69

The extraction capacity of MARGKAN is calculated by linear interpolation in Table 4.4 as a function of the level of the

IJsselmeer. If the capacity of MARGKAN is exceeded, the portions of the extractions for flushing water demands in districts 1 to 14 that come from any node in the North regional system, i.e., nodes 54 to 61, are reduced to zero. The link flows in the North are recalculated, and if the maximum capacity of MARGKAN is still exceeded, the desired flows on HARLNGSL, DELFZISL, STATZIJL, and DOKKUMEE are reduced to their minimum flows as needed. The flows in the North are calculated again, and then, if necessary, the portions of the sprinkling demands in districts 1 to 14 that come from nodes 54 to 61 are reduced as needed to meet the capacity constraint.

The FRIELAND (node 54) discharge distribution key is

```
FRIELAND DIS MARGKAN 0.67 DOKKUMEE 0.33 FRIEHARL 0.0 STABOKAN 0.0
```

The discharges at the FRIELAND node from district 1 would be used first to fill the desired flows on the DOKKUMEE and FRIEHARL links and the demands on STABOKAN. Any extra discharge would normally be divided between MARGKAN and DOKKUMEE in a ratio of 67:33. However, this key is modified in the DM to reflect the actual operating policy that first discharges up to 25 m^3/s on DOKKUMEE and then divides any remaining discharges in the 67:33 ratio; i.e., the distribution key is modified to operate as if the desired flow at DOKKUMEE is 25 m^3/s at high discharges.

Technical tactics considered in screening for increasing the supply capacity to the North Region included increasing the capacity of the Van Starkenborghkanaal by increasing the lock bypass capacity at Garkeuken and increasing the capacity of the Stadskanaal by expanding the pumping capacity along that canal. Both of these tactics can be represented in the DM by changing the capacities of the corresponding links (link 82, STABOKAN, and link 88, STADSKAN, respectively). Another technical tactic evaluated in screening was to change the discharge location of the Noordoostpolder from the present location on the IJsselmeer (pumping stations at Lemmer and Urk) to the IJmeer by building a pipeline and pumping station to carry the discharges from the southeast corner of the Noordoostpolder to the discharge canals of Flevoland to be transported to the IJmeer. This tactic can be approximated in the DM by changing the discharge distribution key for the Noordoostpolder to direct the discharges from the IJsselmeer to the IJmeer.

4.3.4. Managerial Rules for the Northeast Highlands Regional System

Figure 4.5 contains a map of the Northeast Highlands Region and includes the waterways represented by the Northeast Highlands regional system. Figure 4.6 contains the links and nodes of the Northeast Highlands regional system and the districts that have at least a portion of their demands at the nodes of that system.

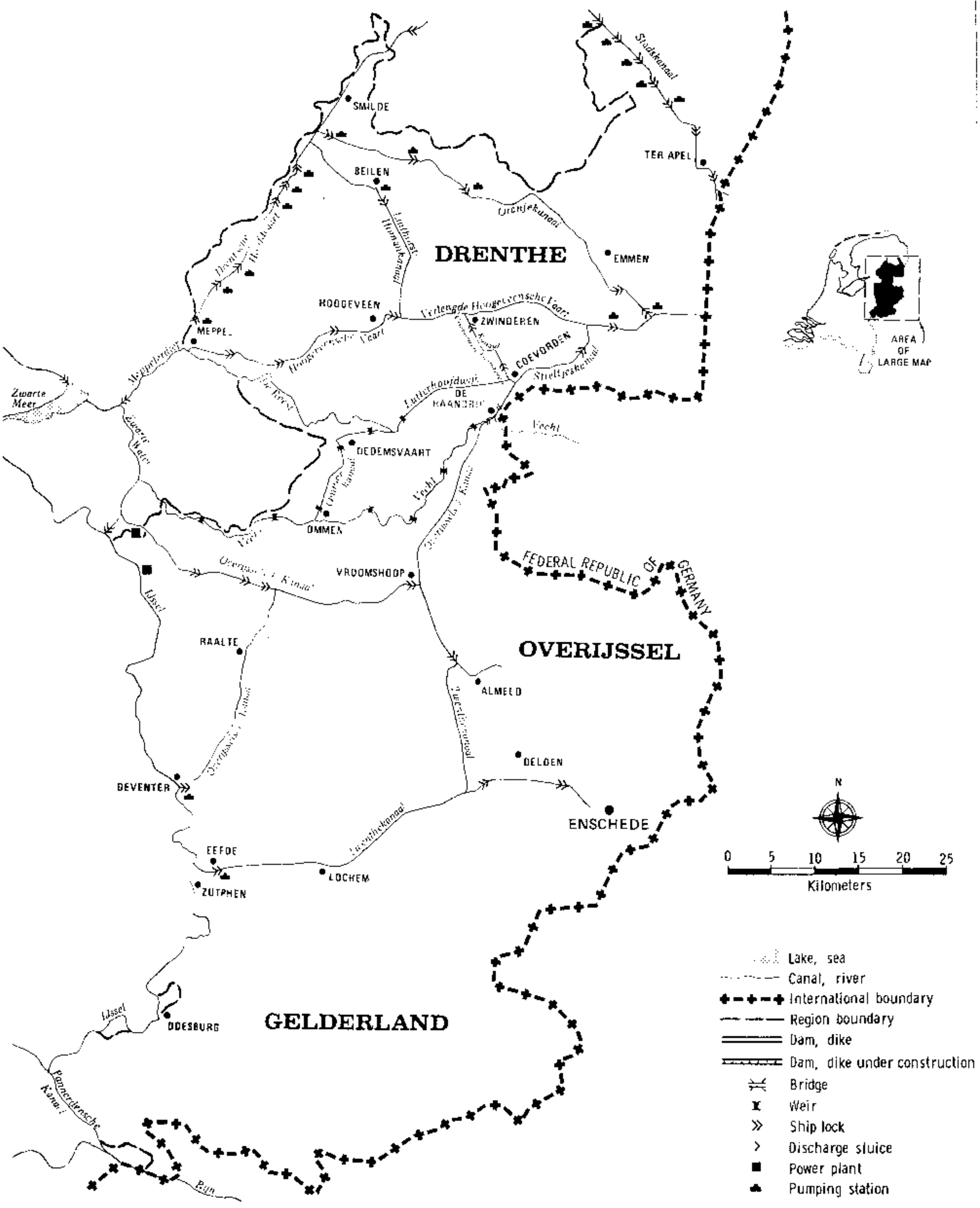


Fig. 4.5--Region 2: Northeast Highlands

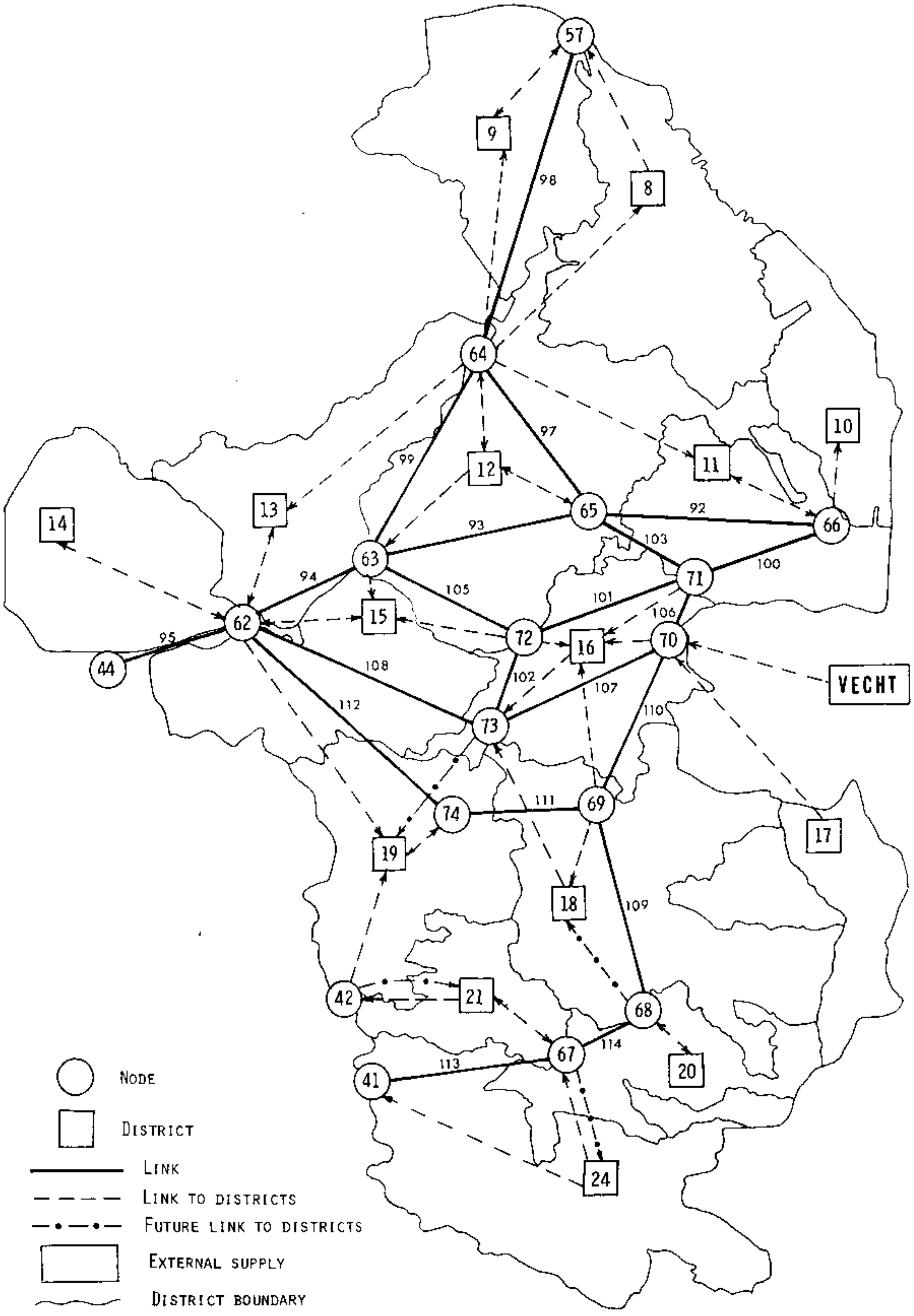


Fig. 4.6--The Northeast Highlands regional system

There are currently three main supply sources for this regional system. The Overijsselsche Vecht River (links 107 and 108, OVIJVEC1 and OVIJVEC2) crosses the border from W. Germany near De Haandrijk, and its discharge is entered at node 70 (HAANDRIK). This river provides part of the supply in the highlands in the province of Overijssel by gravity (to districts 16, 18, 19, and 20), but during dry periods its discharge is insufficient to meet the demands of these districts (in the summer of 1976 its average discharge was less than 2 m^3/s) and must be supplemented by supply from the southern route described below.

On the southern route, water is pumped from the IJssel River at Eefde and sent along the Twenthekanaal (link 113, TWENKAN1, pumping cap. = 11.0 m^3/s, lock loss = 1.75 m^3/s, and link 114, TWENKAN2, lock capacity = 5.0 m^3/s), and then along the Overijsselsch Kanaal (link 109, OVIJKAN1, and link 110, OVIJKAN2). From there it can be transported farther along the Overijsselsch Kanaal (link 111, OVIJKAN3) or along the Coevorden-Vechtkanaal (link 106, COVORKAN) and the Lutterhoofdwijk (link 101, LUTHOFWK) since these canals are all at the same level. This route supplies all or a portion of districts 15, 16, 18, 19, 20, 21, and 24.

The northern route extracts water from the Zwartemeer (link 95, RAMSDIEP) and transports it along the Meppelerdiep (MEPLDIEP, link 94); then the water is pumped along the Drentsche Hoofdvaart (link 99, DRENTHOF, pumping cap. = 4.3 m^3/s, lock loss = 0.1 m^3/s) and the Linthorst Homankanaal (link 97, LINHOKAN, pumping cap. = 3.3 m^3/s, lock loss = 0.1 m^3/s) to the Hoogeveensche Vaart (link 93, HOGVART) and the Verlengde Hoogeveensche Vaart (link 92, VHOGVART). This supply route serves all or a portion of districts 8, 9, 10, 11, 12, and 13.

There are fixed demands upon the Northeast Highlands regional system for leakage losses from canals to groundwater for the Drentsche Hoofdvaart, Hoogeveensche Vaart, Verlengde Hoogeveensche Vaart, Linthorst Homankanaal, and the Oranjekanaal. These are represented as fixed extraction demands at nodes: node 63, MEPPEL, leakage loss = 0.14 m^3/s; node 65, HOGEVEEN, leakage loss = 0.075 m^3/s; node 64, SMILDE, leakage loss = 0.075 m^3/s; and node 67, LOCHEM, leakage loss = 0.15 m^3/s, respectively. There is a desired (and minimum) flow on the Reest River (link 105, REEST2) of 0.25 m^3/s to freshen a nature preserve. There are fixed lock losses of 0.1 or 0.2 m^3/s on several of the links: HOGVART (link 93), LINHOKAN (link 97), NOWILKAN (link 98), DRENTHOF (link 99), STIELKAN (link 100), LUTHOFWK (link 101), OMMERKAN (link 102), KANCOZWI (link 103), OVIJKAN3 (link 111), and OVIJKAN4 (link 112).

The managerial rules in the DM for the Northeast Highlands regional system are designed to reduce demands by the districts when capacities of the links are exceeded. Table 4.5 lists the links for which managerial rules are included in the DM and the districts whose desired extractions may be cut back when capacities in those links are exceeded.

If the capacity of a link in Table 4.5 is exceeded, those portions of the extractions for flushing water for the districts that are supplied

Table 4.5

DISTRICTS SUPPLIED BY LINKS
WITH CAPACITY CONSTRAINTS

Districts Supplied	Links 92	93	97	99	100	113
8				N		
9				N		
10	N	N	N	N	ES	ES
11	N	N	N	N	ES	ES
12		N	N	N	ES	ES
13				N		
15						S
16						S
18						S
19						S
20						S
21						S
24						S

NOTE: An N denotes a district currently supplied from the northern supply route; an S denotes a district that is currently supplied by the southern supply route; and an ES denotes a district that may also be supplied by the southern supply route if that route is extended to include the Stieltjeskanaal (link 100, STIELKAN) by adding a pumping station on that canal.

by the link are reduced to zero. Then the flows in the regional system are recalculated, and if the capacity constraint is still exceeded, the district sprinkling demands that come from that link are reduced as necessary to meet the constraint.

Many of the technical tactics in Vol. II for the Northeast Highlands region provide additional supply by either enlarging the capacity of the two existing supply routes or by adding new routes. Other tactics add to the capacities of the links connecting the districts to the nodes and can be handled directly by increasing the capacities of those links.

One possible new supply route would add pumping along the Hoogeveensche Vaart (HOGVART, link 93) from Meppelerdiep, thereby supplementing the existing capacity on the northern route. Another technical tactic modifies the southern route by increasing the pumping capacity to the Twenthekanaal at Eefde (link 113, TWENKAN1), building a lock bypass at the Almelo lock (link 114, TWENKAN2), and adding pumping capacity on the Stieltjeskanaal (link 100, STIELKAN) so that the southern route could also supply districts 10, 11, and part of 12. Both of these modifications to the regional system can be defined in the DM through changes in the node extraction distribution keys and the link capacities.

Two of the possible new supply routes were eliminated from consideration in screening by cost comparisons with other technical tactics that supply the same districts, and no managerial rules are included for these routes in the DM. One of these routes would pump water south from the North regional system via the Noord-Willemskanaal (NOWILKAN, link 98) and the Linthorst Homankanaal (LINHOKAN, link 97); the other would pump water east on the Overijsselsche Vecht River (OVIJVEC2, link 108, and OVIJVEC1, link 108) and then north on the Coevorden-Vechtkanaal (COVORKAN, link 106) and Stieltjeskanaal (STIELKAN, link 100).

4.3.5. Managerial Rules for the Midwest and Utrecht Regional System

Figure 4.7 contains a map of the Midwest and Utrecht Region and includes the waterways represented by the Midwest and Utrecht regional system. Figure 4.8 contains the links and nodes of the Midwest and Utrecht regional system and the districts that have at least a portion of their demands at the nodes of that system.

The supply for this regional system comes from the Nieuwe Maas (node 12, IJSLMOND) via the Hollandsche IJssel (link 119, HOLIJSEL) and the inlet at Gouda (link 125, GOUWE, capacity = 32.0 m^3/s), from the Lek via the Merwedekanaal (link 115, MERWKAN2, capacity = 0.5 m^3/s, at low Lek flows), from the Amsterdam-Rijnkanaal to Woerden via the Leidsche Rijn (link 122, LEIDRIJN, capacity = 3.5 m^3/s), from the Amsterdam-Rijnkanaal to the Vaartsche Rijn and the Doorslaag by pumping at Jutphaas (link 117, JUTGEMAL, pumping cap. = 12.0 m^3/s), and from the Amsterdam-Rijnkanaal via the Angstel (link 135, ANGSTEL, capacity = 7.0 m^3/s).

There are demands for flushing water for salinity control at Halfweg and Spaarndam (link 131, HARLMEER, desired flow = 5.0 m^3/s, minimum flow = 3.0 m^3/s), at Katwijk (link 126, KATWIJK, desired flow = 3.0 m^3/s, minimum flow = 1.0 m^3/s), at Scheveningen (link 128, SCHEVING, desired flow = 0.4 m^3/s, minimum flow = 0.4 m^3/s), and at Parksluis (link 130, VLIET, desired flow = 5.6 m^3/s, minimum flow = 4.0 m^3/s). There is also a demand for flushing water to flush the city canals of Utrecht (link 116, MERWKAN3, desired flow = 2.0 m^3/s, minimum flow = 2.0 m^3/s).

The combined supply capacity of 12.5 m^3/s for JUTGEMAL and MERWKAN2 has a special restriction on its use. Due to a capacity constraint at the Doorslaag which transports the combined flow to the west, the sum of the flow in JUTGEMAL and the flow in MERWEDE2 minus the flow in MERWKAN3 must be less than or equal to 8.0 m^3/s. The combined supply capacity from JUTGEMAL and MERWKAN2 is sufficient to fulfill the demands of districts 40 and 41 and the flushing of Utrecht, and, with the added supply from LEIDRIJN, the demands of districts 43 and 44. Any remaining capacity can be used to supply the Midwest via OUDERIJN (link 123) as part of the Midwest emergency supply.

The supply capacity from ANGSTEL is sufficient to meet the demands of districts 37 and 39, and any remaining capacity (up to the capacity of

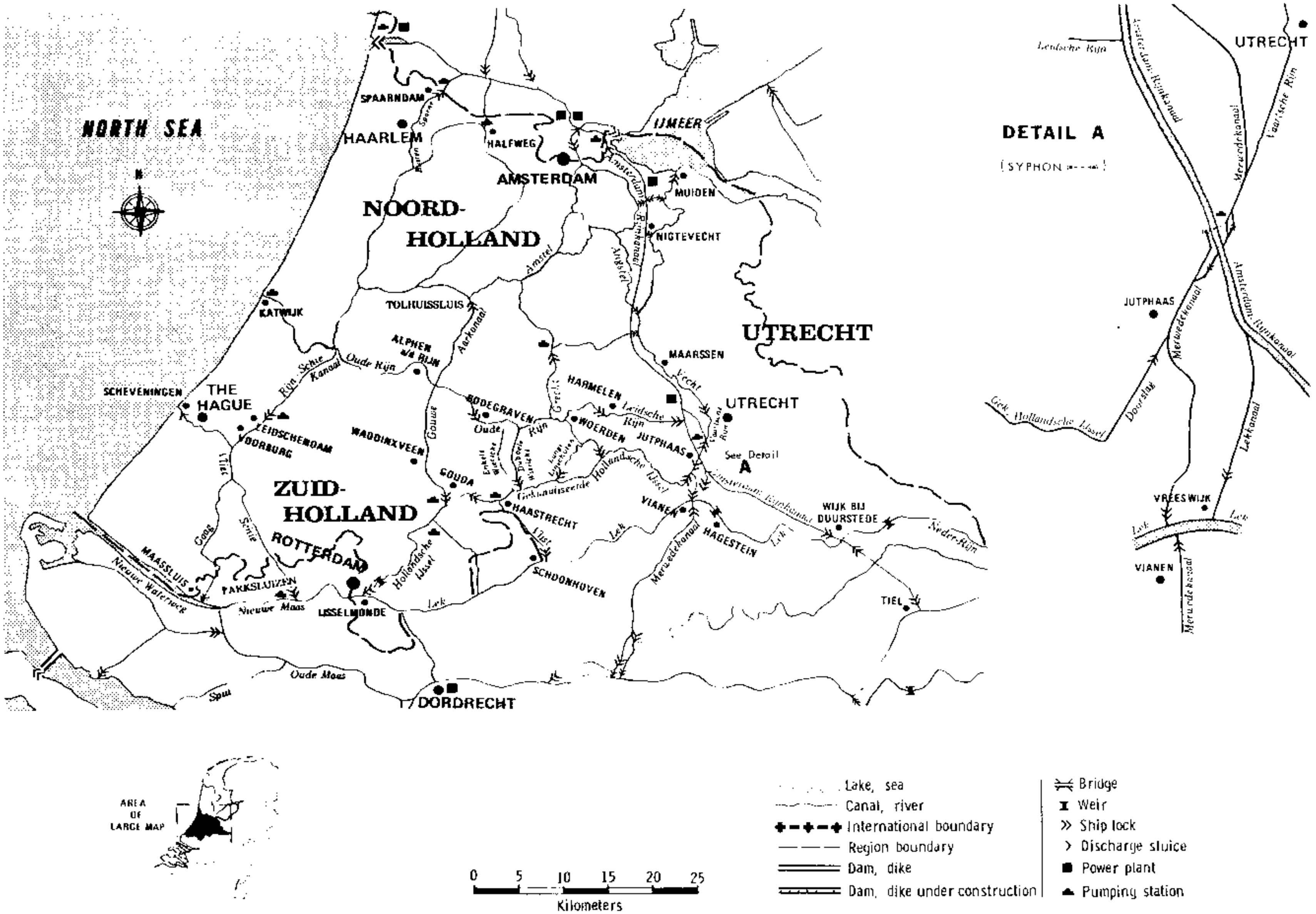


Fig. 4.7--Region 5: Midwest and Utrecht

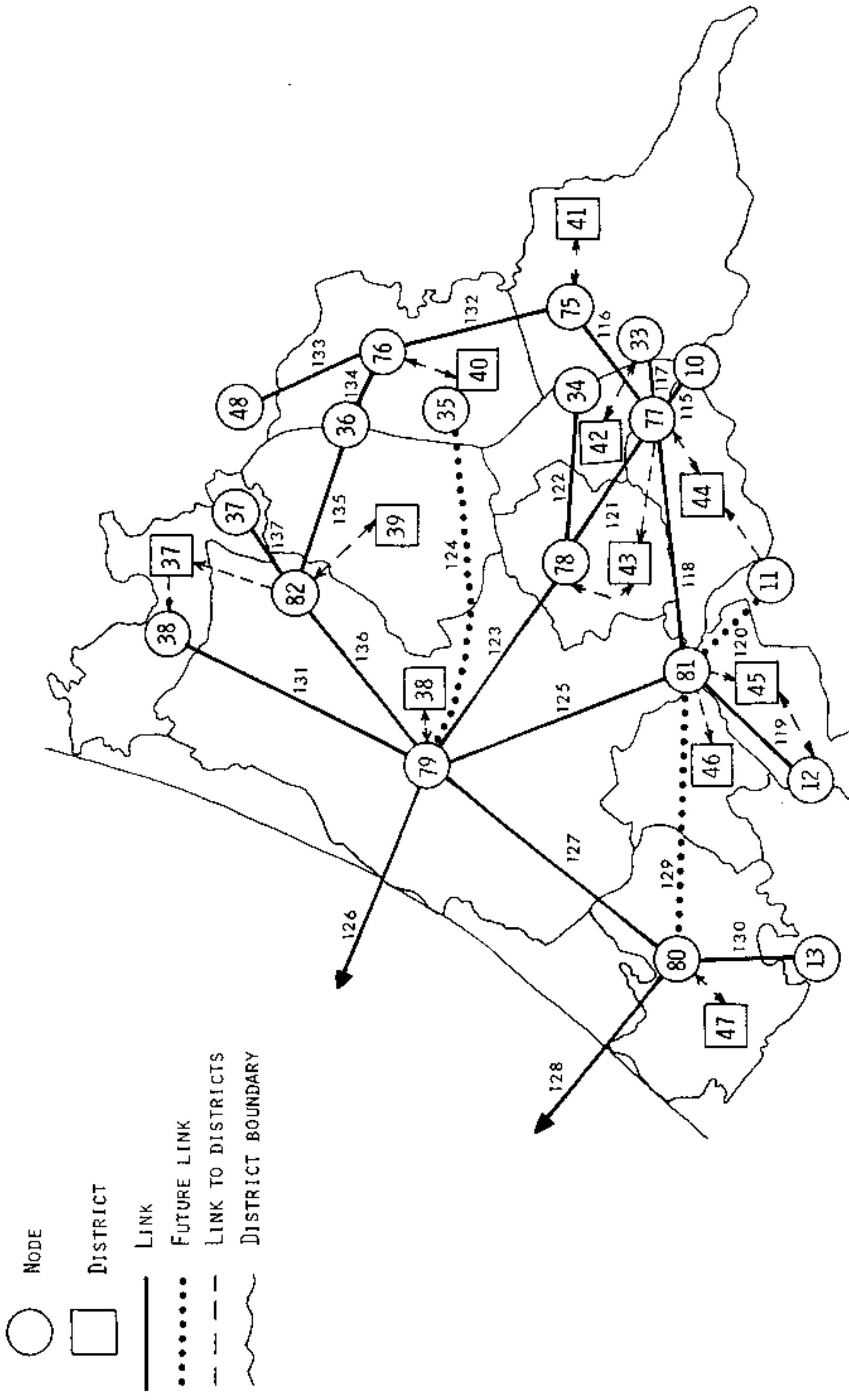


Fig. 4.8--The Midwest and Utrecht regional system

3.0 m^3/s on link 136, TOLHUIS) can be used as part of the Midwest emergency supply.

The supply for Delfland (district 47) and the flushing water for salinity control at the salt-fresh locks at Parksluizen (link 130, VLIET) come via the Rijn-Schiekanaal and the pump at Leidschendam (LEIDSDAM, link 130, capacity = 8.0 m^3/s). If the capacity of this link is exceeded, the following steps are taken, in the order given and as necessary to meet the capacity constraint: the flushing of district 47 is reduced to zero; the desired flow on VLIET is reduced to the minimum flow; the sprinkling in district 47 is reduced; and the flushing water for VLIET is further reduced as needed.

The supply to the Midwest is normally provided by the Hollandsche IJssel via the inlet at Gouda unless the salinity is high at the inlet due to the Rotterdam salt wedge. If the capacity of the inlet (link 125, GOUWE, capacity = 32.0 m^3/s) is exceeded, the flushing demands for links 131, 126, 128, and 130 (HARLMEER, KATWIJK, SCHEVING, and VLIET) are reduced to their minimum values, and any flushing demands for districts 45 and 46 from the GOUDA node are reduced to zero. (Although districts 38 and 47 also have flushing demands, flushing from these districts provides part of the minimum flushing flows for links in the Midwest so that reducing their flushing demands saves no water.)

If the Rotterdam salt wedge reaches the Hollandsche IJssel (Sec. 5.3.6), the <u>Midwest emergency supply</u> is used to provide as much of the demands as possible, thereby reducing the intake of saline water from the Hollandsche IJssel. If the Gouda inlet is still used to provide part of the supply, flushing demands on the links HARLMEER, KATWIJK, SCHEVING, and VLIET are reduced to their minima, and any flushing demands by districts 45 and 46 are reduced to zero.

The current Midwest emergency supply facilities consist of the TOLHUIS link (capacity = 3.0 m^3/s), the extra capacity from JUTGEMAL, MERWKAN2, and LEIDRIJN via OUDERIJN to Rijnland (node 79, RIJNLAND), and the existing capacity in the Krimpenerwaard to bring water from the Lek to the Hollandsche IJssel via a pump at Gouderak (KRIMPKAN, link 120, capacity = 6.0 m^3/s).

A number of alternatives for expanding the supply to the Midwest were examined in screening (Vol. II). These included tactics that increase the supply to Delfland (district 47)--expansion of the pumping capacity at Leidschendam (link 127, LEIDSDAM), a new Waddinxveen-Voorburg canal (link 129, KAWADVOR), or a Maas-Delfland pipeline--and tactics that expand or replace the current Midwest emergency supply--a canal through Lopikerwaard (link 120, KRIMPKAN, and link 115, MERWKAN2), a canal through Lopikerwaard plus expansion of the Leidsche Rijn (link 122, LEIDRIJN), a canal through Krimpenerwaard (link 120, KRIMPKAN), and a Maarssen-Bodegraven canal (link 124, MARBOKAN). These tactics can be represented in the DM by changes in the node distribution keys and link capacities for the appropriate links.

4.3.6. Managerial Rules for the Linge Regional System

Figure 4.9 contains a map of the Large Rivers and Northern Delta Region and includes the waterways of the Linge regional system. Figure 4.10 contains the links and nodes of the Linge regional system and the districts that have at least a portion of their demands at the nodes of that system.

The supply to this regional system is from the Pannerdensche Kanaal via an inlet sluice to the Linge River at Dornenburg (link 138, LINGE1, capacity = 7.3 m^3/s) and the Neder-Rijn via an inlet facility (for high Lek levels) or the pump Mr. Kuyk (link 139, LINGEKAN, capacity = 2.5 m^3/s).

The only extraction demands upon this regional system are for level control, flushing, and sprinkling in districts 55 and 57. If the extraction demands of districts 55 and 57 exceed the supply capacity of LINGE1 and LINGEKAN, the portions of the flushing demands of those districts that are provided by the regional system are reduced to zero. If the capacity constraint is still exceeded, the portion of the sprinkling demands of those districts that comes from the regional system is reduced as necessary to meet the capacity constraint.

4.3.7. Managerial Rules for the South Regional System

Figures 4.11 and 4.12 contain maps of the West Brabant and Southern Delta Region and the Southeast Highlands Region and include the waterways of the South regional system. Figure 4.13 contains the links and nodes of the South regional system and the districts that have at least a portion of their demands at the nodes of that system.

The supply to this regional system is from the Maas in the southeast via the Zuid-Willemsvaart (link 142, ZUIDWLM1, capacity = 20.0 m^3/s) and the Kanaal Wessem-Nederweert (link 144, WESNWERT, pumping cap. = 3.0 m^3/s, lock loss = 2.0 m^3/s, reducible to 1.0 m^3/s when a water shortage exists), from the Amer in the north via the Donge River (link 150, DONGE, capacity = essentially unlimited), and from the Zoommeer (when fresh) in the west via the Roosendaalsche Vliet (link 154, ROSVLIET, capacity = 100 m^3/s).

There are fixed demands upon the system for leakage losses from canal sections to district groundwater for both the Zuid-Willemsvaart and Wilhelminakanaal. These are represented as fixed extractions at nodes: (node 15, MASTRICT, leakage loss = 0.8 m^3/s; node 85, LOOZEN, leakage loss = 0.2 m^3/s; node 86, WEERT, leakage loss = 0.3 m^3/s; and node 88, HELMOND, leakage loss = 1.0 m^3/s). (See Table 3.5.) There are demands for lock losses on the Wessem-Nederweert (link 144, WESNWERT, desired flow = 2.0 m^3/s, minimum flow = -2.0 m^3/s; see above), the Zuid-Willemsvaart (link 147, ZUIDWLM4, desired flow = 1.7 m^3/s, minimum flow = 0.3 m^3/s), and the Wilhelminakanaal (link 149, WILHEKAN, desired flow = 1.7 m^3/s, minimum flow = 0.3 m^3/s).

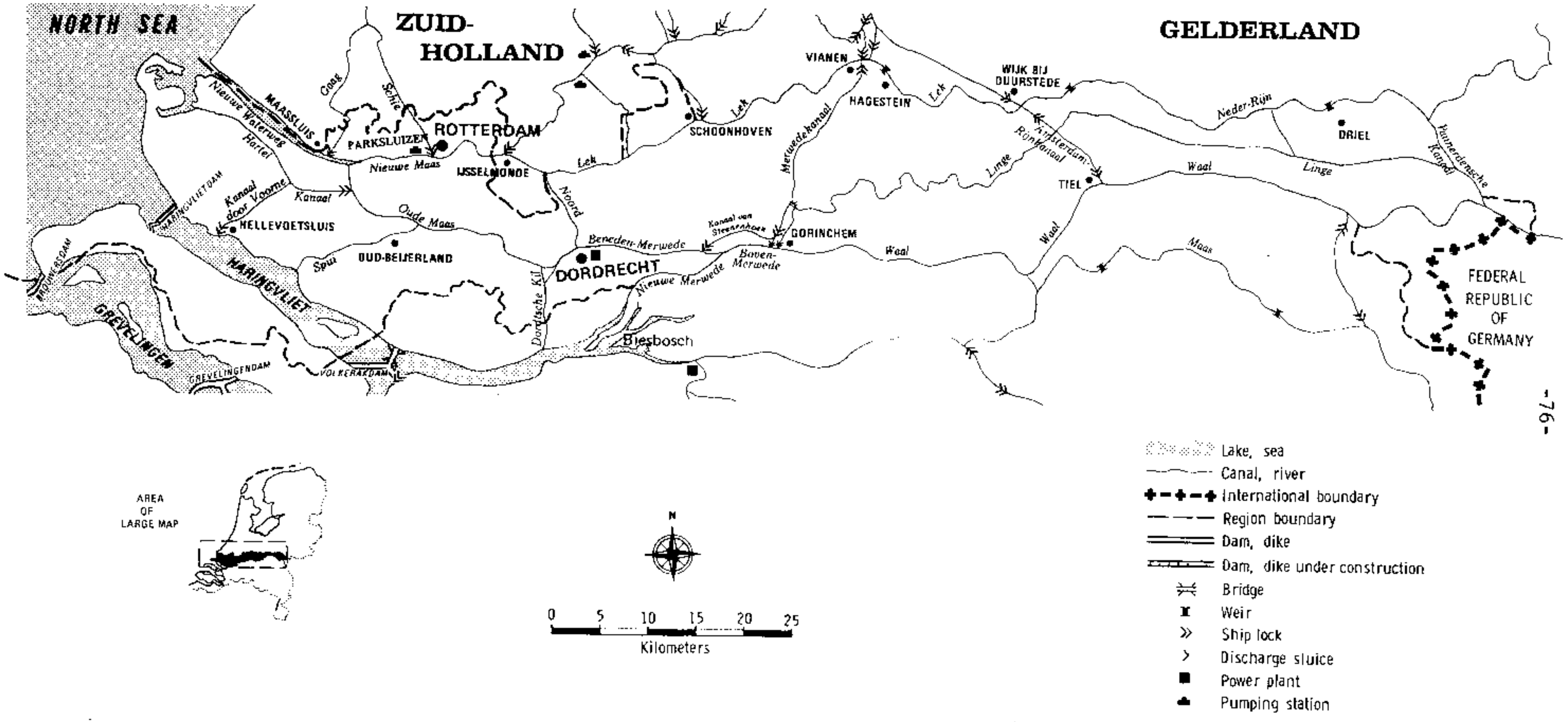


Fig. 4.9--Region 6: Large Rivers and Northern Delta

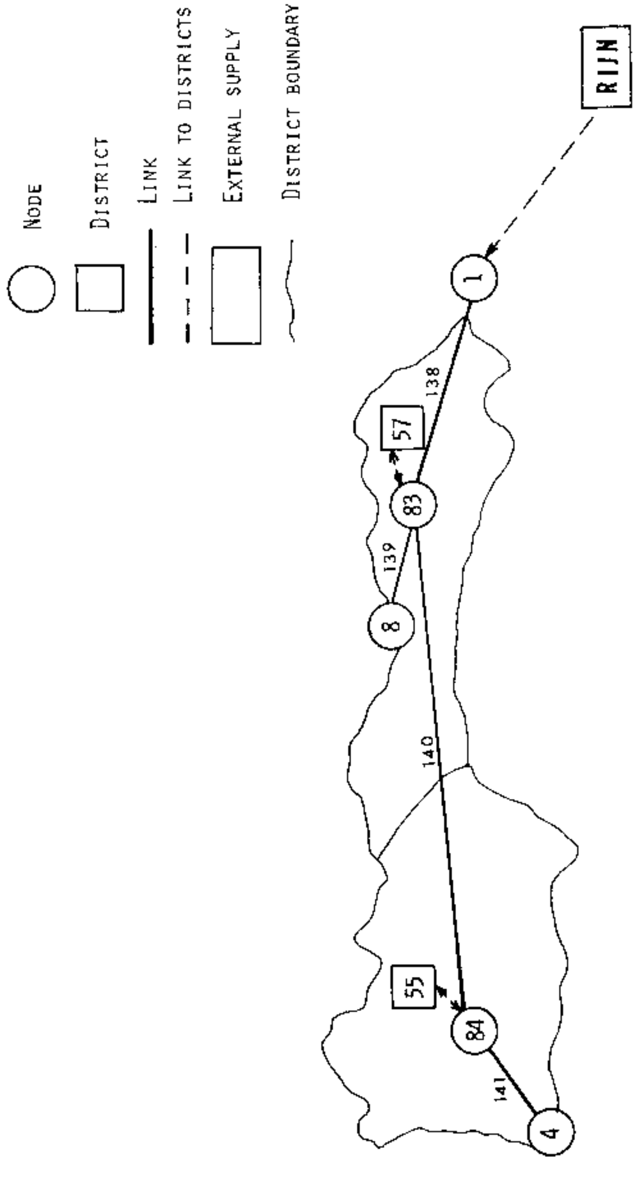


Fig. 4.10-- The Linge regional system

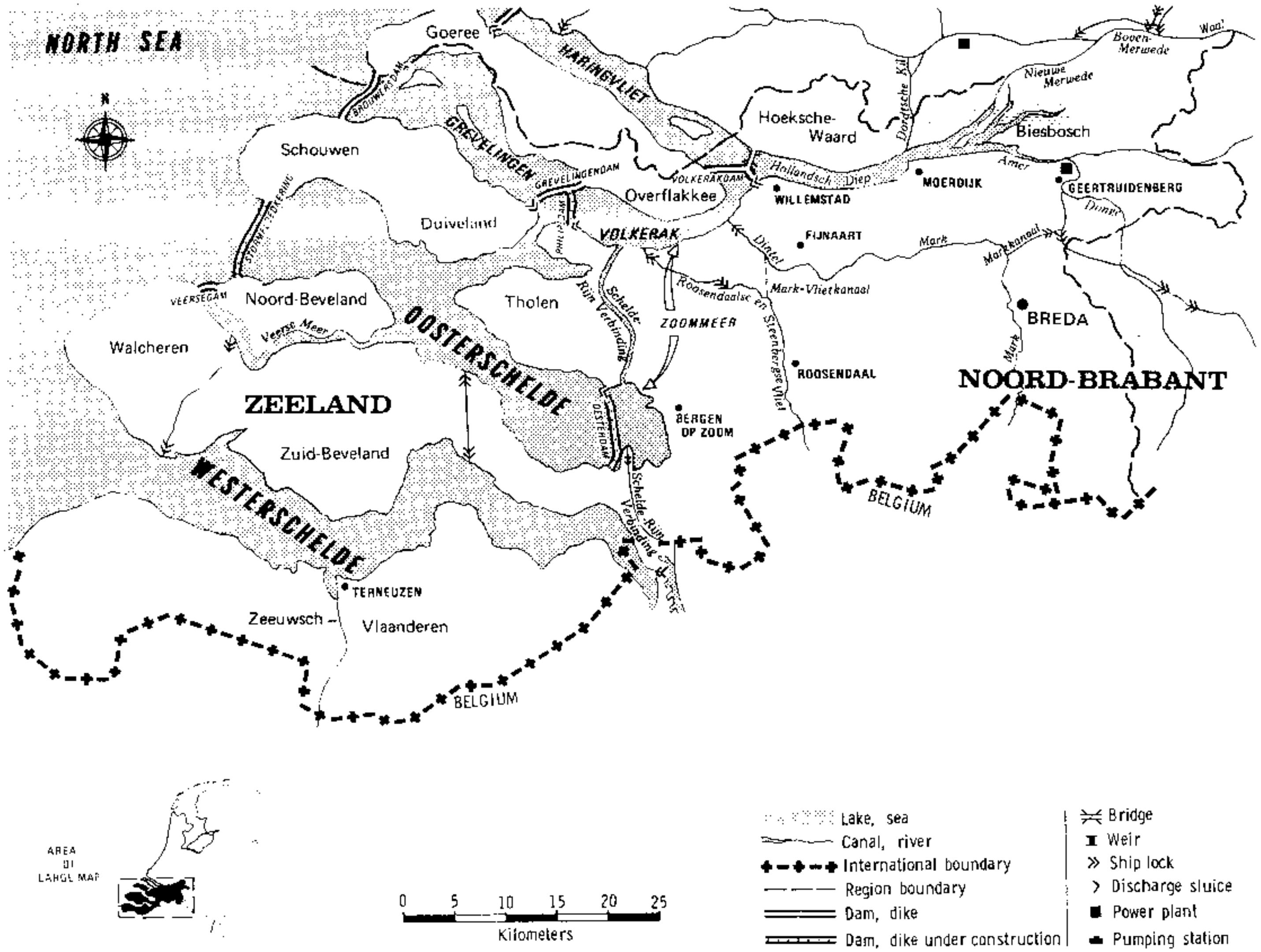


Fig. 4.11--Region 7: West Brabant and Southern Delta

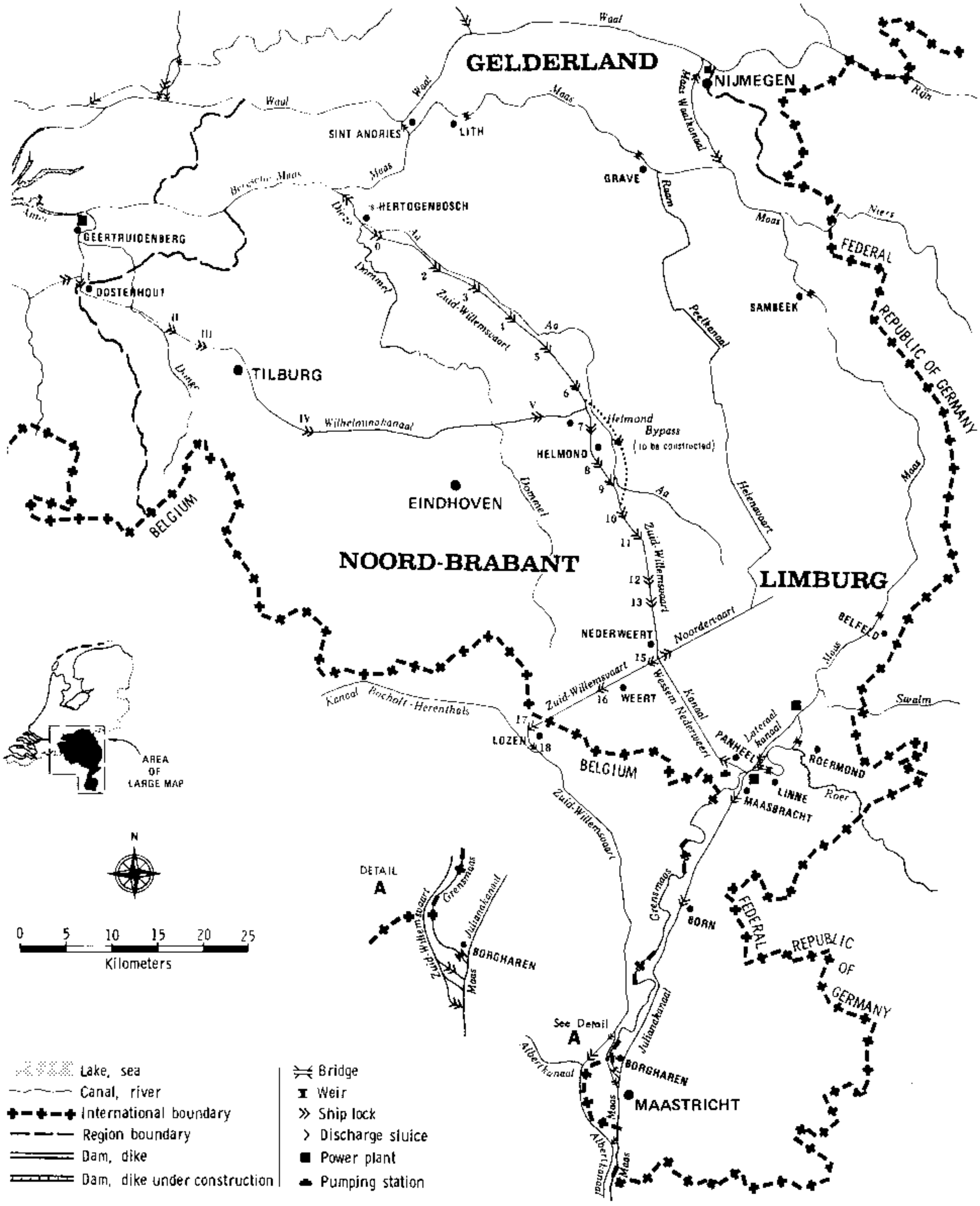


Fig. 4.12--Region 8: Southeast Highlands

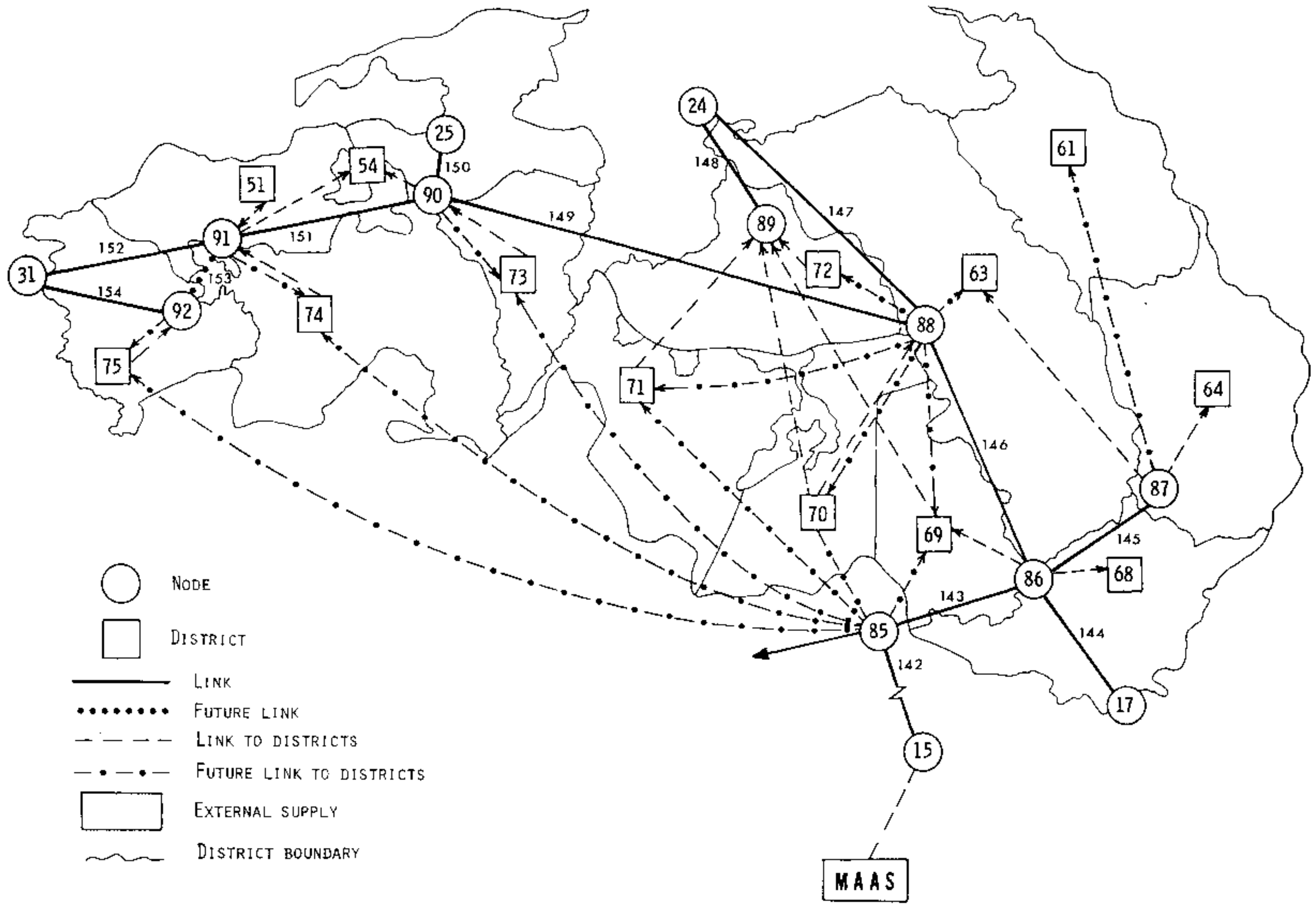


Fig. 4.13--The South regional system

The supply available in the Southeast Highlands depends upon the Maas discharge and the distribution rule at Maastricht that divides the Maas discharge among the Zuid-Willemsvaart, Maas, and Julianakanaal (Sec. 5.3.1). The actual supply available is the sum of what returns from Belgium via the Zuid-Willemsvaart (link 143, ZUIDWLM2) to node 85 (LOOZEN) and the 2.0 m^3/s available at node 86 (WEERT) after the lock loss from the Kanaal Wessem-Nederweert (link 144, WESNWERT) to the Maas is subtracted from the pumping capacity at Panheel. This supply is used to meet the demands on the South regional system that are supplied from the Zuid-Willemsvaart--the lock losses and canal seepage demands on the Zuid-Willemsvaart and Wilhelminakanaal and the district demands of districts 61, 63, 64, 68, 69, 70, 71, and 72.

All or parts of districts 61, 63, and 64 are supplied from the Zuid-Willemsvaart via the Noordervaart (link 145, NORDVART, capacity = 4.0 m^3/s, lock loss = 0.5 m^3/s). If the capacity of the latter link is exceeded, those portions of the extractions used for flushing in those districts are reduced to zero. If the capacity is still exceeded, the district sprinkling demands that come from that link are reduced as needed to meet the constraint.[2]

If the sum of the supply to the Zuid-Willemsvaart at LOOZEN and WEERT is exceeded, those portions of the extractions for flushing water for the districts that are supplied from the Zuid-Willemsvaart are reduced to zero. Then the flows in the links are recalculated, and if the supply is still exceeded by the demand, the desired flows for lock losses on ZUIDWLM4 and WILHEKAN are reduced to the minimum for those links. If the demand still exceeds the supply, the district sprinkling demands that come from the Zuid-Willemsvaart are reduced as necessary to meet the constraint.

Parts of districts 51 and 54 are currently supplied via the Markkanaal and Mark River (link 151, MARK1, capacity = 8.0 m^3/s) from the Donge River (link 150, DONGE, capacity = essentially unlimited) and the lock losses from the Wilhelminakanaal (link 149, WILHEKAN). If waterboard plans are implemented for districts 73 and 74 and the Mark-Vlietkanaal is completed, districts 73, 74, and 75 will also be supplied by this route. If the capacity of MARK1 is exceeded, those portions of the flushing demands for districts 51, 54, 73, 74, and 75 that are supplied by that link are reduced to zero. If the capacity constraint is still exceeded, those portions of the district sprinkling demands that come from that link are reduced as necessary to meet the capacity constraint.

When the Zoommeer is assumed to be fresh (see Sec. 3.1.2.3), the demand at node 91, FIJNAART, in excess of the capacity of MARK1 can be supplied from the Zoommeer (link 152, capacity = 50 m^3/s) by modifying the extraction distribution key at node 91 (see Table 4.2).

A number of tactics that would help alleviate water shortage problems in the south during dry periods were evaluated in screening (Vol. II). These may be categorized as tactics to supplement the Maas flow by pumping Waal water up the Maas, tactics to reduce shipping delay losses on the Julianakanaal, and tactics to increase the supply directly to the Southeast Highlands. The first two categories apply to the national system and are discussed in Sec. 5.3. Tactics to increase the supply capacity to the Southeast Highlands include: expansion of the supply capacity along the Zuid-Willemsvaart, increased capacity from the Zuid-Willemsvaart to the Noordervaart by expanding the existing syphon or building a new pumping station, increased capacity from the Maas to the Kanaal Wessem-Nederweert by increased pumping at Panheel, and the building of pumping capacity on the Wilhelminakanaal and/or the Zuid-Willemsvaart to bring water south from the Amer. All of these tactics can be input to the DM by appropriate changes in node distribution keys and capacities on links.

When implemented, the tactics that pump water south on the Zuid-Willemsvaart or the Wilhelminakanaal provide the main source of supply to district extractions at node 88, HELMOND. Any demand at that node above the pumping capacity south is met by bringing water north on the Zuid-Willemsvaart from the Maas, as was the case without the tactic.

If the demand north on the Zuid-Willemsvaart exceeds the supply, the following steps are taken in sequence and as needed to reduce the demand to meet the supply: if the flow north on the Zuid-Willemsvaart exceeds the desired flow for lock losses on ZUIDWLM3, flushing in districts extracting from HELMOND is reduced to zero; district sprinkling extractions at HELMOND are reduced as needed until the flow on ZUIDWLM3 equals the desired lock loss; flushing for districts extracting at nodes 86, WEERT, and 87, MEYEL, is reduced to zero; sprinkling demands at nodes 86 and 87 are reduced as necessary to meet the supply.

NOTES

1. All values given in this chapter for link capacities, desired flows, minimum flows, and district flushing demands are in m^3/s. They are the values used in production runs of the DM to represent the current situation.
2. The Noordervaart is supplied from the Zuid-Willemsvaart via a syphon under the Wessem-Nederweert (the Kanaal Wessem-Nederweert is at a lower level than both of these canals; see Vol. II). In the DM it is assumed that the supply via the syphon is sufficient to meet the (final) demand from the Noordervaart. This assumption was valid in the runs made for screening and impact assessment but need not always be so. The DM would be improved by a managerial rule that constrained the flow to the Noordervaart to the flow in the syphon.

REFERENCES

4.1. MW-154 (unpublished PAWN memorandum), "Distribution Network and Worksheets 1, 2, 3, RWS District South-East," February 1979.
4.2. Unpublished information from the Rijkswaterstaat, Directie Waterhuishouding en Waterbeweging, District Noord and District Zuidwest, concerning network distribution keys, July 1979.

Chapter 5

WATER DISTRIBUTION AND MANAGEMENT IN THE NATIONAL SYSTEM

As with the regional systems, water distribution and management in the national system are combined in a single chapter because the two topics are interdependent--water availability and anticipated water distribution problems evoke water managerial rules that determine the actual water distribution. This interaction is implemented in the DM by first finding a trial water distribution for a decade with default or standard managerial rules and then applying a second facet of the rules in an "if this happens, then do that" mode that forces a desired change in the water distribution.

5.1. THE NATIONAL SYSTEM

In the DM the national system, shown in Fig. 5.1, consists of the major rivers (Rijn and Maas), and their extensions, that bring water into and through the country; those waterways that carry water to the northern half of the country (the IJssel River and the Amsterdam-Rijnkanaal); the major lakes that serve or may serve as freshwater reservoirs (the IJssel lakes, Zoommeer, and Grevelingen); those waterways that interconnect the major rivers (the Merwedekanaal and Maas-Waalkanaal and the St. Andries Connection); and those waterways and waterworks that connect the foregoing to the North Sea (the Nieuwe Waterweg, the Noordzeekanaal, and the discharge sluices of the Haringvliet, Afsluitdijk, Zoommeer, and Grevelingen).

In the PAWN network the national system is comprised of nodes 1 to 50 and links 1 to 71 (Fig. 5.2). In addition to the waterways, lakes, and waterworks named above, the national system of nodes and links contains an artificial node (node 14, NOORDZEE), to which all discharges to the North Sea are directed, and an artificial link (link 71, NZDISCH) emanating from the North Sea node, whose flow is the total discharge to the North Sea from all sources in the PAWN network.

5.2. WATER DISTRIBUTION IN THE NATIONAL SYSTEM

Water distribution in the national system for a decade time step is determined from the solution of a system of linear equations whose variables are the flows in the links. The coefficients in the system of equations are defined by the infrastructure of the national system, and the constant terms by the water demands at the nodes of the national system, by the flows specified for certain links, and by managerial rules that control the water distribution in the national and regional systems.

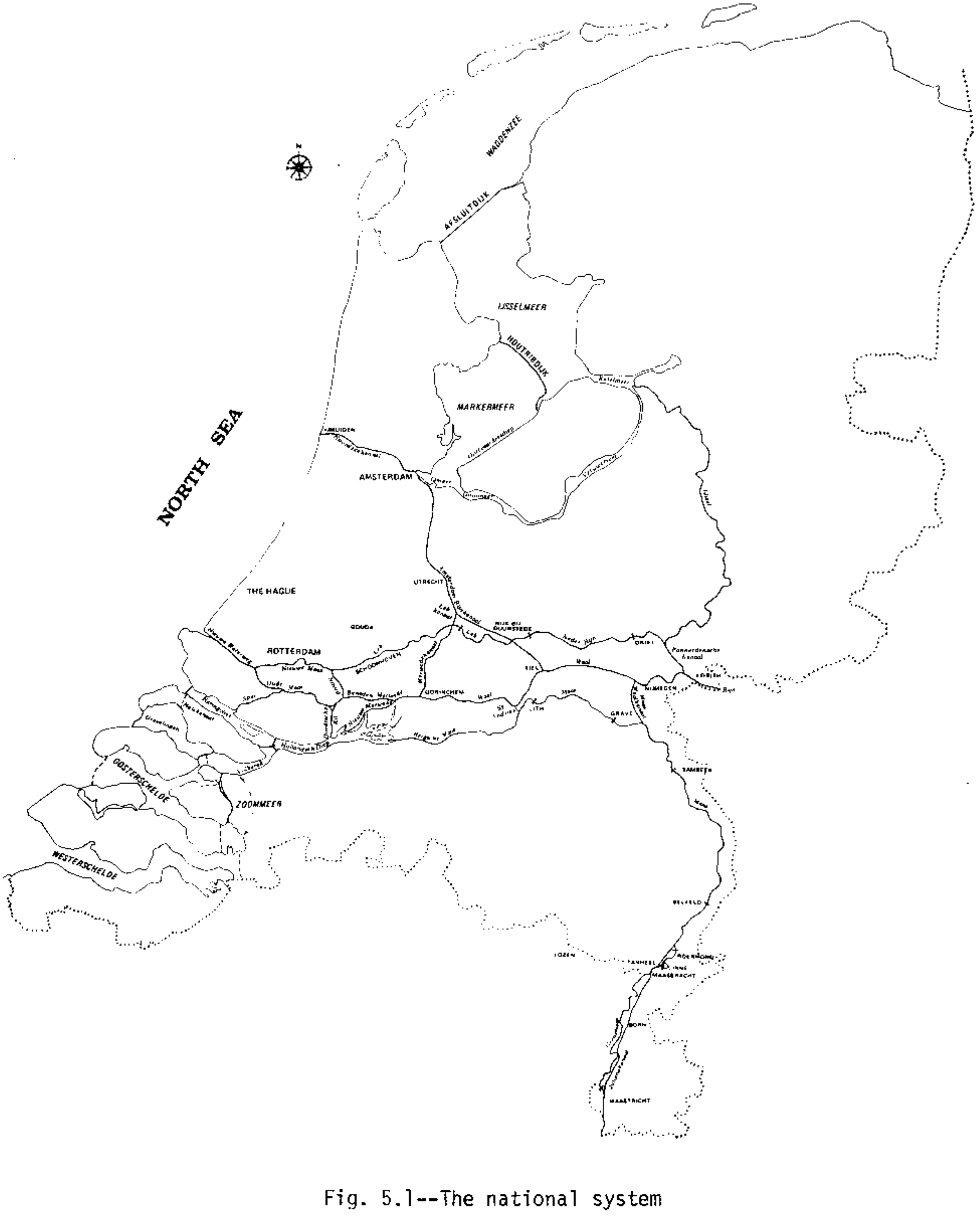


Fig. 5.1--The national system

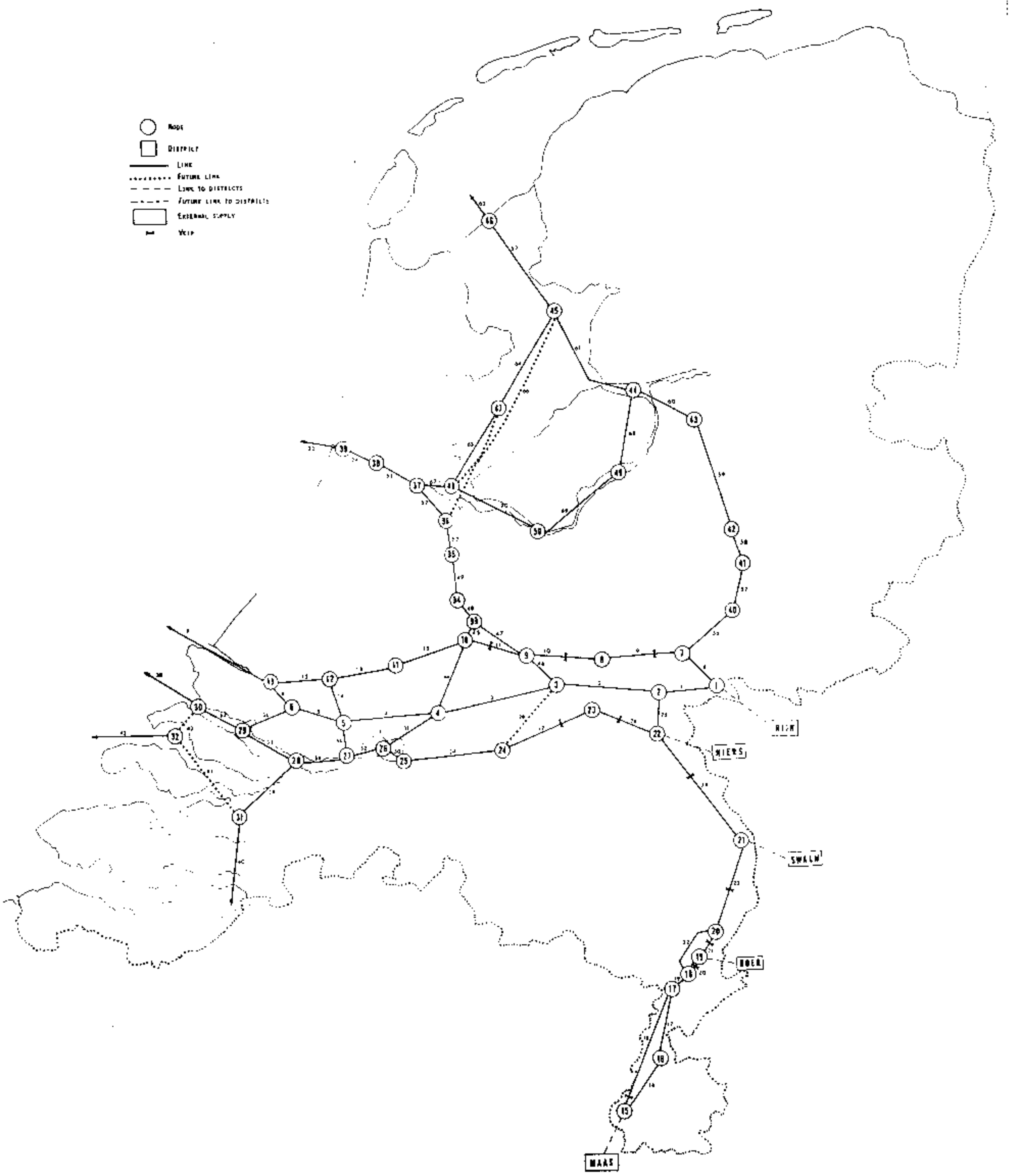


Fig. 5.2--Nodes and links in the national system

5.2.1. General Procedure

The determination of the flows in the national system for a decade is an iterative procedure involving a number of steps:

1. Discharges and extractions are established at each national node from river discharges, external drainage, canal seepage, and demands of industry and drinking-water companies (see Sec. 3.4).
2. Discharges and desired extractions by districts are obtained from DISTAG and allocated to the nodes by the district distribution keys (see Sec. 3.4).
3. Discharges and extractions for level control at nodes with storage are calculated.
4. Discharges and desired extractions at the national nodes by the regional systems are calculated (Chap. 4).
5. Flows that meet the demands given in steps 1 to 4 are determined in the national links.
6. The flows in the national system are tested against maximum and minimum flow capacities set for each link.
7. Remedial action is taken if flow constraints are not met (storage levels may be lowered, flushing and cooling water demands on links decreased, flushing and sprinkling on croplands in districts decreased, the setting of the weir at Driel changed, the North-South Connection used, etc.; see Sec. 5.3).
8. The process is repeated from steps 2, 3, 4, or 5 if remedial action is necessary to meet some constraint. The desired extractions may have been decreased due to cutbacks in flushing, sprinkling, etc., and the levels may have been lowered in the IJssel lakes, Zoommeer (if fresh), and the Maas weir ponds.

At each repetition of this iterative procedure, a set of flows established at step 5 meets the demands then being placed at the national nodes by the districts, etc. Some flow constraints on the national system may still be violated after all the remedial action has been taken in implementing the managerial rules designed to reduce the demands to meet the constraints. In this event, a message is printed in the output for the decade describing the problem so that the user is alerted to the fact that inputs may be incorrect or that a policy may need to be changed.

5.2.2. A Linear System of (71) Link Flows

In step 5 of the preceding section, the DM treats the flows in the 71 links in the national system as a set of 71 variables whose values are obtained through the solution of a system of 71 linear equations (or constraints). Water balances at the 50 nodes of the national system provide 50 of the linear equations (see Sec. 5.2.3); the setting of the weir at Driel provides two equations (see Sec. 5.2.4); and there are three equations used to interrelate flows in the lower rivers sections of the Rijn and Maas rivers (see Sec. 5.2.5). This leaves a requirement for 16 additional linear flow constraints of the 71 required to solve for the 71 link flows; these are met by specifying the flows on 16 of the national links (see Sec. 5.2.6).

5.2.3. Water Balance at Nodes (50 Constraints)

By water balance at a node, we simply mean that the total water flow into the node must be equal to the total water flow out of the node. The water balance equation is best defined by means of an example. Consider the IJSLMEER node (node 45), and, for convenience, define the flow toward the IJSLMEER node as the positive direction of flow for all links connecting the IJSLMEER node to other nodes. Then the balance equation for the IJSLMEER node is

$$Q61 + Q45 + Q62 + Q76 + Q64 + Q66 + C = 0$$

where

$$C = DE14 + DE81 + DE53 + DE + \text{Net rain} + QLC$$

Q61 is the flow in link 61, Q45 is the flow in link 45, etc.; DE14 is the discharge minus the extraction by district 14 from the IJSLMEER node, etc.; DE is the difference between discharges and extractions from drinking-water companies and industry at the ISSELMEER node; Net rain is the flow equivalent of the rain minus evaporation on the storage area of the IJSLMEER node plus the rain minus evaporation on the areas of all the links ending in the IJSLMEER node; and QLC is the flow equivalent of any level change in the storage at the IJSLMEER node during the decade, i.e.,

$$QLC = - (\text{Level change}) \times (\text{IJsselmeer area})/\text{Decade length}$$

5.2.4. Weir at Driel and IJssel Canalization (2 Constraints)

An input weir schedule (or weir program), which may be modified by managerial rules (Sec. 5.3.2), controls the division of the Rijn discharge among the IJssel, Neder-Rijn, and Waal rivers (see App. A). From this schedule, the Rijn flow and water balance at nodes 1 (PANDNKOP) and 7 (IJSELKOP), the flows on link 1 (WAAL1), link 8 (PANDKAN), link 9 (NEDRIJN1), and link 56 (IJSSEL1) are determined. The net effect of the weir at Driel and IJssel canalization is to add two constraints--two linear equations that set the flows in links 8 (PANDKAN) and 9 (NEDRIJN1).

5.2.5. Lower Rivers (3 Constraints)

The links representing the sections of the Rijn and Maas in the delta region form a lower rivers network. In App. B, linear equations are presented that approximate the flows in three links of this network as functions of the flows in the Lek, Waal, and Maas and extractions and discharges at the nodes in the lower rivers network. Three linear equations that relate the flows in links 5 (OUDEMAS1), 6 (OUDEMAS2), and 33 (DORDTKIL) to the flows in the other links are added to represent these approximations to the flows in the lower rivers sections.

5.2.6. Specified Link Flows (16 Constraints)

From Secs. 5.2.3, 5.2.4, and 5.2.5 we have 55 equations (50 water balance equations at nodes, 2 equations from the Weir at Driel, and 3 equations from the lower rivers approximations) of the required 71 needed to determine the 71 link flows in the national system. The remaining 16 are obtained by specifying flows on 16 links, either directly by inputs setting the minimum, maximum, and desired flows to the same value, or by the water managerial rules of Sec. 5.3.

The selection of 16 links for which to specify flows is not arbitrary--they must be selected to give a combined set of 71 independent equations so that there is a unique solution to the system of equations. The set of 16 links actually specified in the DM depends upon inputs that define the infrastructure of the national system; certain of the links will always be specified, while for others there are alternatives. The following indicates the various possibilities.

Links with specified flows:

(1) JULKANL1, (2) LATRAKAN, (3) MAWAKAN, (4) SANDRIES, (5) MERWKAN1, (6) LEKKANAL, (7) ARKANAL1, (8) ARKANAL2, (9) HARINGSL, (10) ORANJESL, (11) IJSYPHON, (12) VELMGOIM or VELMKETM, (13) OSTVARDP or MARKMIJM, (14), (15), (16) three links from VOLKERAK, ZOOMERSL, GREVDAM, HALSKAN, and BROUWDAM.

The flow on the Julianakanaal, JULKANAL1, is set by the managerial rule defined by the distribution rule at Maastricht (Sec. 5.3.1). The managerial rule that divides the Maas flow at Linne between the Maas and the Lateraalkanaal determines the flow on LATRAKAN (Sec. 5.3.1). The flows on MAWAKAN, SANDRIES, MERWKAN1, LEKKANAL, ARKANAL1, ARKANAL2, HARINGSL, ORANJESL, and IJSYPHON are initially set equal to the respective minimum flows on those links (e.g., for lock losses). The final flows for these links depend upon the managerial rules described in the subsections of Sec. 5.3. The flow in either the VELMGOIM or VELMKETM must be specified by inputs (e.g., the flow in VELMGOIM may be set to zero in summer and that of VELMKETM set to zero in winter). The flow in OSTVARDP is set to zero unless the second Oostvaardersdijk is implemented as a tactic, in which case the flow of

MARKIJM is set to zero by specifying its capacity as zero. Which three link flows to specify from the five links listed in 14, 15, and 16 above depends upon the infrastructure for the Zoommeer and Grevelingen (Sec. 5.3.9).

5.2.7. An Illustrative Manual Procedure

To provide some insight into the structure of the system of linear equations for the link flows in the national system, we shall outline a straightforward, but lengthy, manual procedure for solving the system of linear equations. With no loss of generality, we assume the current (1980) infrastructure and ignore the water demands on the system at the nodes (these affect the constant terms in the balance equations and therefore the values of the link flows--but not the solution technique).

For the current national infrastructure, the links with specified flows (Sec. 5.2.6) are:

(1) JULKANL1; (2) LATRAKAN; (3) MAWAKAN, 1.0; (4) SANDRIES, 0.0; (5) MERWKAN1, 0.0; (6) LEKKANAL, 2.1; (7) ARKANAL1; (8) ARKANAL2; (9) ORANJESL; (10) IJSYPHON, 0.0; (11) HARINGSL; (12) VELMGOIM, 0.0; (13) OSTVARDP, 0.0; (14) VOLKERAK, 25.0; (15) GREVDAM, 0.0; (16) HALSKAN, 0.0,

where a value following the link indicates the flow (m^3/s) specified--a flow value of 0.0 indicates those national links not in the current infrastructure, and nonzero values indicate fixed flows for lock losses and/or flushing. The values for the other specified link flows are set by water managerial rules (Sec. 5.3).

The link flows in the national system may be found by taking the following steps:

1. Upper rivers. Using the 2 equations from the Weir at Driel and the water balance equations at nodes 1 and 7 (PANDNKOP and IJSELKOP), we determine the flows in links 1, 8, 9, and 56 (WAAL1, PANDKAN, NEDRIJN1, and IJSSEL1).
2. Lek and Waal. From water balance equations at nodes, we determine the flows on the Neder-Rijn and Lek links in order, starting from link 10 (NEDRIJN2) and ending at link 13 (LEK3). Similarly, we determine the flows on the Waal starting from link 2 (WAAL2) and ending at link 4 (BENEMERW).
3. Maas. From water balance equations at nodes, we determine the flows on the Maas (including JULKANL2), starting with link 18 (MAAS1) and ending with link 30 (AMER1).
4. Zoommeer and Grevelingen. In the current infrastructure the Grevelingen discharges only to the North Sea. Thus, the flows in links 41 and 42 (GREVDAM and HALSKAN) have been set to zero, and the flow in link 43 (BROUWDAM) has been set to the value of any discharge to the North Sea from the Grevelingen, i.e., from the storage volume at node 32 (GREVLING). Since the flow in

link 39 (VOLKERAK) is specified, the flow in link 40 (ZOOMERSL) is determined from the water balance equation at node 31 (ZOOMMEER).

5. Haringvliet sluices. The total discharge to the North Sea via the Haringvliet sluices and the Nieuwe Waterweg may now be determined as the sum of the flows in links 4, 13, and 30 minus the flow in link 39, which are known from steps 1 to 4. But the flow in link 38 (HARINGSL) is a function of the total discharge (Sec 5.3), so that we can determine the flow in link 38 and, by subtraction from the total discharge, the flow in link 7 (NEWATWEG).
6. Lower rivers. We next solve for the flows in the remaining links of the combined lower rivers sections of the Rijn and Maas using the equations on Fig. B.2 of App. B, as modified to account for discharges and extractions at nodes.
7. IJssel River and Amsterdam-Rijnkanaal. At this point all flows in the southern half of the country have been determined. We next determine the flows on the IJssel River, from link 57 (IJSSEL2) to link 60 (IJSSEL5), from water balance equations at nodes 40 (the flow in link 56, IJSSEL1, has already been determined in step 1) to node 43, respectively. Similarly, flows on the Amsterdam-Rijnkanaal from link 48 (ARKANAL3) to link 52 (ARKANAL5) are determined from water balance equations at nodes 33 to 36, respectively.
8. Noordzeekanaal. Since the flow in link 52 (ARKANAL5) is known from step 7 and the flow in link 67 (ORANJESL) is specified, we can now determine the flows in the Noordzeekanaal, links 53 (NZKANAL1) through 55 (NZKANLSL), from water balance equations at nodes 37 to 39, respectively.
9. IJsselmeer. Since the flow in link 69 (VELMGOIM) is specified, we can determine the flow in link 68 (VELMKETM) and then link 70 (GOIMIJME) through water balance equations at nodes 49 (VELUWMER) and 50 (GOOIMEER), respectively. Also, since the flow in link 60 (IJSSEL5) is known from step 7, the flow in link 61 (KETLIJSL) can be determined from the water balance equation at node 44 (KETLMEER). Finally, from the specified flows in links 67 (ORANJESL) and 51 (IJSYPHON) and the water balance equation at node 48 (IJMEER), we determine the flow in link 65 (MARKMIJM) and then the flows in links 64 (IJSLMARK) and 62 (IJSLWADZ) from the water balance equations at nodes 47 (MARKMEER) and 45 (IJSLMEER).

Table 5.1 summarizes the usage of the 71 linear equations in solving for the link flows by the above procedure.

5.3. WATER MANAGEMENT IN THE NATIONAL SYSTEM

Water distribution in the national system is controlled to a large degree. Although the preponderance of the supply (the discharges of the major rivers, precipitation, and drainage) is determined by external factors, the setting of the weir at Driel on the Neder-Rijn,

Table 5.1

LINEAR EQUATIONS DETERMINING LINK FLOWS IN THE MANUAL PROCEDURE
(1980 National System)

	Link	Nodes	Eq.[1]		Link	Nodes	Eq.[1]		Link	Nodes	Eq.[1]
1	WAAL1	1- 2	1	25	MAWAKAN	2-22	S	49	ARKANL4A	34-35	34
2	WAAL2	2- 3	2	26	MAAS7	22-23	22	50	ARKANL4B	35-36	35
3	WAAL3	3- 4	3	27	MAAS8	23-24	23	51	IJSYPHON	47-36	S
4	BENEMERW	4- 5	4	28	SANDRIES	3-24	S	52	ARKANAL5	36-37	36
5	OUDEMAS1	5- 6	LR	29	BERGMAAS	24-25	24	53	NZKANAL1	37-38	37
6	OUDEMAS2	6-13	LR	30	AMER1	25-26	25	54	NZKANAL2	38-39	38
7	NEWATWEG	13-15	13	31	NIEWMERW	4-26	26	55	NZKANLSL	39-15	39
8	PANDKAN	1- 7	WD	32	AMER2	26-27	27	56	IJSSEL1	7-40	WD
9	NEDRIJN1	7- 8	7	33	DORDTKIL	5-27	LR	57	IJSSEL2	40-41	40
10	NEDRIJN2	8- 9	8	34	HOLLDIEP	27-28	28	58	IJSSEL3	41-42	41
11	LEK1	9-10	9	35	HARINGV1	28-29	29	59	IJSSEL4	42-43	42
12	LEK2	10-11	10	36	SPUI	6-29	6	60	IJSSEL5	43-44	43
13	LEK3	11-12	11	37	HARINGV2	29-30	30	61	KETLIJSL	44-45	44
14	NOORD	12- 5	5	38	HARINGSL	30-15	S	62	IJSLWADZ	45-46	45
15	NIEWMAAS	12-13	12	39	VOLKERAK	28-31	S	63	AFSLUISL	46-15	46
16	JULKANL1	15-16	S	40	ZOOMERSL	31-15	31	64	IJSLMARK	45-47	17
17	JULKANL2	16-17	16	41	GREVDAM	31-32	S	65	MARKMIJM	47-48	48
18	MAAS1	15-17	15	42	HALSKAN	30-32	S	66	OSTVARDP	45-48	S
19	MAAS2	17-18	17	43	BROUWDAM	32-15	32	67	ORANJESL	48-37	S
20	MAAS3	18-19	18	44	MERWKAN1	4-10	S	68	VELMKETM	44-49	S
21	MAAS4	19-20	19	45	LEKKANAL	10-33	S	69	VELMGOIM	49-50	49
22	LATRAKAN	18-20	S	46	ARKANAL1	3- 9	S	70	GOIMIJME	50-48	50
23	MAAS5	20-21	20	47	ARKANAL2	9-33	S	71	NZDISCH	14	14
24	MAAS6	21-22	21	48	ARKANAL3	33-34	33				

[1] Numbered equations are water balance equations at correspondingly numbered nodes; equation WD denotes one of the two equations for the Weir at Driel; equation LR denotes one of the three equations from lower rivers; equation S denotes a link whose flow is specified.

the flows in the major canals, the discharges in the Haringvliet and Volkerak, the extractions from the IJssel lakes, etc., may all be managed to help meet a desired division of the supply among the competing demands. However, control of the water distribution in the national system is not complete, and many of the technical and managerial tactics considered in Vol. II are designed to provide even greater control over the water resources in the national system (e.g., IJssel canalization, North-South Connection, St. Andries Connection, Merwedekanaal, etc.).

In this section, we describe the water managerial rules implemented in the DM for the national system. The managerial rules take a variety of forms, some of which are controlled by the user via model inputs, while others are built into the model structure as fixed rules. Although many of the managerial rules described in this section affect water supply to the regions, we refer to them as managerial rules for the national system because they are concerned with actions taken to deal with a problem or situation created by the water distribution in the national system.

5.3.1. Water Managerial Rules for the Maas

The portion of the PAWN network representing the Maas River starts at node 15 (MASTRICT) and ends at node 25 (GERTRUID). The Maas discharge (from external supply files, Sec. 3.1.1) is entered at node 15 as a discharge along with other discharges and extractions at that node (Secs. 3.2.6 and 3.2.7).

5.3.1.1. Distribution Rule at Maastricht. The input Maas discharge at the MASTRICT node is divided among several demands:

- Extractions by Belgium (for the Albertkanaal).
- Extractions by industry and drinking-water companies.
- Level control on the Maas above Maastricht and the Julianakanaal.
- Lock losses on the Julianakanaal.
- Flow on the Zuid-Willemsvaart.
- Flow on the Maas (i.e., Grensmaas, see Fig. 5.1).

The apportionment of the net discharge at MASTRICT takes place in several steps: first, the discharge is reduced by the extractions by Belgium and industry and drinking-water companies; then the storage levels at node 15 (MASTRICT), representing the storage section consisting of the Maas above Maastricht and the Julianakanaal above Born, and at node 16 (BORN), representing the storage section on the Julianakanaal between Born and Maasbracht, are brought to target levels; next, water is assigned to meet user-defined minimum flows on the Grensmaas (link 18, MAAS1), the Zuid-Willemsvaart (link 142, ZUIDWLM1), and the Julianakanaal (link 16, JULKANL1); then any remaining water is divided among these three links in proportion to a user-defined ratio (e.g., 4:2:1). Any water assigned by this rule that exceeds the specified maximum capacity for one or the other of ZUIDWLM1 or JULKANL1 is reassigned to MAAS1 and the link whose maximum capacity is not exceeded, ZUIDWLM1 or JULKANL1, according to the input ratio for the two links; if the maximum capacities of both ZUIDWLM1 and JULKANL1 are exceeded, the excess water is assigned to MAAS1.

5.3.1.2. Extractions by Belgium at Lozen. The extraction by Belgium at Lozen on the Zuid-Willemsvaart (node 85, LOOZEN) is set by a treaty between the Belgians and the Dutch at 11 m^3/s (see Sec. 3.2.6). However, the DM allows this extraction to be reduced to a user-supplied input value during decades when the Maas flow is so low that the treaty extraction value cannot be met. The extractions by Belgium at Lozen are used for lock losses on the Kanaal Bocholt-Herenthals, which carries shipping traffic into Belgium, and the extraction reduction implies increased shipping delay costs to the

Belgians. However, the extraction reduction occurs only during decades when the shipping delay costs in the Netherlands are sufficiently high that much of the border-crossing shipping traffic might simply choose to wait for decades with higher Maas flows, thereby requiring less water at Lozen--the costs to Belgian shipping from such a policy have not been investigated.

5.3.1.3. Level Control on the Maas. When the flow on the Maas is sufficiently low, the weirs along the river are raised, and the weir ponds behind the weirs are used as storage sections (Sec. 3.1.2.3). Each of these storage sections has a target level, an emergency level, and a minimum level specified for it. Each of the locks on the Julianakanaal and alongside the weirs on the Maas has a desired and minimum lock loss represented by the desired and minimum flows on the link immediately downstream of the node (except for the weir at Borgharen, link 18, MAAS1, where minimum and desired flows are specified for pollution control on the Grensmaas, e.g., 1 and 10 m^3/s, respectively).

If the demand at some lock on the Julianakanaal or on the Maas north of the Julianakanaal cannot be met with the available supply, then the levels in the storage sections are lowered in steps. Starting with the lock farthest upstream, at Born, and working downstream, the flows on the Julianakanaal and the Maas are compared with the minimum flows. If the actual flow is less than the minimum flow (i.e., the minimum lock loss), the levels in the storage sections are lowered as needed (or to their emergency levels, whichever is higher) to create the minimum flow, starting with the storage section immediately upstream of the lock, and proceeding farther upstream. If more water is needed, the same procedure is repeated, but using the minimum levels specified for the storage sections. (Note that this procedure keeps as much water as possible in the storage sections farthest upstream for use in following decades, and that the water released from a storage section is available at all locks downstream of the storage section.) If the minimum lock loss is still not met at some lock, those portions of the district flushing demands whose supply source is the Maas upstream of the lock are reduced to zero.

5.3.1.4. Flows at Low Maas Discharges. The discussion in the preceding sections assumes that the Maas discharge is sufficient to meet certain minimum demands. When the Maas discharge is too low to meet all the demands, managerial rules cut back reducible demands to minimum values as necessary. However, the Maas discharge may still be insufficient to meet even the minimum demands. Here, we describe how the current managerial rules are implemented and what happens when the rules fail to sufficiently decrease the demand.

The distribution rule at Maastricht (Sec. 5.3.1.1) assumes that there is sufficient Maas discharge to provide for the extractions by Belgium for the Albertkanaal and by industry and drinking-water companies, and for the minimum flow on the Grensmaas. Part or all of the remaining Maas discharge is allocated to the Zuid-Willemsvaart to meet the desired minimum flow on ZUIDWLM1. If the flow allocated to

ZUIDWLM1 is insufficient to meet the Belgium extraction at Lozen and the minimum return flow from Belgium on ZUIDWLM2 (2 m^3/s), both the extraction by Belgium and the return flow are reduced proportionally until the supply to Lozen is in balance with the demand.

The flow allocated to the Zuid-Willemsvaart by the distribution rule at Maastricht is considered (initially) to be the maximum flow available to meet the demands on that supply route. The supply available to the Netherlands from the Zuid-Willemsvaart is the maximum flow at Lozen minus the extraction at Lozen plus the amount pumped up the Wessem-Nederweert from Panheel (see Sec. 4.3.7). If this combined supply is insufficient to meet the demands, the demands are cut back to minimum values as necessary to meet the supply. However, there are still demands for minimum lock losses, leakage and evaporation from the canals, and level control needs in the districts. If this demand is larger than the supply, the flow on the Zuid-Willemsvaart from Maastricht is increased as needed to meet the remaining demand.

Since water balance is maintained at the Maastricht node, any increase of the flow on ZUIDWLM1 comes from the Grensmaas and Julianakanaal. After allocating the minimum flow on the Grensmaas, any remaining Maas discharge is reallocated between the Grensmaas and Julianakanaal according to the ratio used in the distribution rule at Maastricht. Of course, there may be no remaining Maas discharge to allocate, or the remaining Maas discharge value may be negative. A negative Maas discharge will lower the weir pond level above Born and will create negative flows on the Julianakanaal when the weir pond reaches its minimum level. There is no managerial rule to correct for this negative flow, and if it is unrealistic, the only corrective action is to reduce the demands by setting lower minimum flows, reducing extractions, or setting a lower level on the weir pond. Or, the DM may be modified to include a managerial rule to automatically reduce the demands.

The DM does provide an alternative, however. As described in Sec. 5.3.1.2, the user may input a value for a parameter called BELGMIN that allows the extraction by Belgium at Lozen to be reduced as needed to BELGMIN whenever the flow on the Julianakanaal is negative (the actual reduction made is just sufficient to produce a zero flow). The value by which the extraction is reduced may be interpreted as an actual reduction or as the reduction necessary in the irreducible demands to meet the Maas discharge shortfall.

5.3.1.5. Pumping at Panheel. The distribution rule at Maastricht (Sec. 5.3.1) will ordinarily send enough water along the Zuid-Willemsvaart to meet the total demands on that supply route, including the desired flow for a lock loss of 2.0 m^3/s from the Kanaal Wessem-Nederweert (link 144, WESNWERT) to the Maas at node 17 (PANHEEL). However, in dry periods the flow on the Zuid-Willemsvaart may be insufficient to meet the total demand. In this event, the lock loss on the Kanaal Wessem-Nederweert is reduced from 2.0 to 1.0 m^3/s by a water-saving feature at the lock (resulting in increased shipping delays at the lock), and the pump at Panheel (current pumping capacity = 3.0 m^3/s) is used to replace the lock loss and provide an additional supply to the Southeast Highlands via the Kanaal Wessem-Nederweert and the Zuid-Willemsvaart (links 144, WESNWERT, and 146, ZUIDWLM3).

5.3.1.6. Pumping at Linne. There is no pumping capacity at Linne in the current infrastructure. However, several of the technical tactics evaluated in screening (Vol. II) involve pumping water up the Maas during periods of low Maas flows to provide additional supply above that available from the Maas. One tactic uses the St. Andries Connection (link 28, SANDRIES) to transport water from the Waal to the Maas, and another uses the Maas-Waalkanaal (link 25, MAWAKAN)--see Sec. 5.3.1.8. Another tactic pumps Roer water from below Linne to above Linne so that water from the Roer River (see Sec. 3.1.1.2) is made available at nodes 17 (PANHEEL) and 18 (LINNE). A pumping capacity input at node 18 gives the maximum value that can be pumped back at Linne.

5.3.1.7. Lateraalkanaal. The total flow available at node 18 (LINNE) is divided between the Lateraalkanaal (link 22, LATRAKAN) and the Maas (link 20, MAAS3). The flow on the LATRAKAN link is obtained by linear interpolation in Table 5.2. From Vol. IX, the division of the total Maas flow given by the table minimizes the sum of the shipping delay losses on the Lateraalkanaal and at the lock on the Maas bypassing the weir at Linne.

Table 5.2

LATERAALKANAAL FLOW VERSUS MAAS FLOW ABOVE LINNE

Flow at LINNE	<3	4	5	6	7	8	9	10	>11
Flow in LATRAKAN	0	1.5	3.0	4.0	5.0	6.5	7.5	8.5	9.5

5.3.1.8. Maas-Waalkanaal and the St. Andries Connection. The Maas-Waalkanaal (link 25, MAWAKAN) connects the Maas to the Waal at Nijmegen, and the St. Andries Connection (link 28, SANDRIES) connects the Maas to the Waal below Lith. Neither of these waterways is used to transport water in the current infrastructure (the Maas-Waalkanaal has a lock loss of 1.0 m^3/s). However, tactics in Vol. II involve pumping water from the Waal to the Maas via one of these two waterways and then up the Maas to node 18 (PANHEEL) for subsequent use in the Southeast Highlands. These tactics are implemented in the DM by specifying capacities larger than the lock losses for links 25 (MAWAKAN) or 28 (SANDRIES). Another tactic uses the St. Andries Connection to increase the flow in the Maas for power plant cooling at the Amer power plant. This tactic is implemented by specifying a fixed flow between the Waal and Maas on link 28, SANDRIES.

5.3.1.9. Extraction Cutbacks. As discussed in Sec. 5.3.1.3, flushing demands in those districts in the Southeast Highlands whose supply is from the Maas are reduced to zero whenever the levels of the storage sections on the Maas are reduced to their minimum levels.

Then, if the demands from the Maas still exceed the supply, lock losses on the Zuid-Willemsvaart and Wilhelminakanaal and district flushing and sprinkling demands are reduced for those districts supplied from the Maas (Sec. 4.3.7).

5.3.2. Weir at Driel and IJssel Canalization

The weir at Driel can be lowered to control the amount of water flowing in the three branches of the Rijn--the Waal, Neder-Rijn, and IJssel rivers. When the weir is lowered to decrease the flow in the Neder-Rijn, the remaining Rijn discharge is divided between the Waal and the IJssel in approximately a 4 to 1 ratio. In App. A, equations are presented that give the flows in the IJssel and Waal as functions of the Rijn discharge and the flow in the Neder-Rijn. Equations are also given for the flows in the Rijn branches as functions of the Rijn discharge when the weir is completely open. If the IJssel is canalized (by building a series of weirs on the IJssel), the flows in both the IJssel and the Neder-Rijn can be completely controlled within the limits set by the completely closed and completely open weirs. Equations giving the flows in the Waal and Neder-Rijn as functions of the Rijn discharge and the IJssel flow when the weir at Driel is completely open are also presented in App. A. These equations allow the DM to handle the situations with and without IJssel canalization by a five-parameter vector input whose values set the weir schedule. The five parameters are:

1. The minimum Neder-Rijn flow
2. The desired IJssel flow
3. The minimum IJssel flow
4. The desired Neder-Rijn flow
5. The desired Waal flow

which will be referred to in abbreviated form as

Weir Schedule: Min NR/Des IJssel/Min IJssel/Des NR/Des Waal

We shall first define these inputs for the case with IJssel canalization and then the case without. The minimum Neder-Rijn flow and minimum IJssel flow values are the minimum flows on the Neder-Rijn and IJssel. These values must be sufficiently small that they can be met by the smallest Rijn flow to be considered for any decade. The desired Waal flow has next priority, i.e., as the Rijn flow increases from very low flows, the flow in the Neder-Rijn and the IJssel are kept at their respective minimum values until the desired Waal flow is reached. As the flow in the Rijn is increased further, the IJssel has next priority if the desired IJssel flow is nonzero and the desired Neder-Rijn flow is zero (e.g., weir schedule: 25/300/50/0/1000), in which case the Neder-Rijn is kept at the minimum Neder-Rijn flow, the Waal is kept at the desired Waal flow, and the IJssel increased until it reaches the desired IJssel flow. Then, further increases in the Rijn flow keep the Waal at the desired Waal flow and the IJssel at the desired IJssel flow and increase the Neder-Rijn flow. Modification of this general procedure occurs when either the weir at Driel or the weir on the IJssel becomes fully open at some step in the procedure; further increases in the Rijn discharge then also increase at least one of the flows (nominally) fixed at their desired values.

If the weir schedule has the desired IJssel flow equal to zero and a nonzero desired Neder-Rijn flow (e.g., weir schedule: 25/0/50/250/1000), then the Neder-Rijn has priority over the IJssel and is increased to its desired value before increasing the IJssel flow; the discussion in the previous paragraph then holds with the words Neder-Rijn and IJssel interchanged. For a discussion of various aspects of IJssel canalization and proposed weir schedules, see Refs. 5.1 and 5.2.

In the current situation (i.e., with no IJssel canalization), the last three entries of the weir schedule vector are set to zero. Then the the weir schedule has the form:

Weir Schedule: Minimum Neder-Rijn Flow/Desired IJssel Flow

As the Rijn flow increases from very low flows, the flow in the Neder-Rijn is kept at the minimum Neder-Rijn flow until the IJssel reaches the desired IJssel flow. As the Rijn flow increases further, the IJssel is kept at the desired IJssel flow and the flow in the Neder-Rijn is increased by opening the weir at Driel. When the Rijn flow becomes sufficiently high, the weir at Driel becomes completely open, and the flows in the three Rijn branches are determined by the natural division of the Rijn flow, i.e., the open river flows.

Figures 5.3 and 5.4 contain the flows in the Neder-Rijn, IJssel, and Waal as a function of the flow in the Rijn for two typical schedules, one with and one without IJssel canalization. Two weir schedules are input to the DM, one to be used when the IJsselmeer is at or above target level and the other to be used when the IJsselmeer is below target level (Sec. 5.3.10).

5.3.3. Haringvliet Sluices

The Haringvliet sluices (link 38, HARINGSL) are used to control the discharge of the Haringvliet to the North Sea and, consequently, to also control the discharge in the Nieuwe Waterweg (link 7, NEWATWEG). At low Rijn discharges the flow in the Nieuwe Waterweg is set as high as possible to help shipping and minimize the effects of the Rotterdam salt wedge (Sec. 5.3.6) by setting the flow in HARINGSL to its specified minimum flow (typically, 5.0 or 10.0 m^3/s to flush the Haringvliet). For higher Rijn discharges, the flow in HARINGSL is set so that the flow in NEWATWEG is equal to its specified maximum flow (typically, 1500 m^3/s for minimal disturbance of shipping and docks in

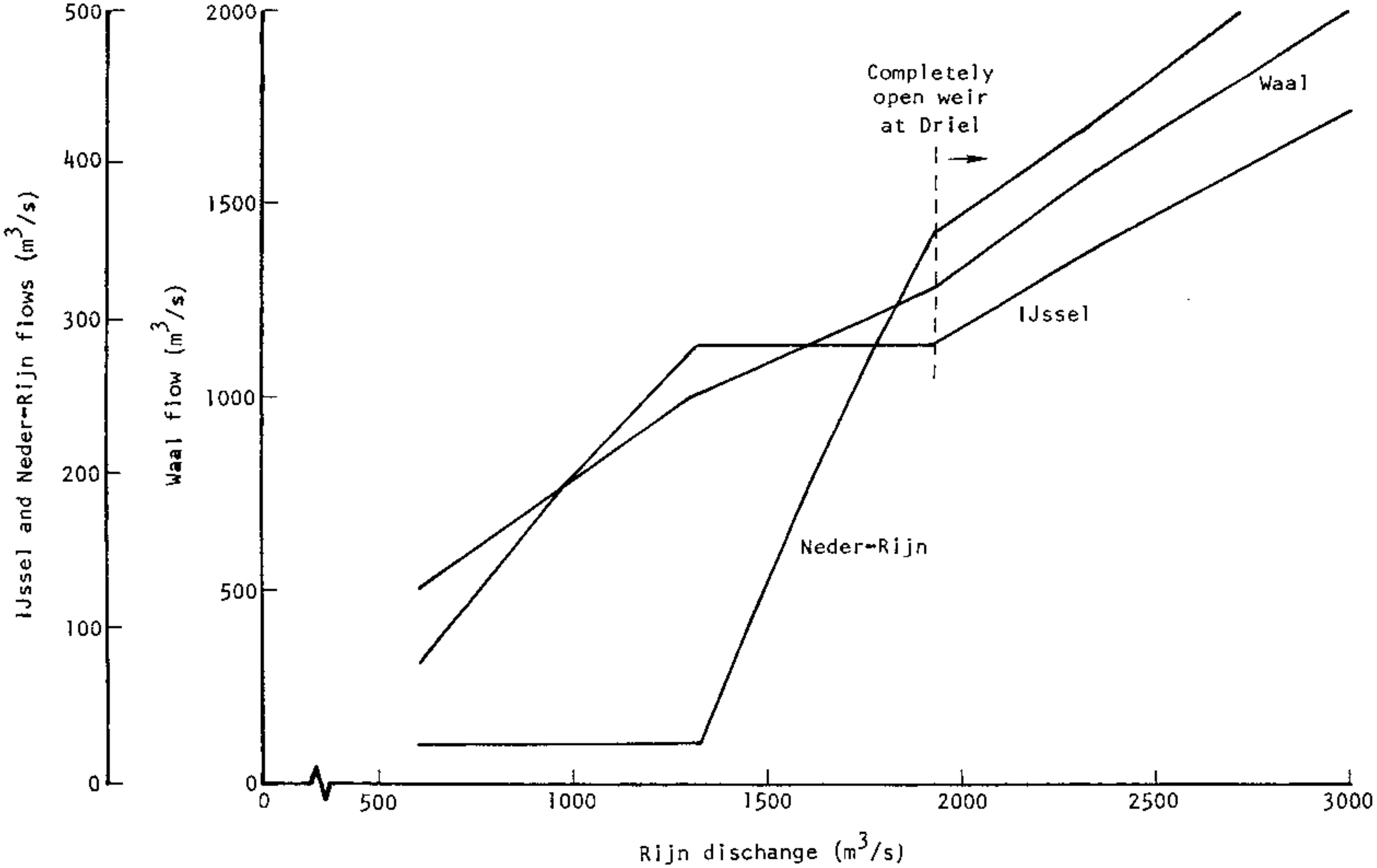


Fig. 5.3--Flows in Rijn branches under weir schedule 25/285

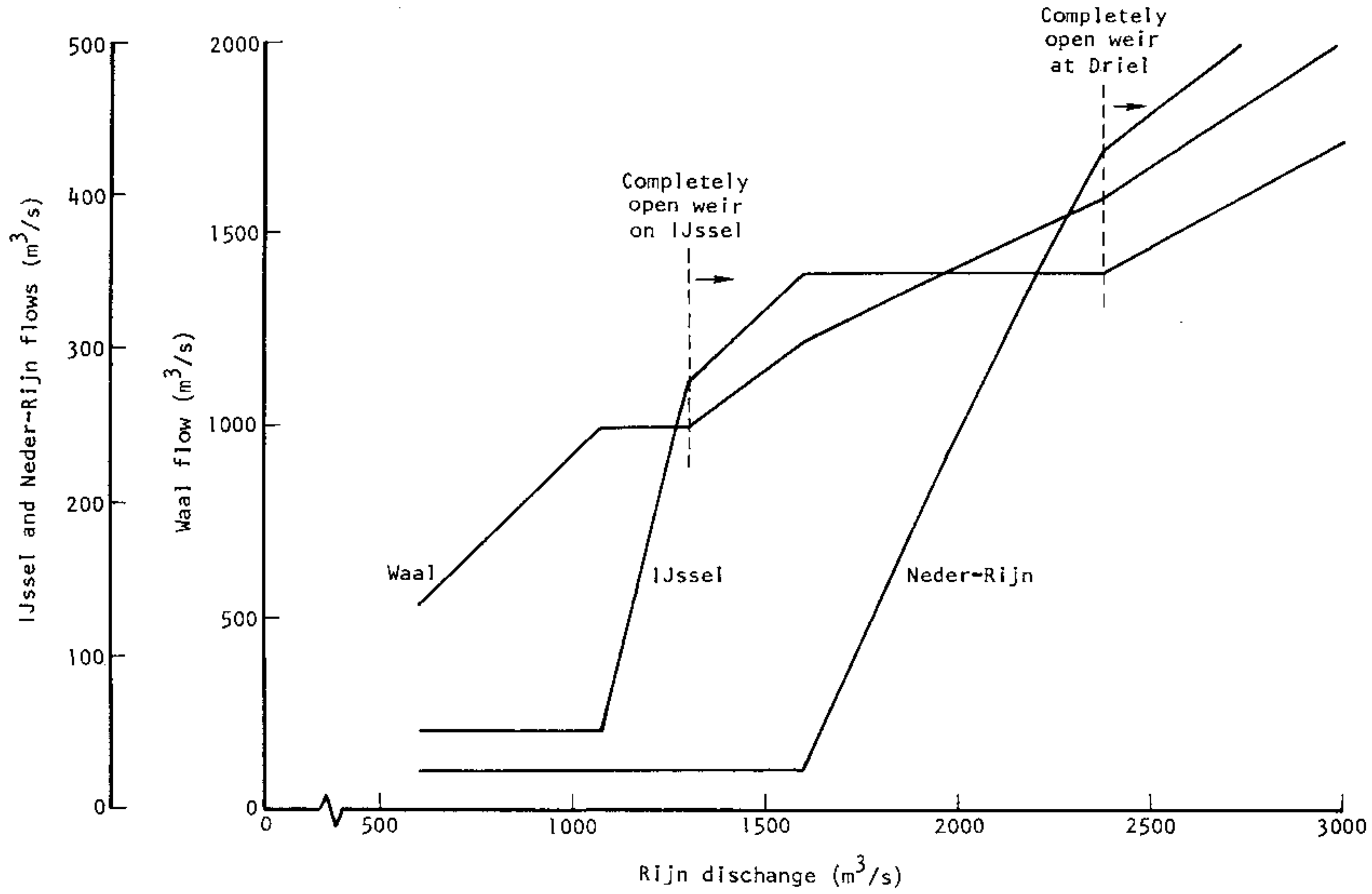


Fig. 5.4--Flows in Rijn branches under weir schedule 25/350/50/0/1000

the Rotterdamse Waterweg). For sufficiently high discharges, the Haringvliet sluices will become completely open by this policy, and the maximum flow in the Nieuwe Waterweg will then exceed the specified maximum value.

5.3.4. Amsterdam-Rijnkanaal

The flow on the Amsterdam-Rijnkanaal is controlled in the DM by the minimum flow specified for the section of the canal between Diemen and Amsterdam (link 52, ARKANAL5). This minimum flow may be input as zero or a value chosen, for example, to achieve a desired flow for cooling water at the Diemen power plant or to provide flushing water for the Noordzeekanaal and cooling water for the Hemweg and Velsen power plants on the Noordzeekanaal (see Sec. 6.3.1). The minimum flow specified for ARKANAL5 is met by the supply of the Amsterdam-Rijnkanaal inlet at Wijk bij Duurstede (link 46, ARKANAL2) and the Lekkanaal (link 45, LEKKANAL). In the current network, the Lekkanaal has no capacity other than for a lock loss of 2.5 m^3/s (but see Sec. 5.3.7 for the use of the Lekkanaal when the North-South Connection is included as a technical tactic).

The following priority list is used for supplying the Amsterdam-Rijnkanaal (the first, third, and fourth entries determine the supply available at the inlet at Wijk bij Duurstede, link 46, ARKANAL2): (1) surplus flow in the Lek over the minimum flow specified for LEK1; (2) supply from the Waal via the Merwedekanaal/Lekkanaal route (links 44 and 45, MERWKAN1 and LEKKANAL); (3) withdrawals from the Waal at Tiel to the Amsterdam-Rijnkanaal (link 46, ARKANAL1); and (4) increasing the flow in the Lek as needed by opening the weir at Driel.

5.3.5. Minimum Flow on the Lek

The minimum flow specified for the Lek between Schoonhoven and IJsselmonde (link 13, LEK3) controls the flow on the Lek. This minimum flow is normally set to a small value (say 5.0 m^3/s) to provide flushing of the Lek. If the minimum flow is not met, the following actions are taken as needed to achieve the minimum flow: first, extractions are increased at Gorinchem to the Merwedekanaal (link 44, MERWKAN1, current capacity = 0.0 m^3/s) up to capacity; then, extractions at Tiel (link 46, ARKANAL1, capacity = 120.0 m^3/s) are increased up to capacity; and, finally, the weir at Driel is raised to increase the flow on the Neder-Rijn, and, consequently, the Lek.

5.3.6. The Rotterdam Salt Wedge

When the flow in the Nieuwe Waterweg is low, salt from the North Sea intrudes into the Nieuwe Waterweg and may reach considerable distances inland. Of primary importance, if this <u>Rotterdam salt wedge</u> reaches the Gouda inlet on the Hollandsche IJssel, salt-sensitive crops in the Midwest (primarily, valuable vegetables and flowers grown in glasshouses) will be damaged by the increased salinity of water taken in at the Gouda inlet for level control and for irrigation of these crops by overhead sprinkling. If the salinity due to the Rotterdam salt wedge at the Gouda inlet (Sec. 6.2.3) is above a specified input maximum value (e.g., 50 mg/l), the following sequence of steps is taken:

1. The Midwest emergency supply (Sec. 4.3.5) is used for as much of the Midwest as possible, replacing the supply from the Gouda inlet. If a new canal through either the Lopikerwaard or Krimpenerwaard is implemented (Sec. 4.3.5), it is treated as part of the emergency supply.
2. Flushing of districts in the Midwest is reduced to zero, and flushing for salinity control at salt-fresh locks in the Midwest is reduced to their specified minima (Sec. 4.3.5).
3. The North-South Connection (Sec. 5.3.7), if available, is used to bring water south from the IJsselmeer to the Lek and send it out the Nieuwe Waterweg to push back the salt wedge.
4. Extractions from the Haringvliet for flushing the Zoommeer and Grevelingen are reduced to their specified minimum values, and the levels of the Zoommeer and Grevelingen are allowed to drop to their minimum levels or as needed to reduce the extractions from the Haringvliet to zero (Sec. 5.3.9).

After each of the steps, a new trial water distribution for the links is calculated, and if either water is no longer taken in at the Gouda inlet or the salt wedge salinity value at Gouda is below the specified maximum value, the remaining steps are omitted.

5.3.7. North-South Connection

Two ways of taking water from the Amsterdam-Rijnkanaal to the Markermeer are implemented:

1. In the North-South Connection, the Markermeer is isolated from the IJmeer by the Second Oostvaardersdijk, and the water is taken from the Amsterdam-Rijnkanaal at Diemen via a syphon under the IJmeer to the Markermeer (link 51, IJSYPHON).
2. In the Poorman's North-South Connection, the water is taken from the Amsterdam-Rijnkanaal at Amsterdam to the IJmeer via the Oranjesluizen and the pump at Zeeburg (link 67, ORANJESL). The Poorman's North-South Connection is used only when the MSDM policy is being implemented (see Sec. 5.4).

5.3.7.1. North-South Connection Flow North. The need to take water north to the IJsselmeer and the availability of water and capacity to do so are evaluated after a trial water distribution in the national system has been determined, considering all the other demands on the Waal and Lek. There is a flow north to the IJsselmeer using the

North-South Connection (as defined by the capacity of link 51, IJSYPHON, being larger than zero) whenever the level of the IJsselmeer is below target level and there is capacity remaining in the links needed to take water north to the IJsselmeer. The amount of water taken north is the minimum of the amount needed to raise the IJssel lakes to target levels, the capacity of IJSYPHON, the combined excess capacity of LEKKANAL and ARKANAL2 (excess to what is needed to fulfill other demands on the Amsterdam-Rijnkanaal, Sec. 5.3.4), and the combined excess capacities of the MERWKAN1 and ARKANAL1 links (excess to what is needed to fulfill demands on these links to meet the minimum flow on LEK3, Sec. 5.3.5, to keep back the Rotterdam salt wedge, Sec. 5.3.6, and the extractions from the Amsterdam-Rijnkanaal, Sec. 5.3.4). The priorities for supplying the Amsterdam-Rijnkanaal when there is a flow north to the IJsselmeer are the same as those given in Sec. 5.3.4.

5.3.7.2. North-South Connection Flow South. The North-South Connection is used to bring water south to the Lek if the Rotterdam salt wedge produces a salt wedge salinity value above the (input) specified maximum value at the Gouda inlet without bringing water south (Sec. 5.3.6). The amount of water brought south is the minimum of the capacity of the IJmeer syphon (link 51, IJSYPHON), the amount of water available in the IJssel lakes (the lakes may be dropped to the emergency level for flushing, Sec. 5.3.10), the capacity of the Lekkanaal (link 45, LEKKANAL), and (depending on the value specified for an input parameter) one of the three alternatives:

1. The amount of water needed to reduce the salt wedge salinity at Gouda to the specified maximum value.
2. The amount of water that would be withdrawn at Tiel without the North-South Connection flow south, i.e., the flow in ARKANAL1 in the trial water distribution.
3. The amount of water supplied from the Waal and the Lek to the Midwest and Utrecht and north on the Amsterdam-Rijnkanaal as measured by the sum of the flows on links 45 (LEKKANAL), 47 (ARKANAL2), 115 (MERWKAN2), 119 (HOLIJSEL), and 120 (KRIMPKAN) in the trial water distribution.

5.3.8. Withdrawals from the Waal at Tiel and the Merwedekanaal

Flows from the Waal to the Lek via the Amsterdam-Rijnkanaal from withdrawals at Tiel (link 48, ARKANAL1) and via the Merwedekanaal from withdrawals at Gorinchem (link 44, MERWKAN1) are set equal to their respective minimum flows (i.e., for lock losses) for the initial trial distribution of link flows. The flows on these links may be increased to meet demands on LEK3 (Sec. 5.3.5), to meet the minimum flow on ARKANAL3 (Sec. 5.3.4), and to send water to the IJsselmeer via the North-South Connection (Sec. 5.3.7). If the MSDM strategy is being implemented, these flows may be further increased (Sec. 5.4).

5.3.9. Zoommeer and Grevelingen

In the current infrastructure the Zoommeer is in open connection to the Oosterschelde, and consequently to the North Sea. The Zoommeer is connected to the Haringvliet via the Volkerak locks and discharge sluices (link 39, VOLKERAK), and there is a user-defined flow in the VOLKERAK link representing lock losses and salinity control flow at these salt-fresh locks. The Grevelingen discharges water in excess of its target level to the North Sea via discharge sluices in the Brouwersdam (link 43, BROUWDAM) but is not connected to any other node in the network.

Fresh Zoommeer. A fresh Zoommeer is included in the infrastructure by setting target, emergency, and minimum levels for the storage at node 31 (ZOOMMEER), desired and minimum flushing values and discharge capacity of the Zoommeer (link 40, ZOOMERSL), and the minimum flow and the capacity of the Volkerak sluices to supply the Zoommeer (link 39, VOLKERAK). The lock losses and salinity control flow for the Philipsdam and Oesterdam locks connecting the Zoommeer to the Oosterschelde and for the Kreekrak locks are included in the ZOOMERSL flushing values (Sec. 6.2.4).

Fresh Grevelingen. A fresh Grevelingen is included in the infrastructure by setting target, emergency, and minimum levels for the storage at node 32 (GREVLING) and setting supply capacities and desired and minimum flushing values and discharge capacities on the appropriate links. The Grevelingen may be supplied directly from the Haringvliet via the Halskanaal (link 42, HALSKAN) or, indirectly, via sluices in the Grevelingendam from the Zoommeer (link 41, GREVDAM). The discharge from the Grevelingen may be to the North Sea via the Brouwersdam (link 43, BROUWDAM), to the Haringvliet via the Halskanaal (link 42, HALSKAN), or to the Zoommeer (link 41, GREVDAM). In the latter case, flushing water for the Grevelingen is used as supply to the Zoommeer.

Level Control and Flushing of the Fresh Zoommeer and Grevelingen. The target levels and desired flushing of the Zoommeer and Grevelingen will be met in a dry period up to the capacities of the supply links unless the policy for the Rotterdam salt wedge (Sec. 5.3.6) reduces the flow from the Haringvliet to just meet the demands necessary to maintain minimum levels. In a wet period the target levels will be maintained as long as the capacities of the discharge links are sufficient to discharge the excess water; otherwise the levels will rise above the target levels.

5.3.10. IJssel Lake Levels

The managerial rules for the IJssel lakes depend upon four user-defined critical levels for each lake that may be varied decade by decade:

1. Target level
2. Emergency level for flushing
3. Emergency level for sprinkling
4. Minimum level

When the lakes reach their target levels, any overflow is discharged to the North Sea via the Afsluitdijk (link 63, AFSLUISL) or the Noordzeekanaal (link 67, ORANJESL), or to the other lakes, subject to capacity constraints (see Sec. 5.3.13). When the lakes fall below their emergency levels for flushing, extractions from the lakes for flushing of polders and boezems in districts, for salinity control at salt-fresh locks, and for cooling water at power plants are reduced to minimum levels or until the emergency levels have been reestablished (see Sec. 5.3.14). If the lakes drop below their emergency levels for sprinkling, the extraction demands for sprinkling are also cut back, until the emergency levels are reestablished or until water supplied for sprinkling has been reduced to zero. When the lakes drop below their minimum levels, no further action is taken; however, the extraction capacities from the lakes of certain links are set to zero or reduced and a message is printed out notifying the user that some remedial action may be necessary.

As the DM is currently designed, it is assumed that the target and emergency levels of the Markermeer, IJmeer, and Gooimeer are all less than or equal to the corresponding levels of the IJsselmeer. This assumption is consistent with current capabilities since the primary source of supply to the IJssel lakes is the IJssel River, and the direction of supply is from the IJsselmeer to the Markermeer via discharge sluices in the Houtribdijk (and from the IJsselmeer to the Markermeer and IJmeer if and when the Second Oostvaardersdijk is implemented).

The pumping station at Colijn (capacity = 21.2 m^3/s) connects the Ketelmeer to Flevoland and supplies both district 30, FLEVLAND, and node 49, VELUWMER (via the canals of Flevoland and the pump at Lovink, capacity = 19.3 m^3/s), from node 44, KETLMEER. In the DM it is assumed that the capacity of this supply route is sufficient to supply Flevoland and keep the Veluwemeer at the levels prescribed by the algorithms described in the following sections. During screening and impact assessment this assumption was valid. However, the assumption may not hold under all conditions, and the DM could be improved by reformulating the algorithms to constrain the extractions to the actual capacities of the supply route.

Table 5.3 gives the critical levels for the lakes that were used in screening (Vol. II) and impact assessment (Vol. I) for the current situation with open connections between the Markermeer and IJmeer and between the IJmeer and Gooimeer.

Table 5.3

IJSSEL LAKE CRITICAL LEVELS
(cm above NAP)

Decades	Critical Level	IJsselmeer	Markermeer/ Gooimeer/ IJmeer	Veluwemeer
1-9	Target	-40	-40	-30
	Flushing	-40	-40	-30
	Sprinkling	-40	-40	-30
	Minimum	-40	-40	-30
10-12	Target	-20	-25	-10
	Flushing	-36	-36	-28
	Sprinkling	-38	-38	-28
	Minimum	-40	-40	-40
13-27	Target	-20	-25	-10
	Flushing	-30	-30	-30
	Sprinkling	-38	-38	-28
	Minimum	-40	-40	-40
28-30	Target	-20	-25	-10
	Flushing	-36	-36	-28
	Sprinkling	-38	-38	-28
	Minimum	-40	-40	-40
31-36	Target	-40	-40	-30
	Flushing	-40	-40	-30
	Sprinkling	-40	-40	-30
	Minimum	-40	-40	-30

NOTE: The critical levels labeled flushing and sprinkling are the emergency levels for flushing and sprinkling, respectively.

5.3.11. Flushing of the Markermeer

If the salinity of the IJsselmeer is lower than that of the Markermeer, water from the IJsselmeer is used to flush the Markermeer to the Noordzeekanaal via the Oranjesluis and pumping station at Zeeburg. Since the salinity of the IJmeer is normally higher than that of the Markermeer and the salinity of the Noordzeekanaal higher than that of the IJmeer, the salinity is reduced all along the discharge route. This flow also serves to provide water for flushing the city canals of Amsterdam and is part of the flow for flushing and cooling water for the Noordzeekanaal (cooling water for the Hemweg power plant at Amsterdam and the Velsen power plant at IJmuiden).

The desired Markermeer flushing is nominally 30 m^3/s in the winter and 70 m^3/s in the summer, with a minimum flow of 10 m^3/s to flush the canals of Amsterdam. These values are input as the desired and minimum flows for the Oranjesluis link (link 67, ORANJESL). The minimum flow is met unless the discharge capacity from the Noordzeekanaal to the North Sea at IJmuiden is reached (link 55, NZKANLSL, capacity = 230 m^3/s), forcing a reduction in the desired flushing or even a flow from the Noordzeekanaal to the IJmeer. The actual amount of flushing depends upon which user-selected strategy is in force (see Sec. 5.4).

5.3.12. Afsluitdijk Maximum Discharge

The discharge from the IJsselmeer to the North Sea (link 63, AFSLUISL) is subject to the capacity constraint of the discharge sluices at Den Oever and Kornwerderzand in the Afsluitdijk. Figure 5.5 contains the total discharge capacity as a function of IJsselmeer level. The DM integrates this curve, taking into account the changing level with time during the decade, to obtain the total discharge capacity for each decade. If the IJsselmeer reaches target level and the desired discharge is larger than the discharge capacity, the IJsselmeer level is raised above that of the Markermeer and IJmeer (if not already above) and any additional discharge capacity via Oranjesluizen and the Zeeburg pump to the Noordzeekanaal (link 67, ORANJESL) and from the Noordzeekanaal to the North Sea via the discharge sluices at IJmuiden (link 55, NZKANLSL) is used to discharge the excess. If this capacity is insufficient, the levels of the Markermeer and IJsselmeer are raised together as necessary to account for the discharge deficit.

5.3.13. Flows When the IJssel Lakes Are at or above Target Levels

For a given time step, the <u>net discharge</u> into the IJssel lakes is the sum of all discharges into the lakes (preponderantly from the IJssel River) minus the extractions from the lakes plus the difference between precipitation on and evaporation from the lakes. A given net discharge into the IJssel lakes will be said to be sufficient to bring the lakes to given levels if, when the lakes are set to these levels and the link flows determined (by the standard procedure of Sec. 5.2), the discharge to the North Sea from the IJsselmeer is nonnegative. When the net discharge is sufficient to bring the lakes to their target levels, all lakes will be brought to their target levels. Any excess net discharge is then discharged to the North Sea through the Afsluitdijk (see Sec. 5.3.12).

The following describes, in general terms, two procedures (for the cases without and with a Second Oostvaardersdijk) for determining the levels of the IJssel lakes and the flows among the lakes when all lakes will be at or above their target levels at the end of the decade being considered. The Second Oostvaardersdijk separates the Markermeer from the IJmeer and creates a canal from the IJsselmeer to the IJmeer between the Markermeer and Flevoland (link 66, OSTVARDP); the IJmeer and Gooimeer are still in open connection, whereas the Markermeer is connected only to the IJsselmeer.

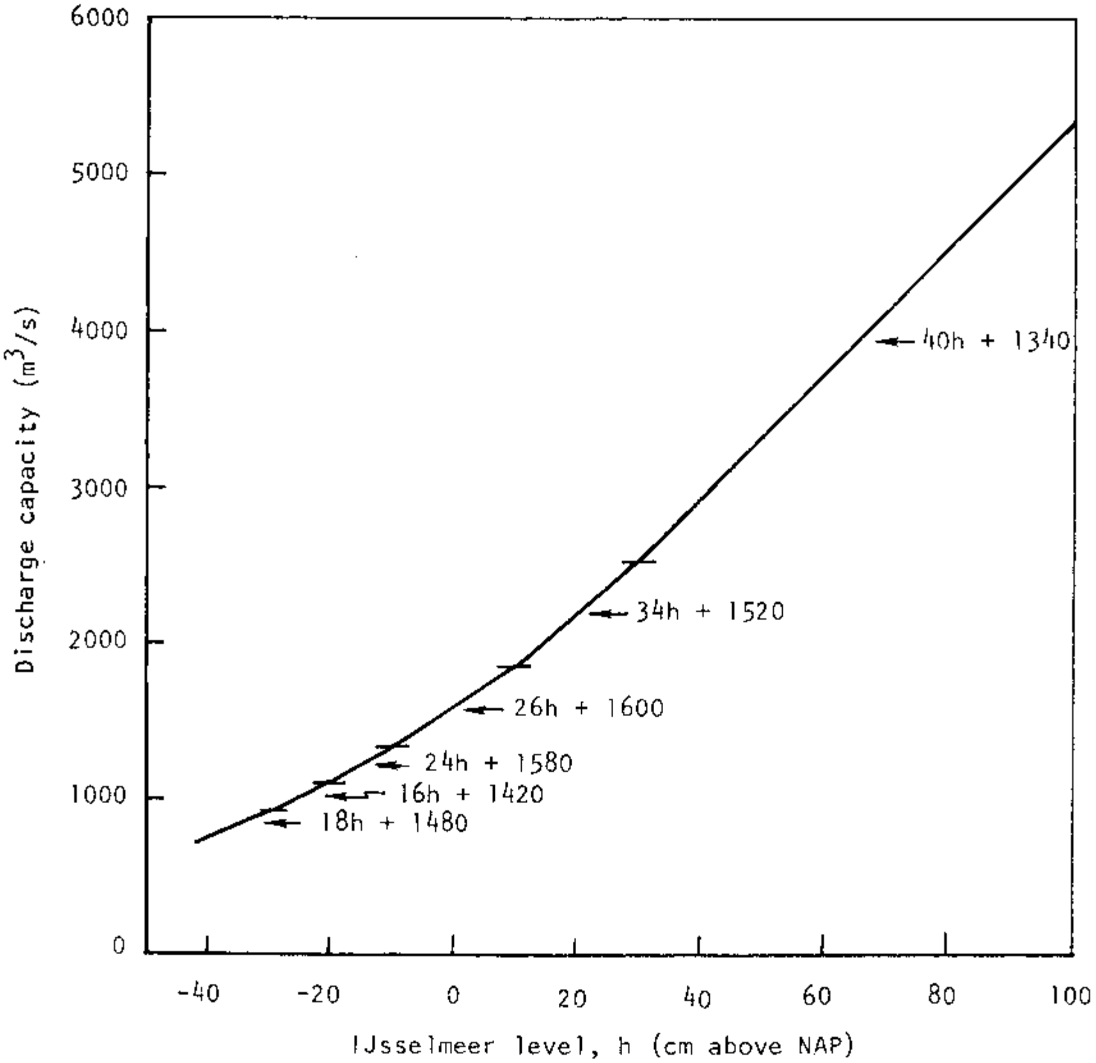


Fig. 5.5--Afsluitdijk discharge capacity
(Den Oever and Kornwerderzand sluices)

Procedure without the Second Oostvaardersdijk:

1. Flushing of the Markermeer from the IJsselmeer to the Noordzeekanaal takes place as described in Sec. 5.3.11.
2. It is assumed that the Veluwemeer level is always maintained above that of the other IJssel lakes and that the flow from the Veluwemeer to either the Gooimeer or the Ketelmeer is specified on input. When the Veluwemeer is at or above target level, it discharges into whichever of these two lakes has an unspecified flow. When the discharge capacity of that link is reached, any remaining Veluwemeer discharge is via the other link.

The following two steps are performed simultaneously in a numerical integration procedure (over the decade time step) that takes into account the maximum discharge capacity of the Afsluitdijk sluices as a function of the (possibly) changing IJsselmeer level (Sec. 5.3.12).

3. If the Markermeer/IJmeer/Gooimeer is at or above its target level, its discharge into the Noordzeekanaal is increased until the latter is used to its maximum capacity. Then, the level of this lake builds up until it exceeds the IJsselmeer level by 1 cm. Finally, it discharges into the IJsselmeer while keeping a 1-cm level difference.
4. If the IJsselmeer is at or above its target level, it discharges through the Afsluitdijk until the sluices are used to their maximum capacity. Then, the level of the lake builds up until it exceeds the Markermeer/IJmeer/Gooimeer level by 1 cm, at which point it begins to discharge into the Markermeer/IJmeer/Gooimeer while keeping a 1-cm level difference.

Procedure with a Second Oostvaardersdijk:

1. It is assumed that the Veluwemeer level is always maintained above that of the other IJssel lakes and that the flow from the Veluwemeer to either the Gooimeer or the Ketelmeer is specified on input. When the Veluwemeer is at or above target level, it discharges into whichever of these two lakes has an unspecified flow. When the discharge capacity of that link is reached, any remaining Veluwemeer discharge is via the other link.

The following three steps are performed simultaneously in a numerical integration procedure (over the decade time step) that takes into account the maximum discharge capacity of the Afsluitdijk sluices as a function of the (possibly) changing IJsselmeer level (Sec. 5.3.12).

2. If the Markermeer is at or above its target level, its level builds up until it exceeds the IJsselmeer level by 1 cm. It then discharges into the IJsselmeer while keeping a 1-cm level difference.
3. If the IJmeer/Gooimeer is at or above its target level, its discharge into the Noordzeekanaal is increased until the latter is used up to its maximum capacity. Then, the level of this lake builds up until it exceeds the IJsselmeer level by 1 cm, at which point it begins to discharge into the IJsselmeer while keeping a 1-cm level difference.
4. If the IJsselmeer is at or above its target level, it

discharges through the Afsluitdijk until the sluices are used to their maximum capacity. Then, the level of the lake builds up until it exceeds the IJmeer/Gooimeer level by 1 cm, at which point it begins to discharge into the IJmeer/Gooimeer while keeping a 1-cm level difference.

5.3.14. Extraction Cutbacks When the Net Discharge Is Insufficient To Bring the IJssel Lakes to Target Levels

If the net discharge into the IJssel lakes is insufficient to bring the lakes to their target levels, flushing and open-air sprinkling demands in excess of minimum requirements may be reduced for those links and districts whose supply is from the IJssel lakes and the IJssel River, i.e., those demands whose supply is water that would otherwise be used to raise the levels in the lakes. Before making these cutbacks, the DM has already determined any necessary cutbacks of extraction demands in the regional systems and districts due to insufficient link capacities or district intake capacities (Chap. 4), and the cutback rules described below are applied to these already reduced demands.

Cutbacks When Levels Are below Target Levels. If the net discharge into the IJssel lakes is insufficient to bring all of the lakes to their target levels and the managerial strategy selected for the run is any strategy other than the current strategy (see Sec. 5.4), the Markermeer flushing (Sec. 5.3.11) is reduced to its minimum value. (If the current strategy is selected, the Markermeer flushing is reduced to its minimum value if the net discharge is insufficient to bring the lakes to their flushing emergency levels.)

Cutbacks When Levels Are below Flushing Emergency Levels. If the net discharge into the IJssel lakes is insufficient to bring all of the lakes to their flushing emergency levels, the Markermeer flushing is reduced to its minimum value and the net discharge into the lakes is redetermined. If the net discharge is still insufficient to bring the lakes to their flushing emergency levels, the desired flows for salinity control and cooling water are reduced to the minimum flows for those links whose source of supply is one of the IJssel lakes or the IJssel River. The net discharge into the lakes is redetermined and if the net discharge is still insufficient to bring the lakes to their flushing emergency levels, the flushing demands in districts whose supply is from the IJssel lakes or the IJssel River are reduced to zero.

Cutbacks When Levels Are below Sprinkling Emergency Levels. If the net discharge into the IJssel lakes is insufficient to bring all of the lakes to their sprinkling emergency levels after the flushing cutbacks described above, surface water sprinkling is reduced in those districts whose supply is from the IJssel lakes or the IJssel River in proportion to the remaining sprinkling demands until either the remaining sprinkling demands have been reduced to zero or all lakes have reached their sprinkling emergency levels.

5.3.15. Flows When the IJssel Lakes Are below Target Levels

The following describes the algorithm for determining the levels of the IJssel lakes and the flows between the lakes when the net discharge into the lakes during a decade is insufficient to bring the lakes to target levels. The algorithm for determining flows when the net discharge is sufficient to bring the lakes to target levels is described in Sec. 5.3.13.

For the purpose of presenting this algorithm, the definition of the net discharge into the IJssel lakes (Sec. 5.3.13) is modified to include lake level changes during the steps of the algorithm, i.e., it is increased by lowering the lake level by an amount equivalent in m^3/s, and correspondingly decreased for any raising of the lake levels.

1a. If the net discharge is sufficient to bring the lakes to their flushing emergency levels, the levels of the lakes are determined as follows: the lake levels are set (tentatively) at their respective flushing emergency levels, and the value of the net discharge is changed accordingly; the Veluwemeer is brought to as high a level between its flushing emergency level and its target level for which the net discharge is sufficient, and the net discharge is reduced accordingly; the levels of the lakes other than the Veluwemeer are raised to use up any remaining positive net discharge and so that the levels of the Markermeer, IJmeer, and Gooimeer are either brought to their target levels or are 1 cm below the level of the IJsselmeer, whichever is lower.

1b. If the net discharge is insufficient to bring the lakes to their flushing emergency levels, the extractions from the lakes for flushing are reduced (as described in Sec. 5.3.14) and the net discharge is redetermined. If the new net discharge is sufficient to bring the lakes to their flushing emergency levels, the final lake levels are determined as in step 1a; otherwise, either step 2a or 2b is taken.

2a. If the net discharge is sufficient to bring the lakes to their sprinkling emergency levels, the levels are first brought to their sprinkling emergency levels, the value of the net discharge reduced or increased accordingly, and then the levels are raised in proportion to the difference between their flushing and sprinkling emergency levels to use up any remaining positive net discharge.

2b. If the net discharge is insufficient to bring the lakes to their sprinkling emergency levels, extractions from the lakes for sprinkling are cut back (Sec. 5.3.14) until either the resultant net discharge is sufficient to bring the lakes to their sprinkling emergency levels or the sprinkling extractions have been reduced to zero. A new net discharge is determined and if it is sufficient to bring the lakes to their sprinkling levels, the final lake levels are determined as in step 2a; otherwise, either step 3a or 3b is taken.

3a. If the net discharge is sufficient to bring the lakes to their minimum levels, the levels are first brought to their minimum levels, the value of the net discharge reduced or increased accordingly, and then the levels are raised in proportion to the difference between their sprinkling emergency levels and their minimum levels to use up any remaining positive net discharge.

3b. If the net discharge is insufficient to bring the lakes to their minimum levels, the levels are first brought to their minimum levels, the value of the net discharge reduced or increased accordingly, and the levels are then lowered together for a level decrease equivalent to the negative net discharge.

4. In certain of the previous steps, the possibility exists that a flow may have resulted from a lake with a lower level to a lake with a higher level. If this occurs, an adjustment is made unless the higher lake is the Veluwemeer. The flow is decreased until the lake with the (originally) lower level is 1 cm higher than the other lake.

5.4. A SET OF ALTERNATIVE MANAGERIAL STRATEGIES

The overall set of managerial rules used to control water usage and distribution in the national system constitutes a water managerial strategy for that system. For use of the DM in screening of managerial and technical tactics (Sec. 1.4) and impact assessment (Sec. 1.5), it was found convenient to be able to select one of a set of different managerial strategies by means of a single keyword input. The differences among the strategies in the set involve differences in only a small subset of the overall set of managerial rules. Only the basic differences among the strategies will be discussed below, not the variants, common to all of the strategies, which may be obtained by parameter changes, e.g., the selection of different weir programs for the weir at Driel.

The first three strategies differ only in the managerial rules for flushing the Markermeer and the Noordzeekanaal. All of the strategies have a desired summer flow of 70 m^3/s, a desired winter flow of 30 m^3/s, and a minimum flow of 10 m^3/s for flushing the Markermeer, but they differ in the rule for cutting back from desired to minimum flows.[1] All of the strategies are designed to achieve a desired minimum flow of at least 40 m^3/s in summer on the Noordzeekanaal for flushing and cooling water for the Hemweg plant at Amsterdam and the Velsen power plant at IJmuiden (40 m^3/s is the nominal minimum amount of cooling water needed for the Velsen power plant to meet the 7-deg standard for the temperature difference between intake and outlet, Sec. 6.3; the requirement at Hemweg is less).

Current Strategy. This strategy is based on the current policies for flushing the Markermeer and for salinity control in the northern section of the Amsterdam-Rijnkanaal. It has a minimum flow of 30 m^3/s

in winter and 70 m^3/s in summer for flushing the Markermeer/IJmeer directly to the Noordzeekanaal (link 67, ORANJESL). If the salinity of the IJsselmeer is greater than the salinity of the Markermeer or the level of the IJsselmeer drops below its flushing emergency level, the flow in ORANJESL is reduced to the minimum of 10 m^3/s (to flush the canals of Amsterdam). This strategy places a requirement of 10 m^3/s for salinity control on the Amsterdam-Rijnkanaal at Diemen (link 52, ARKANAL5). The minimum flow at Diemen is obtained by taking the water from the Markermeer via link 67 (IJSYPHON) to simulate an actual flow from the IJmeer to Diemen via Muiden and the Vecht River. Note that this flow also serves to flush the Markermeer.

Velsen Strategy. This strategy is designed to provide a flow of at least 40 m^3/s in the Noordzeekanaal. It places a desired minimum flow of 30 m^3/s in winter and 70 m^3/s in summer for flushing the Markermeer/IJmeer directly to the Noordzeekanaal (link 67, ORANJESL). If the salinity of the IJsselmeer is greater than the salinity of the Markermeer or the level of the IJsselmeer drops below its target level, the flow in ORANJESL is reduced so that the flow at IJmuiden (link 55, NZKANLSL) in the Noordzeekanaal is equal to the desired flow of 40 m^3/s. It places a minimum requirement of 5 m^3/s for salinity control on the Amsterdam-Rijnkanaal at Diemen (link 52, ARKANAL5). The minimum flow at Diemen is obtained from a flow up the Amsterdam-Rijnkanaal.

RWS Strategy. This strategy places a requirement for a minimum flow of 30 m^3/s in winter and 70 m^3/s in summer for flushing the Markermeer/IJmeer directly to the Noordzeekanaal (link 67, ORANJESL). If the salinity of the IJsselmeer is greater than the salinity of the Markermeer or the level of the IJsselmeer drops below its target level, the flow in ORANJESL is reduced to the minimum of 10 m^3/s (to flush the canals of Amsterdam). It places a requirement for a minimum flow of 20 m^3/s on the Amsterdam-Rijnkanaal at Diemen for salinity control, cooling water for the power plants at Utrecht and Diemen, and flushing and cooling water for the Noordzeekanaal. This latter flow is obtained from flows up the Amsterdam-Rijnkanaal.

In addition to the flows in the Amsterdam-Rijnkanaal and from the IJmeer via the Oranjesluizen and the Zeeburg pumping station, there are desired and minimum flows for pollution control on link 131, HARLMEER, and link 173, ZAAN, that contribute to the discharge of the Noordzeekanaal. Also, there are discharges from industry, drinking-water companies, and districts directly into the Noordzeekanaal at the AMSTEDAM and HALFWEG nodes. Table 5.4 summarizes the minimum flows into the Noordzeekanaal under the three managerial strategies.

As can be seen from the table, all three strategies achieve at least the desired minimum flow of 40 m^3/s in the Noordzeekanaal under nominal summer conditions, i.e., when the salinity of the IJsselmeer is less than that of the Markermeer. The current strategy emphasizes flushing of the Markermeer at the expense of maintaining target levels in the IJsselmeer. However, the Markermeer flushing is reduced from

Table 5.4

MINIMUM SUMMER FLOWS INTO THE NOORDZEEKANAAL
(m^3/s)

	From the Markermeer				From the Lek or Waal	
Strategy	IJmeer[1]	Vecht	Harlmeer	Zaan	A-R Canal	Total[2]
Current	60,60,10	10	5,5,3	7	0	84,84,32
Velsen	70,21,23	0	5,5,3	7	5	87,40,40
RWS	70,10,10	0	5,5,3	7	20	102,44,42

[1] Multiple entries are flows when: (1) IJssel lakes are at target levels; (2) IJssel lakes are between target and sprinkling emergency levels; and (3) flows have been reduced to their minimum values by cutback rules.

[2] Multiple entries are defined as in note 1. The total includes a nominal value of 2 m^3/s for discharges from industry, drinking-water companies, and districts.

the desired to the minimum flushing value whenever the salinity of the IJsselmeer is greater than the salinity of the Markermeer or during an extended drought period when the IJssel lakes have been drawn down below emergency levels. The Velsen strategy emphasizes maintaining the desired minimum flow in the Noordzeekanaal for as long as possible in an extended drought period by cutting back early on the desired flushing of the Markermeer (as soon as the lakes drop below target levels). The RWS strategy also reduces the desired flushing of the Markermeer early but goes a step further in trying to maintain the IJssel lake levels by providing a sizable part of the flow in the Noordzeekanaal from the Lek or Waal via the Amsterdam-Rijnkanaal, at the expense of any increased costs due to lowering the flow on the Lek or Waal (see Sec. 7.2.1).

MSDM Strategy. This strategy is an adaptation of part of the technique used in the Managerial Strategy Design Model (Vol. V) to find preferred water managerial strategies under various conditions. It starts with the same basic strategy as the Velsen strategy (it could be modified to start from either of the other two strategies also) and attempts to improve upon it by finding new link flows that minimize a loss function--the sum of the low water shipping losses on the Waal and IJssel (Sec. 7.2.1), the dredging costs on the Waal (Sec. 7.2.3), a proxy for the salinity losses due to the Rotterdam salt wedge (Sec. 6.2.3), and the (future) loss due to any decrease in the water stored in the IJssel lakes.

The independent variables whose values are determined by the loss minimization procedure are the setting of the weir at Driel and the withdrawal from the Waal to the Amsterdam-Rijnkanaal at Tiel. Opening the weir at Driel increases the flow on the Neder-Rijn (and consequently the Lek) and decreases the flow on the Waal and IJssel. Increasing the withdrawal at Tiel increases the flow on the Lek, decreases the flow on the Waal a like amount, and causes a sandbar to form on the Waal below Tiel that must be dredged away or additional low water shipping costs will be incurred until the sandbar is washed away (Sec. 7.2.3). Increasing the flow on either the Lek or the Waal reduces the salinity values due to the Rotterdam salt wedge, but increasing the flow on the Lek is more effective in this reduction (Sec. 6.2.3). Thus, opening the weir at Driel decreases the salinity losses due to the salt wedge but increases the low water shipping losses on the IJssel and Waal and the loss due to any decreased storage on the IJsselmeer, whereas increasing the withdrawal at Tiel decreases the loss due to the salt wedge but increases the low water shipping costs on the Waal (there are no low water shipping costs on the Lek or Neder-Rijn) and dredging costs on the Waal.

The independent variables are constrained to lie between minimum and maximum values. The Neder-Rijn is constrained to lie between a user-selected minimum flow and the flow when the weir is completely open. The withdrawal at Tiel is constrained to lie between an input lock loss flow and the capacity of the Amsterdam-Rijnkanaal between the Waal and the Lek. The values of the independent variables must also be such that the minimum flow constraint on the Lek is met (Sec. 5.3.5). In addition, if the levels of the IJssel lakes drop below minimum levels, the flow up the Amsterdam-Rijnkanaal from Tiel to the IJssel lakes is increased to bring the lakes to their minimum levels, up to the capacity of that supply route.

The loss minimization algorithm is initiated from the set of link flows determined under the Velsen strategy. If, for example, this strategy has the weir at Driel set so that the flow on the Neder-Rijn is at its minimum value and the extraction at Tiel set so that the demands from the Amsterdam-Rijnkanaal (Sec. 5.3.4) and the minimum flow constraint on the Lek (Sec. 5.3.5) are just met (a typical situation during a drought period), then the loss minimization procedure determines whether increasing the flow on the Lek by either opening the weir at Driel or increasing the withdrawals at Tiel will decrease the loss function. If so, it finds the optimum Lek flow increase from each of these sources of supply.

The components of the loss function due to shipping losses on the Waal and IJssel and the dredging costs on the Waal due to withdrawals at Tiel are computed as functions of the flows on appropriate links (Sec. 7.2). The components of the loss function due to the effects of the Rotterdam salt wedge and the (future) value of water stored in the IJssel lakes are discussed below.

Saline water due to the Rotterdam salt wedge is extracted at the Gouda inlet and increases the salinity of the water in the boezems and ditches of the Midwest. Irrigation water from the ditches causes agriculture losses due to salinity effects on salt-sensitive crops, predominantly flowers and vegetables grown under glass. The determination of the total damage done by the incremental increase in salinity in a decade due to the salt wedge is not known a priori; it depends upon how much of the incremental salinity gets from the boezems to the ditches and then to the root zone of the crops. Before the salinity gets to the crop root zone, it may be flushed out of the ditches and boezems by flushing water brought into the Midwest specifically for flushing or by the natural flushing of rainfall (in fact, calculating the effects of these processes is precisely what the DM and DISTAG salinity models are designed to do).

Since the salinity losses due to the salt wedge depend upon future values of rainfall and amounts of flushing water, quantities which are unknown, a very approximate representation for the component of the loss function for the salinity losses in the Midwest due to the Rotterdam salt wedge must be used. It has the form (from Vol. V),

$$\mathrm{LOSS} = \mathrm{SDPARM} \times \mathrm{VG} \times \mathrm{CG}$$

where LOSS is the salinity damage to agriculture in the Midwest due to the Rotterdam salt wedge (Dflm), SDPARM is the salt damage coefficient for the salt-sensitive crops at risk in the Midwest (Dflm per 1000 kg), VG is the amount of water extracted at Gouda during the decade (m^3), and CG is the incremental salinity at Gouda due to the salt wedge (mg/l). VG and CG are calculated values, whereas SDPARM is a user-supplied input.

The (future) loss due to any decrease in the water stored in the IJssel lakes is the change in the water volume stored in the lakes (a negative value if there is an increase) multiplied by a constant. An estimate of the future value (and the one used in impact assessment) based on the 44-year DM run described in Sec. 1.4 is 0.00122 Dfl/m^3 (see Vol. V).

To summarize, the MSDM strategy (or SIMPLE MSDM, as it is called in Vol. V) attempts to improve on one of the existing strategies (the VEL strategy is currently used in the DM) by finding, for each decade, the setting of the weir at Driel and the flow in the Amsterdam-Rijnkanaal at Tiel that minimizes a loss function that is the sum of:

- Low water shipping losses on the Waal and IJssel.
- Dredging costs on the Waal due to withdrawals at Tiel.
- A proxy for the salinity losses in the Midwest due to the Rotterdam salt wedge.
- The (future) loss due to any decrease in the volume of water in the IJssel lakes.

When the MSDM strategy is used, an input value must be provided for the salinity damage coefficient SDPARM. Since the salinity damage from a given amount of salt introduced into the Midwest depends upon how much of the salt reaches the root zone of the crops before the remainder is flushed out, the value of SDPARM also depends on how much salt reaches the root zone. One way to arrive at a value for SDPARM would be to make a series of runs with the multiyear version of the DM (see Sec. 1.4) using the MSDM strategy and various values for SDPARM and determine the value of SDPARM giving the best overall multiyear results. For impact assessment, time and available resources did not allow this to be done. Instead, we made runs of the DM for several different years and values of SDPARM. Using these runs, we selected a value for SDPARM of 1.4 Dfl/kg for use in impact assessment. The value is arbitrary but was chosen because it did as well as the VEL strategy in all the years examined and decreased the losses in the very dry year DEX (see Sec. 1.4), by increasing the flow in the Rotterdam Waterweg and thereby decreasing the effect of the Rotterdam salt wedge in some decades, but did not unduly decrease the level of the IJsselmeer during the summer (as larger values of SDPARM did). A more thorough analysis would undoubtedly find a different and better value for SDPARM (in general, a different value could be found for each infrastructure change), but the one chosen did serve to improve upon the results for the VEL strategy. A comparison of the MSDM strategy results with those of the VEL and RWS strategy is given in Vol. I.

NOTE

1. The cutback rule that abruptly reduces the flushing of the Markermeer from 70 m^3/s to 30 m^3/s when the salinity of the IJsselmeer is higher than the salinity of the Markermeer can cause unexpected results. A DM run made for screening came up with the conclusion that there were negative benefits for a tactic designed to reduce the salinity of the IJsselmeer by sending the highly saline discharges of the Wieringermeer polder (district 31) to the North Sea instead of to the IJsselmeer. The negative benefits resulted because the reduction in the salinity of the IJsselmeer caused the Markermeer to have the higher flushing value for a longer period than the base case, so that the lakes were reduced to their sprinkling emergency levels earlier. This, in turn, caused reduced sprinkling and increased water shortage losses to agriculture that were larger than the benefits due to the reduced salinity.

REFERENCES

5.1. Rijkswaterstaat, Directie Waterhuishouding en Waterbeweging, District Zuidoost, Ijsselkanalisatie Enige Globale Plannen In Het Kader van het PAWN-Onderzoek (Some Global Plans for the PAWN Study), Nota 78.2, March 1978.

5.2 Unpublished information from the Rijkswaterstaat, "Aspecten IJsselkanalisatie: Stuwprogrammas" (Aspects of IJssel Canalization: Weir Programs), (PAWN file DW-051a), undated.

Chapter 6

POLLUTANTS

The DM has the capability of calculating pollutant concentrations for up to six pollutants: salt (chloride ion), heat, phosphate, BOD, nitrogen, and chromium. Salt concentrations are always calculated but the other pollutants are optional. Pollutant concentrations at the beginning of a decade are combined with point-source pollutant discharges at each node (and diffuse-source discharges in each district for phosphate, BOD, and nitrogen) to obtain the average and final values of the concentrations at each node and in each district (with the exception that thermal pollution is not calculated in the districts).

The pollutant concentrations are calculated once per decade, after the final values for the link flows in the decade have been determined. Thus, any managerial rules dependent upon pollutant concentrations must use the concentrations at the end of the previous decade, e.g., the rule for flushing the Markermeer (Sec. 5.3.11). However, the increase in salinity at the Gouda inlet (node 81, GOUDA) caused by the Rotterdam salt wedge (Sec. 6.2.3) is calculated for each trial set of flows made while implementing changes due to the managerial rule for the salt wedge (Sec. 5.3.6) since the policy depends upon that increase in salinity.

6.1. THE GENERAL CALCULATION PROCEDURE

The calculation procedure for determining pollutant concentrations is similar for all of the pollutants. In this section we describe the common portion of the general procedure and in Secs. 6.2 to 6.4, the features unique to each of the pollutants. Pollutant concentrations are milligrams of pollutant per liter of water (i.e., parts per million, ppm, by weight) for phosphate, BOD, and nitrogen; micrograms of pollutant per liter of water for chromium (i.e., parts per billion, ppb, by weight); and degrees Celsius (i.e., megacalories per cubic meter, Mcal/m^3) for the excess temperature of water caused by thermal pollution. Units for the other parameters and variables introduced in this section are given in later sections.

6.1.1. Initial Concentrations at Nodes

At the beginning of a DM run, initial values for the concentrations of each pollutant at each node and in each district are read from input datasets, except for thermal pollution, where the heat decay is sufficiently rapid in winter that the initial values are of no consequence.

6.1.2. Pollutant Concentrations in External Supply

Pollution concentrations in the major border-crossing rivers (Rijn, Maas, Overijsselsche Vecht, Roer, Niers, and Swalm) at the Dutch border are read from input datasets at the beginning of each decade. Any decay in these concentrations between the border and the first node in the network on these rivers (PANDNKOP for the Rijn and MASTRICT for the Maas) is calculated, and the (diminished) concentrations are multiplied by the flows and entered as pollutant discharges at those nodes along with any pollutants discharged directly at the nodes.

6.1.3. Internal Pollutant Sources

Point-source pollutant discharges (e.g., from industry and sewage treatment plants) are entered into the PAWN network at nodes and into the districts. Values of the point-source pollutant discharges are read from input datasets. Diffuse-source pollutant discharges from agriculture and nature preserves are calculated in the DM and entered into districts and at nodes. Salt intrusion via salt-fresh locks, seepage into bodies of water represented as storage at nodes, and salt intrusion due to the Rotterdam salt wedge are calculated in the DM and entered as salinity increases or salt discharges at nodes. Seepage directly into districts is calculated in the DISTAG submodel.

6.1.4. Pollutant Concentration Changes along Links

As pollutants are transported along waterways represented by the links of the network, their concentrations may change. Any evaporation from the water surface or pollutant release from bottom sediments will increase concentrations, but dilution by rainfall and losses of pollutants to the air (for thermal pollution), to bottom sediments (for phosphates and chromium), and via chemical processes to other forms (for BOD) will decrease concentrations. In the DM, only salt is assumed to be conserved, i.e., not subject to any loss from the water over time. Decay rates (i.e., loss rates) for the other pollutants are obtained either from calibration from actual data (Sec. 6.4) or, in the case of thermal pollution, by assumption (Sec. 6.3). Decay rates are read from external datasets for each pollutant (except thermal) for each link in the network. Pollutant losses in water being transported over a link are assumed to result in concentration decreases of the form (ignoring rainfall and evaporation in this definition but not in its implementation)

$$Ce = Cb \exp(-kV/Q) \tag{6.1}$$

for pollutants other than thermal, and for thermal pollution,

$$Ce = Cb \exp(-RA/Q) \tag{6.2}$$

where Cb = the pollution concentration at the upstream end of the link,
Ce = the pollution concentration at the downstream end of the link,
k = the decay rate for the pollutant,
V = the volume of water in the link,
Q = the flow in the link,
R = the decay (i.e., heat loss) rate for thermal pollution,
A = the surface area of the link.

6.1.5. Pollutant Concentrations at Nodes

Both the average concentration over the decade and the concentration at the end of the decade are calculated at each node.

Nodes without Storage. Let $\bar{C}in$ be the average concentration of all flows into the node and C(0) and C(1) be the concentrations at the node at the beginning and end of the decade. Let P be the rate at which a pollutant is being discharged directly into the node and Q be the total flow into (and out of) the node. Then the average rate at which pollutant is entering the node, S, and the average concentration over the decade, $\bar{C}$, at a node without storage are

$$S = P + Q \times \bar{C}in \tag{6.3}$$

$$\bar{C} = C(0) + S/Q \tag{6.4}$$

Then, using the approximation

$$\bar{C} = [C(0) + C(1)]/2 \tag{6.5}$$

and solving for C(1),

$$C(1) = 2\bar{C} - C(0) \tag{6.6}$$

which is used for the value of the concentration at the end of the decade.

Nodes with Storage. At nodes with storage a model for pollutant concentrations is adopted that takes into account both (possibly) changing water volume and pollution decay in the storage at the node. A key assumption needed for this model is that all water and pollutants in the storage are uniformly mixed at all times (see Vol. V for a complete discussion of the assumptions leading to this model). A consequence of this assumption is that all extractions from the node have the same (time-varying) concentration as the storage at the node. The model assumes that the pollutant concentration at any time in the decade is given by the solution of the differential equation

$$dC/dt = S/V - kC - RAC/V - DC/V \tag{6.7}$$

where C = the pollutant concentration at time t,
S = the rate (assumed constant) at which pollutant is being discharged into the storage volume (the sum of any direct discharges plus any pollutant transported to the node via links),
V = the storage volume at time t,
A = the storage volume surface area (assumed constant),
k = the decay rate for pollutants other than thermal and is zero for thermal pollution,
R = the decay (i.e., heat loss) rate for thermal pollution and is zero for other pollutants,
D = the rate of storage volume change caused by discharges into storage plus rain on storage minus evaporation from storage.

In Eq. 6.7 the term S/V is the rate of increase in pollutant concentration due to pollutants being added to storage, kC and RAC/V are the rates of concentration decrease due to pollutant decay, and DC/V is the rate of concentration decrease (or increase) due to dilution (or concentration) by water being added to (or evaporated from) the storage volume. Note that extractions from the storage volume enter into Eq. 6.7 only as they affect the volume since extractions are assumed to have the same pollutant concentration as the storage volume.

Although analytic solutions exist for Eq. 6.7 in special cases, in general the equation must be solved by numerical methods to obtain the concentration as a function of time and then the average over the decade (see App. C).

The System of Linear Equations for Concentrations at Nodes. The rate S at which a pollutant enters a node is not, in general, constant as assumed in Eq. 6.7 since it may depend upon the (possibly) changing concentrations at upstream nodes. But we make the approximation that S be replaced by its average value over the decade. Then solutions of Eqs. 6.4 and 6.7 for the average concentrations at a node can be written in the common form (see App. C)

$$\bar{C}_j = a_j C_j(0) + b_j S_j \tag{6.8}$$

$$= a_j C_j(0) + b_j(Pj + \text{sum } Q_{ij} \bar{C}_i d_{ij}) \tag{6.9}$$

where the subscript j denotes the jth node, the summation (on the i subscript) is over all nodes with links connecting to the jth node, and

$\bar{C}_j$ = the average concentration over the decade at node j,
$C_j(0)$ = the concentration at the beginning of the decade at node j,
S_j = the rate at which pollutant is being discharged at the node during the decade (assumed constant),
a_j, b_j = coefficients depending only upon the initial volume, flows into and out of the node, and the decay coefficent,
Q_{ij} = the flow from node i to node j (and is zero if the flow is from node j to node i),
d_{ij} = the concentration decay on the link from node i to node j (see Eqs. 6.1 and 6.2),
P_j = the rate at which pollutant is being discharged directly into node j.

The set of equations, one for each node, represented by Eq. 6.9 is a linear system of 92 equations in the 92 unknown average concentrations. These equations are solved using an efficient sparse matrix solution technique developed for use in IMPLIC [6.1], a Dutch model for flows in complex river and channel networks.

After determining the average concentration, the concentration at the jth node at the end of the decade, $C_j(1)$, is simply

$$C_j(1) = c_j C_j(0) + d_j \bar{C}_j \tag{6.10}$$

where c_j and d_j are functions of the volume at the beginning of the decade, the flows into and out of the node, and the decay rate (see Eq. 6.6 and App. C).

6.2. SALINITY

In the DM, salinity is that part of the total salinity that is measured by the chloride ion concentration. The predominant part of the salt entering the country is brought in by the Rijn. The salt in the Rijn and the other rivers enters the PAWN network by being discharged at nodes as part of the external supply. Salt also is discharged into the network from districts, and by salt intrusion from the North Sea and other brackish waters via salt-fresh locks, seepage, and the Rotterdam salt wedge. Salt in the surface water is assumed to be conserved, i.e., not subject to losses over time, so that salt entering the network stays there until flushed out to the North Sea or extracted by the districts.

Salt enters districts in the extractions from the main network, by saline seepage in low-lying districts along the coast, by being washed into the open water of the districts from urban areas, by fertilizers applied to the agricultural land, and even a small amount from the atmosphere in rainfall. Salt leaves the district primarily by being flushed into the main system or, for districts along the coast, into the North Sea.

6.2.1. External Supply

Rijn Salinity. In 1876 the average salt concentration of the Rijn at Lobith was less than 20 mg/l, and in 1976 this average was over 200 mg/l. Most of this increase has been due to industrial-related activity. If we interpret the salinity of the Rijn in 1876 as the the natural salinity of the Rijn, these numbers suggest that perhaps as much as 90 percent of the salt in the Rijn is due to industrial activity.

The salt load in the Rijn is the rate at which salt is being transported into the Netherlands by the Rijn in kg/s (as measured at Lobith) and is related to the Rijn salt concentration (mg/l) and Rijn discharge (m^3/s) by

$$\text{Load (kg/s)} = \text{Concentration (mg/l)} \times \text{Discharge } (m^3/s)/1000$$

Rijn salt concentrations are typically from 100 to 300 mg/l, and salt loads from 200 to 400 kg/s.

In the DM the user has the option of using Rijn salt concentrations read from datasets along with the decade discharges, as described in previous paragraphs, or using a model for Rijn salinity in which the average annual salt load due to industrial activity is specified as an input parameter. The model then computes the Rijn salt concentration as a function of the Rijn discharge and the decade of the year (reflecting seasonal variations). The model is based on the assumption that the salt in the Rijn discharge at Lobith comes primarily from three sources:

- A <u>natural</u> or <u>background</u> salt concentration always present in the Rijn discharge.
- A salt load change caused by a change in the Rijn discharge.
- Salt <u>dumped</u> into the Rijn by industry.

The change in the salt load in the Rijn due to a change in the Rijn discharge is included to represent (a portion of) the salt load due to surface water runoff from urban areas and cropland. The contributions from the three sources are added together so that the Rijn salt load has the general form

$$\begin{aligned}\text{Load} &= \text{Natural load} + \text{Load due to change in Rijn discharge} \\ &\quad + \text{Annual dump} \times \text{Seasonal factor} \qquad (6.11)\end{aligned}$$

For the average salt load in a decade, the terms in Eq. 6.11 are given specific forms such that

$$\begin{aligned}L_i &= bQ_i + r(Q_i - Q_{i-1}) \\ &\quad + D(1 + s1\ \sin1 + c1\ \cos1 + s2\ \sin2 + c2\ \cos2) \qquad (6.12)\end{aligned}$$

where L_i = average salt load in the ith decade (kg/s),
b = <u>natural</u> concentration of the Rijn (g/l),
= 0.0255 (or 25.5 mg/l),
Q_i = Rijn discharge during decade i (m^3/s),
r = the increase in Rijn concentration due to an increase in the Rijn discharge of 1 m^3/s (g/l),
= 0.0190 (or 19 mg/l),
D = <u>annual</u> (or <u>Rijn</u>) <u>salt dump</u> (kg/s), i.e., the salt dump averaged over the entire year,
s1 = 0.0769,
sin1 = sin(2 × pi × i/36),
c1 = 0.0452,
cos1 = cos(2 × pi × i/36),
s2 = -0.0198,
sin2 = sin(4 × pi × i/36),
c2 = -0.017,
cos2 = cos(4 × pi × i/36),
pi = 3.14

The numerical values given for the parameter coefficients b, r, s1, c1, s2, c2 and the values for the annual salt dump D (a separate value for each year) were obtained by fitting Eq. 6.12 to measured Rijn discharges and salt loads (averaged over decades) for the years 1960-1977 [6.2]. The seasonal factor, i.e., the multiplier of D in Eq. 6.12, is plotted in Fig. 6.1. The shape of this curve may reflect a decrease in industrial activity contributing to the salt load in summer, or factors creating a positive dependence of salt load with discharge (such as rain runoff from urban areas) and the generally lower Rijn discharges in summer.

For the years (1960-1977) to which the model was fit and the model parameters estimated, the average decade salt load predicted by the model was within 10 percent of the measured value in 65 percent of the decades. A comparison of the predicted values with the measured values showed that the measured values have more decade-to-decade variation than the predicted values. This is also evidenced by the fact that when the decade values are combined to form monthly averages the model predictions come within 10 percent of the measured values 92 percent of the time. The relatively large decade-to-decade variations in the measured values may be due to pulse load inputs from industry or to salinity measurement errors.

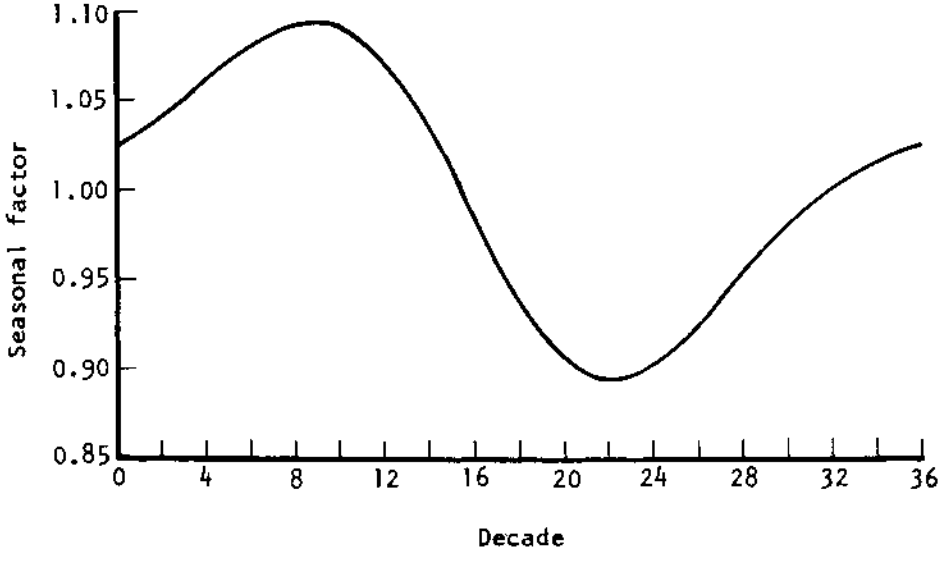


Fig. 6.1--Seasonal factor for the Rijn salt dump

For years other than 1960-1977, the annual salt dump can be estimated from the relation

$$\text{Annual salt load} = \text{Annual salt dump} + b \times \text{Annual discharge} \qquad (6.13)$$

where the adjective annual indicates an average over the year and $b = 0.0255$, as estimated above. (Equation 6.13 can be obtained by averaging Eq. 6.12 over the 36 decades of the year and discarding the numerically small term $r(Q_{36} - Q_1)/36$). Table 6.1 contains values for the annual discharge, average salt concentration, annual salt loads, and the annual salt dump for the Rijn for the years 1930-1979. Figure 6.2 contains a plot of the annual Rijn salt dump (from Table 6.1) for the years 1930-1979 and a trend line fit to that data. The trend-line equation is

$$D = 40 + 5.9(\text{Year} - 1930) \qquad (6.14)$$

where D is the annual salt dump (kg/s) for the specified year.

Using the trend line from Fig. 6.2, the values projected for the Rijn salt dump for some future years are given in Table 6.2.

In 1976, five nations (the Netherlands, France, West Germany, Switzerland, and Luxembourg) reached an agreement on cleaning up the Rijn. Among other matters, the agreement called for the amount of salt being dumped into the Rijn by the Alsatian potash mines in France (the worst single polluter of the Rijn) to be reduced by 60 kg/s (from 160 kg/s). Although approved by the other four nations, the French National Assembly has thus far refused to ratify the treaty or make the agreed-upon reduction. To reflect the uncertainty in the future values of the Rijn salt dump, the DM has currently built into the model a set of four scenario values for the Rijn salt dump from which the user may select a keyword input (see Table 6.3 and Sec. D.1.2.1).

Other Rivers and Drainage. The salinities of the discharges of the other rivers input into the DM--the Maas, Overijsselsche Vecht, Swalm, Niers, and Roer--are read from the external supply data files along with the river flows (see Sec. D.1.1.2). The salinities of the external drainage discharges (Sec. 3.1.1.3) are set equal to the salinity of the Maas.

6.2.2. Salinity in Discharges

The flows and their salinities from external supply (Sec. 6.2.1) and the district discharges and their salinities (obtained from DISTAG, Sec. 6.2.7) are entered at the appropriate nodes for use in the salt

Table 6.1

RIJN ANNUAL DISCHARGE AND SALT STATISTICS

Year	Discharge (m^3/s)	Concentration (mg/l)	Load (kg/s)	Dump (kg/s)
1930	2556	49	125	60
1931	2738	44	120	50
1932	2068	56	115	62
1933	1605	69	110	69
1934	1340	86	115	81
1935	2374	57	135	74
1936	2684	54	145	77
1937	2561	59	150	85
1938	1818	88	160	114
1939	3050	61	185	107
1940	2804	57	160	88
1941	2757	63	175	105
1942	1892	85	160	112
1943	1447	114	165	128
1944	2333	54	125	66
1945	2170	69	145	92
1946	2091	69	145	92
1947	1569	108	170	130
1948	2439	70	170	108
1949	1190	155	185	155
1950	1862	107	200	153
1951	2209	100	220	164
1952	2539	79	200	135
1953	1730	130	225	181
1954	1900	129	245	197
1955	2271	114	260	202
1956	2364	108	255	195
1957	2079	132	275	222
1958	2543	98	250	185
1959	1581	164	260	220
1960	2157	136	294	239
1961	2384	121	288	227
1962	2099	133	280	226
1963	1784	160	286	241
1964	1421	201	286	250
1965	3134	115	359	279
1966	3067	115	353	275
1967	2498	137	342	278
1968	2772	129	357	286
1969	2248	157	353	296
1970	3179	117	371	290
1971	1452	226	328	291
1972	1506	211	318	280
1973	1756	194	340	295
1974	2168	173	375	320
1975	2172	156	338	283
1976	1353	210	284	251
1977	2208	159	352	296
1978	2341	167	391	331
1979	2514	163	411	347

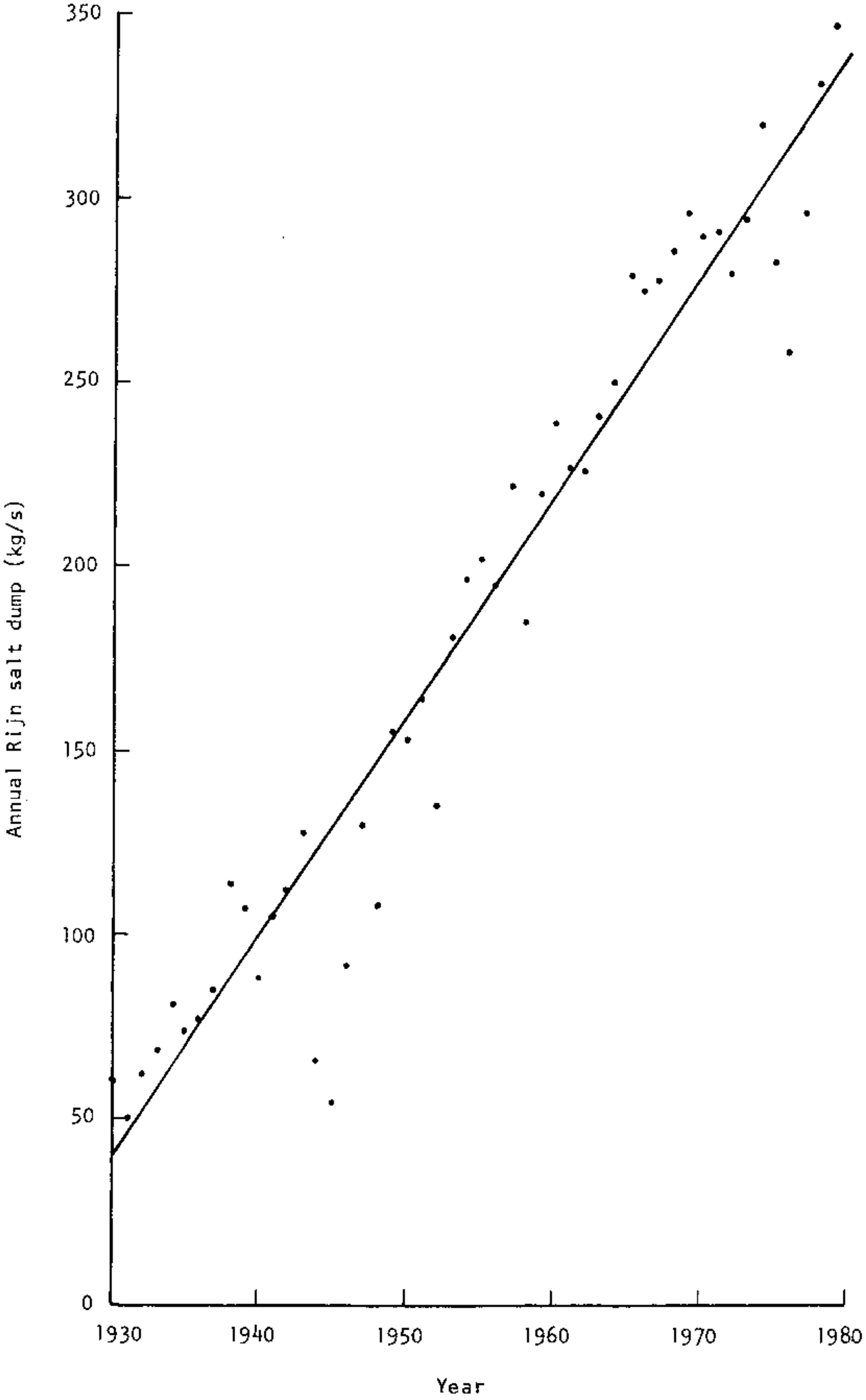


Fig. 6.2--Rijn salt dump

Table 6.2

TREND-LINE VALUES FOR
THE RIJN SALT DUMP
(kg/s)

Year				
1980	1985	1990	1995	2000
335	365	394	424	453

Table 6.3

RIJN SALT DUMP VALUES IN THE DM

Keyword	Rijn Salt Dump (kg/s)	Source
RSDLOW	251	Actual 1976 value
RSDINT	305	1985 trend-line value minus 60 kg/s
RSDMED	311	1976 trend-line value
RSDHI	365	1985 trend-line value

balance equations (Sec. 6.1.5). In addition, discharges and their salinities are entered at nodes as user-supplied inputs to represent discharges by industry, sewage treatment plants, etc. (see Sec. D.1.2.2).

6.2.3. Rotterdam Salt Wedge

During periods of low Rijn and Maas discharges, saline water from the North Sea intrudes into the Rotterdamse Waterweg. Of primary importance, at very low discharges this Rotterdam salt wedge will reach IJsselmonde, the intersection of the Hollandsche IJssel and the Nieuwe Maas, causing salinization of the Hollandsche IJssel and the extractions by the Midwest at the Gouda inlet.

In Vol. XIX, equations have been developed that estimate salt concentrations due to the salt wedge at locations in the Rotterdam Waterweg and at the Gouda inlet in the Hollandsche IJssel as functions of the discharge in the Nieuwe Waterweg and the flow in the Nieuwe Maas, assuming typical values for other factors affecting the salt wedge penetration, e.g., mean tidal conditions at the mouth of the Nieuwe Waterweg. These equations are used in the DM to give representative values for salt concentrations due to the salt wedge at the network nodes affected by the salt wedge: SCHEUR, OUDBIJER, IJSLMOND, and GOUDA.

Define

QNW = flow in Nieuwe Waterweg (m^3/s)
QNM = flow in Nieuwe Maas (m^3/s)

QOM = flow in Oude Maas (m^3/s)
CIJ = salinity at IJsselmonde due to salt wedge (mg/l)
CG = salinity at Gouda inlet due to salt wedge (mg/l)
CSC = salinity at Scheur (junction of Nieuwe Maas and Oude Maas) due to salt wedge (mg/l)
CSP = salinity at junction of Spui and Oude Maas due to salt wedge (mg/l)

then, from Vol. XIX,

$$CIJ = 0.0 \qquad QNM \geq 600$$

$$= 1000 \exp(0.318 - 0.00106QNW) \exp(2.14 - 0.0111QNM) \qquad QNM < 600$$

$$CG = CIJ \qquad CIJ \geq 2200$$

$$= 1.56(CIJ - 800) \qquad 2200 > CIJ \geq 1530$$

$$= -74.32 + 0.2417CIJ - 0.07388 \times 10^{-3}CIJ^2 + 0.2902 \times 10^{-6}CIJ^3 \qquad 1530 > CIJ \geq 310$$

$$= 0.0 \qquad CIJ < 310$$

$$CSC = 15800C1 \exp(-1.172 \times 10^{-3}QNW)$$

$$C1 = 1.0 - 0.323 \times 10^{-6}(QNW - 700)^2 \qquad QNW \geq 700$$

$$= 1.0 \qquad QNW < 700$$

$$CSP = 0.0 \qquad QOM \geq 600$$

$$= C1 - (C1 - C2)(QNW - 400)/400 \qquad QOM < 600$$

$$C1 = 6137 - 49.6QOM + 0.1564QOM^2 - 2.238 \times 10^{-4}QOM^3 + 1.208 \times 10^{-7}QOM^4$$

$$C2 = 4037 - 31.8QOM + 0.0999QOM^2$$

$$- 1.444 \times 10^{-4}QOM^3 + 7.917 \times 10^{-8}QOM^4$$

The formulas above for CIJ hold for withdrawals at the Gouda inlet below 40 m^3/s (current capacity = 32 m^3/s) (see Vol. XIX). The equations for CSC and CSP were obtained by fitting the curves given in Vol. XIX for the salinity due to the salt wedge at Scheur and at the junction of the Spui and Oude Maas, respectively.

The DM uses these equations for the salinities due to the salt wedge, substituting the flows in links NEWATWEG, NIEWMAAS, and OUDEMAS2 for the quantities QNW, QNM, and QOM, respectively. Although the model uses the flows in the Nieuwe Waterweg, Nieuwe Maas, and Oude Maas, it is of greater utility to the user of the DM in interpreting DM results to have the salt wedge salinities expressed in terms of the discharges of the Waal, Lek, and Maas. Figure 6.3 presents the salt concentration at the Gouda inlet (i.e., the GOUDA node) due to the salt wedge as a function of the discharge in the Nieuwe Waterweg and the difference between the flow in the Lek (immediately before the junction of the Lek and the Noord) and the extractions from the Hollandsche IJssel (in the DM, this <u>difference</u> is calculated as the difference between the flow in link 15, NIEWMAAS, and the flow in link 14, NOORD).

The curves in Fig. 6.3 were obtained by using Eqs. B.1 to B.3 to express the flow in the Nieuwe Maas as a function of the flow in the Nieuwe Waterweg and the difference between the flow in the Lek and the extractions in the Hollandsche IJssel. A result of this substitution is that the salt concentrations due to the salt wedge at IJsselmonde and the Gouda inlet may be represented as a decreasing function of the single combined variable

$$QNW + 1.1 \times QLH \tag{6.15}$$

or, equivalently, of the single combined variable

$$QW + QM + 2.1 \times QLH \tag{6.16}$$

where QNW = the discharge in the Nieuwe Waterweg,
QLH = the flow in the Lek minus the extractions from the Hollandsche IJssel,
QW = the Waal discharge,
QM = the Maas discharge.

Thus, from Eq. 6.16, increasing the flow in the Lek (or decreasing the extraction at Gouda) is 2.1 times as effective as increasing the flow

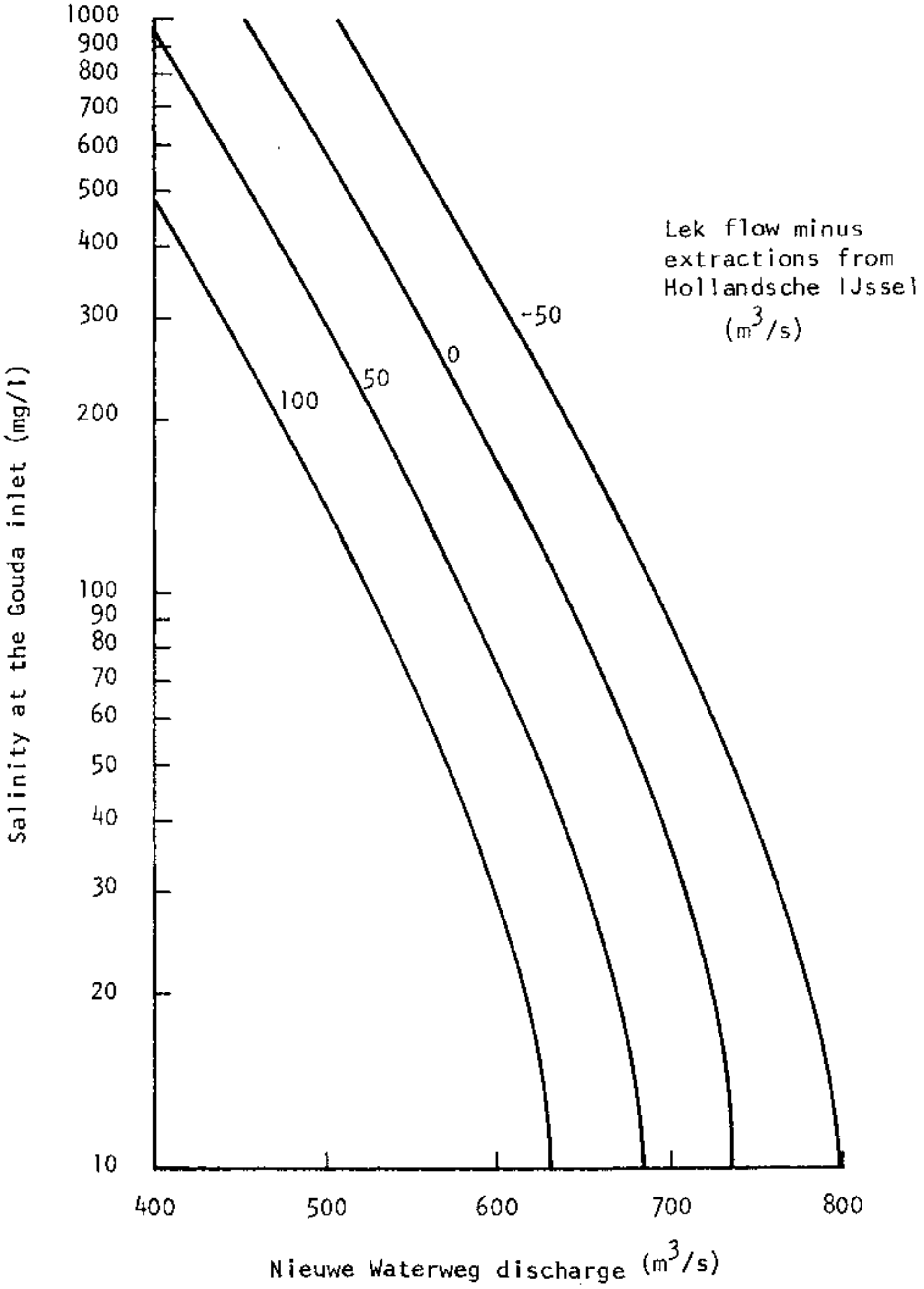


Fig. 6.3--Salinity at the Gouda inlet due to the Rotterdam salt wedge

in the Waal or the Maas in decreasing the salinity due to the salt wedge at both IJsselmonde and the Gouda inlet.

6.2.4. Salt Intrusion at Salt-Fresh Locks

Salt intrusion takes place at ship locks in the lowlands that connect fresh water in waterways and lakes to the North Sea or to brackish canals or waterways (e.g., the Noordzeekanaal, Nieuwe Waterweg, and the Volkerak). When a lock opens to the salt side, salt water will mix with the less saline water in the lock chamber. When the lock chamber subsequently opens to the fresh side, the saline water in the lock chamber can then contaminate the fresh water in the vicinity of the lock and diffuse back into the body of fresh water. Salt intrusion at salt-fresh locks during locking operations is included in the DM at thirteen lock locations that will be categorized, for convenience, into two groups:

Lake locks are those locks whose fresh side is a large body of water (e.g., IJsselmeer, Zoommeer, Haringvliet). The salt concentrations may vary considerably in these lakes, being higher in the vicinity of the locks, but a very complex model would be needed to include the many factors that affect this variability. We make the simplifying approximation that a fraction of the salt entering the fresh side leaves the lake through discharge sluices next to the locks (the exact amount depends upon the flow through the discharge sluices), and the remainder is completely and instantaneously mixed with the water in the lake.

Canal locks are those locks whose fresh side is a canal. The salt entering the fresh side of the lock increases the salt concentration in the canal in the vicinity of the lock such that the concentration in the canal decreases as the distance from the lock increases (Sec. 6.2.5). Salt concentrations in extractions from the canal thus depend upon the exact location of the extraction point on the canal. Included for each of these canal locks is a separate calculation that takes this varying concentration into account in estimating the salinity damage to the salt-sensitive crops in the part of each district that extracts from the canal (Sec. 7.1.3.2).

Table 6.4 contains locational information on the salt-fresh locks that are contained in the DM. The two sets of locks in the Afsluitdijk--Kornwerderzand and Den Oever--are combined in the DM, and we shall refer to the combination as the Afsluitdijk locks.

In the table, a flushing link is the link whose flow represents both freshwater lock loss due to locking operations and any additional flushing that serves to decrease the amount of salt reaching the fresh side of the lock. For canal locks, desired and minimum flows are input by the user for the flushing links to control the salinity reaching the extraction points on the canals. In general, the desired flow would be determined so that the salt reaching the fresh side of the lock would cause relatively small losses to the salt-sensitive crops at

Table 6.4

SALT-FRESH LOCKS IN THE DM

Lock	PAWN Node	Salt Side--Fresh Side	Canal or Lake	Flushing Link
Delfzijl	DELFZIJL	North Sea--Eemskanaal	Canal	EEMSKAN
Harlingen	HARLNGEN	North Sea--Van Harinxmak.	Canal	FRIEHARL
Kornwerderzand	AFSLDIJK	North Sea--IJsselmeer	Lake	IJSLWADZ
Den Oever	AFSLDIJK	North Sea--IJsselmeer	Lake	IJSLWADZ
Den Helder	DENHELDR	North Sea--Noordholland. K.	Canal	NOHOLKAN
IJmuiden	IJMUIDEN	North Sea--Noordzeekanaal	Canal	NZKANL2
Spaardnam	HALFWEG	Noordzeekanaal--Rijnland	Canal	HARLMEER
Parksluizen	SCHEUR	Nieuwe Waterweg--Schie	Canal	VLIET
Volkerak	WILEMSTD	Volkerak--Haringvliet	Lake	VOLKERAK
Philipsdam	ZOOMMEER	Oosterschelde--Zoommeer	Lake	ZOOMERSL
Oesterdam	ZOOMMEER	Oosterschelde--Zoommeer	Lake	ZOOMERSL
Kreekrak	ZOOMMEER	Westerschelde--Zoommeer	Lake	ZOOMERSL
Bruinisse	GREVLING	Oosterschelde--Grevelingen	Lake	GREVDAM

risk. The minimum flow would be determined by the maximum damage to the crops at risk (and/or the maximum shipping delay loss at the lock) compatible with other uses of the available water. The desired flow is met whenever there is an abundant water supply and the minimum flow is always met.

For lake locks, the desired and minimum flows on the flushing links also determine the amount of flushing for salinity control: the ZOOMERSL link for the Zoommeer when it is fresh and the VOLKERAK link from the Haringvliet when the Zoommeer is not fresh. The desired and minimum flows for the Grevelingen, if it is fresh, are input for the flushing link specified: GREVDAM, HALSKAN, or BROUWDAM (see Sec. 6.2.7). The minimum flow input for the IJSLWADZ link determines the minimum flushing of the IJsselmeer for salinity control at the Afsluitdijk locks.

The salt intrusion into the fresh side of the salt-fresh locks is a function of the ship traffic, parameters describing the physical situation at the lock, salt concentrations on the salt and fresh sides of the lock, and the amount of water used for salinity control at the locks. Tables calculated in the lock analysis (Vol. IX) have been input into the DM, giving the increased salt concentrations on the fresh side for canal locks and the amount of salt to be entered at the node for the lake locks. These tables are functions of the flows in the flushing links, the month (reflecting seasonal differences in shipping traffic intensities), and the shipping traffic scenario (1976 or 1985). For Kreekrak-type locks (Kreekrak and Philipsdam) the tables are also a function of a user-supplied input indicating whether or not the water regain feature of these locks is to be used. When the water regain feature is used, the locks lose less fresh water to the salt side of the lock but at the expense of increased salt intrusion.

The lock losses at the Philipsdam and Kreekrak locks are freshwater losses due to ship lockings; they are considered part of the flushing of the locks, which, in turn, is part of the flushing of the Zoommeer via the ZOOMERSL link. Thus, the minimum flushing value for ZOOMERSL should be input so that it is at least as large as the sum of the lock losses at the two locks. The flushing values for the Philipsdam and Kreekrak locks may be input by the user, or, in default, the water loss values in Table 6.5 will be used as the flushing values.

Lock losses at the other locks are small and are considered part of the minimum flushing values on the flushing links for those locks. For some of the locks--Harlingen, Kornwerderzand, Den Oever, Den Helder, and Parksluizen--there is actually a net gain of water to the fresh side of the lock; i.e, the saltwater side of the lock is higher than the fresh side and salt water is used to bring the levels to equilibrium during the locking operation. However, for these locks, additional flushing for salinity control is always sufficiently large that the net flow from the fresh side to the salt side is positive.

As mentioned above, salt intrusion at salt-fresh locks depends upon the salinities on both the salt and fresh sides of the locks. For most of the locks, nominal values for these salinities are assumed in the lock analysis in deriving the input tables (Vol. IX). However, for two locks, Parksluizen and Spaarndam, the salinity on the salt side may vary considerably from decade to decade and the tables are made explicit functions of the salinity on the salt side. For Parksluizen this is the salinity in the Nieuwe Maas outside of the locks. The value of this salinity is obtained by linearly

Table 6.5

LOCK LOSSES AND SALT INTRUSION FOR KREEKRAK-TYPE LOCKS

	Lock Losses (m^3/s)				Salt Intrusion (mln kg/day)			
	1976		1985		1976		1985	
Lock	R	NR	R	NR	Regain	No Regain	Regain	No Regain
Philipsdam								
Jan-Feb	4.4	8.3	7.1	13.1	0.897	0.105	1.448	0.166
Mar, Nov-Dec	5.0	9.4	7.0	13.1	1.025	0.119	1.435	0.167
April-May	5.2	9.8	7.3	13.7	1.076	0.125	1.507	0.175
June-July	5.3	10.1	7.4	14.1	1.094	0.128	1.532	0.179
Aug	5.6	10.1	7.5	14.4	1.153	0.128	1.552	0.182
Sep-Oct	5.5	9.8	7.4	14.0	1.235	0.124	1.527	0.177
Kreekrak								
Jan-Feb	5.2	9.9	6.8	12.4	0.260	0.030	0.344	0.038
Mar-Aug	5.8	10.5	7.5	12.9	0.291	0.032	0.379	0.040
Nov-Dec	5.8	10.5	7.5	12.9	0.291	0.032	0.379	0.040
Sep-Oct	6.1	10.9	8.1	14.4	0.306	0.034	0.406	0.044

interpolating (on distance) between the values of the salinity at the SCHEUR and IJSLMOND nodes as

$$CPA = CBIJ + CIJ + 12372(CSC - CIJ)/18455$$

where CBIJ = the background salinity (mg/l) at the IJSLMOND node, i.e., the salinity in the absence of the Rotterdam salt wedge,
CSC = the salinity (mg/l) at the SCHEUR node due to the Rotterdam salt wedge (Sec. 6.2.3),
CIJ = the salinity (mg/l) at the IJSLMOND node due to the Rotterdam salt wedge (Sec. 6.2.3).

For the Spaarndam lock, the salinity on the salt side is taken to be the salinity value in the Noordzeekanaal at its junction with the canal Zijkanaal C, the canal leading to the Spaarndam lock. The salinity at this location is given by Eq. 6.19 in the next section.

6.2.5. Salinities in Canals Upstream from Salt-Fresh Locks

In Vol. IX, the salinity in the canal on the fresh side of a canal lock is approximated as simple exponential decay as a function of the distance upstream from the lock. The general equation is

$$C = Cfl + (Cfr - Cfl) \exp[-dQ/(DA)] \qquad (6.17)$$

where C = the salinity (mg/l) at a distance d upstream from the lock,
Cfl = the salinity (mg/l) of the (flushing) water when it enters the canal,
Cfr = the salinity (mg/l) on the fresh side of the canal immediately upstream of the lock,
Q = the net amount of water (m^3/s) passing from the fresh side to the salt side of the lock due to lock losses and any additional flows in the sluices alongside the locks,
d = the distance (m) upstream from the lock,
D = the salinity diffusion (m^2/s) coefficient for the canal,
A = the cross-sectional area (m^2) of the canal.

For the Delfzijl, Den Helder, Harlingen, Parksluizen, and Spaarndam locks, salinities in the canals upstream from the locks where intake points for districts are located are used in Sec. 7.1.3.2 to estimate the damage done to crops in those districts by the extra salinity in the intake water.

Salinities in the Noordzeekanaal due to salt intrusion at the IJmuiden lock are estimated at the locations of the canal Zijkanaal C leading to the Spaarndam lock (this salinity is used for the salinity at the HALFWEG node and for the salinity on the salt side of the Spaarndam lock) and the AMSTEDAM node. The AMSTEDAM node is taken to be 28000 m from the IJmuiden lock, at which location the average salinity in the upper 10-m layer of the Noordzeekanaal is estimated from Eq. 6.17 with $D = 1100\ m^2/s$ and $A = 2200\ m^2$ (Vol. IX). Thus

$$Cam = Cfl + (Cfr - Cfl) \exp[-28000Q/(1100 \times 2200)] \qquad (6.18)$$

where Cam = the salinity at the AMSTEDAM node,
Cfr = the salinity on the fresh side of the IJmuiden lock,
Cfl = the salinity of the flushing water in the Noordzeekanaal (the salinity of the combined flows of the ZAAN, ORANJESL, and ARKANAL5 links),
Q = the flow in the flushing link (NZKANSL) for the IJmuiden lock.

The average salinity in the upper 6 m of the canal (the depth of the Zijkanaal C) is estimated to be 0.77 times the average salinity in the upper 10 m. Since the Zijkanaal C is located 8000 m from the IJmuiden lock, the salinity at that location is

$$Csp = 0.77[Cfl + (Cfr - Cfl) \exp[-8000Q/(1100 \times 2200)]] \qquad (6.19)$$

where Csp is the salinity at the location of the Zijkanaal C (also taken to be the salinity at the HALFWEG node and the salt side of the Spaarndam lock), and Cfr, Cfl, and Q are defined as above (following Eq. 6.18).

6.2.6. Zoommeer and Grevelingen

When the Zoommeer and Grevelingen are not fresh, the initial values for the salinities at the ZOOMMEER and GREVLING nodes (10000 and 13000 mg/l, respectively) read in at the beginning of the run are maintained as the salinities for these two storage nodes over the entire run.

When the Zoommeer and Grevelingen are fresh, each is treated as a lake with three sections (Sec. 3.1.2.3). The levels of the sections in each lake are the same, but each section is considered as a separate storage node with respect to salinity concentration calculations. For example, the only salt interchange among the sections is that caused by direct flows between sections for level control, discharges, and extractions. The only interactions between the Zoommeer and Grevelingen sections and the other nodes are via extractions from the Haringvliet at the WILEMSTD and STELNDAM nodes (using the VOLKERAK and

HALSKAN links) so that the average and final salinity concentrations for the six sections may be solved as a separate system (as described in Sec. 6.1.5) after the average salinities for WILEMSTD and STELNDAM have been calculated. The extractions and discharges of district 77 are from section G2 of the Grevelingen, and the extractions and discharges of district 76 are from section Z2 of the Zoommeer. Salt intrusion and freshwater losses from the Kreekrak and Oesterdam locks are from section Z3; from the Philipsdam lock from section Z2; and from the Bruinisse lock from section G1 (see Sec. 6.2.4). In addition to salt intrusion at salt-fresh locks, additional salt intrusion is included in the DM for seepage into the Grevelingen from the Oosterschelde under the Grevelingendam (into section G1) and from the North Sea under the Brouwersdam (into section G3). Values currently assumed for the seepage rates are 0.4 kg/s into section G1 and 0.7 kg/s into section G3 [6.3].

6.2.7. Salinities in Districts

The salinities in the districts are calculated in the DISTAG submodel (Vol. XII). The interactions between the district salinities and the DM take place via the salinities of the district discharges and extractions at the nodes of the DM. At the beginning of each decade, DISTAG is called in the request mode to determine district discharges and extraction demands for the decade. Initial estimates of the salinities of the extractions by the districts are made from the salinities at the nodes at the end of the previous decade and passed to DISTAG. The salinities of the district discharges are then passed back to the DM from DISTAG for use in determining the average and final decade salinities at the nodes. At the end of the decade, DISTAG is called again with the actual values of the district extractions as allocated by the DM (some may be less than requested) along with the salinities of the extractions. DISTAG then uses the final values of the extractions and salinities to determine the salinities in the districts at the end of the decade.

6.3. THERMAL POLLUTION

Thermal pollution occurs whenever heat is added to a waterway or to water being discharged into a waterway. The natural or background temperature of a waterway is the temperature the waterway would have in the absence of thermal pollution. The heat in any body of water caused by thermal pollution is the excess heat in the water, and the temperature rise above the natural temperature is the excess temperature of that water. The major sources of thermal pollution in Dutch waterways (and the only ones considered in the DM) are the electrical power generating plants in the Netherlands (they add waste heat to power plant cooling water) and the heat that has been added to the Rijn and Maas before these rivers reach the Dutch border.

In the PAWN models it is assumed that heat discharged into a body of water raises the excess temperature of that body of water and then the heat is dissipated over time until the excess temperature is reduced to zero. Thus, the excess temperature caused by a heat discharge decreases over time in storage or as the heat is transported downstream. The DM takes a heat rate input at each node where heat is discharged and calculates the excess temperature caused by that heat at every node in the network. The total excess temperature at a node from all heat sources is then simply the sum of the excess temperatures from each source, i.e., from each power plant and the heat measured by the excess temperature of the Rijn and Maas at the border.

As a result of the Pollution of Surface Waters Act of 1970 [6.4], there is currently a thermal pollution standard of 3 deg C for the excess temperatures of the rivers in the Netherlands. The standard applies to the excess temperature averaged over the river cross-section. In the lower rivers area, where the tidal action influences the excess temperature, the standard is applied to the excess temperature averaged over both the river cross-section and the tidal cycle. In PAWN, we have assumed that the 3-deg standard would be extended to all waterways, or, as a less stringent assumption, that all other waterways would have a 7-deg standard.

For a given run of the DM, we can determine the cost of meeting a thermal standard by using the DM to determine the excess temperatures and the EPRAC (Electric Power Reallocation and Cost) model (Vol. XV) to find the optimum distribution of power generation among the several power plants that meets an assumed power demand schedule. By doing this for two cases, one meeting the standard and one ignoring it, and taking the cost difference between the two cases, we have the cost of meeting the standard.

6.3.1. Electrical Power Plants

There are currently thirty-eight electrical power generating plants in the Netherlands. However, a number of these power plants are not subject to the thermal standard since they discharge their waste heat either directly into the North Sea or into bodies of water with an open connection to the North Sea. A few other (small) power plants are not considered in the DM because the waste heat from their generating units is either used for city heating, discharged into city canals where the surface area is used as a large cooling pond, or discharged into the air. Some plants are located in close proximity to one another and may be combined insofar as their heat discharge locations are concerned. Table 6.6 presents in summarized form the power plants subject to the thermal standard and their locations in the PAWN network. Volumes V and XV contain capacity, heat discharge, and fuel cost data for all generating units at all power plants.

Volumes V and XV also contain figures giving the (actual) 1976 and (projected) 1985 average electricity demand by hour of day for both summer and winter. From these figures, the peak summer demands are 6141 MW for 1976 and 9315 MW for 1985. Comparing these peak demands

Table 6.6

POWER PLANT LOCATIONS, CAPACITIES, AND HEAT DISCHARGES

		1976		1985	
Node	Power Plants	Effective Capacity[1] (MW)	Peak Heat Discharge[2] (Mcal/s)	Effective Capacity[1] (MW)	Peak Heat Discharge[2] (Mcal/s)
GRONIGEN	Helpman	742	261	610	199
	Hunze				
FRIELAND	Bergum	613	172	613	172
	Leeuwarden				
ZWOLLE	Zwolle	691	237	857	238
	Harculo				
NIJMEGEN	Gelderland 1	565	194	897	266
	Gelderland 2				
	Gelderland Z				
	Dodewaard				
IJSLMEER	Flevo	817	248	817	248
UTRECHT	Lage Weide	667	215	637	202
	Merwedekanaal				
IJMUIDEN	Velsen 1	1014	342	1014	342
	Velsen 2				
DIEMEN	Diemen	351	110	351	110
AMSTEDAM	A'dam Noord	574	221	768	236
	Hemweg				
	Vuilverbr.				
SCHEUR	Galileistraat	1221	388	1144	362
	Schiehaven				
	Waalhaven				
DORDRECT	Dordrecht	481	165	856	246
GERTRUID	Amer	1716	493	1830	525
	Donge				
BELFELD	Buggenum	683	247	504	166
LINNE	Maasbracht	0	0	1203	344
	All other	2766		3418	
	Total	12901		15566	

[1] The <u>effective capacity</u> is the <u>gross capacity</u> of all the generating units at the plants minus the capacity reserved for use by the plants (the residual is called <u>net capacity</u>) minus 5 percent of the net capacity that is assumed to serve as a spinning reserve for emergency use.

[2] The <u>peak heat discharge</u> is the heat discharged when all plants at the node are being used at their maximum effective capacities.

with the total effective capacities in Table 6.6, we see that the Netherlands as a whole has a considerable excess capacity in summer (winter demands are about 25 percent higher than summer). This excess capacity will be effectively reduced during dry periods when diminished water flows constrain the peak power that can be generated at some plants in order to meet the thermal standard and by constraints on the amount of power that can be transmitted from one region of the country to another. However, the usable capacity will still be sufficient to meet the demands, and the net effect of these constraints will be to increase costs due to the use of less efficient plants than would otherwise be necessary.

6.3.2. Excess Temperatures of the Maas and Rijn at the Border

By tentative agreements with the countries upstream of the Netherlands, the excess temperatures of the Rijn and Maas are not to exceed 3 deg C at the Dutch border. At low flows we assume that the 3-deg standard is just met at the border, but at high flows that the amount of excess heat is either constant (for the Rijn) or slowly decreasing (for the Maas). Figures 6.4 and 6.5 show the actual curves adopted for the excess temperatures as a function of the flows for the Rijn and Maas, respectively. (See Vol. XV for a discussion of the tentative agreements and the rationale behind the selection of these curves.)

The node on the Rijn in the PAWN network that is closest to the border is PANDNKOP, representing Pannerdensche Kop, the junction of the Rijn, Waal, and Pannerdensche Kanaal. The excess temperature of the Rijn is reduced using Eq. 6.20 and an area of 2.1 km^2 for the surface area of the section of the Rijn between the border and Pannerdensche Kop, and the resultant excess heat is discharged into the Rijn at the PANDNKOP node. The excess heat in the Maas at the border is discharged into the Maas at the MASTRICT node since the storage at that node includes the section of the Maas starting at the border.

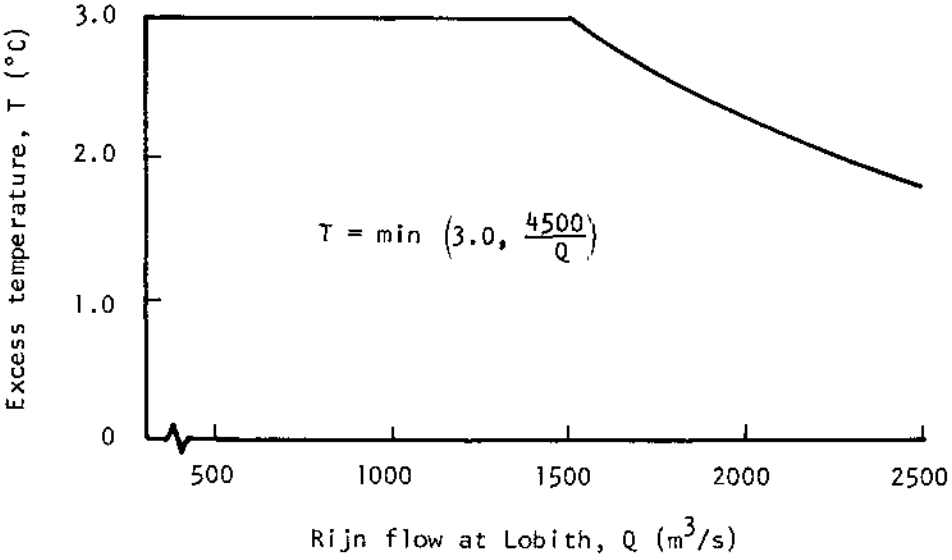


Fig. 6.4--Excess temperature in the Rijn at Lobith

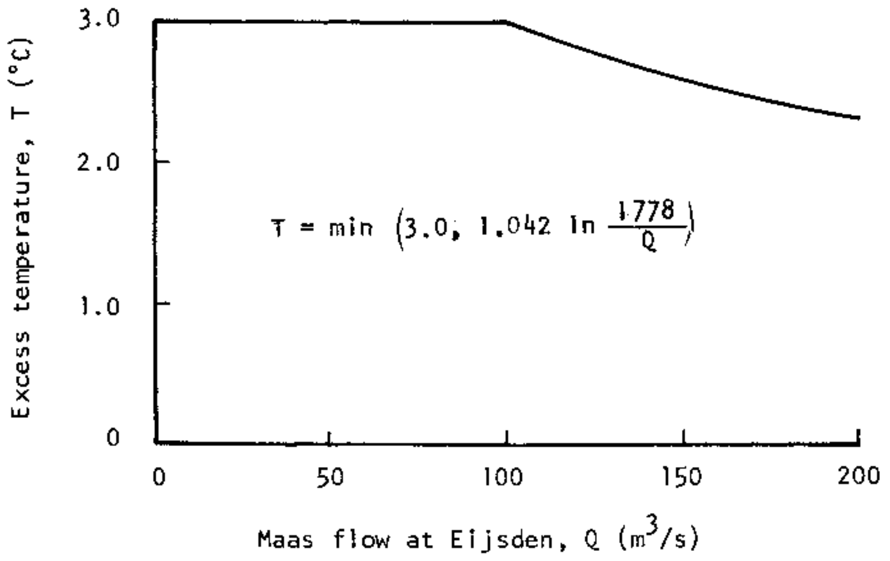


Fig. 6.5--Excess temperature in the Maas at Eijsden

6.3.3. Excess Temperature at Nodes

We use the model adopted by the Dutch (Vol. XV) for the transfer of the excess heat caused by thermal pollution from water to air. For heat being transported downstream in waterways, this model has the form

$$Te = Tb \exp(-RA/Q) \qquad (6.20)$$

where Tb = the excess temperature (C) at the upstream end of the waterway,
Te = the excess temperature (C) at the downstream end of the waterway,
R = the heat loss rate ((Mcal/s)/(km^2 × C)),
A = the surface area of the waterway (km^2),
Q = the flow in the waterway (m^3/s).

The heat loss rate is highly variable in reality, depending upon the wind velocity, the relative humidity, the surface temperature of the water, and the size and shape of the body of water. It can vary from 2 to 50 [6.5], but we have used a nominal value of 10 for all waterways, on the advice of our Dutch colleagues.

For determining excess temperatures at nodes, we extend the model represented by Eq. 6.20 by using the following form of the <u>pollutant differential equation</u> in App. C:

$$dT/dt = H/V - RAT/V - DT/V \qquad (6.21)$$

where T = the excess temperature at the node (C),
H = the rate at which heat is entering the node (Mcal/s),
V = the volume of water in storage at the node (m^3),
R = the heat loss rate ((Mcal/s)/(km^2 × C)),
A = the surface area of the storage at the node (km^2),
D = the rate of storage volume change caused by discharges into storage plus rain on storage minus evaporation from storage (m^3/s).

Using Eq. 6.20 and solutions of Eq. 6.21, a system of linear equations is solved for the average excess temperatures over the decade at the nodes (Eqs. 6.8 and 6.9), and the excess temperatures at the nodes at the end of the decade are then obtained fom Eq. 6.10.

6.3.4. Cooling Circuits

Several of the power plants are located a distance away from the main waterway that provides the cooling water for the power plant. In such cases, the sections of the waterways connecting the inlet point to the power plant, the power plant to the outlet point, and between the inlet and outlet points on the main waterway create a <u>cooling circuit</u> in which water can be circulated to provide additional cooling. Figure 6.6 illustrates in schematic form a generic cooling circuit.

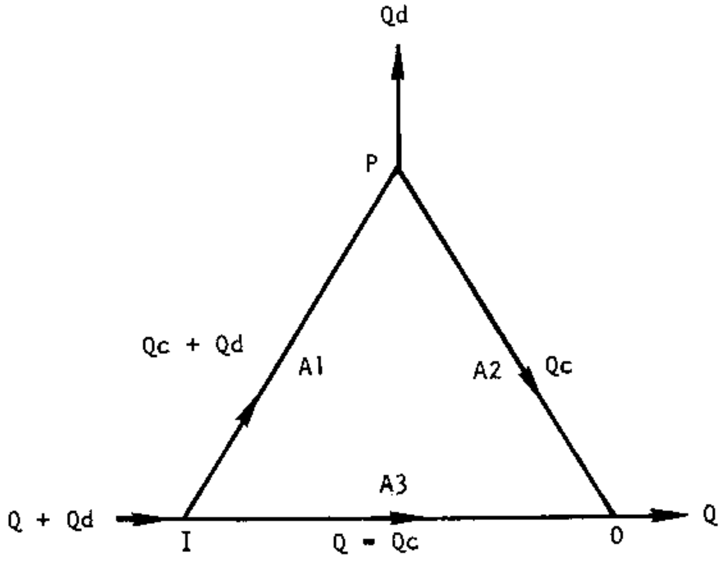


Fig. 6.6--Generic cooling circuit

In the figure, the power plant is located at the point marked P, the inlet point is at I, and the outlet point is at O. Cooling water is circulated in a clockwise direction with an amount Qd sent along other waterways, and an amount Qc returned to the main waterway. A1, A2, and A3 are the surface areas of the three legs of the cooling circuit. Q is the flow in the main waterway at a point to the right of the outlet point, with the positive flow direction being from left to right in the main waterway.

Let H be the heat generated by the power plant in MCal/s, Tp be the temperature rise at the power plant, i.e., $Tp = H/(Qc + Qd)$, and To be the temperature in the main waterway at the outlet point. Define

$$Q1 = Qc + Qd, \quad Q2 = Qc, \quad Q3 = |Q - Qc|$$

and

$$R1 = \exp(-10A1/Q1), \quad R2 = \exp(-10A2/Q2), \quad R3 = \exp(-10A3/Q3),$$

so that Q1, Q2, and Q3 are the flows and R1, R2, and R3 are temperature reduction multipliers in the legs of the cooling circuit.

In determining the temperature in the main waterway at the outlet point, we distinguish four cases depending on the direction of the flows in the main waterway. Equations can then be established for each of these cases as follows:

1. $To = TpR2Q2/Q \qquad Q > 0,\ Q \geq Qc$

2. $To = (ToR3R1Q3/Q1 + Tp)R2 \qquad Q > 0,\ Q < Qc$

   $= TpR2/(1 - R1R2R3Q3/Q1)$

3. $To = (ToR3R1 + Tp)R2Q2/Q3 \qquad Q \leq 0,\ |Q| \geq Qd$

   $= (TpR2Q2/Q3)/(1 - R1R2R3Q2/Q3)$

4. $To = (ToR3R1Q3/Q1 + Tp)R2Q2/Q3 \qquad Q \leq 0,\ |Q| < Qd$

   $= (TpR2Q2/Q3)/(1 - R1R2R3Q2/Q1)$

where the equations for cases 2, 3, and 4 are obtained by equating the temperature at the outlet point to that obtained from one loop around the cooling circuit in a clockwise direction starting from the outlet point.

In addition to the thermal standard of 3-deg set by the Pollution of Surface Waters Act of 1970 [6.4], the temperature difference of the water taken in and the water discharged by an electrical power plant must not exceed 7 deg in the summer and 15 deg in the winter (except for power plants that use seawater for cooling, in which case the standard is 10 deg in the summer and 15 deg in the winter). This standard has been interpreted as a requirement for a water throughput capacity of 40 m^3/s per 1000 MW of capacity at each power plant that uses fresh water for cooling (this is consistent with a heat discharge of 280 Mcal/1000 MW). Thus, we have assumed that power plants with cooling circuits have a cooling water capacity, i.e., Qc + Qd in Fig. 6.6, equal to 40 m^3/s per 1000 MW of effective power capacity.

Table 6.7 contains the areas and cooling water capacities for each of the power plant locations for which cooling circuits were used in the DM (except Groningen, explained below):

Table 6.7

COOLING CIRCUIT WATERWAY AREAS
AND COOLING WATER CAPACITIES

Node	Main Power Plant	A1 (km^2)	A2 (km^2)	A3 (km^2)	Cooling Water Cap. (m^3/s)
AMSTEDAM	Hemweg	0.285	0.649	0.621	40.0
FRIELAND	Bergum	0.6	0.9	3.0	26.2
DIEMEN	Diemen	0.014	0.160	0.195	15.4
IJMUIDEN	Velsen	0.086	0.437	0.405	42.8

The cooling circuit for the Helpman and Hunze power plants at Groningen can be schematized as shown in Fig. 6.7. In the figure, the power plant is located at the point marked P, the inlet point is at I, and the outlet point is at O. An amount of cooling water Qc is circulated past the power plant from the inlet point to the outlet point. A1, A2, A3, and A4 are the surface areas of the indicated waterway sections. Qe is the flow in link 83, EEMSKAN; Qw is the flow in link 87, WINDIEP1; and Qd = min(10, Qe + Qw), where 10 m^3/s is the capacity of the pump at Dorkwerd on the Eemskanaal.

Let H be the heat generated by the power plant in MCal/s, Tp be the temperature rise at the power plant, i.e., Tp = H/Qc, and To be the temperature in the main waterway at the outlet point. Define

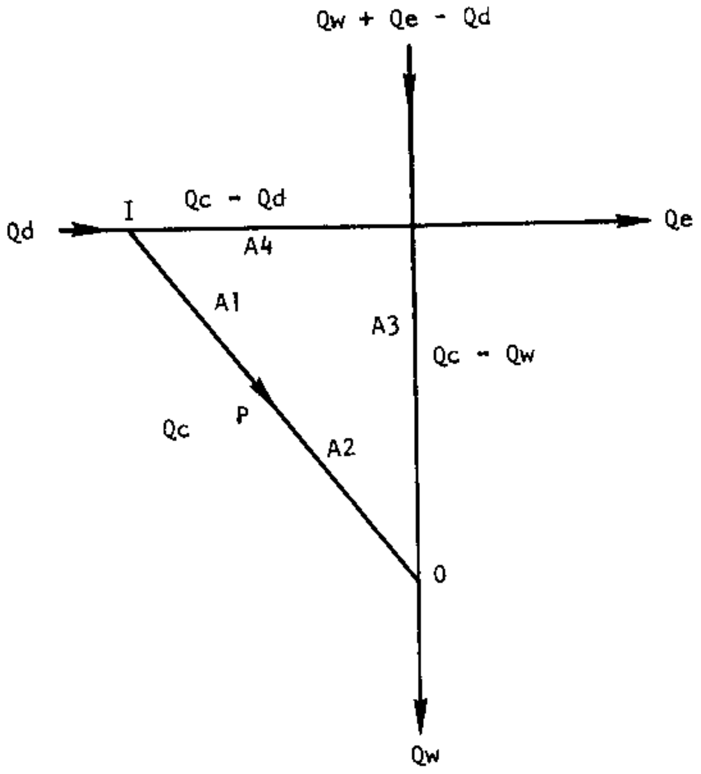


Fig. 6.7--Cooling circuit at Groningen

$$Q1 = Qc, \quad Q2 = Qc, \quad Q3 = |Qc - Qw|, \quad Q4 = |Qc - Qd|,$$

and

$$R1 = \exp(-10A1/Q1), \quad R2 = \exp(-10A2/Q2),$$

$$R3 = \exp(-10A3/Q3), \quad R4 = \exp(-10A4/Q4),$$

so that Q1, Q2, Q3, and Q4 are the flows and R1, R2, R3, and R4 are temperature reduction multipliers in the sections indicated.

In determining the temperature in the main waterway at the outlet point, we distinguish three cases depending upon flow directions. Equations can be established for each of these cases as follows:

1. $To = TpR2/Qw \qquad Qw \geq Qc$

2. $To = TpR2/Qc \qquad Qw < Qc,\ Qd \geq Qc$

3. $To = [ToR1R3R4(Qc - Qw)(Qc - Qd)/(Qc(Qc - Qd + Qe)) + Tp/Qc]R2$

$$= TpR2/[Qc - R1R2R3R4(Qc - Qw)(Qc - Qd)/(Qc - Qd + Qe)]$$

$$Qw < Qc,\ Qd < Qc$$

where cases 1 and 2 are established from the temperature reduction in section 2, and case 3 is established by equating the temperature at the outlet point to that obtained from one loop around the cooling circuit in a counterclockwise direction starting from the outlet point. The estimated surface areas of the four sections are $A1 = 0.02$ km^2, $A2 = 0.07$ km^2, $A3 = 0.1288$ km^2, and $A4 = 0.04$ km^2; and the cooling water capacity, Qc in Fig. 6.7, is 25.0 m^3/s.

6.3.5. Special Calculation for the Amer and Donge Power Plants

The Amer and Donge power plants discharge their cooling water into the GERTRUID node, which represents the junction of the Bergsche Maas, Donge, and Amer. This location is sufficiently close to the sea that it is subject to considerable tidal action at low Maas flows. The back-and-forth flow between flood and ebb tides creates, in effect, a cooling pond. At zero Maas flow, for example, the cooling capacity of this cooling pond averaged over the tidal cycle is equivalent to the cooling capacity of a flow of 20 m^3/s in the absence of tidal action. Figure 6.8 [6.6] shows the effect of the tidal action for flows from zero to 200 m^3/s in the Amer. For flows above 200 m^3/s, tidal action is assumed to have no effect, and for negative flows, i.e., when the flow in the Maas is so low that extractions below Tiel cause a reversal of flow in the Amer, we assume that the tidal action creates the same cooling capacity as for a positive flow. The extra cooling capacity for the Amer power plant created by the tidal action is represented in the DM by using a virtual flow in the temperature calculations

$$Qv = 23.33 + 0.883Qa \qquad Qa \leq 200$$

$$= Qa \qquad Qa > 200$$

where Qa is the absolute value of the flow in link 30, AMER1 (m^3/s), and Qv is the virtual flow used in place of the actual flow (m^3/s).

The cooling capacity averaged over the tidal cycle is used in the DM in the calculation of the excess temperature at the GERTRUID node. Thus, in this special case, the thermal standard is changed from an instantaneous requirement to an average requirement over a tidal cycle.

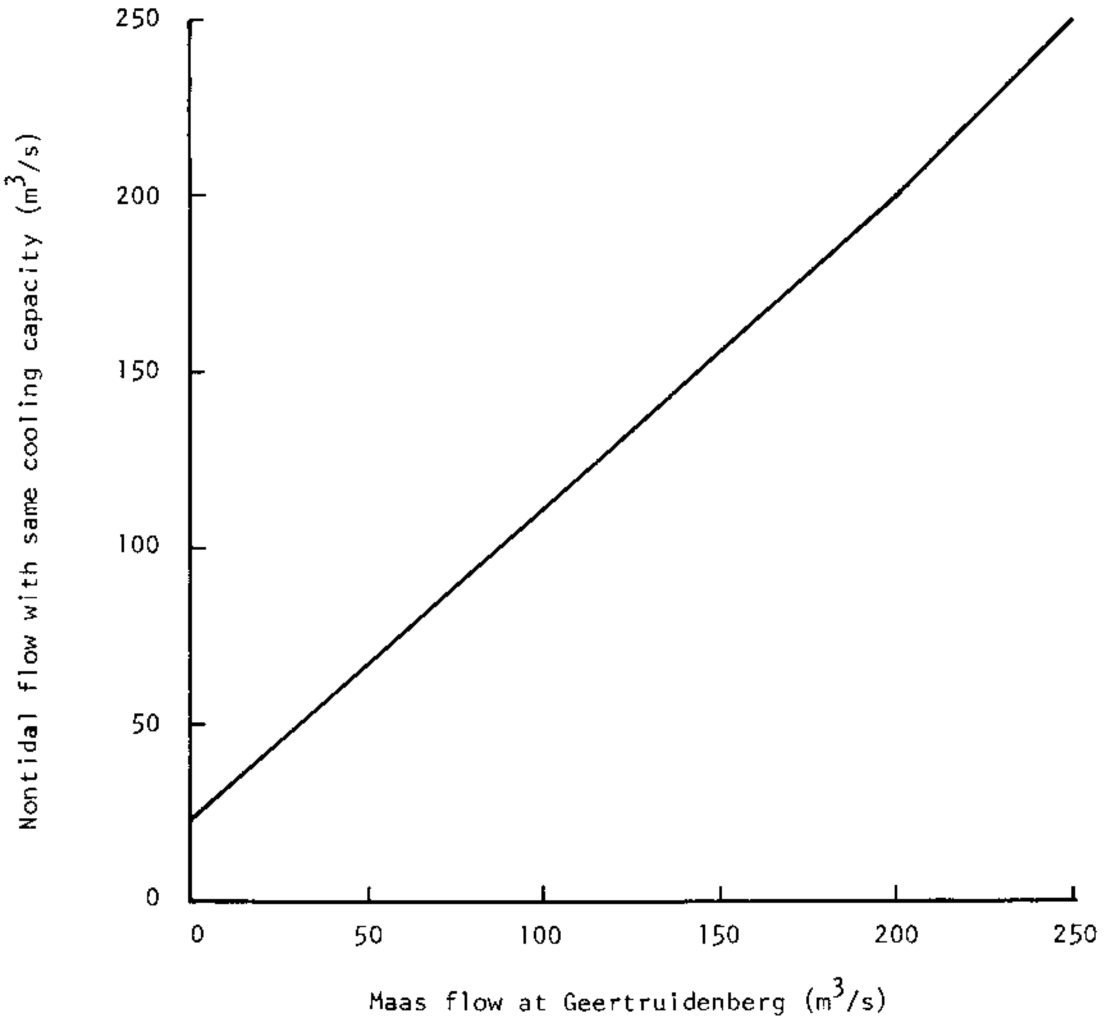


Fig. 6.8--Virtual Maas flow at the Amer power plant

6.3.6. DM Output for EPRAC

For use by EPRAC, the DM takes a user-supplied heat discharge at each node with a power plant and creates, for each decade, an output 16 x 16 excess temperature matrix. The row entries of the matrix are the excess temperatures that the nominal heat discharge at each power plant node (and the excess temperatures in the Rijn and the Maas) create at each of these heat-discharge nodes, i.e., at the 14 power plant nodes and at PANDNKOP and MASTRICT. To obtain the excess temperatures created by a heat discharge other than the nominal, the row entries need only be scaled by the ratio of the new to the nominal heat discharge. EPRAC can thus determine the excess temperatures at the power plant nodes for a given power generation distribution by scaling the row entries in the matrix according to the heat discharges at the power plant nodes, and then adding up the column entries to get the total excess temperature at the power plant node represented by the column.

If the excess temperatures at the power plant nodes meet the standard, the standard will be met everywhere. That this is so can be argued as follows. Consider first the case of a 3-deg standard everywhere. The standard is met at each heat-discharge node by assumption, and we make the further assumption that the standard is met everywhere at the beginning of the decade. The excess temperature at each node without a heat discharge is obtained as a mixture by weighting the excess temperatures of the flows into the node and the storage at the node according to their relative volumes and, therefore, is smaller than the maximum of the excess temperatures in the flows and the storage water. But the water in each of the flows may be traced upstream to either a heat-discharge node where the standard is met or to a source with no excess temperature. Since excess temperatures can only decrease in the downstream direction, the excess temperatures in each of the flows must be less than the standard. For the case with a 7-deg standard everywhere except where there is currently a 3-deg standard, the same argument holds except where potential 7-deg water flows into a 3-deg node, i.e., for the infrastructure containing a North-South Connection with flows from the Amsterdam-Rijnkanaal into the Markermeer or to the Lek. Here, we make the pragmatic argument that the remaining excess heat in the Amsterdam-Rijnkanaal water has been insufficient to raise the excess temperature in the Markermeer or the Lek above the standard in any run made thus far.

To illustrate how EPRAC uses an excess temperature matrix from the DM, Table 6.8 contains an example of the excess temperatures at the power plant nodes for the optimal power generating distribution for a peak demand period during a dry decade and the 1985 power plant supply and demand scenarios when the thermal standard is ignored.

6.4. PHOSPHATE, BOD, NITROGEN, AND CHROMIUM

Most water pollutants (in addition to salt and thermal pollution) may be placed in one of three categories: oxygen-consuming substances, substances that contribute to eutrophication, and toxic substances. The reader is referred to Vols. III, V, and VI for a discussion of the importance of these three categories on environmental quality in the Netherlands and of the PAWN work on water quality and water quality methodology.

In the DM we model the water transport of one water quality parameter from each of the above-named categories: BOD, an index of oxygen-consuming substances; phosphate, a necessary nutrient in many eutrophication processes; and chromium, a heavy metal with toxic properties. A fourth pollutant, nitrogen (another nutrient), is also included, but decay rates (Sec. 6.4.5) were not estimated for nitrogen

Table 6.8

EXAMPLES OF EXCESS TEMPERATURES DURING A DRY DECADE
(1985 Supply and Demand Scenario, No Thermal Standard)

Node	Peak Heat Discharge[1] (Mcal/s)	Flow[2] (m^3/s)	Cooling Factor[3]	Excess Temperatures Local[4] (C)	Remote[5] (C)	Total[6] (C)
GRONIGEN	0.0	3.9	0.55	0.0	0.0	0.0
FRIELAND	171.7	13.2	0.38	4.9	0.0	4.9
ZWOLLE	152.5	187.0	1.0	0.8	1.6	2.4
NIJMEGEN	251.0	737.0	1.0	0.4	2.7	3.1
IJSLMEER	137.9	---	---	0.0	0.0	0.0
UTRECHT	101.4	7.7	1.0	13.1	0.1	13.2
IJMUIDEN	342.0	33.3	0.81	8.3	0.8	9.1
DIEMEN	0.0	11.7	1.0	0.0	0.2	0.2
AMSTEDAM	144.7	21.6	0.73	4.9	0.0	4.9
SCHEUR	N.A.					
DORDRECT	159.6	587.0	1.0	0.3	1.4	1.7
GERTRUID	322.9	35.0	0.65	6.0	0.0	6.0
BELFELD	0.0	34.0	0.43	0.0	1.4	1.4
LINNE	344.0	15.1	0.41	9.4	0.0	9.4

[1] This is the peak heat discharge from the power plants at each node for the optimal generating schedule with no thermal standard.

[2] Total flows leaving the node via all links. The flows were taken from a DM run for a decade with low flows in the Rijn (951 m^3/s) and Maas (34.2 m^3/s).

[3] The cooling factor is the factor by which the heat discharge must be multiplied to account for cooling circuits, tidal cooling at GERTRUID, or the surface area at a node with storage to obtain the local excess temperature.

[4] The local excess temperature is the product of the peak heat discharge and the cooling factor divided by the flow.

[5] The remote excess temperature is due to heat discharges upstream of the given node.

[6] The total excess temperature is the sum of the local and remote excess temperatures.

due to a lack of time. It has been kept in the model since input data for pollutant discharges were prepared for it and some future use of the model may make it worthwhile to go through the calibration process that determines the decay rates. Without the decay rates the DM produces values of nitrogen concentrations that are too high but may have some use as upper bounds to the actual concentrations.

The forms of the four pollutants included in the DM are total phosphate, BOD5, total chromium, and Kjeldahl nitrogen. Hereafter in this note the words phosphate, BOD, chromium, and nitrogen will mean these forms.

The three pollutants chosen to represent the three pollutant categories--BOD, phosphate, and chromium--were chosen on the basis of their importance and the availability of data for pollutant discharges and for estimating pollution decay rates. In the use of the DM in impact assessment, runs with and without proposed tactics were made under a variety of future scenarios and the output examined for any effects on the number of locations, i.e., nodes, where pollution standards were violated. Presumably, the effect on the three pollutants included in the DM also gives an indication of the effect on other pollutants.

6.4.1. Initial Values

At the beginning of a run, initial values of the pollutant concentrations at nodes and in districts are read in from data files (see Sec. D.1.1.3). The values input for nodes are average values for the month of January 1976, as taken from a computer-readable data base created by RIZA (Rijksinstituut voor Zuivering van Afvalwater) called WAKWAL for locations in state waters and other sources for regional waters (see Vol. VA for a discussion of the data base and the way it was gathered). The WAKWAL data base is also available in printed form [6.7]. The values used for each node were the closest locations on the same waterway for nodes connecting sections of rivers and canals and averages for locations in the individual lakes for nodes representing the IJssel lakes (see Table 6.9). For districts we found few data values that could be used. Most districts had no measurement data, and the measurements in districts were at specific locations seldom representative of the district as a whole. We set all initial values in the districts equal to zero except for chromium, where runs of the DM during the calibration process indicated that 7 μg/l was a reasonable value in the districts in winter. For phosphate and BOD, the initial values are not very important since the decay rates for these pollutants imply residence times on the order of days to weeks (Sec. 6.4.5), and the effect of the initial value is quickly lost. For chromium, the residence time may be several weeks, but the effect of the initial value should be lost after the first month or so.

6.4.2. Pollutant Concentrations in the Border-Crossing Rivers

The pollutant concentrations for the major border-crossing rivers--the Rijn, Maas, Overijsselsche Vecht, Roer, Niers and Swalm--are read in from datasets as monthly averages. Such datasets have been prepared for two scenarios--the 1976 scenario containing pollutant concentration averages actually observed in 1976, and a 1985 scenario designed to represent a mid-1980s situation in which actions have been taken to limit the amount of pollution in the rivers. In the 1985 scenario it is assumed that the maximum concentrations in the rivers do not exceed 10 μg/l for chromium, 2 mg/l for BOD, and 0.3 mg/l for total phosphates; the actual value used for each month is the minimum of the corresponding 1976 monthly average and the specified maximum

Table 6.9

INITIAL VALUES FOR POLLUTANTS AT NODES

Node		Phos.	BOD	Chrom.	Node		Phos.	BOD	Chrom.
No.	Name	(mg/l)	(mg/l)	(µg/l)	No.	Name	(mg/l)	(mg/l)	(µg/l)
1	PANDNKOP	0.8	6.3	36.0	47	MARKMEER	0.4	4.9	7.5
2	NIJMEGEN	0.7	6.3	36.0	48	IJMEER	0.4	4.8	7.5
3	TIEL	0.7	7.4	36.0	49	VELUWMER	0.2	3.7	7.5
4	GORINCHM	0.6	4.1	19.0	50	GOOIMEER	0.9	5.6	12.0
5	DORDRECT	0.6	5.1	32.0	51	SCHERMER	0.4	1.0	7.0
6	OUDBIJER	0.6	6.2	30.0	52	DENHELDR	0.6	10.0	7.0
7	IJSELKOP	0.8	6.9	30.0	53	AMSTMEER	0.1	0.3	7.0
8	WAGINGEN	0.8	6.0	30.0	54	FRIELAND	2.0	4.8	7.0
9	DURSTEDE	0.7	6.0	30.0	55	HARLNGEN	2.9	3.8	7.0
10	VIANEN	0.6	6.0	28.0	56	LAUWMEER	1.8	3.8	7.0
11	SCONOVEN	0.6	6.6	28.0	57	GRONIGEN	2.1	10.0	7.0
12	IJSLMOND	0.7	6.6	37.0	58	DELFZIJL	1.4	1.0	7.0
13	SCHEUR	0.7	3.5	28.0	59	HOGEZAND	1.1	3.0	7.0
14	NOORDZEE	0.0	0.0	0.0	60	TERAPEL	5.2	10.0	7.0
15	MASTRICT	0.4	2.7	28.0	61	WINSHOTN	1.0	10.0	7.0
16	BORN	0.3	1.8	25.0	62	ZWARTMER	0.4	2.7	7.0
17	PANHEEL	0.5	2.9	23.0	63	MEPPEL	0.4	3.6	7.0
18	LINNE	0.6	2.0	21.0	64	SMILDE	0.7	2.0	7.0
19	ROERMOND	0.7	3.4	19.0	65	HOGEVEEN	0.7	3.8	7.0
20	BELFELD	0.5	1.8	17.0	66	ERICASLU	0.7	2.0	7.0
21	SAMBEEK	0.4	4.0	15.0	67	LOCHEM	0.9	7.0	5.0
22	GRAVE	0.4	4.3	13.0	68	DELDEN	7.4	6.6	7.0
23	LITH	0.4	2.3	7.0	69	VROMSHOP	0.2	6.3	7.0
24	DENBOSCH	0.4	1.6	7.0	70	HAANDRIK	0.8	14.5	7.0
25	GERTRUID	0.5	6.6	7.0	71	COVORDEN	0.5	17.4	7.0
26	BIESBOSH	0.6	4.9	19.0	72	DEDEMSVA	0.7	4.5	7.0
27	MOERDIJK	0.6	6.7	20.0	73	OMMEN	0.7	7.5	7.0
28	WILEMSTD	0.5	4.8	20.0	74	SALLAND	0.1	5.3	7.0
29	HELVOETS	0.5	5.3	15.0	75	UTREVECH	3.9	10.1	13.0
30	STELNDAM	0.5	8.1	7.0	76	NIGTVECH	1.6	6.7	7.0
31	ZOOMMEER	0.3	2.0	7.5	77	LOPIKWAR	1.8	5.0	7.0
32	GREVLING	0.3	2.0	7.5	78	WOERDEN	1.0	1.0	7.0
33	JUTPHAAS	0.8	6.7	30.0	79	RIJNLAND	0.9	2.3	7.0
34	UTRECHT	0.8	7.1	25.0	80	DELFLAND	0.6	2.2	7.0
35	MAARSSEN	0.8	7.0	20.0	81	GOUDA	0.7	6.3	7.0
36	DIEMEN	0.8	6.2	15.0	82	AMSTLAND	0.4	2.6	7.0
37	AMSTEDAM	0.6	6.1	3.5	83	BETUWE	0.2	1.4	7.0
38	HALFWEG	0.8	5.2	3.0	84	TIELWARD	0.2	1.5	7.0
39	IJMUIDEN	0.6	3.9	6.0	85	LOOZEN	0.6	3.4	7.0
40	DIEREN	0.6	7.0	30.0	86	WEERT	0.7	2.0	7.0
41	ZUTPHEN	0.5	7.5	30.0	87	MEYEL	0.7	2.0	7.0
42	DEVENTER	0.5	8.3	30.0	88	HELMOND	0.7	2.0	7.0
43	ZWOLLE	0.7	6.7	25.0	89	BOXTEL	0.6	2.0	7.0
44	KETLMEER	0.5	3.8	21.0	90	OSTRHOUT	0.6	2.8	7.0
45	IJSLMEER	0.3	2.0	7.5	91	FIJNAART	0.9	3.3	7.0
46	AFSLDIJK	0.0	0.0	0.0	92	ROSENDAL	0.5	6.6	7.0

value for the concentration. Tables 6.10 through 6.12 contain the concentrations for the 1976 scenario. Note that the chromium concentrations are given as zero for the Overijsselsche Vecht, Swalm, and Niers. There were no chromium measurements available for these rivers and the concentrations were simply taken as zero. For the Roer there were also no measurements available, but the substantial contribution of the Roer flow to that of the Maas in the summer of 1976 made it desirable to include some value of chromium concentration for the Roer in order to fit the chromium measurements downstream on the Maas. A constant chromium concentration of 5 µg/l was arbitrarily input for the Roer as a proxy for the amount of chromium needed to improve the estimated concentrations on the lower Maas.

6.4.3. Point-Source Discharges

Using preliminary data from a new survey on existing and planned wastewater treatment plants, and annual reports and water quality plans of the different regional water quality boards, a team from RIZA, DHL, and WW compiled a document [6.8] containing line entries for each identified discharge source--both industry and wastewater treatment plants. The document gives either direct discharges of pollutants, population equivalents discharged, or population equivalents input to the wastewater treatment plants. Data are given for both 1976 and 1985. Also identified are the PAWN network node and district to which the source discharged pollutants. These data were processed by members of the PAWN team to provide the total discharges at each node for phosphate, BOD, nitrogen, and chromium. Volume VA describes the steps

Table 6.10

TOTAL PHOSPHATE CONCENTRATIONS IN MAJOR BORDER-CROSSING RIVERS: 1976 SCENARIO
(mg/l)

Month	Rijn at Lobith	Over-ijsselsche Vecht	Maas at Eijsden	Roer at Roermond	Swalm	Niers at Gennep
Jan	0.79	0.80	0.45	3.0	1.99	1.99
Feb	0.74	1.34	0.88	2.64	1.58	1.58
Mar	0.96	0.82	0.47	2.28	1.59	1.59
Apr	1.06	0.35	0.49	2.30	2.86	2.86
May	1.05	0.59	0.68	1.99	2.99	2.99
Jun	0.86	0.34	0.97	2.21	1.69	1.69
Jul	1.02	0.34	0.90	2.49	2.14	2.14
Aug	0.80	0.29	1.16	2.19	2.49	2.49
Sep	0.99	0.19	1.62	2.21	5.34	5.34
Oct	1.03	0.60	1.40	2.65	3.97	3.97
Nov	1.15	1.11	1.26	2.04	3.55	3.55
Dec	0.92	0.0	0.74	2.66	2.22	2.22

Table 6.11

BOD CONCENTRATIONS IN MAJOR BORDER-CROSSING RIVERS: 1976 SCENARIO
(mg/l)

Month	Rijn at Lobith	Over-ijsselsche Vecht	Maas at Eijsden	Roer at Roermond	Swalm	Niers at Gennep
Jan	6.31	14.50	2.72	10.79	12.89	12.89
Feb	7.21	20.33	5.09	15.84	14.24	14.24
Mar	9.11	15.00	3.89	10.0	14.99	14.99
Apr	10.35	6.75	5.69	9.59	30.49	30.49
May	12.39	15.25	4.84	11.99	13.34	13.34
Jun	9.76	7.50	7.57	10.89	23.76	23.76
Jul	14.47	7.38	9.34	7.64	36.49	36.49
Aug	13.19	7.33	7.01	5.09	66.99	66.99
Sep	11.64	5.00	4.59	10.19	73.99	73.99
Oct	9.51	5.25	3.84	7.49	21.29	21.29
Nov	12.49	9.25	4.47	8.99	36.49	36.49
Dec	7.14	0.0	4.72	20.99	21.32	21.32

Table 6.12

CHROMIUM CONCENTRATIONS IN MAJOR BORDER-CROSSING RIVERS: 1976 SCENARIO
(μg/l)

Month	Rijn at Lobith	Over-ijsselsche Vecht	Maas at Eijsden	Roer at Roermond	Swalm	Niers at Gennep
Jan	36.0	0.0	28.0	5.0	0.0	0.0
Feb	43.0	0.0	17.0	5.0	0.0	0.0
Mar	65.5	0.0	7.0	5.0	0.0	0.0
Apr	71.0	0.0	8.0	5.0	0.0	0.0
May	55.0	0.0	9.0	5.0	0.0	0.0
Jun	43.0	0.0	5.0	5.0	0.0	0.0
Jul	55.66	0.0	1.0	5.0	0.0	0.0
Aug	45.0	0.0	3.0	5.0	0.0	0.0
Sep	61.0	0.0	2.0	5.0	0.0	0.0
Oct	51.5	0.0	6.0	5.0	0.0	0.0
Nov	57.5	0.0	5.0	5.0	0.0	0.0
Dec	52.0	0.0	10.0	5.0	0.0	0.0

taken to process the data and contains tables giving the pollutant discharges at each node and each district for each of the two years.

6.4.4. Diffuse-Source Discharges

Within the PAWN districts there are discharges of nitrogen and phosphates from four diffuse sources: natural production from plants, fertilizers, seepage, and animals and other sources. BOD is also produced by the "animals and other sources" category, mostly from disposal of animal manure. We had no measurement data on the amount of pollutants produced by these sources, but rather than omit them we decided that we would create less of an error by representing them by a simple pollutant balance model. Since the pollutants from these diffuse sources are a small percentage of the total pollutant load, large percentage errors in our crude diffuse-source model will be much smaller in the pollutant concentrations at the nodes of the network, except at a few regional nodes where the diffuse-source discharges are relatively large.

From the natural production by plants and from fertilizers, the following amounts are assumed to be produced annually by leaching from the soil into the drainage water of the districts:

- From nature areas: nitrogen 15 kg/ha, phosphate 0.22 kg/ha.
- From grass: nitrogen 15 kg/ha, phosphate 0.4 kg/ha.
- From all other crops: nitrogen 30 kg/ha, phosphate 0.4 kg/ha.

Seepage water into the districts is assumed to contain 10 mg/l of nitrogen and 2 mg/l of phosphate. The annual amounts produced by animals and other sources are assumed to be 10 kg of nitrogen and 0.5 kg of phosphate for each hectare of grass in the district.

The nitrogen and phosphate produced by plants, fertilizers, and seepage are assumed to leave the district via the drainage water. It is also assumed that the drainage concentration for each pollutant is constant over the year; the concentration is determined by taking the total annual load in the district from these sources and dividing it by the average annual drainage from the district (Vol. XII).

Nitrogen and phosphate from the animals and other sources category are assumed to discharge constantly from the district over the year, regardless of the amount of drainage. BOD produced by the animals and other sources category is assumed to appear in the district discharge water at a concentration of 2.5 mg/l. Table 6.13 contains the constant load and the concentrations in the drainage water generated by the above assumptions for each of the districts.

6.4.5. The Calibration Procedure for Pollutant Decay Rates

In the models adopted for pollutant transport in the PAWN network--Eq. 6.1 for waterways represented by the PAWN links and Eq. 6.9 for nodes with storage--decay rates for the loss of pollutants from the water over time must be provided as DM inputs.

Decay rates reported in the literature have considerable variation. For example, decay rates given for BOD range from 0.1 to 3.0 per day with most of the rates falling between 0.1 and 0.6 [6.9]; DHL's Rijn water quality model [6.10] estimates the decay rate for BOD in the

Table 6.13

PHOSPHATE AND NITROGEN CONSTANT LOADS AND DRAINAGE WATER CONCENTRATIONS

District No.	District Name	Drainage (m3/s)	Phosphate Constant Load (g/s)	Phosphate Drainage Conc. (mg/l)	Nitrogen Constant Load (g/s)	Nitrogen Drainage Conc. (mg/l)
1	FRIELAND	27.0	3.25	0.33	64.91	5.98
2	HETBILDT	1.5	0.07	0.35	1.37	7.86
3	LAUWMEER	8.7	0.39	0.61	7.80	7.64
4	UITHUIZN	1.2	0.03	0.28	0.69	7.80
5	EEMSKANN	4.0	0.17	0.57	3.35	8.36
6	OLDAMBT	3.8	0.07	0.31	1.31	8.88
7	WESTWOLD	4.5	0.10	0.13	1.99	8.94
8	NWDRENTE	5.0	0.26	0.11	5.26	6.85
9	WESKWART	4.5	0.40	0.11	7.98	5.48
10	NEDRENTE	2.5	0.04	0.12	0.79	8.60
11	SEDRENTE	4.1	0.21	0.12	4.26	7.13
12	SWDRENTE	8.3	0.70	0.12	13.96	6.11
13	VOLENHOV	4.5	0.44	0.11	8.80	5.17
14	NEPOLDER	5.1	0.11	2.37	2.24	18.53
15	MASTBROK	3.8	0.50	0.12	10.07	4.99
16	OVIJVECT	3.9	0.31	0.11	6.21	6.01
17	DINKEL	2.2	0.19	0.11	3.75	5.33
18	TWENTHE	7.3	0.62	0.11	12.50	5.38
19	SALLAND	4.2	0.47	0.12	9.41	5.31
20	TWENTKAN	5.4	0.38	0.10	7.64	5.32
21	SHIPBEEK	2.5	0.19	0.10	3.82	5.30
22	IJSELGEB	2.5	0.15	0.09	3.00	4.83
23	NEVELUWE	5.1	0.27	0.09	5.31	4.80
24	BERKEL	6.2	0.69	0.13	13.79	6.10
25	OUDEIJSL	5.7	0.58	0.13	11.66	6.25
26	ARNHEM	0.7	0.03	0.09	0.52	5.01
27	SEVELUWE	1.7	0.07	0.08	1.40	4.83
28	SWVELUWE	8.8	0.49	0.09	9.74	4.72
29	NWVELUWE	5.6	0.28	0.09	5.65	4.65
30	FLEVLAND	10.8	0.08	2.48	1.67	18.22
31	WIERGMER	2.0	0.02	3.11	0.42	23.05
32	AMSTLMER	2.1	0.16	0.61	3.14	9.38
33	MEDMBLIK	1.7	0.17	0.44	3.45	8.94
34	HOORN	0.5	0.07	0.16	1.33	7.91
35	SCHERMER	5.1	0.57	0.57	11.47	9.00
36	WATRLAND	0.5	0.08	0.39	1.50	7.11
37	NZKANGEB	1.2	0.07	0.31	1.43	7.93
38	RIJNLAND	8.3	0.45	0.64	8.97	8.13
39	AMSTLAND	3.2	0.20	1.09	4.06	8.16
40	GOOI	1.6	0.17	0.13	3.44	6.36
41	KROMRIJN	3.4	0.22	0.09	4.39	4.95
42	LEIDRIJN	0.8	0.08	0.13	1.69	6.16
43	WOERDEN	0.8	0.17	0.21	3.48	9.10
44	LOPIKWAR	1.2	0.14	0.13	2.88	5.94
45	KRIMPWAR	0.7	0.13	0.19	2.60	8.65
46	SCIELAND	1.7	0.07	0.80	1.33	8.80
47	DELFLAND	1.8	0.18	0.26	3.62	7.49
48	VOORNE	3.4	0.10	0.81	1.98	9.16
49	GOEREE	1.2	0.00	1.03	0.00	11.15
50	IJSLMOND	1.6	0.04	0.55	0.84	9.49
51	HOLNDIEP	4.1	0.13	0.52	2.54	8.84
52	DORDRECT	1.4	0.02	0.97	0.37	9.33
53	ABLASWAR	3.0	0.31	0.67	6.22	6.86
54	BIESBOSH	2.3	0.16	0.14	3.20	8.07
55	TIELWARD	3.8	0.43	0.13	8.55	6.40
56	DENBOSCH	3.0	0.32	0.14	6.47	7.10
57	BETUWE	2.7	0.24	0.13	4.83	6.82
58	MAASWAAL	1.7	0.20	0.13	3.91	6.35
59	RECMAASN	0.7	0.07	0.13	1.43	6.47
60	RECMAASM	0.7	0.05	0.15	1.03	9.02
61	MASKANTE	3.1	0.28	0.14	5.64	7.39
62	MASKANTW	1.8	0.17	0.14	3.46	7.04
63	AA	6.4	0.51	0.13	0.11	7.02
64	DEPEEL	3.0	0.20	0.16	4.01	9.52
65	RECMAASS	1.5	0.07	0.15	1.48	9.52
66	ROERMOND	1.5	0.05	0.11	1.05	7.03
67	SLIMBURG	5.4	0.27	0.11	5.48	6.82
68	MLIMBURG	2.4	0.17	0.16	3.31	9.47
69	EDOMMEL	2.2	0.16	0.13	3.28	7.30
70	MDOMMEL	2.2	0.19	0.13	3.71	7.29
71	WDOMMEL	2.7	0.20	0.13	4.03	7.13
72	NDOMMEL	2.4	0.21	0.13	4.12	6.86
73	DONGE	2.3	0.17	0.12	3.48	6.27
74	MARK	4.1	0.34	0.12	6.78	6.61
75	ROSENDAL	2.4	0.12	0.13	2.42	8.22
76	ZOOM	6.0	0.09	0.78	1.84	11.37
77	SCHOUWEN	3.5	0.03	1.19	0.65	11.10
78	MARKWARD	5.2	0.05	0.73	0.90	9.88

Rijn at 0.3 per day. In general, the decay rates may depend upon temperature, the mixture of chemical forms of the pollutant, the physical dimensions of the body of water, the flow rate in the body of water, the direction and velocity of the wind, and other factors.

As implied by the foregoing, we expect that decay rates will differ among pollutants and among waterways. There may be seasonal effects and even differences between weekdays and weekends. To evaluate the influence of these (and other) factors on the decay rates for each waterway would require a large number of measurements taken over a long period of time. The data, resources, and time required to carry out a definitive analysis of decay rates for the large number of waterways in the PAWN network were simply not available for the PAWN study. Instead, we obtained estimates of the decay rates by calibrating the DM pollutant model to the 1976 situation. For PAWN, pollutant concentration measurement data were available for locations across the country for the years 1975 through 1977 (see Vol. VI for a discussion of the sources of the measurement data). Pollutant discharge data were available for 1976, and an effort had already been made to match flow and level data in the waterways in the PAWN network for that year.

We refer to the procedure used to estimate the decay rates as calibrating the DM for pollutants. By calibration, we mean determining decay rates for the links and at the nodes so that the output concentrations of the DM match as closely as possible the measured concentration data at locations throughout the network. The distribution model provides flows throughout the network on a decade-by-decade basis and average pollutant concentrations at the nodes for each decade for any input set of decay rates. Given the pollutant concentrations in the discharges of the major border-crossing rivers (Sec. 6.4.2) and the inventory of pollutant discharges at the nodes (Secs. 6.4.3 and 6.4.4), an iterative scheme was used to determine the best-fitting decay rates. Starting with initial estimates of the rates, we estimated pollutant concentrations at the nodes from a run of the DM. Comparison of the estimated concentrations with the measured concentrations then suggested improved decay rates to be tried with a subsequent run. The procedure was then repeated until no more improvement could be found.

The calibration procedure was developed late in the PAWN project, after the lengthy period required to obtain and process the necessary pollutant discharge and concentration measurement data, and after flows calculated by the DM were matched as closely as possible to the estimated 1976 flows. Pollutant decay rates were estimated only for the year 1976 (available time and resources did not allow for calibrating for other years). The estimated decay rates should be considered tentative, perhaps applicable only to the conditions obtaining during the drought year 1976, unless they are validated for other years. Since the PAWN study was primarily concerned with the effects of drought years and 1976 was the only drought year for which data was available for pollutants, it was the obvious choice for a single year to use for calibration. Chapter 8 contains a comparison of the pollutant concentrations calculated by the DM after calibration with measured values of pollutant concentrations at several locations in 1976.

Decay Rates for Phosphate and BOD. Table 6.14 contains the estimated decay rates for total phosphate and BOD in the various waterways for which estimates were made. For waterways in the regional systems that are not listed in the table, insufficient measurement data existed to make estimates, and we made the conservative assumption that the decay rates are zero (this assumption is conservative in the sense that it leads to overestimates of the concentrations).

Table 6.14

ESTIMATED DECAY RATES FOR PHOSPHATE AND BOD
(Fraction per Day)

Waterway	Phosphate	BOD
Waal	0.15	0.25
Neder-Rijn and Lek	0.15	0.10
Nieuwe Waterweg	0.15	0.50
Maas	0.10	0.10
Haringvliet and Hol. Diep	0.10	0.10
Amsterdam-Rijnkanaal	0.10	0.10
Noordzeekanaal	0.15	0.10
IJssel River	0.15	0.20
IJssel lakes	0.10	0.10
Northeast Highlands	0.0	0.05
Zwartemeer	0.10	0.05
Midwest	0.0	0.10
Linge	0.0	0.20

Bottom Release of Phosphate. The PAWN study of nutrients in lakes (Vol. III) demonstrated that a steady release of phosphate occurs from the bottom sediments of many lakes. In the initial calibration attempts using the DM, bottom release of phosphate was ignored. The result was that phosphate concentrations required zero or essentially zero decay rates in order to approach average concentrations in several water basins. A much better fit to the data in the water basins was obtained by using decay rates for phosphate that were equal to the decay rates in nearby waterways and adding release of phosphate from bottom sediments at fixed rates over the year. Table 6.15 contains the estimated decay rates and bottom release rates for the water basins.

BOD from Algae in Lakes. In the initial attempts to estimate BOD decay rates, a result similar to that for phosphate occurred--the average BOD concentrations were too low even with zero decay rates. Moreover, the estimated concentrations were relatively high in the winter and low in the summer compared with the measured concentrations. A major source of BOD in many lakes is the growth and subsequent death of algae blooms, particularly in the summer months when algae blooms are large. To better match the measurements, we assumed that the BOD decay rates were the same as those in nearby waterways and introduced an internal source of BOD representing algae BOD production that is proportional to the solar energy at the surface over the year. Table 6.15 contains the estimated decay rates and bottom release rates for BOD for the water basins, and Table 6.16 contains values of solar energy intensity at the surface used for 1976. The release rates for BOD given in Table 6.15 are treated as average release rates over the year, and the release rate for each decade is taken to be the average release rate multiplied by the ratio of the solar energy value for the decade to the average of the decade solar energy values for the year, as given in Table 6.16.

Decay Rates for Chromium. Chromium concentration measurements for 1976 were available for only a few waterways and at monthly intervals (except for the Rijn at Lobith and the Maas at Lith, where measurements were taken at biweekly intervals). The decay rates for chromium estimated by calibration are 0.2 for the Neder-Rijn, Lek, Waal, and in the Rijn delta, 0.25 for the IJssel, and 0.05 elsewhere. All of these values are considered unreliable since there are so few measurements at so few locations. For impact assessment it was decided to use a decay rate of 0.05 everywhere as a conservative assumption on the effect of decay.

Pollutant Concentrations and Decay Rates in Districts. Pollutant concentrations in the districts are calculated using solutions of Eq. 6.7, assuming a constant storage volume. The district surface water volumes used for the districts are given in Vol. XII. The pollutant concentrations represent only those portions of the total pollutant concentrations that are due to point-source discharges into the surface water of the districts (Sec. 6.4.3) and to the extractions by

Table 6.15

INTERNAL RELEASE RATES AND DECAY RATES FOR PHOSPHATE AND BOD IN WATER BASINS

	Phosphate		BOD	
Water Basin	Release Rate ($g/m^2/day$)	Decay Rate (1/day)	Release Rate ($g/m^2/day$)	Decay Rate (1/day)
Haringvliet and Hollandsch Diep	0.09	0.1	0.0	0.1
Amsterdam-Rijnkanaal	0.05	0.15	0.0	0.1
IJsselmeeer	0.09	0.1	2.5	0.1
Markermeer	0.06	0.1	1.3	0.1
IJmeer	0.06	0.1	1.2	0.1
Veluwemeer	0.035	0.1	1.15	0.1
Gooimeer	0.13	0.1	1.85	0.1

Table 6.16

SOLAR ENERGY AT THE SURFACE
OF THE IJSSELMEER IN 1976
(Joules/cm^2/day)

Month	Decade in Month		
	1	2	3
January	1024	1514	2616
February	2504	2747	4948
March	6465	5406	7511
April	9951	11684	13334
May	13161	15398	12036
June	15308	16109	17180
July	17714	12564	12027
August	13604	12935	11226
September	8660	6330	5269
October	3887	3989	2756
November	2754	1542	1208
December	1945	1195	1787

the districts of surface water from the network; i.e., no contribution is included for the diffuse-source discharges of Sec. 6.4.4. Decay rates were not estimated for the district surface water volumes because of the partial nature of the concentrations calculated in the DM, the few concentration measurements available for the districts, and the complex set of waterways represented by the district surface water volumes. However, single decay rates that are applied to all districts are input to the DM for each pollutant. In the PAWN study the decay rates used for the districts were 0.1/day for phosphate, 0.2/day for BOD, and 0.05/day for chromium.

6.4.6. Pollutant Concentration Output

The DM prints output tables giving pollutant concentrations for each pollutant at each node and in each district for each decade (except for thermal pollution; see Sec. 6.3). In addition, there are output tables giving the number of decades in which pollutant standards are violated, summed over all nodes for both national and regional nodes. The pollution standards used are those resulting from the Pollution of Surface Waters Act of 1970, as given in the plan called Indicatief Meerjarenprogramma (Prospective Multi-Year Program), or IMP. The water quality standards contained in this plan are referred to as the old IMP standards since a new plan is in preparation. The old IMP actually contains two sets of standards--one places provisional limits on the values of certain water quality parameters, and the other places target values for those same parameters (see Table 6.17). Volumes V and VA contain discussions of the basis for these standards and other water quality standards proposed for the Netherlands.

Table 6.17

OLD IMP WATER QUALITY STANDARDS

Standard Type	Total P (mg/l)	BOD5 (mg/l)	Kjd N (mg/l)	Total Cr (mg/l)	Salt (mg/l)
Provisional limit	0.3	5.0	3.0	0.05	200.0
Target value	0.05	3.0	1.0	----	150.0

REFERENCES

6.1. Rijkswaterstaat, Directie Waterhuishouding en Waterbeweging, District Zuidwest, Systeemdocumentatie "OPTIMP" (System Documentation "OPTIMP"), Projectnummer 71.001.19, May 1977.

6.2. MR-293 (unpublished PAWN memorandum), "Scenarios for Salt Loads at Lobith," June 1979.

6.3. Personal communication from J. W. Pulles, RWS.

6.4. Rijkswaterstaat, Voorstel voor een aantal vergunningseisen ingevolge de WVO te stellen aan koelwaterlozingen van elektriciteitscentrales (Proposal for a Number of Regulations Which Have To Be Established in Compliance with the Surface Water Pollution Act on the Discharges of Cooling Water from Power Plants), The Hague, 1976.

6.5. Sweers, H. E., "A Nomogram To Estimate the Heat-Exchange Coefficient at the Air-Water Interface as a Function of Wind Speed and Temperature; a Critical Survey of Some Literature," Journal of Hydrology, Vol. 30, Elsevier Scientific Publishing Co., Amsterdam, 1976.

6.6. Rijkswaterstaat, Directie Waterhuishouding en Waterbeweging, District Zuidwest, Temperatuurmating Amer oog.Juli 1976, (Temperature Measurements in the Amer in July 1976), Nota nr. 46,004,01, Dordrecht, July 1977.

6.7. Rijksinstituut voor Zuirering van Afvalwater, Jaarboek der waterkwaliteit (Water Quality Yearbook), Lelystad, 1976.

6.8. Unpublished data on pollutant discharges at nodes (PAWN file DW-398).

6.9. Thomann, Robert V., Systems Analysis and Water Quality Management, Environmental Research and Applications, Inc., New York, 1972, p. 92.

6.10. Delft Hydraulics Laboratory, Waterloopkundig Laboratorium, Waterkwaliteitsmodel Rijn (Modeling the Quality of the Rijn), Delft, April 1977.

Chapter 7

COSTS

In order to determine the monetary benefits (or disbenefits) of technical and managerial tactics, all benefits and costs to agriculture and shipping that may be affected by tactics, as well as the direct costs of the tactics, are included in the DM. The costs of a technical tactic are estimated in Vol. XVI as a fixed cost plus a variable energy cost that is a function of the flow in the network link to which the tactic applies (if any). For agriculture, the costs of tactics include the costs of implementing waterboard plans for local water infrastructure improvements, the investment costs of any new sprinkling equipment, the energy and labor costs of operating sprinkler equipment, and losses to agriculture due to water shortage and water salinity. The benefits (or disbenefits) to agriculture from a tactic are the changes in the losses due to water shortage and water salinity by the addition of the tactic. The cost components of shipping that may be affected by a tactic are those that are affected by changes in the water distribution in the network. Decreased water flows increase costs on shipping routes by lowering waterway depths and thereby forcing ships to carry less than full cargoes, and by providing less water for locking operations, thereby increasing delay times at locks.

7.1. AGRICULTURE

7.1.1. Cost of Waterboard Plans and New Sprinkler Equipment

An important component of any future scenario for water demand in the Netherlands is the amount of increase in crop irrigation by sprinkling (and the areal distribution of that increase across the country). Construction of <u>sprinkling scenarios</u> (see Vols. II and XIV) involved evaluating 65 waterboard plans for expanding local infrastructure, thereby increasing the area having access to surface water, and estimating the increase in the sprinkled areas of croplands in each district. When these future scenarios are used in the DM, the costs of (implemented) waterboard plans and the investment costs of any new sprinkling equipment for previously unirrigated croplands are input from datasets and simply added to the output cost summary.

7.1.2. Sprinkler Operating Costs

The energy and labor costs of crop irrigation by sprinkling are calculated in the DM by the DISTAG submodel (Secs. 3.3 and 7.1.3.1) for each district and each decade for both surface water and groundwater sprinkling.

7.1.3. Agricultural Losses Due to Water Shortages and Water Salinity

By agricultural losses we mean the decrease in monetary value of the crops actually produced compared with the monetary value of the crops that would have been produced in the ideal situation where the crops receive optimal amounts of water of sufficiently low salinity that the crop harvest is maximized for the given climatological conditions. The losses due to lack of moisture in the root zone (i.e., the losses due to water shortage) are large even in years with average precipitation and river flows--most of the croplands receive moisture only from precipitation, which is insufficient for maximum production of crops in average years in many districts. Agricultural losses from water salinity are due to damage to the crops from salinity in the water in the crop root zone. The salinity in the root zone comes primarily from the salt contained in the sprinkling water and thus depends upon both the amount of sprinkling and the salinity of the sprinkling water.

7.1.3.1. Agricultural Losses from DISTAG. After the determination of the water distribution for a decade, the DISTAG submodel is called by the DM (Sec. 3.3) and the amount and salinity of the water allocated to each district are passed to the submodel. DISTAG then calculates the moisture and salinity content in the root zone of each plot and returns to the DM the losses due to salinity and lack of moisture for each crop grown in each district. The values actually passed to the DM are losses due to salinity and total losses. The DM then sets water shortage losses equal to total losses minus losses due to salinity; since large losses due to salinity and large losses due to water shortage do not occur together (large losses due to salinity are suffered by glasshouse crops that do not suffer water shortage losses), only a very small error occurs in the accounting for water shortage damage. Note, however, that both total damage and damage due to salinity are reported correctly in the DM.

7.1.3.2. Losses to Salt Intrusion at Salt-Fresh Locks. Salt intrusion at salt-fresh canal locks in the lowlands diffuses upstream in the canals on the fresh side of the locks. Water extracted by the districts from these canals has increased salinity over the background salinity of the water that would obtain in the absence of salt intrusion (Sec. 6.2.5). Estimates for the losses to agriculture due to this increased salinity are included in the DM for the canal locks at Delfzijl, Den Helder, Harlingen, Parksluizen, and Spaarndam. These estimates are based on a simple model and are considered to be only rough approximations to the actual losses.

The first (major) intake point was identified on each canal [7.1]: for Delfzijl the first intake point was sufficiently far from the lock that the minimum flushing assumed for the lock (1.0 m^3/s) reduced the additional salinity damage to essentially zero; for Den Helder the first major intake is for the Anna Paulowna polder; for Harlingen, at Franeker; for Parksluizen, the connection of the Noorderkanaal and the Delfshavense Schie; and for Spaarndam, south of the Haarlem polder. Estimates of the parameters of Eq. 6.17 were made for these locations, yielding the following salinity increases due to salt intrusion at the first major intake locations:

Den Helder: $S_{in} = S \exp(-2.0Q)$ (7.1)

Harlingen: $S_{in} = S \exp(-2.4Q)$ (7.2)

Parksluizen: $S_{in} = S \exp(-1.3Q)$ (7.3)

Spaarndam: $S_{in} = S \exp(-1.0(Q-2.0))$ (7.4)

where Sin = the increase in salinity at the intake point (mg/l),
S = the increase in salinity on the fresh side of the lock (mg/l),
Q = the discharge through the lock plus any additional flushing in the discharge sluices alongside the lock (m^3/s) (the total discharge is the flow in the appropriate flushing link given in Table 6.4). For Spaarndam, Eq. 7.4, the value of 2 m^3/s subtracted from the flow represents that part of the flow in the flushing link for Spaarndam (HARLMEER) that is a discharge at Halfweg and does not affect the salt intrusion at Spaarndam.

The damage to the crops affected by these salinity increases was estimated for each intake point as given by Table 7.1.

Table 7.1

DAMAGE FROM SALT INTRUSION AT SALT-FRESH LOCKS
(Dfl/(mg/l)/Decade)

Crop Type	Den Helder	Harlingen	Parksluizen	Spaarndam
Bulbs	1100	60	0	500
Veg.	0	65	0	0
Veg. under glass	0	140	1200	0
Flow. under glass	100	135	1200	1500
Totals	1200	400	2400	2000

NOTE: The totals are valid for the growing season (April-Sept.) only. Outside of the growing season, the subtotals for glasshouse crops (100, 275, 2400, and 1500, respectively) are used.

The estimated agricultural losses due to salt intrusion at salt-fresh canal locks are obtained by multiplying Eqs. 7.1 to 7.4 by the appropriate totals from Table 7.1. As noted above, these agriculture loss estimates were obtained by considering only the first major intake point on each canal; in extreme circumstances when flushing flows have been severely reduced, the salt intrusion may affect other intake points and these estimated losses will be too low.

7.2. SHIPPING LOSSES

The low water shipping losses and the shipping delay losses at Southeast Highlands locks, described below in Secs. 7.2.1 and 7.2.2, are given for both 1976 and 1985 traffic scenarios. In general, the 1985 scenario reflects a predicted increase in the shipping tonnages over the 1976 scenario and postulated changes in the shipping fleet. The losses to shipping given in these sections are the losses independent of which country's cargoes and ships are included in the shipping traffic. In the shipping loss summaries printed out by the DM, these losses have been multiplied by 0.63 in 1976 and 0.61 in 1985 as estimates of the Dutch component of the shipping losses (except for losses on the Wilhelminakanaal, where the Dutch fraction is taken to be 1.0).

7.2.1. Low Water Shipping Losses

When the flows in the major rivers are low, the water levels in the rivers drop accordingly, and the larger ships must reduce their cargoes in order that the low levels can provide sufficient keel clearance. The result is that more trips must be made to carry the same cargo and the shipping costs are higher. In extreme cases, the levels may become so low that the extra burden on the shipping fleet forces goods to be off-loaded and stored until the water levels rise. In the shipping analysis (Vol. IX), the shipping routes, i.e., the waterways traveled between shipping origins and destinations, have been aggregated into seven route groups: Lower Rijn-Waal, Upper Rijn-Waal, Waal-Maas, Upper Rijn-IJssel, Maas-IJssel, Lower Rijn-IJssel, and Waal-IJssel (the Upper Rijn and Lower Rijn designations indicate Rijn shipping routes beginning or ending on the Rijn in West Germany north and south of Cologne, respectively). A <u>low water loss function</u>, developed for each route, relates the incremental cost of shipping to the <u>critical depth</u> on the route, i.e., the smaller of the minimum depths of the two major rivers on each route. Figures 7.1 through 7.4 contain the low water loss functions for the 1976 and 1985 traffic scenarios.

Functions were developed in PAWN that relate the minimum depths of the rivers to the flows in the rivers. These minimum depths are the depths of the rivers at <u>critical points</u> where the minimum depths of the rivers occur. On the sections of the Rijn designated Upper Rijn and Lower Rijn, there are single critical points, and the minimum shipping depths are

$$DLR = 8.738 + 0.01405QR$$

$$DUR = 5.67 + 1.75(QR/100) - 0.0418(QR/100)^2$$

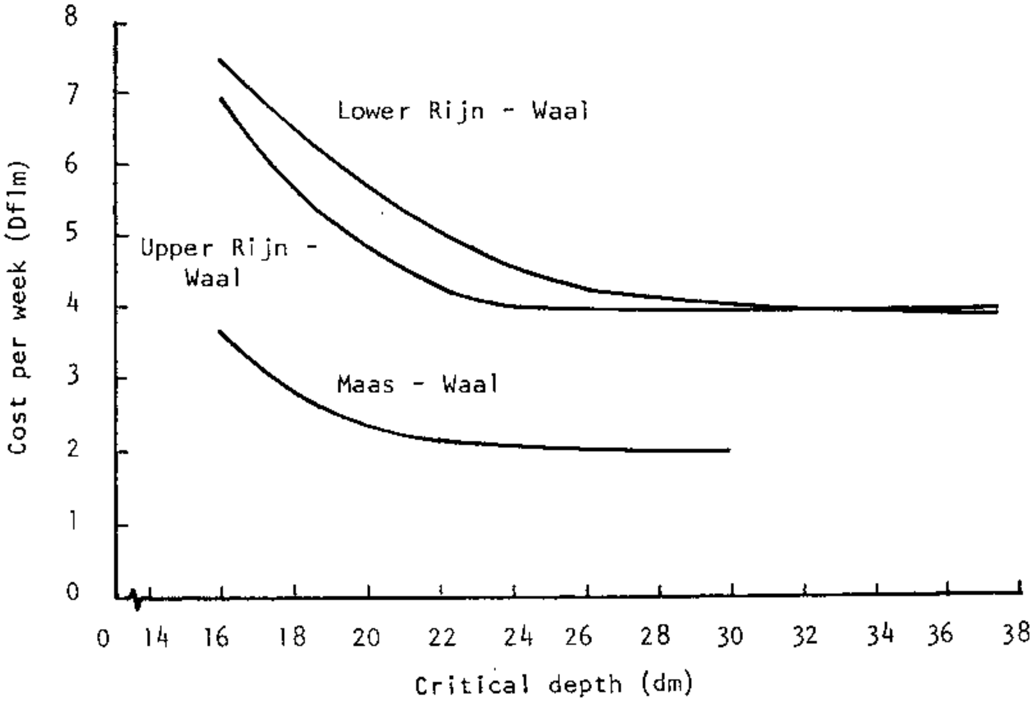


Fig. 7.1--Low water loss functions (1976)(part 1)

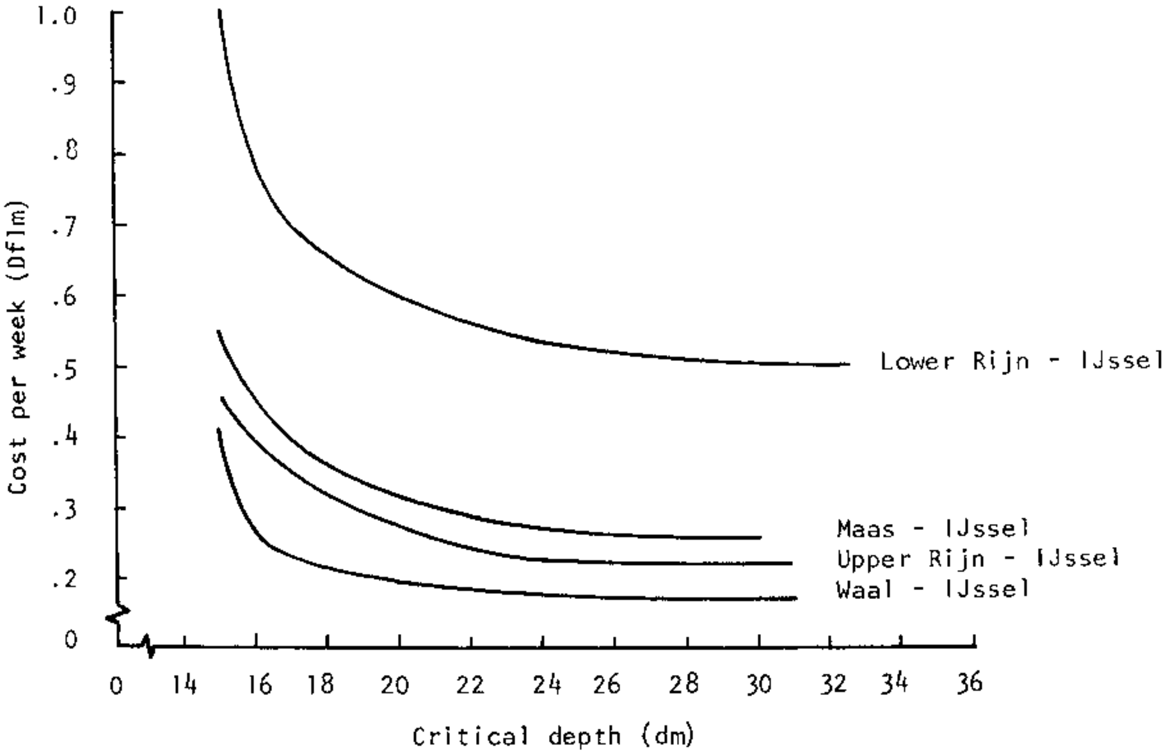


Fig. 7.2--Low water loss functions (1976)(part 2)

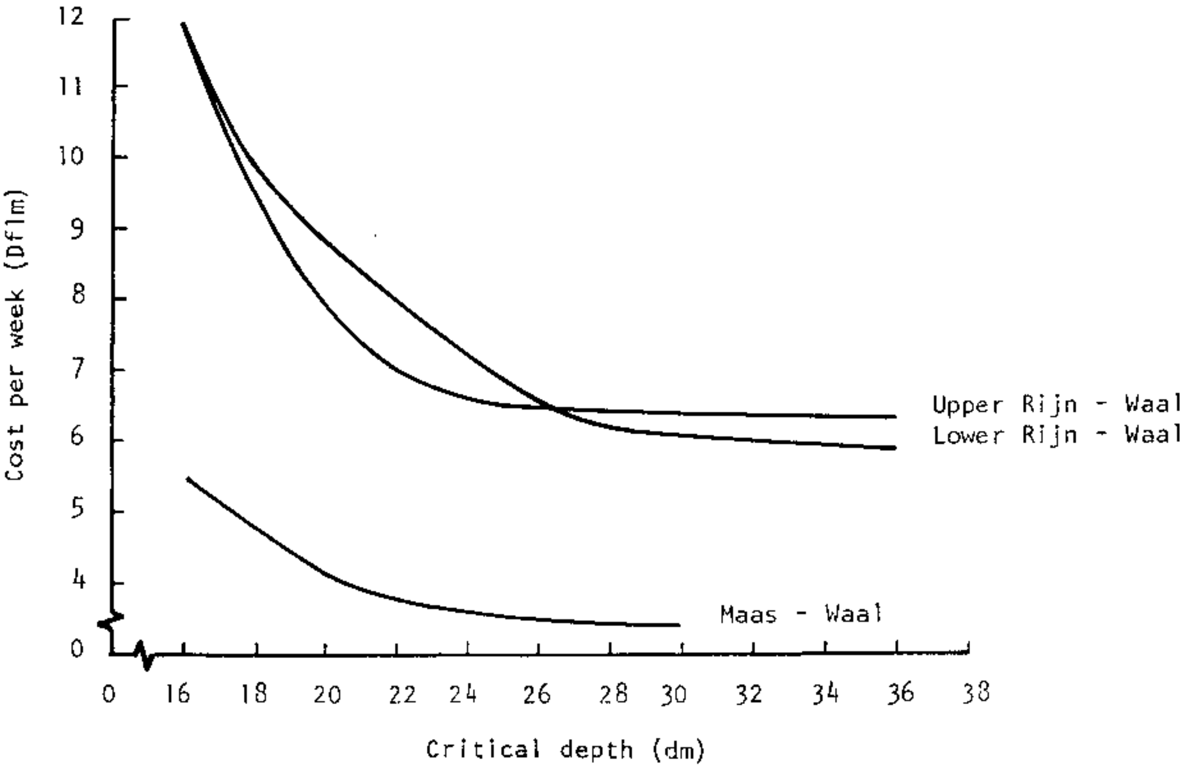


Fig. 7.3--Low water loss functions (1985)(part 1)

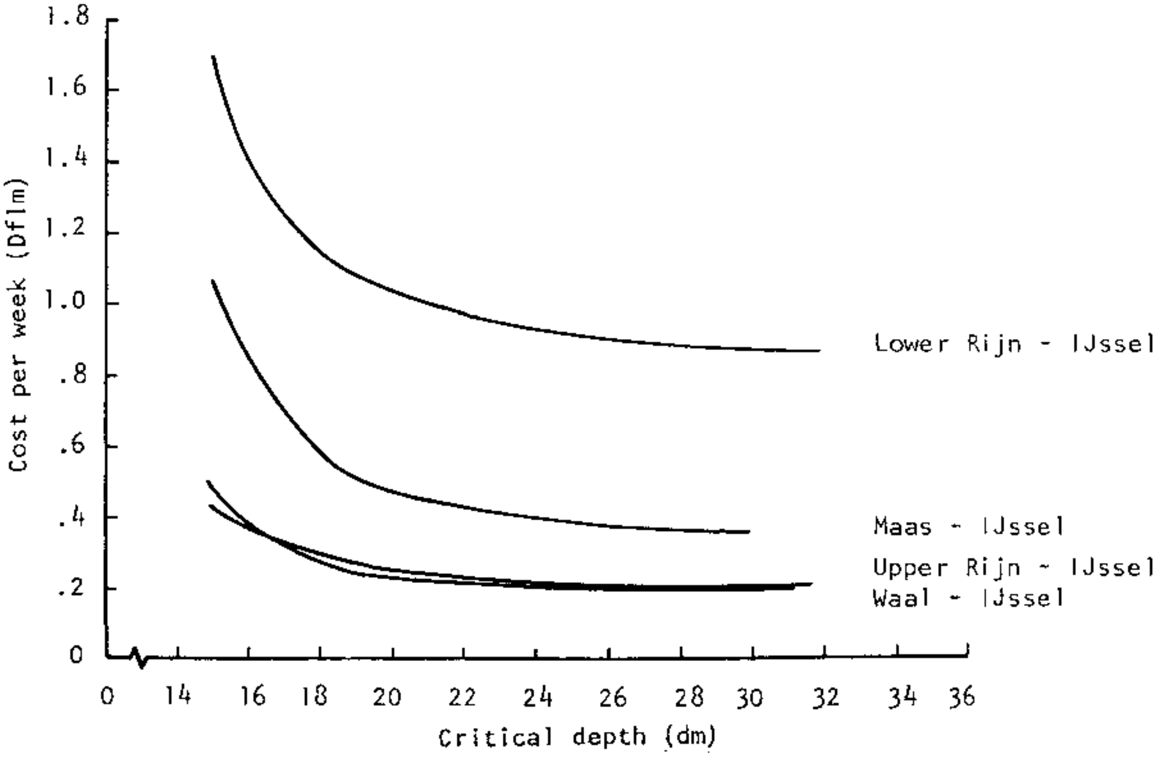


Fig. 7.4--Low water loss functions (1985)(part 2)

where DLR and DUR are the minimum shipping depths on the Upper Rijn and Lower Rijn (dm), respectively, and QR is the Rijn discharge (m^3/s).

For the Waal there are two critical points that may be limiting--one below Tiel and one below St. Andries. The one below Tiel gives the minimum shipping depth for the Waal unless there are withdrawals at St. Andries (link 28, SANDRIES) to send Waal water to the Maas. (The St. Andries Connection is a technical tactic (Vol. II).) The equations for the shipping depths on the two sections are

$$DWa = 5.986 + 0.0226Q2 - 0.03(Q2 - Q3 - Q28)$$

$$DWb = 12.947 + 0.01774Q3 - \max(0,\ 0.0526Q28 - 0.001257Q3)$$

where DWa and DWb are the shipping depths (dm) in the sections above and below St. Andries, respectively; Q2 is the flow (m^3/s) in the Waal (link 2, WAAL2) into Tiel (node 3, TIEL); the expression Q2 - Q3 - Q28 represents all the extractions (m^3/s) from the Waal in the vicinity of Tiel; Q3 is the flow (m^3/s) in the Waal (link 3, WAAL3) west of St. Andries; and the expression containing Q28 (the flow in link 28, SANDRIES) gives the change in the depth of the Waal (dm) due to the extraction at St. Andries. The shipping depth on the Waal is the minimum of DWa and DWb.

On the IJssel, critical points in the river sections north of the Twenthekanaal are limiting, and the shipping depth (dm) estimated from these critical points is

$$DIJ = 3.373 + 0.0922Q57 - 0.1[Q56 - Q58 + 0.5(Q58 - Q59)]$$

where Q57 is the flow (m^3/s) in the IJssel (link 57, IJSSEL2) into Eefde (node 41, ZUTPHEN), the expression Q56 - Q58 represents all the withdrawals (m^3/s) from the IJssel in the vicinity of Eefde, and the expression Q58 - Q59 represents all the withdrawals (m^3/s) from the IJssel in the vicinity of Deventer (node 42, DEVENTER).

During low flows, the Maas is canalized by raising weirs at seven locations (Sec. 3.1.2.3), and the shipping depth on the Maas is the minimum of the levels in the seven weir ponds formed by the raised weirs. The levels in the weir ponds vary because the ponds are used as storage reservoirs whose water may be used during periods of water shortages (Sec. 5.3.1).

When the shipping depths get so low that the shipping fleet cannot carry all of the cargo, the excess cargo must be stored until cargo space becomes available. In Vol. IX it is shown that the extra shipping costs can be represented as the sum of two storage costs, one a function of the shipping depth on the Waal and the other a function of the shipping depth on the IJssel (Figs. 7.5 and 7.6).

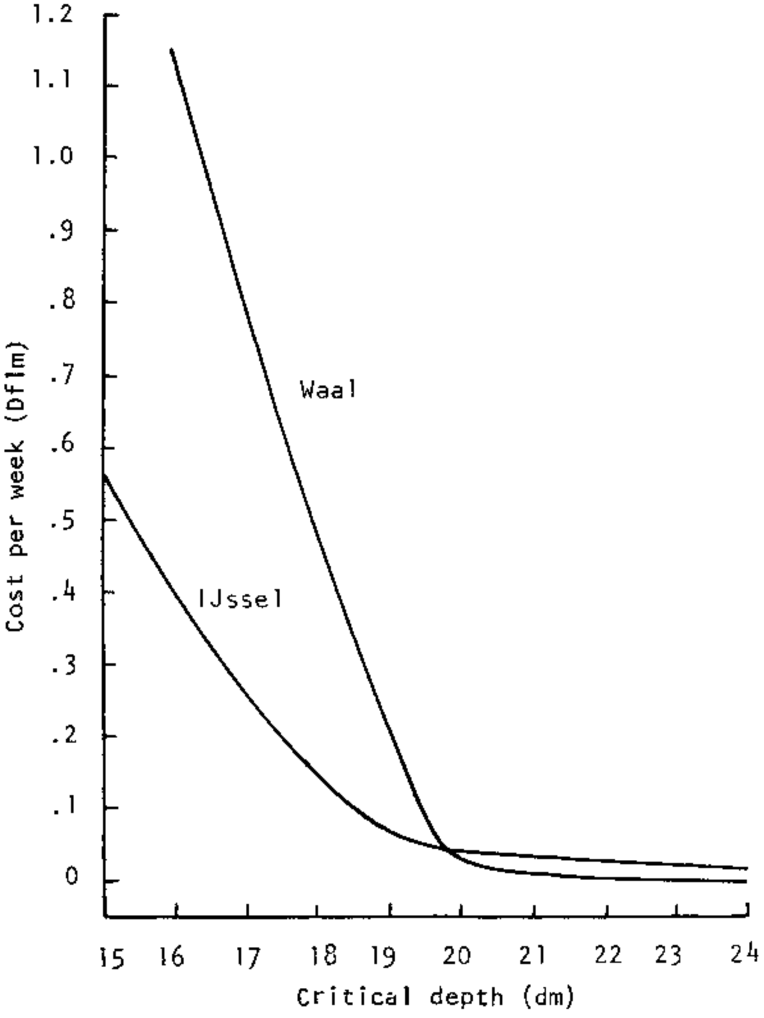


Fig. 7.5--Storage cost functions (1976)

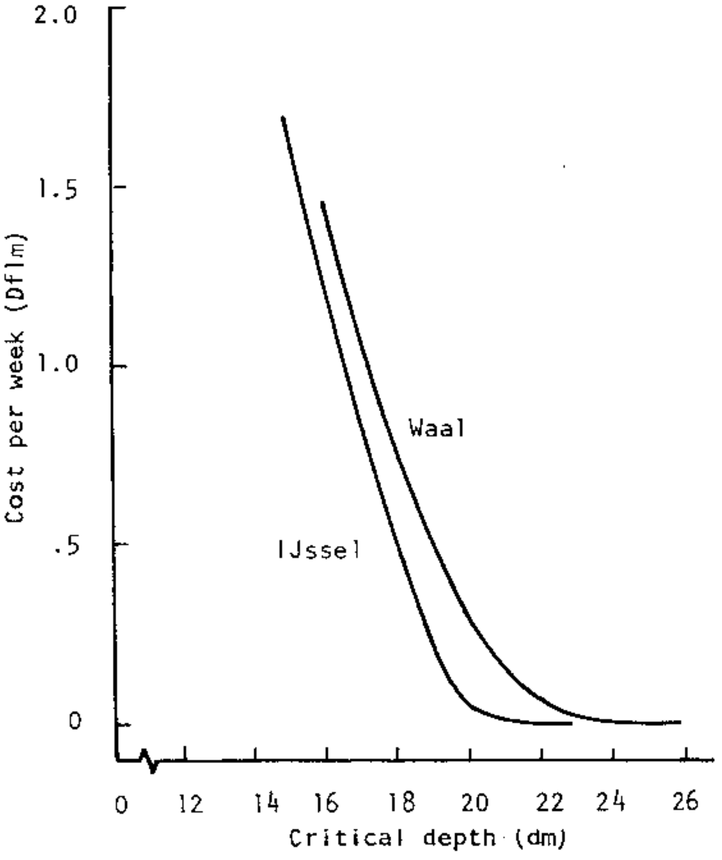


Fig. 7.6--Storage cost functions (1985)

7.2.2. Shipping Delay Losses

When the water available at locks is less than that needed for optimal locking operations, ships are delayed resulting in increased operating costs. Shipping delay loss functions were developed in the shipping analysis (Vol. IX) for eight locks in the Southeast Highlands (Figs. 7.7 to 7.10). In the figures, 1976 shipping traffic is assumed except at Born and Maasbracht, where adequate data were available to make reasonable projections for 1985 shipping traffic as well as for 1976. On the Julianakanaal, only the larger of the losses from the locks at Born and Maasbracht is used. Since these two locks handle the same traffic, we assume that the one with the smaller computed delay loss provides no additional delays over the one with the higher computed delay loss. The flow used for each is the sum of the flow in the link representing the lock (link 16, JULKANL1, for Born; link 17, JULKANL2, for Maasbracht) plus any pumping capacity back around the lock. The pumping capacities are input directly for Born and Maasbracht since the Cap.1 inputs for links (Table 2.1) that are used for pumping capacities on other links are used for the minimum flows on the Julianakanaal links (Sec. 5.3.1).

7.2.3. Cost of Dredging Sediment from the Waal

When water is withdrawn from the Waal at Tiel to be sent up the Amsterdam-Rijnkanaal (link 46, ARKANAL1), or if the St. Andries Connection (link 28, SANDRIES) is used to transport water from the Waal to the Maas (a technical tactic), the reduction in flow velocity in the Waal will cause a sandbar to form downstream from the extraction location. The sandbar moves slowly downstream until it reaches critical shallow points of the Waal several months later. The shipping depth at the critical point (a different location on the Waal for each of the extraction locations) will then be reduced for several years until the sandbar completely passes the critical point--unless the sandbar is removed by dredging. In Vol. XVIII, calculation procedures are derived for estimating the amount and cost of dredging to remove the sandbar as a function of the pattern of extractions over time. Versions of these procedures have been included in the DM. The cost of this dredging has been assigned to shipping costs since the alternative of no dredging will impose increased low water shipping losses in following years. The increased low water shipping losses incurred if no dredging is done is estimated to be 15 times the cost of dredging for the 1976 shipping scenario and 25 times the cost of dredging for the 1985 shipping scenario (Vol. V).

The PAWN Sedimentation Model, a set of equations that approximately reproduces the results of complex physical sedimentation models of the RWS, divides the sedimentation process into two phases--a build-up phase (lasting 12 decades for withdrawals at Tiel and 24 decades for withdrawals at St. Andries) during which the sandbar is forming, and a fully formed phase in which the depth of the sandbar is fixed but the length of the sandbar continues to increase. For a constant extraction rate at Tiel of Q (m^3/s), the depth D (m) and the volume V

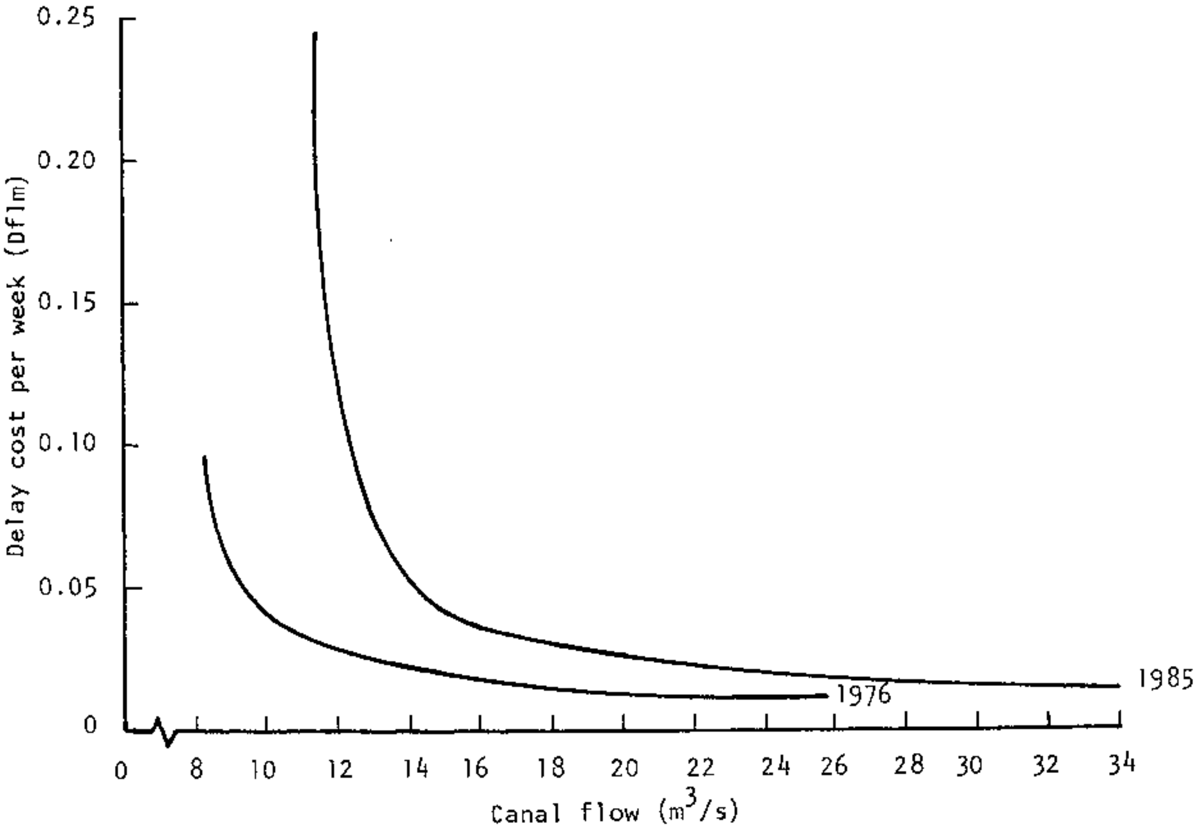


Fig. 7.7--Shipping delay loss functions for Maasbracht

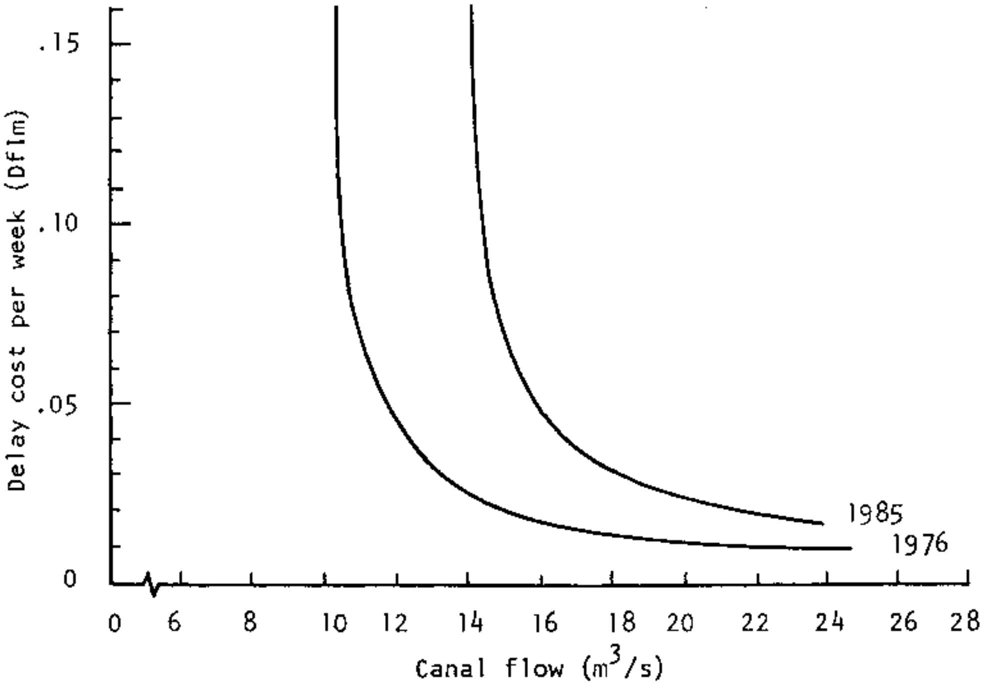


Fig. 7.8--Shipping delay loss functions for Born

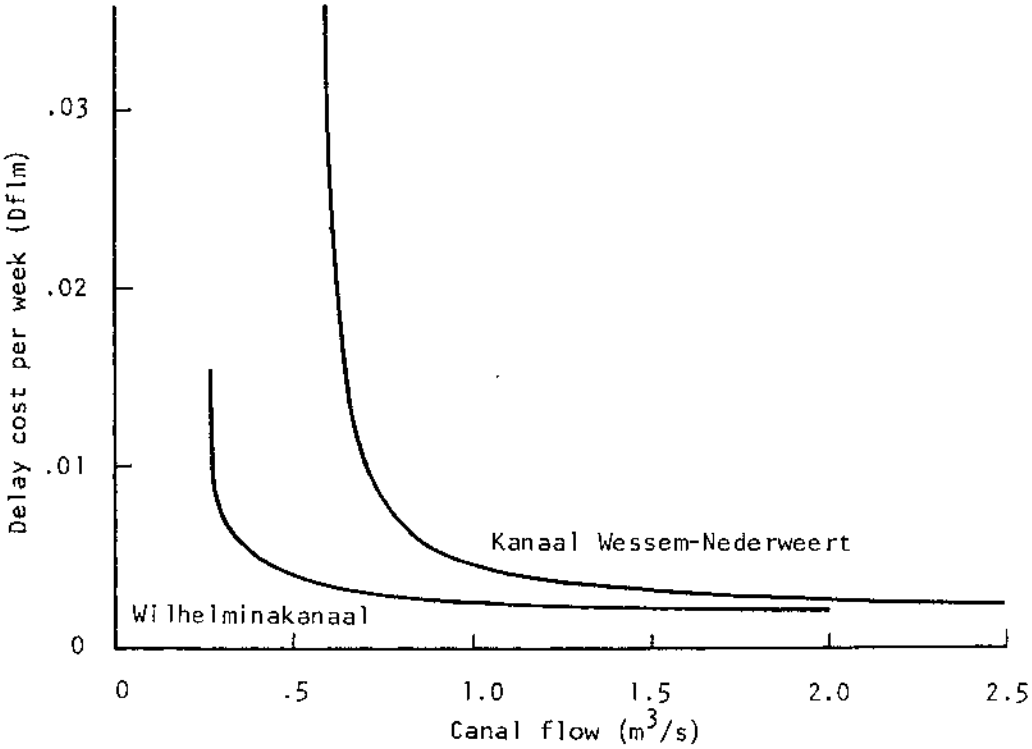


Fig. 7.9--Shipping delay loss functions for Wilhelminakanaal and Kanaal Wessem-Nederweert

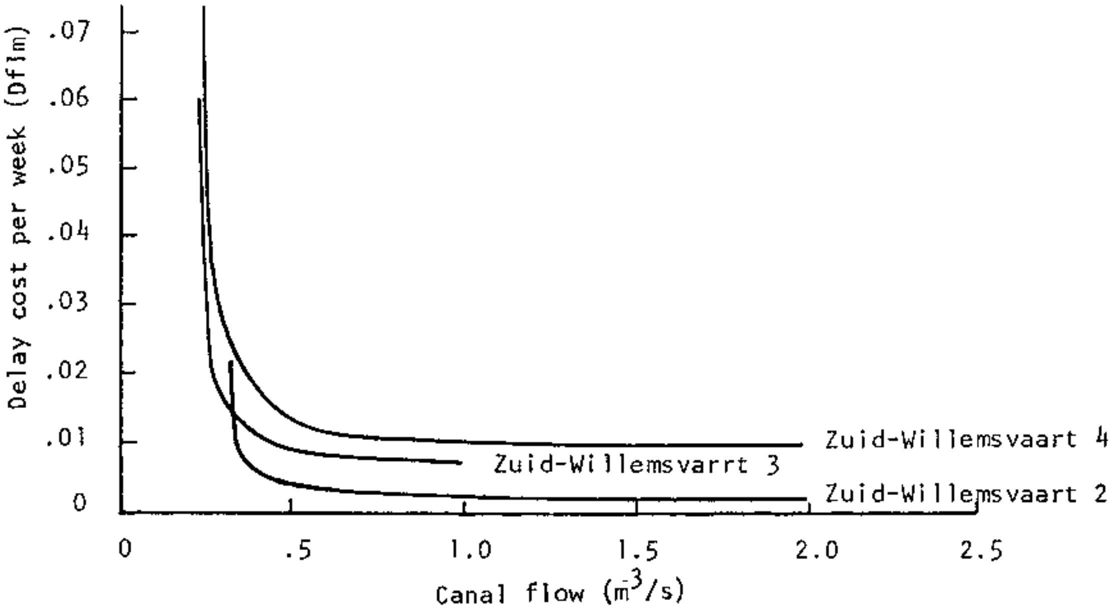


Fig. 7.10--Shipping delay loss functions for Zuid-Willemsvaart

(m^3) of the sediment reaching the critical point downstream from Tiel due to the extractions up to time t (decades) during the build-up phase are

$$D = 0.0073Qt/(1 + 0.1t) \qquad t \le 12 \qquad (7.5)$$

$$V = 160000D \qquad t \le 12 \qquad (7.6)$$

After the build-up phase, the sedimentation depth Dmax and the volume v reaching the critical point during a decade are both constant until the withdrawals stop:

$$Dmax = 0.004Q \qquad t > 12 \qquad (7.7)$$

$$\begin{aligned} v &= Vel \times Width \times Dmax \\ &= 64 \times 220 \times 0.004 \times Q \\ &= 56.3Q \qquad t > 12 \qquad (7.8) \end{aligned}$$

where Vel (m/s) is the velocity at which the sandbar moves downstream and Width (m) is the width of the Waal at the critical point. Equations 7.5 through 7.8 are used in a modified form that is also applied to decade-by-decade variation in the extraction rate. From Eq. 7.5, the time corresponding to a given sedimentation depth during the build-up phase is

$$t = D/(0.0073Q - 0.1D) \qquad (7.9)$$

Now, using this equation to define the equivalent time during the build-up phase for (possibly) varying extraction rates, we write

$$t = D_{i-1}/(0.0073Q_i - 0.1D_{i-1}) \qquad (7.10)$$

where D_{i-1} is the sedimentation depth at the end of the (i-1)st decade $D_o = 0$, and Q_i is the extraction rate during the ith decade. Then, using Eqs. 7.5 and 7.7, the depth change d_i and the volume of sediment v_i reaching the critical point due to the extraction during the ith decade are

$$d_i = D_i - D_{i-1}$$

$$= 0.0073Q_i[(t + 1)/[1 + 0.1(t + 1)] - t/(1 + 0.1t)] \qquad t \leq 12 \qquad (7.11)$$

$$= 0 \qquad t > 12 \qquad (7.12)$$

$$v_i = 160000d_i \qquad t \leq 12 \qquad (7.13)$$

$$= 56.3Q_i \qquad t > 12 \qquad (7.14)$$

A similar development holds for extractions at St. Andries. The equations corresponding to Eqs. 7.10 through 7.14 are

$$t = 24 - 24 \text{ sqrt}(1 - 263.1d_i/Q_i) \qquad (7.15)$$

$$di = D_i - D_{i-1}$$

$$= 0.0158 - 3.29 \times 10^{-6}Q_i[(t + 1)^2 - t^2] \qquad t \leq 24 \qquad (7.16)$$

$$= 0 \qquad t > 24 \qquad (7.17)$$

$$v_i = 84000d_i \qquad t \leq 24 \qquad (7.18)$$

$$= 37.6Q_i \qquad t > 24 \qquad (7.19)$$

The cost of removing the sandbar from the critical points is based on using dredges to lift the sediment and move it downstream to locations that will not become critical. This cost is conservatively estimated to be 16.2 Dfl/m^3 (Vol. XVIII).

7.3. TECHNICAL TACTIC COSTS

In the screening of technical and managerial tactics stage of the PAWN study, over 100 tactics were evaluated. The DM was used in the evaluation to estimate the monetary benefits (or disbenefits) to agriculture and shipping from implementing the tactics (Sec. 1.4). The estimated cost of each of the tactics is given in Vol. XVI. These cost estimates are input into the DM so that the costs of individual or combinations of tactics can be part of the DM output for any run containing the tactic(s).

The costs of a tactic are given as two cost components--fixed and variable costs. The fixed costs are the fixed investment costs plus the fixed portion of the operating costs. These have been combined and prorated to give the annualized fixed cost of the tactic. The variable costs are primarily due to consumption of energy (e.g., by a pumping station) and may vary from day to day. These are called daily energy costs.

Table 7.2 contains excerpts from the tactic cost input table in its actual input format. The Tactic Label entry is an 8-character identifier for the tactic. The DM user inputs the tactics used in a run by an input card for each tactic that contains the tactic label and (if needed) a parameter value for the tactic (either a link capacity or a storage level; see below). The Tactic Type entry identifies the tactic as one of four types: LINK, DISTRICT, LEVEL, or OTHER. A LINK tactic is one whose costs depend upon the capacity specified for a link. The costs may be due to a new or increased pumping capacity, a new or expanded canal, a bypass at a lock, etc. Similarly, a DISTRICT tactic depends upon the capacity specified for a district link. A LEVEL tactic raises the maximum level or lowers the minimum level of a storage lake. The OTHER tactic category contains all tactics that are in none of the other three categories.

For a LINK tactic type, the annualized fixed cost (Dflm) and the daily energy cost (Dflm) are

$$\mathrm{COSTf} = \mathrm{a1} + \mathrm{a2} \times \mathrm{CAP} \tag{7.20}$$

$$\mathrm{COSTe} = \mathrm{b1} + \mathrm{b2} \times \mathrm{CAP} + \mathrm{b3} \times \mathrm{Qpump} \tag{7.21}$$

where CAP is the capacity specified for the link (m^3/s), and Qpump is the average amount pumped during a day (m^3/s). The line entry in the table used for the tactic cost coefficients depends upon the Flow Dir. entry specification for the table. If the specification is other than UP&DOWN, the line entry used is the first one for the tactic in which the Cap. entry is larger than the new throughput capacity given for the link (or until the last line entry in the table is reached); if the Flow Dir. entry is blank, the energy costs are applied for flows in both directions; if the Flow Dir. entry is UPSTREAM, the energy costs are applied only to negative flows; and if the Flow Dir. entry is DNSTREAM, the energy costs are applied only to positive flows. The energy cost for a decade is obtained by adding the flow in the link to any lock loss for the link to obtain Qpump and multiplying the daily energy costs by the number of days in the decade.

Table 7.2

EXCERPTS FROM THE TACTIC COST INPUT TABLE

Tactic Label	Tactic Type	Link/Node/ District	Flow Dir. or Node	Cap.[1] or Level	Cost Coefficients				
					a1	a2	b1	b2	b3
1.1	LINK	MERWKAN1							
1.1				30.00	0.0	0.030	0.0	1.108E-05	3.062E-05
1.1				40.00	1.161	0.0	0.0	1.108E-05	3.062E-05
1.1				200.00	13.250	0.163	0.0	1.108E-05	3.062E-05
2.1	LINK	LEKKANAL	UP&DOWN						
2.1				30.00	0.277	0.207	0.0	4.270E-06	1.180E-05
2.1				30.00	0.277	0.207	0.0	1.451E-05	4.000E-05
2.1				80.00	3.736	0.092	0.0	4.270E-06	1.180E-05
2.1				80.00	3.736	0.092	0.0	1.451E-05	4.000E-05
2.1				150.00	0.314	0.134	0.0	4.270E-06	1.180E-05
2.1				150.00	0.314	0.134	0.0	1.451E-05	4.000E-05
9.4	OTHER								
9.4				0.0	0.678	0.0	0.0	0.0	0.0
11.1	LEVEL	IJSLMEER							
11.1				0.0	7.696	38.476	0.0	0.0	0.0
11.1				0.30	7.696	96.196	0.0	0.0	0.0
11.1				0.70	20.681	52.902	0.0	0.0	0.0
11.2	LEVEL	IJSLMEER							
11.2				-0.60	11.428	-2.855	0.0	0.0	0.0
11.2				-0.50	-50.100	-105.407	0.0	0.0	0.0
11.2				-0.40	-10.401	-26.005	0.0	0.0	0.0
18.1	LINK	STABOKAN	DNSTREAM						
18.1				20.00	0.317	0.0	0.0	0.0	0.0
18.1				25.00	-0.868	0.068	0.0	1.748E-05	4.828E-05
18.1				40.00	-2.414	0.136	0.0	2.175E-05	5.956E-05
19.2.1	DISTRICT	SEDRENTE	SMILDE						
19.2.1				10.00	-0.137	0.205	0.0	0.0	0.0
20.2.2	LINK	WESNWERT	UPSTREAM						
20.2.2				17.30	1.050	0.072	0.0	0.0	3.200E-04
20.2.2				19.00	0.661	0.095	0.0	0.0	3.200E-04
20.2.2				999.00	3.496	0.095	0.0	0.0	3.200E-04
20.5.1	LINK	MAWAKAN							
20.5.1				999.00	0.636	0.0	0.0	0.0	0.0

[1] For LINK and DISTRICT tactics the Cap. or Level entry is a link capacity (m^3/s); for a LEVEL tactic it is a minimum or maximum storage level (cm above NAP); for the OTHER tactic the entry is not used.

A DISTRICT tactic has only one line entry, and the annualized investment cost is evaluated as in Eq. 7.20 using the input specified capacity. Energy costs are not (currently) calculated by the DM for DISTRICT tactics and must be added to the output costs for the tactic or ignored (energy costs are generally less than 5 percent of the total costs). There are only three district tactics included in the tactic cost table, and one of these has no energy costs. The district to which the tactic applies is identified by the entry in the Link/Node/District column, and the district link to which the tactic applies is the one to the node specified in the Flow Dir. or Node column.

For a LEVEL tactic, there is no daily energy cost and the annualized investment cost (Dflm) is

$$\text{COSTe} = \text{a1} + \text{a2} \times \text{LEV}$$

where LEV is the (maximum or minimum) level (cm above NAP) specified for the lake.

The OTHER tactic type has only an annualized investment cost (Dflm) which is given by the entry in the a1 cost coefficient column.

Table 7.3 contains a short description of each tactic and the corresponding table in Vol. XVI that presents a cost summary for the tactic.

REFERENCE

7.1. MR-314 (unpublished PAWN memorandum), "Agricultural Damage by Salt Intrusion at Locks," June 1979.

Table 7.3

TACTIC CORRESPONDENCE TABLE

Tactic Label	Description	Table No. (Vol. XVI)	Tactic Label	Description	Table No. (Vol. XVI)
--	Pipeline: N.E. Polder to Flevoland	4.1	19.2.3	Linthorst-Homankanaal: Pumping	5.6
--	Pumping at Leidschendam	7.8	19.3	Hoogeveensche Vaart: Pumping	5.4
--	Portable pumping in Maasbracht	9.19	19.4	Noord-Willemskanaal: Pumping	5.5
--	Permanent pumping station at Maasbracht	9.20	19.5.2	Twenthekanaal: Pumping	5.1
--	Dredging in Waal below Tiel	10.23	19.5.4	Almelo Lock: Bypass	5.2
1.1	Merwedekanaal, Betuwe section	10.21	19.5.6	Stieltjeskanaal: Pumping	5.3
2.1	Bypass at Vreeswijk	10.20	19.6.1	Overijsselsche Vecht (lower sect): Pumping	5.8
2.2	Bypass at Wijk bij Duurstede	10.19	19.6.2	Overijsselsche Vecht (upper sect): Pumping	5.9
3	Canal through Krimpenerwaard	7.1	20.2.2	Expand pumping: WESNWERT	9.11
4.1	Canal through Lopikerwaard	7.2	20.2.5	Expand pumping: WESNWERT improved	9.12
4.2	Canal through Lopikerwaard plus expansion	7.3	20.3.2	Expand pumping: WILHEKAN	9.14
5	Maarssen-Bodegraven canal	7.4	20.3.5	Expand pumping: WILHEKAN improved	9.15
6	Pumping station on the Diemen	10.18	20.4.2.2	Expand flushing: ZUIDWLM2	9.2
7	Extend Amsterdam-Rijnkanaal to Maas	10.22	20.4.2.5	Expand flushing: ZUIDWLM2 improved	9.3
8.1.2	Close Spui: Permanent, lock	7.11	20.4.3.2	Expand flushing: ZUIDWLM3	9.22
8.2.2	Close Oude Maas: Temporary, caissons	7.12	20.4.3.3	Expand pumping: ZUIDWLM3	9.24
8.3	Close Nieuwe Maas: Temporary, caissons	7.13	20.4.3.5	Expand flushing: ZUIDWLM3 improved	9.23
9.1	Bubble screen in Nieuwe Waterweg	7.10	--	Expand pumping: ZUIDWLM3 improved	9.25
9.4	Groin in Nieuwe Waterweg	7.9	20.4.4.2	Expand pumping: ZUIDWLM4	9.5
11.1	Raise summer target level of IJsselmeer	10.9	20.4.4.5	Expand pumping: ZUIDWLM4 improved	9.6
11.2	Decrease minimum level of IJsselmeer	10.13	20.4.5.2	Expand syphon: ZUIDWLM2-NORDVART	9.7
12.1	Raise summer target level of Markermeer	10.10	20.4.5.5	Expand syphon: ZUIDWLM2-NORDVART	9.7
12.2.2	Decrease minimum level of Markermeer	10.14	20.4.6.2	Expand pumping: NORDVART	9.9
13	Redirect Wieringermeerpolder discharges	6.1	20.4.6.5	Expand pumping: NORDVART	9.9
15.1	Raise Flevoland dike	10.1	20.5.1	St. Andries Connection	8.2
15.2	Drainage channel in IJmeer, open connection	10.7	20.5.2	St. Andries Connection & pump to Panheel	9.18
15.3	Drainage channel to Amsterdam	10.6	20.6	New pumping station at Linne Weir	9.17
15.4	Drainage pipe: Flevoland to Amsterdam	10.3	--	Pipeline, Julianakanaal to Panheel	9.16
15.5	Short 2nd Oostvaardersdijk to Marken	10.4	21	Canalize IJssel River	10.26
15.6	Long 2nd Oostvaardersdijk to Durgerdam	10.5	24	Waddinxveen-Voorburgkanaal	7.5
15.7	Pump Flevoland discharges to IJsselmeer	10.2	--	Pipeline from Maas to Delfland (3 pipes)	7.6
15.8	Freshwater syphon in IJmeer	10.5	--	Pipeline from Maas to Delfland (1 pipe)	7.7
15.9	Saltwater channel in IJmeer	10.8	26	Expand pumping capacity at Maasbracht	--
18.1	Van Starkenborghkanaal: Pumping, bypass	4.2	27.1	Wet Markerwaard	10.17
19.1	Drentsche Hoofdvaart: Pumping	5.7	28.1	Modify groins in Waal below Tiel	10.24
19.2.1	Oranjekanaal West: Pumping	5.10	28.2	Narrow Waal around Tiel	10.25
19.2.2	Oranjekanaal East: Pumping at Oranjesluis	5.11	29.3	Inlet in Grevelingendam	8.1
19.2.2	V Hoogeveensche Vaart: Pumping at Ericasluis	5.12			

NOTE: The symbol '--' means that the tactic is a new one, not included in the Tactic Cost Input Table in the DM. Tactic costs presented in Vol. XVI have changed slightly from those presented in Table 7.2.

favorably with the measured values, particularly in the crucial dry summer months.

8.2.1. Discharges from the Highlands

In the initial test runs, the DM produced relatively high discharges from districts in the highlands in the summer months. This caused calculated flows in the Maas to be higher than the measured flows and calculated flows in the Northeast Highlands to be less than measured flows in the supply waterways (the discharges from some districts were providing water to other districts via the discharges at nodes). The excess discharges were not large in absolute terms, but since the demands and flows in the highlands are relatively small, the overall result was to underestimate water shortages. Considerable effort was then spent in comparing calculated discharges with measured flows in the small rivers in the highlands, and several modifications were made to DISTAG to improve the calculated discharges. These modifications are discussed in Vol. XII.

8.2.2. Noordzeekanaal Discharges at IJmuiden

The calculated discharges from the Noordzeekanaal to the North Sea at IJmuiden were 45 to 50 m^3/s lower than the measured values for the month of June and the first decade in July. A review of the measured discharges into the Amsterdam-Rijnkanaal from all sources revealed that the flows from the IJmeer to the Noordzeekanaal were approximately 25 m^3/s higher than the values used in the DM due to the usage of some old pumps. This reduced the discrepancy between the calculated and measured values, but a discrepancy of 20 to 25 m^3/s still remains.

8.3. COMPARISON OF SALINITIES

Calculated salinities were compared with measured salinities at a number of nodes in the network (a discussion of salinity in districts is contained in Vol. XII). The calculated values were generally in good agreement with the measured values, except in a few waterways where the calculated values were too low. The salinities in these waterways and the steps taken, if any, to improve the salinity calculations are discussed in the following sections.

8.3.1. Salinity in the IJsselmeer

The calculated salt concentrations for the IJsselmeer were too low, failing to rise from a starting low value of 200 mg/l to approximately 300 mg/l late in the year. A review of the sources of salt for the lakes (salt intrusion from the locks in the Afsluitdijk and discharges of saline seepage water from the polders adjacent to the lakes) led to modifications in seepage rates and subsequent discharges of the seepage water that increased the maximum salinity of the IJsselmeer to 295 mg/l late in the year, in good agreement with the measured values.

8.3.2. Salinity in the Haringvliet

The monthly averages of measured salt concentrations in the Hollandsche Diep and Haringvliet in 1976 varied from 120 mg/l to 580 mg/l, generally increasing from east to west and from the beginning of the year through November. The calculated salinities in the DM were much lower than the measured values, with the discrepancy increasing with the increase in the measured values.

The only salt introduced into the Haringvliet in the DM other than by river discharges is from salt intrusion at the Volkerak locks and from discharges of saline seepage water from district 48. The salt from these two sources is only sufficient to raise the salinity in the Haringvliet (at the HELVOETS node in the west) about 30 mg/l above that of the Hollandsche Diep (at the BIESBOSH node in the east). The average measured values increase by more than 130 mg/l in going from east to west.

Assuming that the salt introduced by the DM at district 48 and the Volkerak locks is correct and that there are no other significant sources of salt intrusion into the Haringvliet leads to the conclusion that the assumption in the DM of complete mixing of salt and water at each node is incorrect for the Haringvliet. It is well known that the higher density saline water from the Volkerak locks tends to sink to the bottom of the Haringvliet (the relatively deep Haringvliet has pits in the bottom where the salinity reaches high values). In periods of high flows through the Haringvliet, this highly saline water is kept localized in bottom layers or sufficiently mixed with the upper layers to be continuously flushed out. But because low Rijn discharges persisted through November in 1976, low flows persisted in the Haringvliet, and its salinity continued to increase from early to late in the year.

No effort was made to correct the modeling of salinity in the DM to remove the model inadequacy for the Haringvliet. The low salinity values remain and should produce low estimates for the losses due to salinity for those districts extracting from the Haringvliet (districts 48 and 49) when the Zoommeer is saline. When the Zoommeer is fresh, there is no salt intrusion at the Volkerak locks and, to the extent that the model discrepancy is due to that source, the discrepancy will presumably no longer exist.

8.3.3. Salinity at IJsselmonde and the Gouda Inlet Due to the Rotterdam Salt Wedge

Since the closure of the Haringvliet and Volkerak outlet branches in the Rijn delta, salt intrusion from the Rotterdam salt wedge has reached the Gouda inlet on several occasions--in 1971, 1972, and 1976.

The limited measurements from these relatively few occurrences is not sufficient to provide reliable estimates for the relationship between the salt wedge intrusion and the major influencing factors, e.g., tidal effects and the division of the discharge of the Nieuwe Waterweg between the Oude and Nieuwe Maas. Thus, the model for the Rotterdam salt wedge developed in Vol. XIX and used in the DM must be considered as preliminary and unreliable.

Of critical importance is the influence of the so-called Haringvliet effect. Due to varying tidal levels between neap and spring tides, the storage in the Haringvliet and Hollandsch Diep rises and falls cyclically over the 14-day period between spring and neap tides. This causes the discharge in the Rotterdamse Waterweg to vary over a wide range. The exact form of this discharge variation is unknown and must certainly vary considerably over the year. In the salt wedge model this effect is represented by changes in the discharge of plus or minus 250 m^3/s (a value obtained from the tidal salinity model "Rijnmond") varying sinusoidally over a 14-day period. The effects of the salt wedge intrusion are then taken as the average values over the 14-day period.

From [8.1], there were periods of increased salinity at Gouda due to salt wedge intrusion from late January through the middle of February, from early May to late June, from early July through the middle of August, and from early September through October. The DM produced increased salinity at Gouda during two of these periods as indicated in Table 8.2 (increased salinity at IJsselmonde occurred in the DM from March through November).

Table 8.2

Salinities Due to the Rotterdam Salt Wedge
at IJsselmonde and Gouda
(Calculated in the DM, mg/l)

	Decade				
Salinity	JUN3	JUL1	JUL2	AUG2	AUG3
At IJsselmonde	349	794	568	342	563
At Gouda	13	215	92	11	90

From Vol. XIX and [8.1], the average concentration due to the salt wedge was approximately 100 mg/l at Gouda from July 10 through July 19, and at IJsselmonde approximately 800 mg/l from July 8 through July 13 (there is a time lag of several days between high values at IJsselmonde and the appearance of salt intrusion at Gouda--the DM does not provide for such a time lag). For the period corresponding to the AUG3 decade, the average measured concentrations were approximately 100 mg/l at Gouda (from August 28 through September 10) and 700 mg/l at IJsselmonde (from August 25 through August 27).

We do not know why the calculated values are high relative to the measured values in July or why there was no salt intrusion in the other periods during which salt intrusion occurred in 1976--the discharges in the Rotterdamse Waterweg produced by the DM may be incorrect, the model for the salt wedge intrusion may have too much of a thresholding effect (producing too high values at Gouda for high values at IJsselmonde and too low values at Gouda for lower values at IJsselmonde), or the actual conditions prevailing during the 1976 periods of salt wedge intrusion at Gouda may be different from the average conditions represented in the salt wedge intrusion model. For example, the storm surge barrier on the Hollandsche IJssel was closed on July 13, stopping the salt intrusion into the Hollandsche IJssel on that day. Since this would have been a peak day of influence by the Haringvliet effect (see below), the salinity at Gouda may have been decreased by as much as 25 percent by the closure.

The values produced by the salt wedge model are sensitive to both river discharge variations and the Rotterdamse Waterweg discharge variations due to the Haringvliet effect. To examine these effects, daily Rijn discharges and the actual relation between neap and spring tides in the last few days of June and the first two decades of July were used in the procedure in Vol. XIX for averaging the varying discharges in the Rotterdamse Waterweg. The magnitude of the values obtained for the salinities at Gouda were similar to those given in Table 8.2, but the values for JUL1 and JUL2 were interchanged; i.e., the larger value occurred in the second decade of July, as it did in reality.

8.4. COMPARISON OF CALCULATED AND MEASURED VALUES OF PHOSPHATE, BOD, AND CHROMIUM

In this section the results of the calibration of the DM for the three pollutants--BOD, phosphate, and chromium--will be compared with actual measured values of pollutant concentrations at several locations.

Figures 8.1 to 8.24 contain curves of 1976 measured concentrations in the Rijn at Lobith, in the Maas at Eijsden, and at six locations on waterways in the interior of the Netherlands. Included in the figures are the monthly averages of the measured values that were used during calibration for the concentrations of the Rijn discharge at the PANDNKOP node and the Maas discharge at the MASTRICHT node. Also included on these figures for reference points are the values for the old IMP standards from Table 6.17. Included in the figures for the locations on interior waterways are the DM-calculated values for pollution concentrations at nodes in the network corresponding to the measurement locations, for a monthly time-step run for 1976 using the pollutant decay rates estimated by the 1976 calibration. (Monthly time steps were used, in general, during calibration, and calculated values were compared with monthly averages of the measured concentrations to dampen the measurement-to-measurement variations and simplify the calibration process.)

It is apparent from the figures that the calibrated values for BOD and phosphate represent the average values of the measured concentrations over the year fairly well but tend to dampen seasonal variations, e.g., the generally increased values of BOD in July and August and the increased phosphate values from October through December in the Maas at Lith and in the Haringvliet. The pollutant discharges from industry and wastewater treatment plants are input into the DM as constant rates throughout the year. Possibly, more realistic inputs, taking into account seasonal variations in the discharges, would improve the fit of the calculated to the measured values.

For chromium, the most obvious features are the large measurement-to-measurement variations of the values in the Rijn at Lobith (with no apparent seasonal variation) and the large differences between the high concentrations in the Rijn and the low concentrations in the Maas. The calculated values represent the average measured concentrations fairly well but do not follow month-to-month variations in the measured values. This may simply be due to the inherently large variation in the measured chromium concentration values and the small number of samples at each measurement location, since chromium pollution is due almost entirely to the chromium in the Rijn (see Vol. VA). At Vreeswijk on the Lek, however, the relatively poor fit may be due to inaccuracies in the Lek flows since small absolute errors in the relatively small Lek flows lead to large errors in the calculated concentrations.

REFERENCE

8.1. Rijkswaterstaat, Directie Waterhuishouding en Waterbeweging, District Zuidwest, Toetsing resultaten van het onderzoek verziltingsfrekwentie van de Hollandsche IJssel aan de opgetreden situatie in 1976 (Verification of the Results of the Study of Salinization of the Hollandsche IJssel against the 1976 Situation), Projectnummer 11.002.04, August 1978.

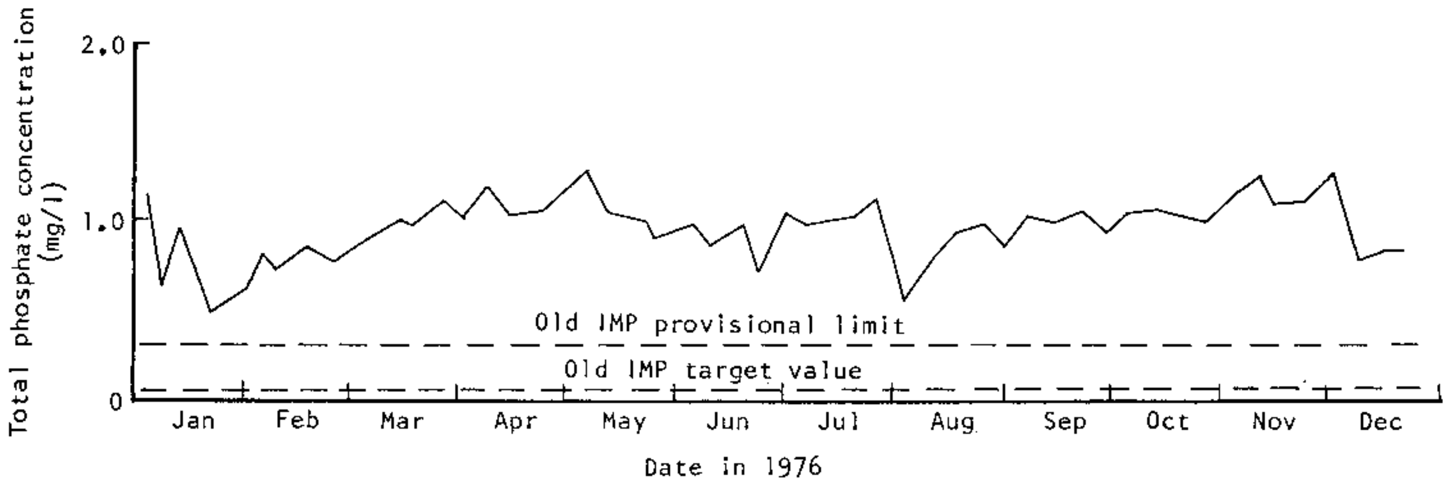


Fig. 8.1--Total phosphate concentration in the Rijn at Lobith in 1976

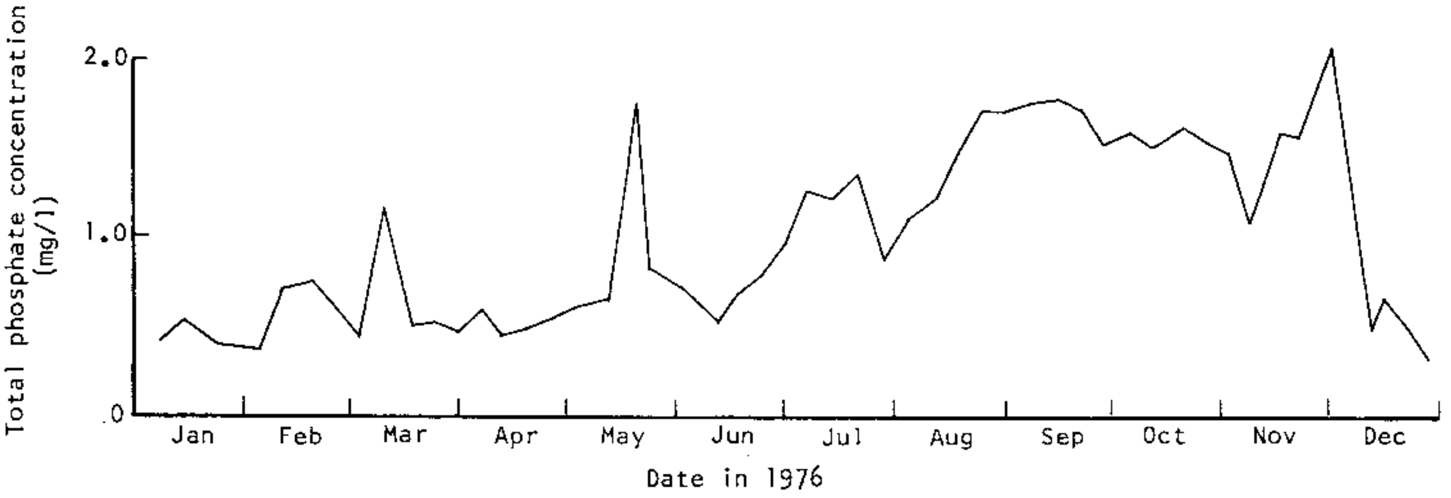


Fig. 8.2--Total phosphate concentration in the Maas at Eijsden in 1976

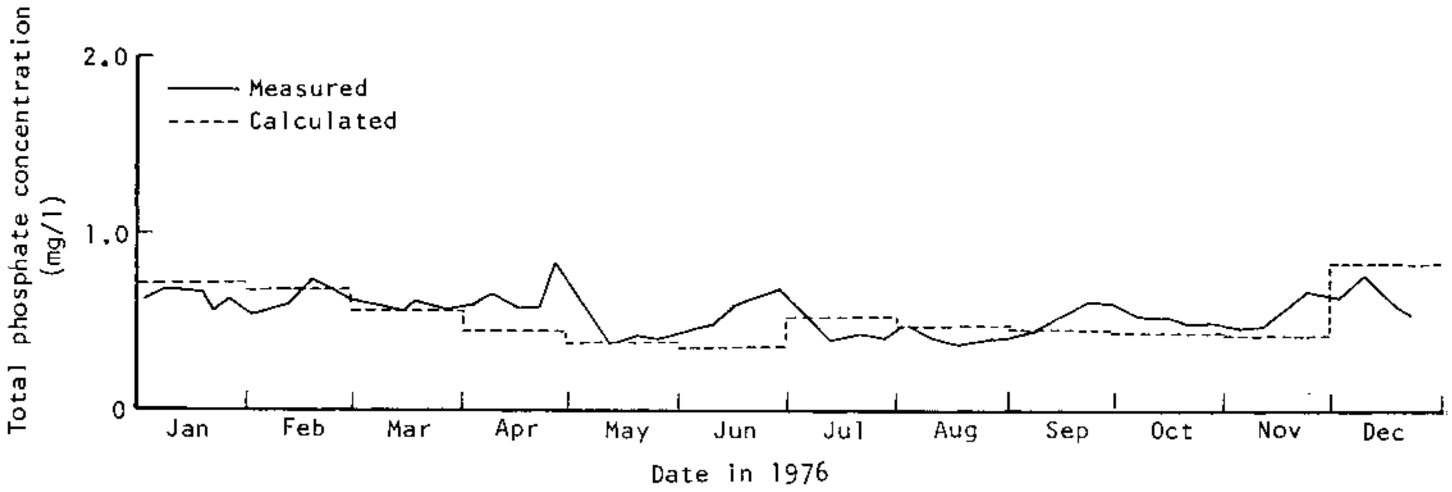


Fig. 8.3--Total phosphate concentration in the Lek at Vreeswijk in 1976

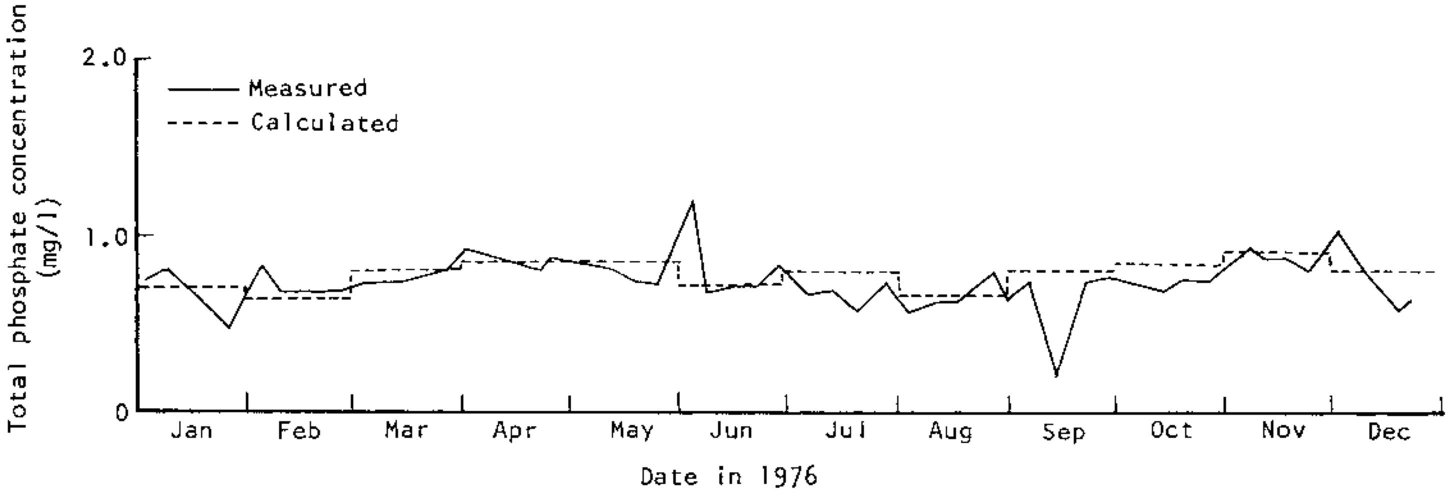


Fig. 8.4--Total phosphate concentration in the Waal at Gorinchem in 1976

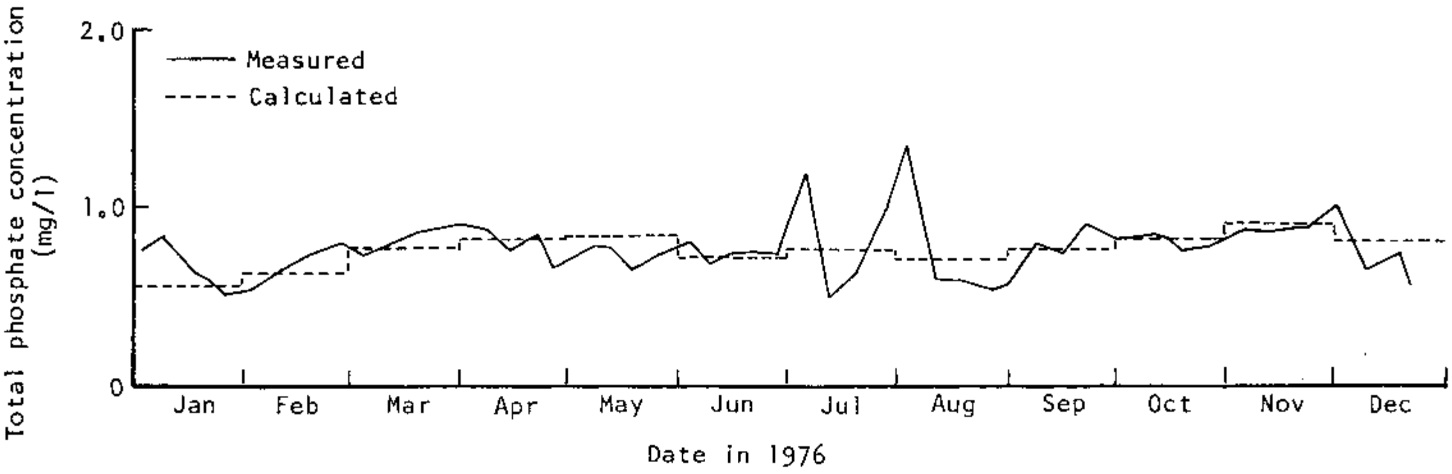


Fig. 8.5--Total phosphate concentration in the IJssel at Kampen in 1976

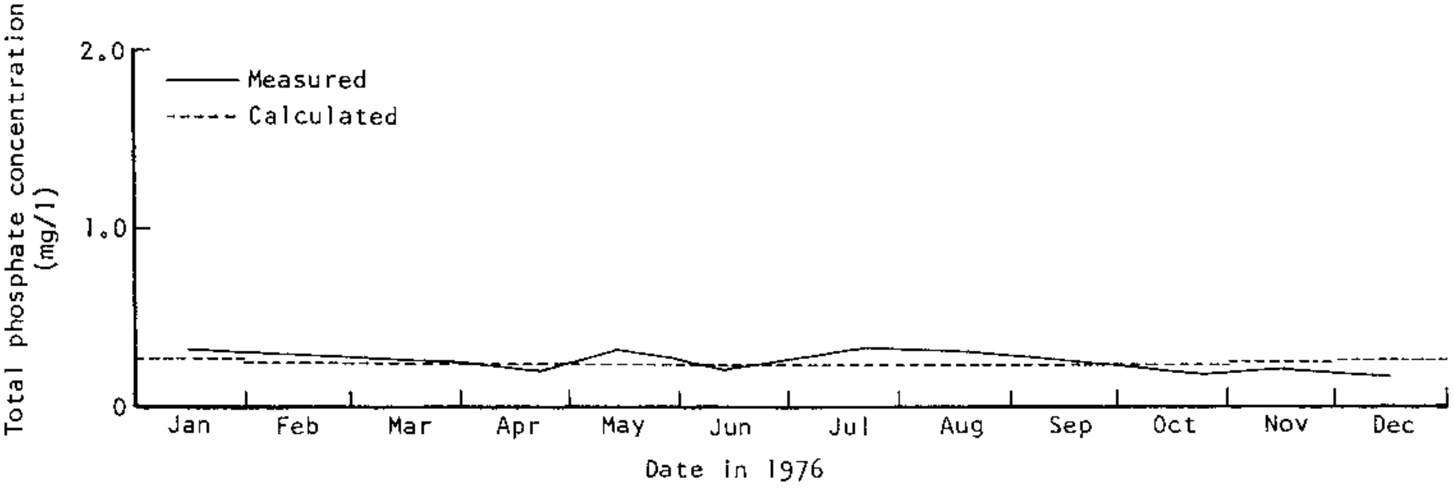


Fig. 8.6--Total phosphate concentration in the IJsselmeer in 1976

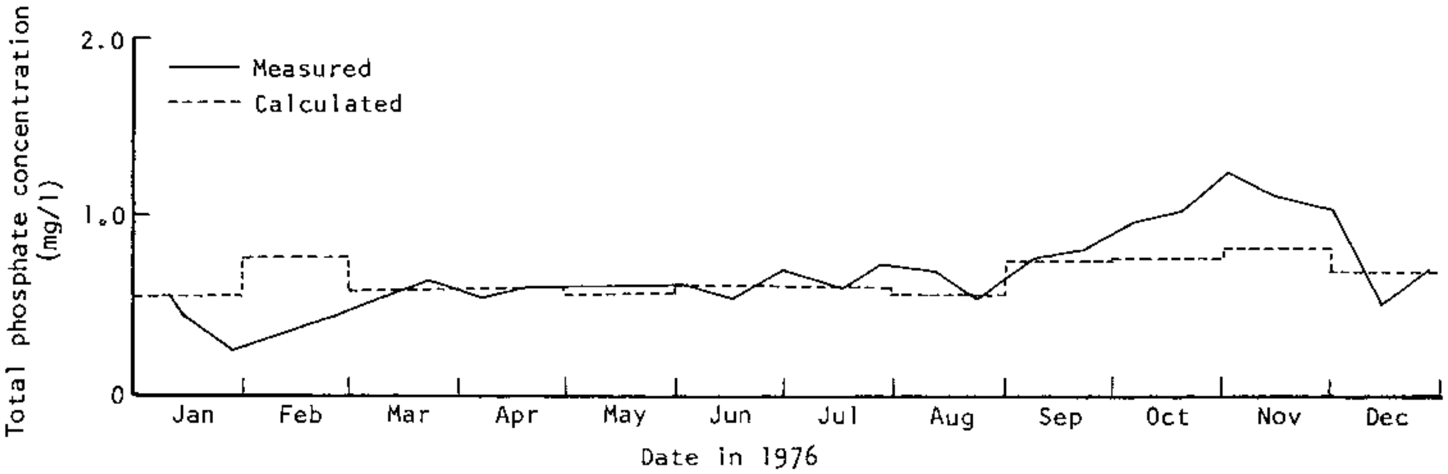


Fig. 8.7--Total phosphate concentration in the Maas at Lith in 1976

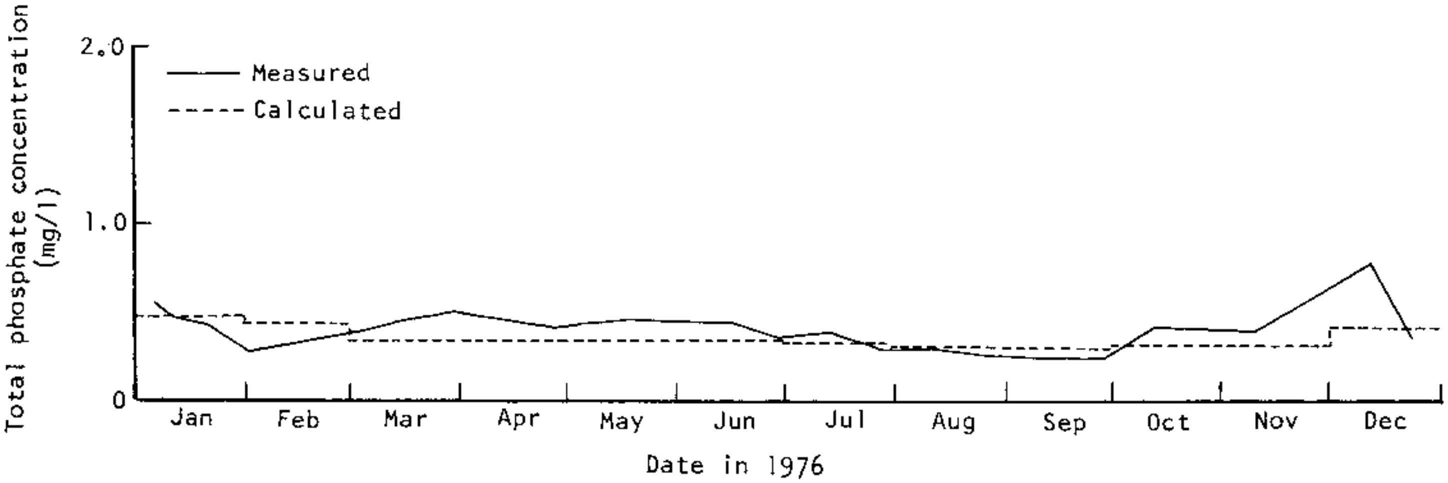


Fig. 8.8--Total phosphate concentration in the Haringvliet in 1976

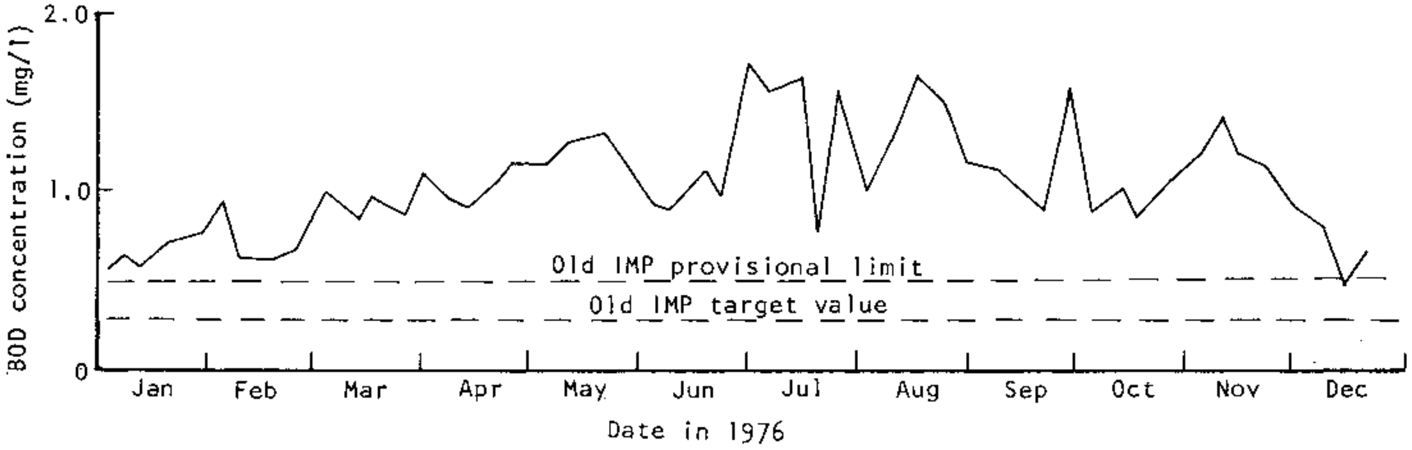


Fig. 8.9--BOD concentration in the Rijn at Lobith in 1976

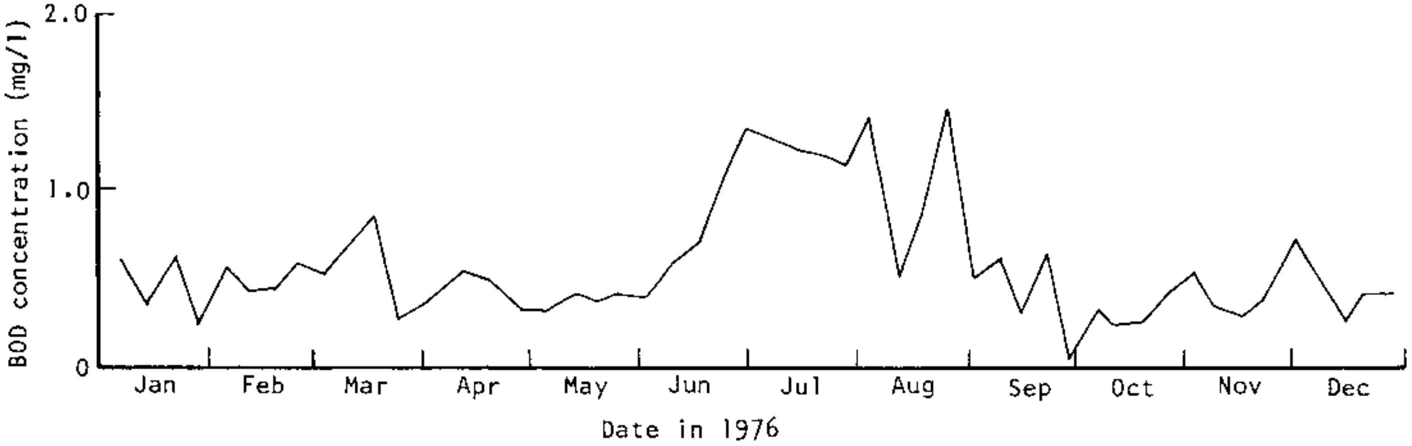


Fig. 8.10--BOD concentration in the Maas at Eijsden in 1976

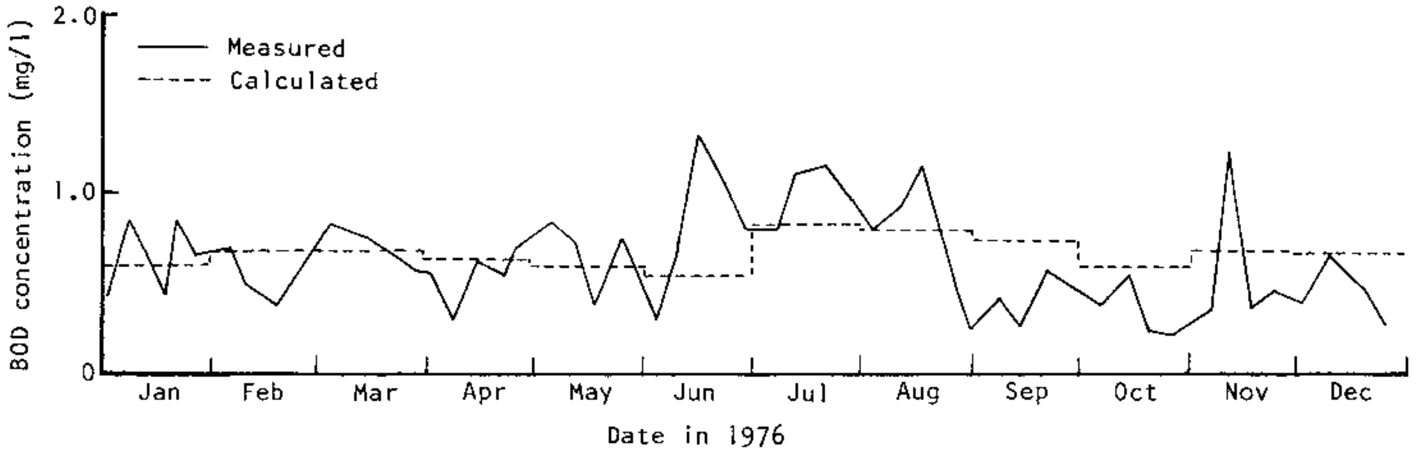


Fig. 8.11--BOD concentration in the Lek at Vreeswijk in 1976

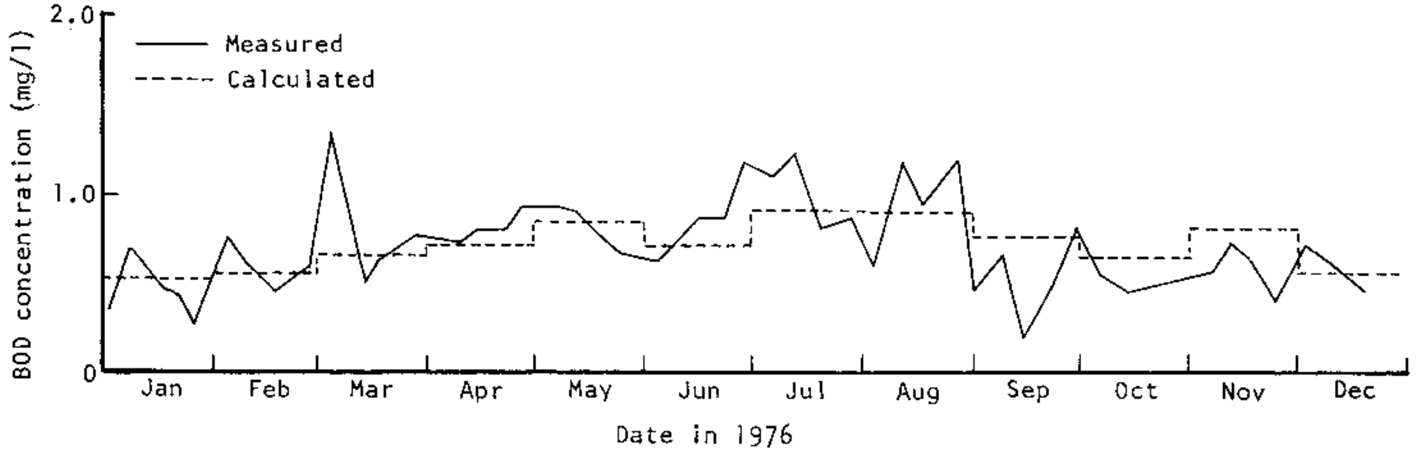


Fig. 8.12--BOD concentration in the Waal at Gorinchem in 1976

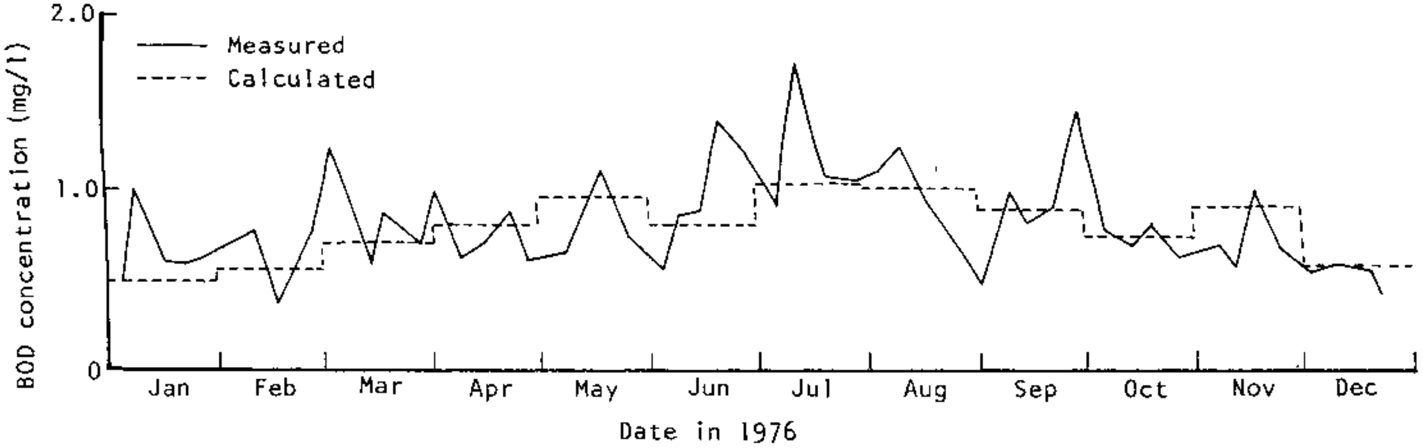


Fig. 8.13--BOD concentration in the IJssel at Kampen in 1976

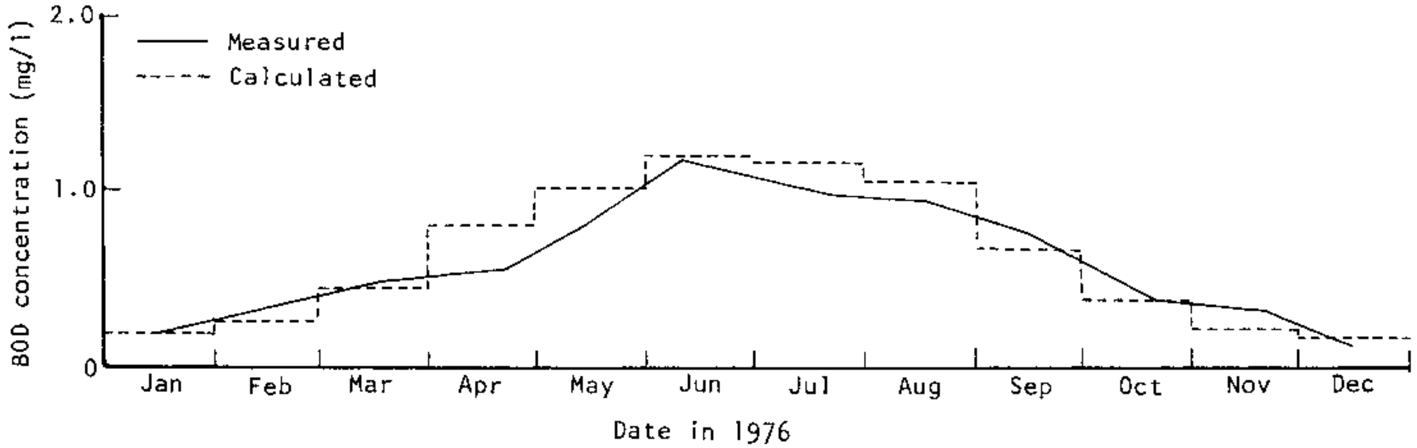


Fig. 8.14--BOD concentration in the IJsselmeer in 1976

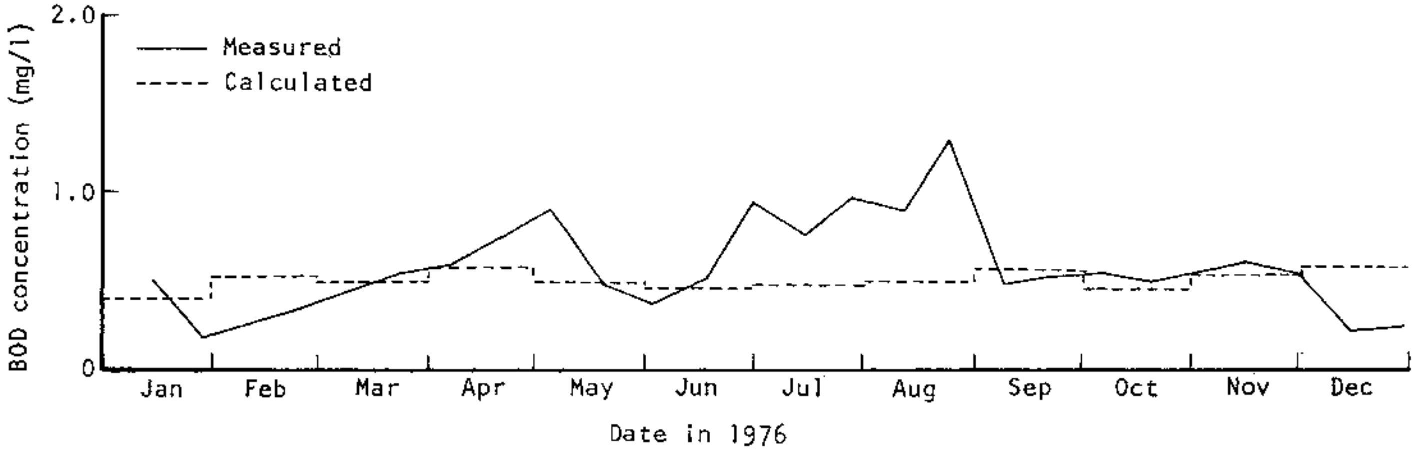


Fig. 8.15--BOD concentration in the Maas at Lith in 1976

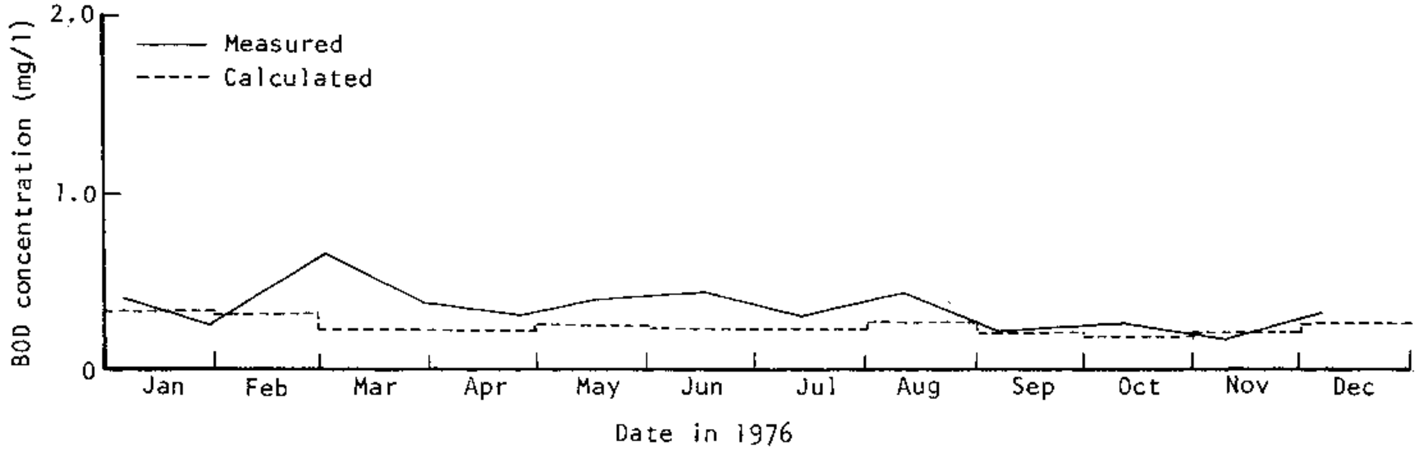


Fig. 8.16--BOD concentration in the Haringvliet in 1976

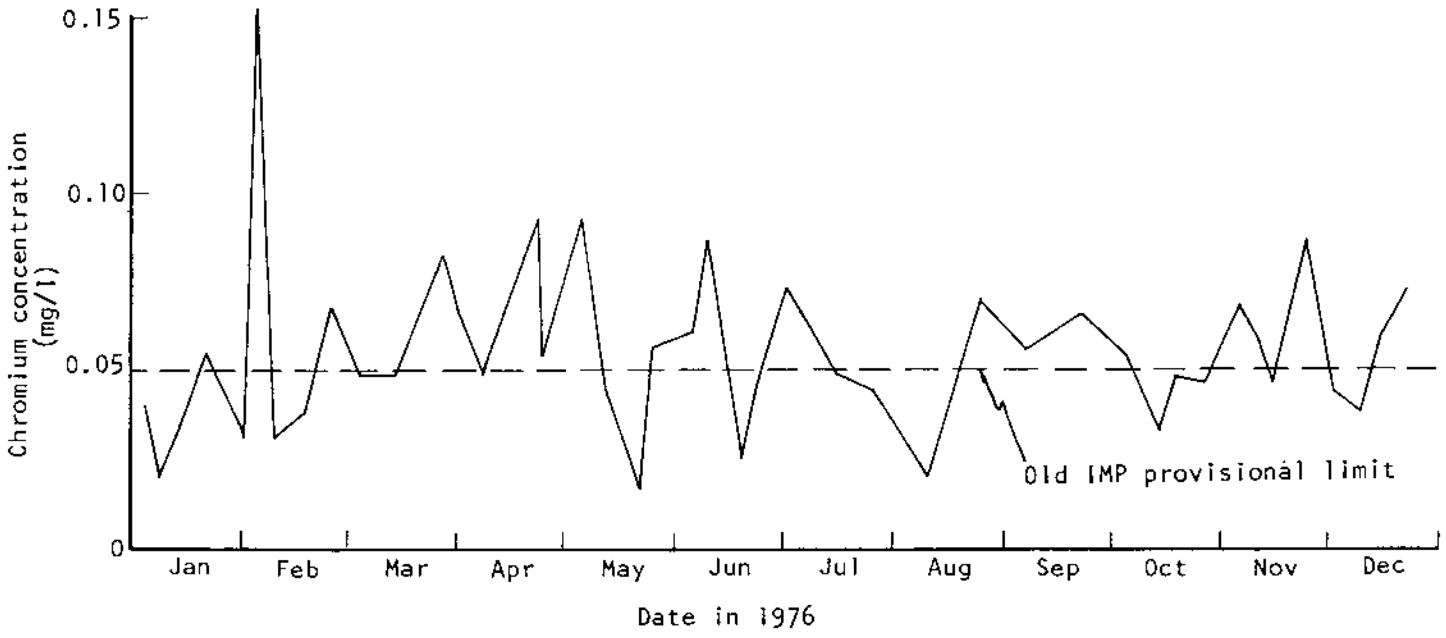


Fig. 8.17--Chromium concentration in the Rijn at Lobith in 1976

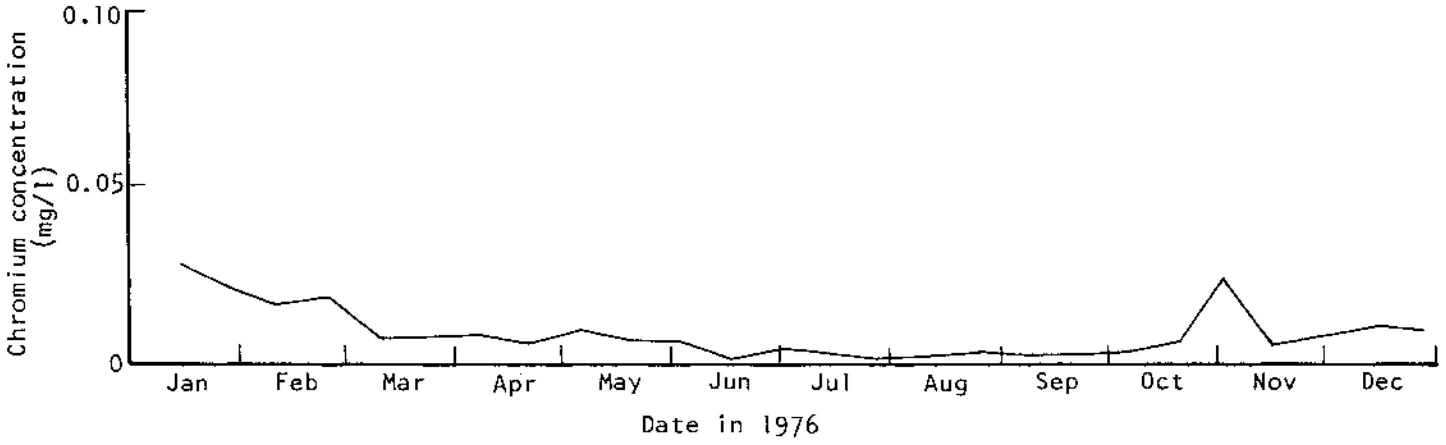


Fig. 8.18--Chromium concentration in the Maas at Eijsden in 1976

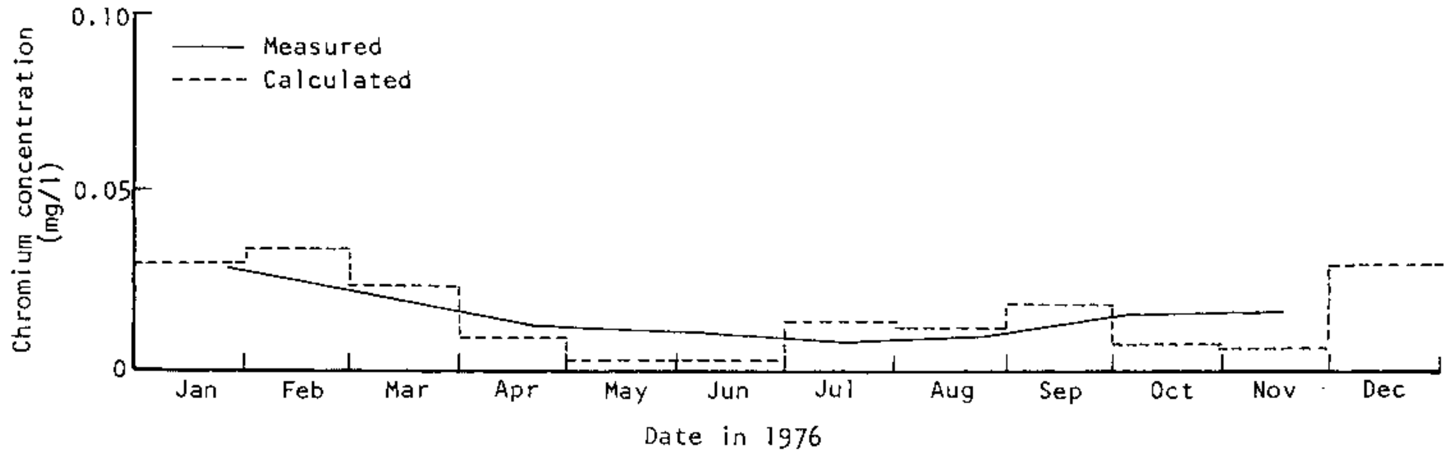


Fig. 8.19--Chromium concentration in the Lek at Vreeswijk in 1976

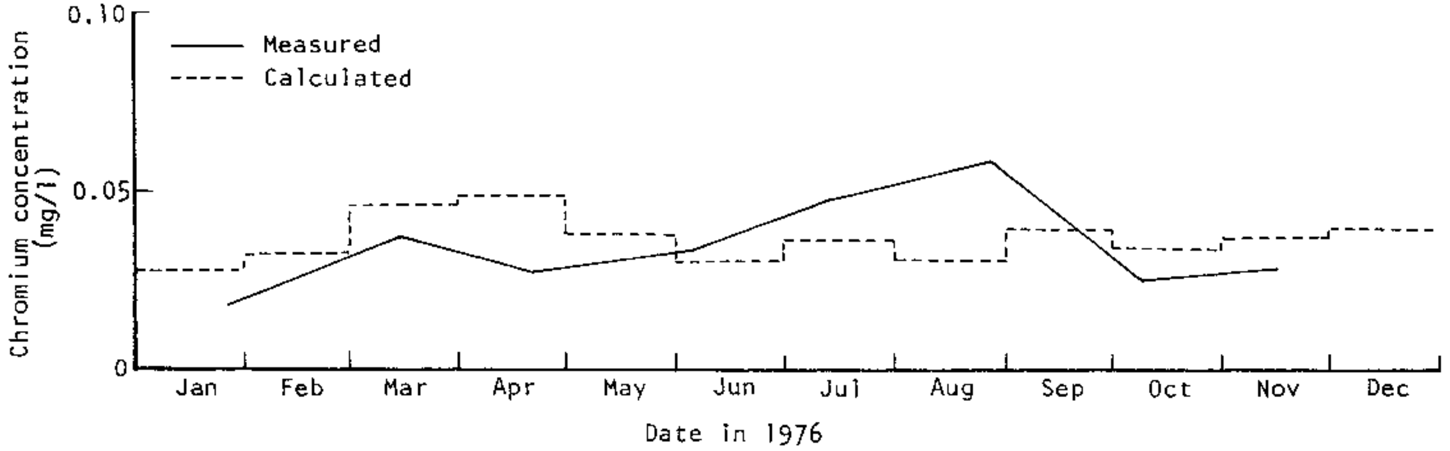


Fig. 8.20--Chromium concentration in the Waal at Gorinchem in 1976

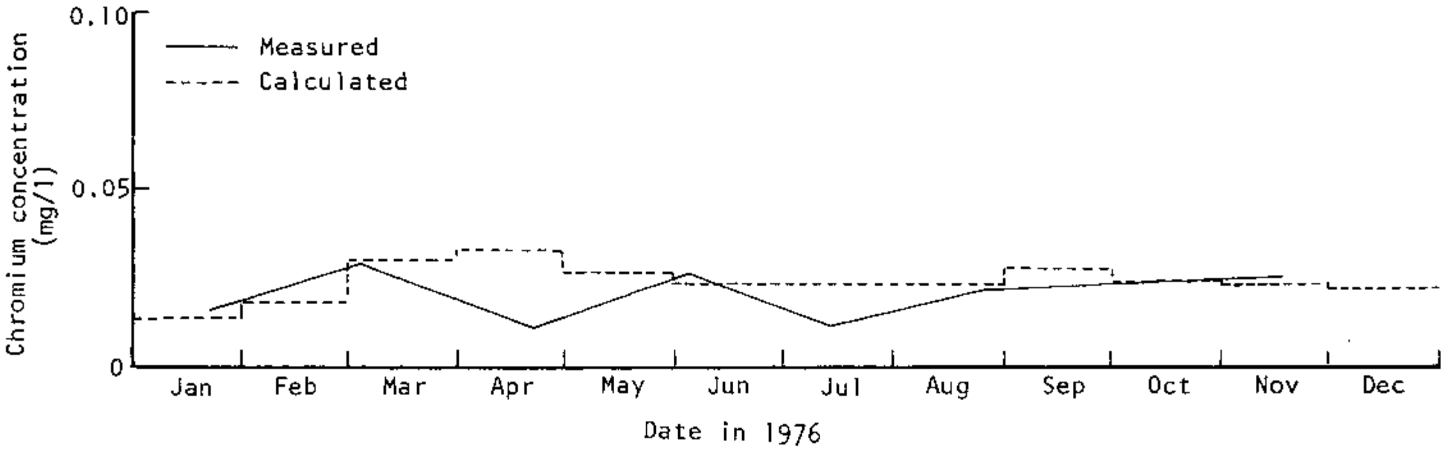


Fig. 8.21--Chromium concentration in the IJssel at Kampen in 1976

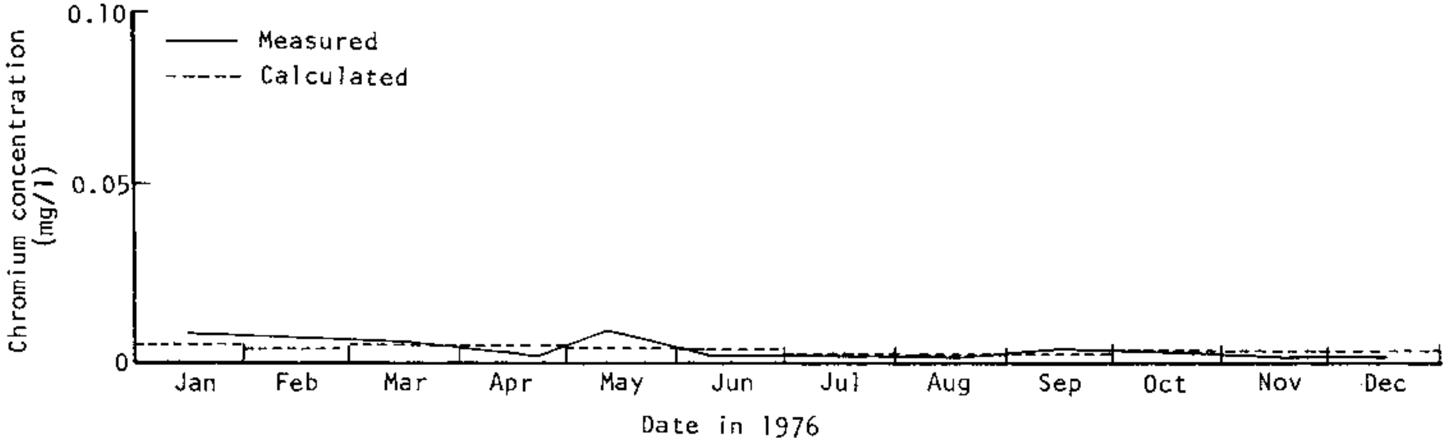


Fig. 8.22--Chromium concentration in the IJsselmeer in 1976

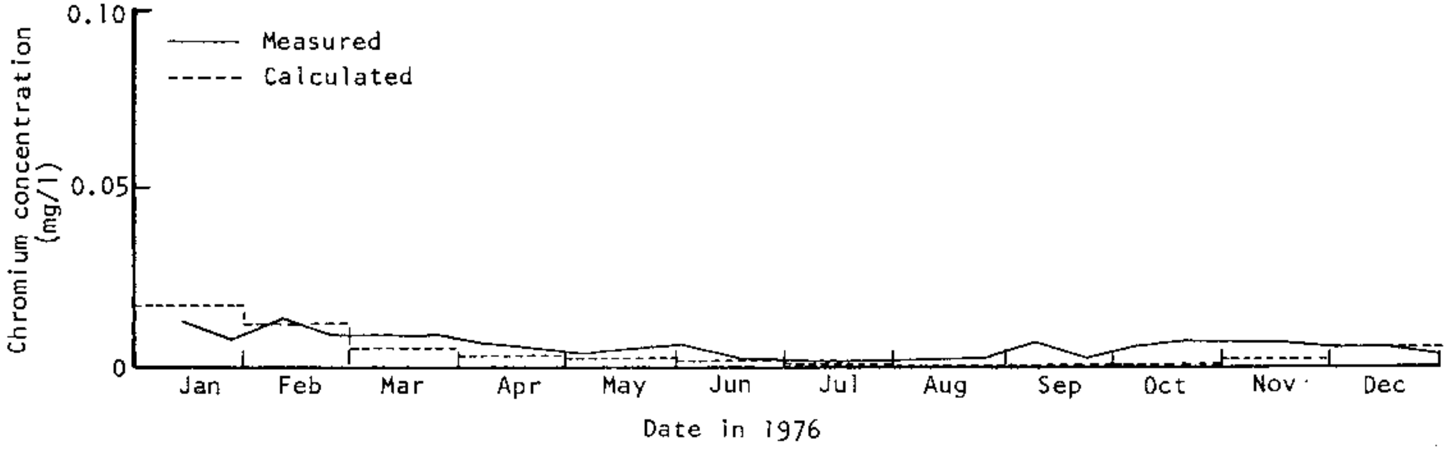


Fig. 8.23--Chromium concentration in the Maas at Lith in 1976

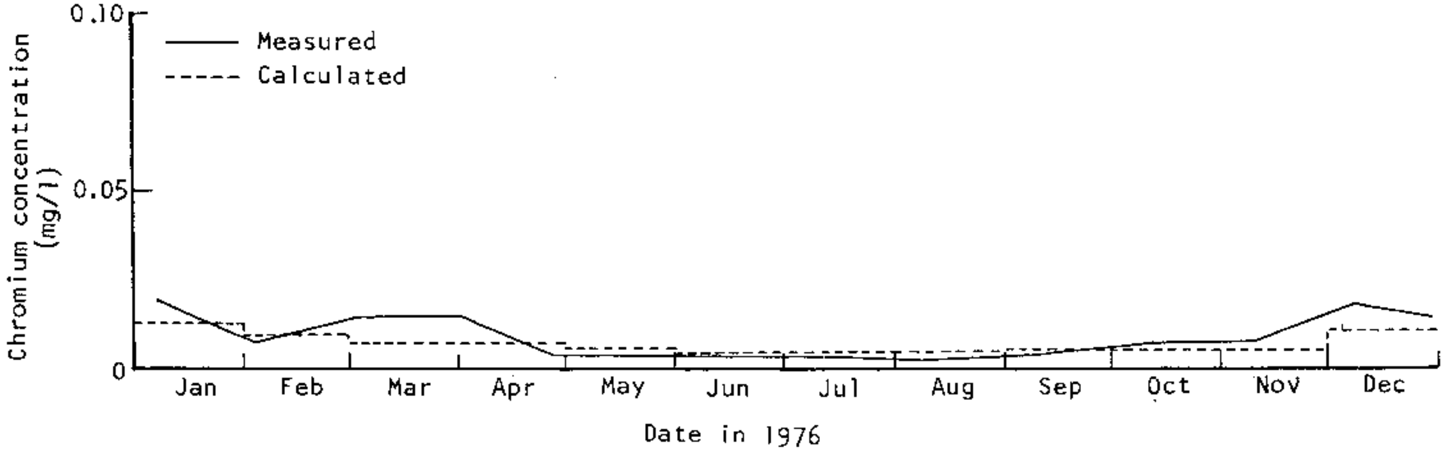
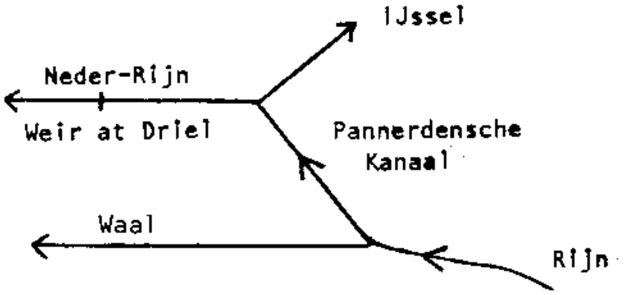


Fig. 8.24--Chromium concentration in the Haringvliet in 1976

Appendix A

WATER DISTRIBUTION IN THE UPPER RIVERS

After the Rijn River crosses the Dutch border, it splits into three branches--the Waal River, and, via the Pannerdensche Kanaal, the Neder-Rijn and IJssel rivers.



The distribution of the Rijn discharge among its three branches is a function of the Rijn discharge and the setting of the weir at Driel on the Neder-Rijn. In the open river situation, i.e., with the weir completely open (raised), the Waal receives approximately 2/3, the Neder-Rijn 1/5, and the IJssel 2/15 of the Rijn discharge. At low Rijn discharges with the weir completely closed, the flow in the Neder-Rijn is stopped and the water that would flow in the Neder-Rijn with the weir open is distributed between the Waal and the IJssel in an approximate 3 to 2 ratio so that the Waal receives 4/5 and the IJssel 1/5 of the Rijn discharge.

Figures A.1 and A.2 contain curves giving the flows in the three Rijn branches as a function of the Rijn discharge for both the open river and the fully closed weir cases. These curves were plotted from data contained in an RWS communication to Rand dated October 4, 1977, and are based on a 1975-1976 upper rivers schematization. When the weir at Driel is fully closed, the island upon which the weir is built starts to be flooded when the water above the weir reaches a level of NAP + 10.25 m, corresponding to a Rijn discharge of 2170 m^3/s, and the flows in the closed weir case approach those for the open river as the Rijn discharge increases above that value. In practice, the weir is gradually raised as the level nears NAP + 10.25 m to prevent the island from being flooded.

For settings of the weir at Driel intermediate to the open and completely closed situations, data from computer listings provided by the RWS (also based on the 1975-1976 schematization) were used to derive the curves in Fig. A.3. These curves give the flow in the IJssel as a function of the Rijn discharge and the flow in the

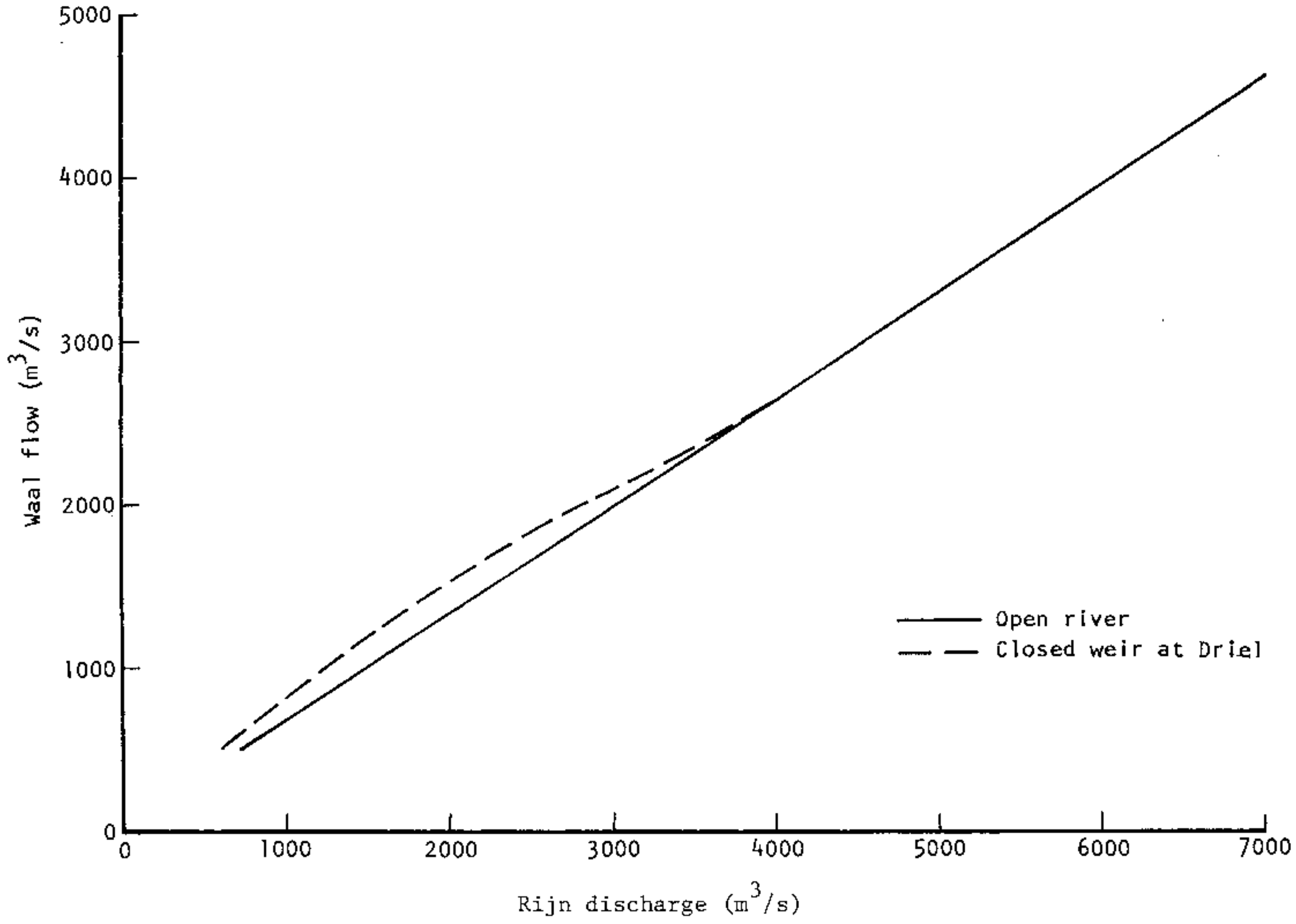


Fig. A.1--Flow on the Waal as a function of the Rijn discharge

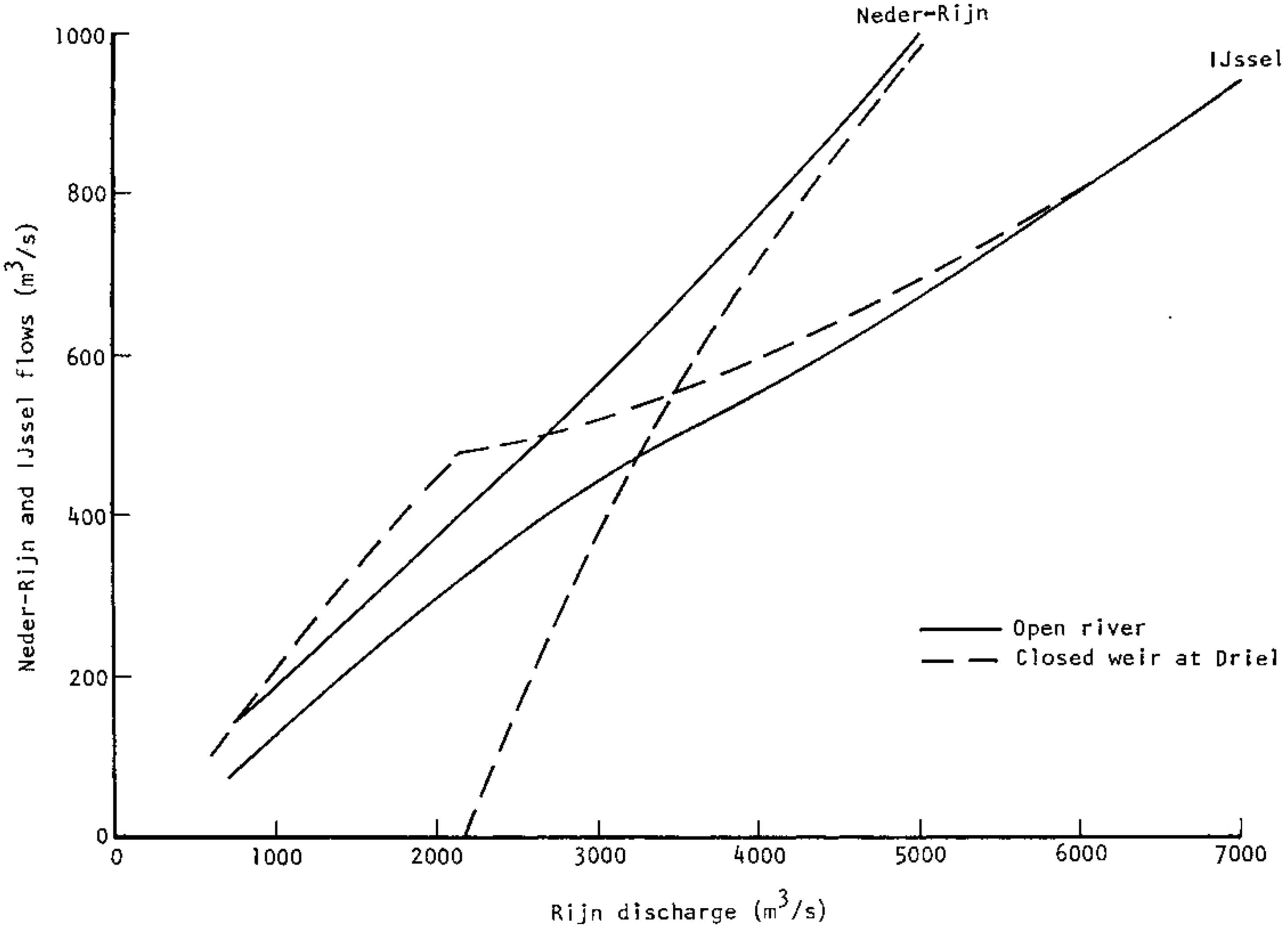


Fig. A.2--Flows on the Neder-Rijn and IJssel as functions of the Rijn discharge

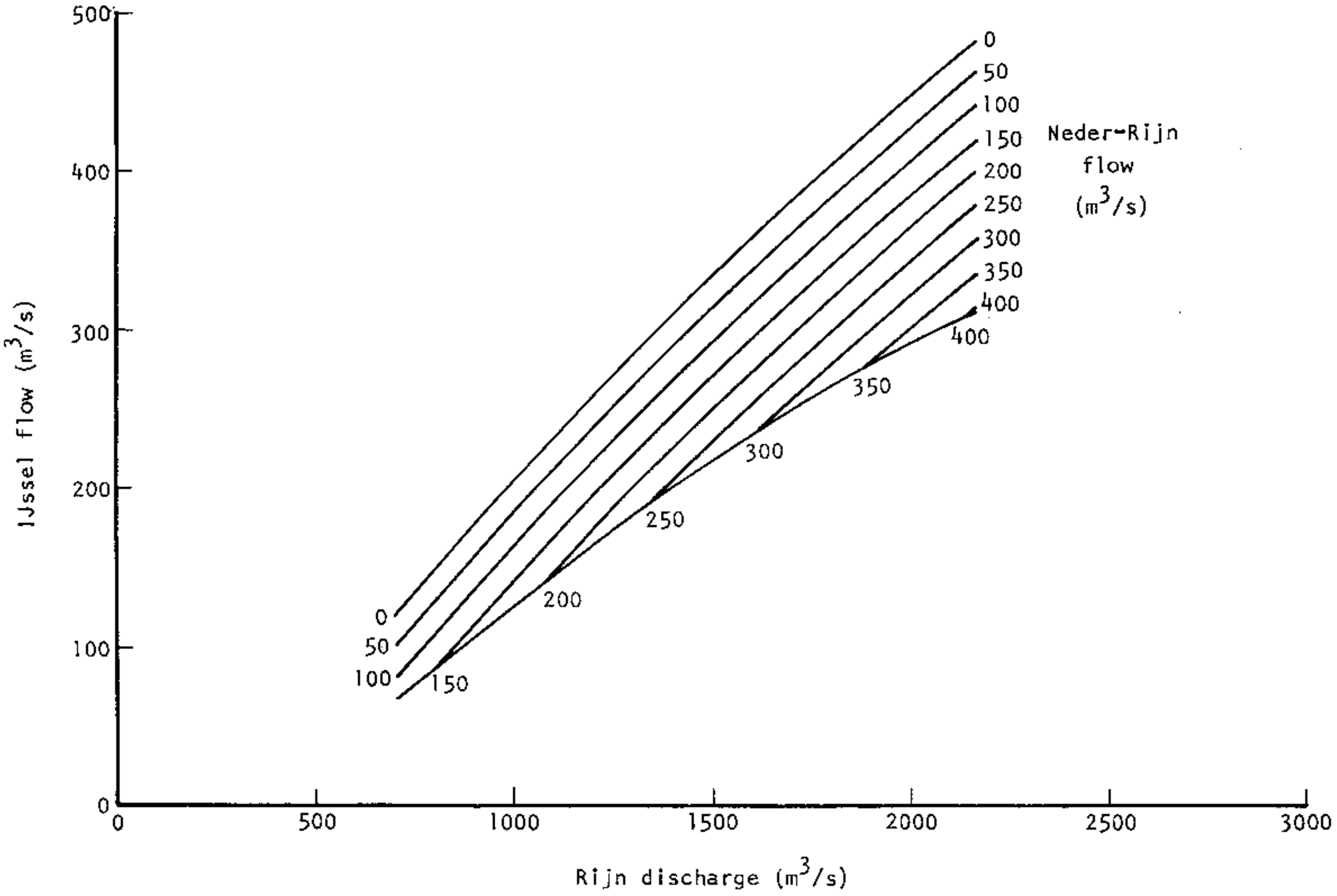


Fig. A.3--Flow on the IJssel as a function of the Rijn discharge and the flow on the Neder- Rijn

Neder-Rijn (the flow in the Waal may then be obtained by subtracting the IJssel and Neder-Rijn flows from the Rijn discharge). The figure encompasses the current redistribution capabilities of the Neder-Rijn open river flow corresponding to Rijn discharges between 700 m^3/s and 2170 m^3/s. Since the long-term average Rijn discharge is 2200 m^3/s and 700 m^3/s approximates the lowest Rijn discharge in the drought year 1976, the figure includes most of the region of interest for the distribution among the three branches at low Rijn discharges. The curves in Fig. A.3 are approximated in the DM by the following equations, which agree in general with the original data points to within 5 m^3/s:

$$R \le 2170$$

$$N \le 0.3165R - 2.6518(R/100)^2 + 0.03962(R/100)^3 - 367 \qquad (A.1)$$

$$I = 0.453R - 1.092(R/100)^2 + 0.0163(R/100)^3 - 0.412N - 151 \qquad (A.2)$$

$$W = R - N - I \qquad (A.3)$$

where R is the Rijn discharge (m^3/s), and W, N, and I are the flows (m^3/s) in the Waal, Neder-Rijn, and IJssel, respectively.

Equations A.1 to A.3 are valid approximations for flows in the Rijn branches as long as the weir at Driel does not overflow. They are used in the DM to implement weir schedules (Sec. 5.3.2) for desired IJssel flows up to 350 m^3/s. The open river flows given by Eqs. A.1 to A.3 (i.e., using the equality sign in Eq. A.1) are valid for Rijn discharges up to 3000 m^3/s. For Rijn discharges between 3000 m^3/s and 18000 m^3/s, the following approximations are used:

$$N = 29 + 809.6(R/5000) + 169.6(R/5000)^2 - 25.1(R/5000)^3$$

$$3000 \le R \le 18000$$

$$I = 182 + 360.5(R/5000) + 127.1(R/5000)^2 - 0.58(R/5000)^5$$

$$3000 \le R \le 18000$$

If the IJssel is canalized by placing a series of weirs on the IJssel, the distribution of the Rijn discharge among the three Rijn branches is controlled by the settings of the weir at Driel and the southernmost weir on the IJssel. The flows on the Neder-Rijn and

IJssel can then be completely controlled between the limits set by the completely open and completely closed weirs. For the situation with a completely open weir on the IJssel, the computer listings described above were used to obtain the following approximations to the flows in the three Rijn branches:

$$I \leq 0.251R - 0.29(R/100)^2 + 0.167(R/100)^5 - 96 \qquad (A.4)$$

$$N = 0.304R - 0.135(R/100)^2 - 0.467I - 45 \qquad (A.5)$$

$$W = R - I - N \qquad (A.6)$$

Equations A.1 to A.6 were used to obtain the flows for the three Rijn branches for the IJssel canalization weir schedules described in Sec. 5.3.2.

Appendix B

WATER DISTRIBUTION IN THE LOWER RIVERS

Figure B.1 presents in schematic form the network of the combined lower rivers portions of the Rijn and Maas rivers. In the DM the flows in the internal links of this lower rivers network are approximated as linear functions of the discharges into and extractions from the network. In this appendix we describe how these approximations were obtained.

In the DM the primary importance of having good approximations to the flows in the lower rivers network is due to the fact that salt intrusion from the Rotterdam salt wedge depends not only upon the total flow in the Nieuwe Waterweg but also upon the division of that flow between the Nieuwe Maas and Oude Maas.

In general, the flows in the lower rivers network are varying functions of time, depending not only on the discharges into and extractions from the network but also on the levels of the tide in the North Sea outside the Nieuwe Waterweg. The determination of the dynamic flows in such a network requires a complex computer model that approximates the solution of a system of partial differential equations derived from the equations of motion that describe such flows. IMPLIC is the name of one such computer model; it was developed in the Netherlands and has been used in a number of investigations of the lower rivers network, as well as for other river and channel networks.

In the DM, we use the flows in the network averaged over a decade when the boundary conditions of discharges into and extractions from the network are assumed to be constant over the decade. When the IMPLIC model is run with such constant boundary conditions for a number of tidal periods (12 hr, 25 min) in which the tidal levels in the Nieuwe Waterweg repeat each cycle, the water flows and water levels in the network sections reach a steady-state condition after a few tidal periods so that the values of these variables a tidal period apart in time are identical. The average flows over a tidal period after the steady-state condition has been reached are thus a good approximation to the average flows over a decade, for the given boundary conditions. Hereafter, in this appendix, the term flow will mean the average flow over a tidal period after the steady-state condition has been reached.

Since the total flows into and out of a node in the network must be equal (from the steady-state assumption), a system of linear equations can be set up for the flows in the river sections of the network. For given discharges into and extractions from the network, given values of flows in three of the sections can determine the flows in the remaining sections. Figure B.2 illustrates how all flows can be determined when the flows are known for the three sections of the Oude

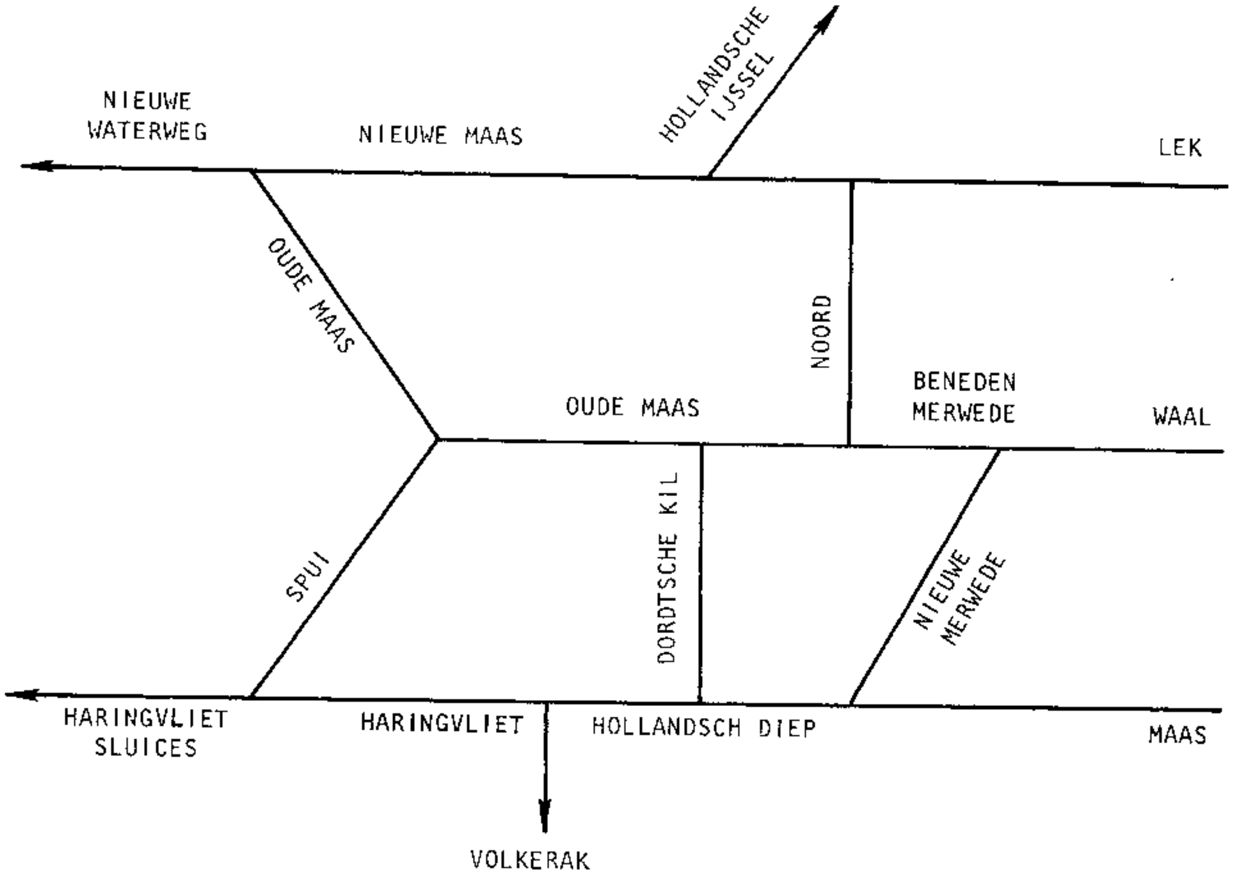
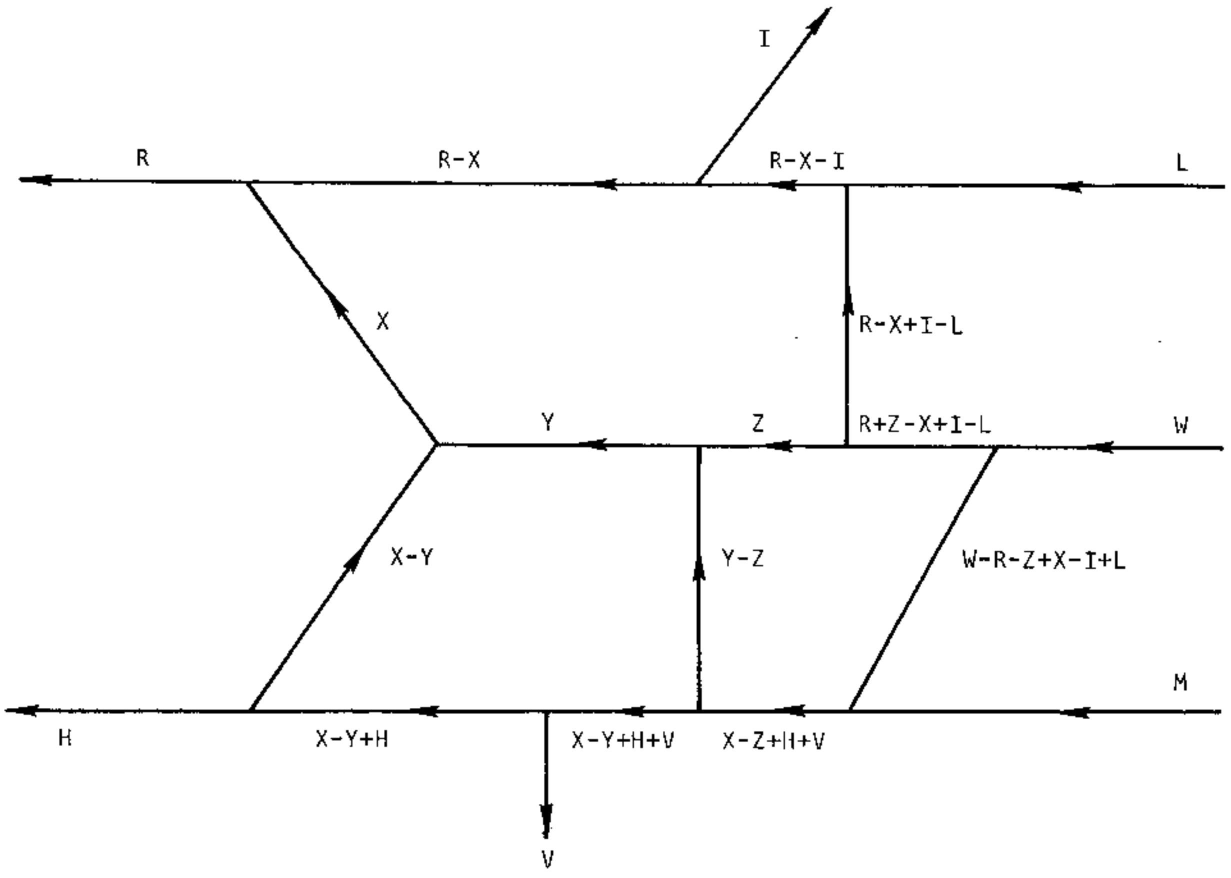


Fig. B.1--Schematic of the lower rivers network



NOTE: L,W,M,I,H and V are assumed to be known so that R = L+W+M-I-H-V

Fig. B.2 --Solution for flows in the lower rivers network

Maas. In the figure, the positive flow directions are indicated by arrows; X, Y, Z are the flows in the three sections of the Oude Maas; W, M, L, I, H, and V are (given) flows on the Waal, Maas, Lek, Hollandsche IJssel, Haringvliet, and Volkerak, respectively.

Forty-seven IMPLIC runs from earlier investigations of the lower rivers network were examined for relationships between the flows in the three sections of the Oude Maas and the boundary condition flows. Linear regression techniques were used to find predictors of the flows in the three Oude Maas sections as linear functions of the boundary condition flows. The results were very encouraging but could not be used for the DM since the runs were made for several different schematizations of the lower rivers network (different values for the parameters that characterize the waterway sections), and only a few of the runs were for the schematization of the current lower rivers situation, the 1976 schematization, the one to be used for the majority of the PAWN DM runs. Also, the set of IMPLIC runs did not cover the full range of boundary condition flows of interest to the PAWN study, and it was not known how good the predictors would be over the full range of boundary condition flows. Consequently, it was decided to make a series of IMPLIC runs using the 1976 schematization in which a range of values was covered for each of the boundary condition flows. The preliminary investigation had shown that for predictive purposes two sets of boundary flows could be combined into single variables--the Lek flow minus the flow in the Hollandsche IJssel, and the flow out of the Haringvliet sluices plus the flow through the Volkerak. Runs were made for Waal flows corresponding to flows in the Rijn of 600, 1000, 1700, and 2200 m^3/s with all combinations of high and low values of Maas flows, high and low values of the Lek flow minus the Hollandsche IJssel flow, and high and low values of the discharge flow at the Haringvliet sluices minus the flow in the Volkerak.

In addition to these 32 (4x2x2x2) IMPLIC runs, 10 others were made for typical boundary flows corresponding to Rijn flows ranging from 600 to 2200 m^3/s. All of the runs were made with the standard 1971 tide at the mouth of the Nieuwe Waterweg shown in Fig. B.3.

The linear predictors obtained for the flows in the three sections of the Oude Maas in terms of the boundary condition flows obtained from this set of IMPLIC runs are

$$X = 0.639(W + M) + 0.136(L - I) - 0.648(H + V) + 20 \tag{B.1}$$

$$Y = 0.453(W + M) + 0.149(L - I) - 0.430(H + V) + 21 \tag{B.2}$$

$$Z = 0.121W - 0.193M + 0.157(L - I) + 0.198(H + V) - 23 \tag{B.3}$$

The average (absolute) prediction errors for X, Y, and Z over the 42 runs are 4, 5, and 8 m^3/s, respectively. These errors are well within the measurement errors for actual flows in the lower rivers network.

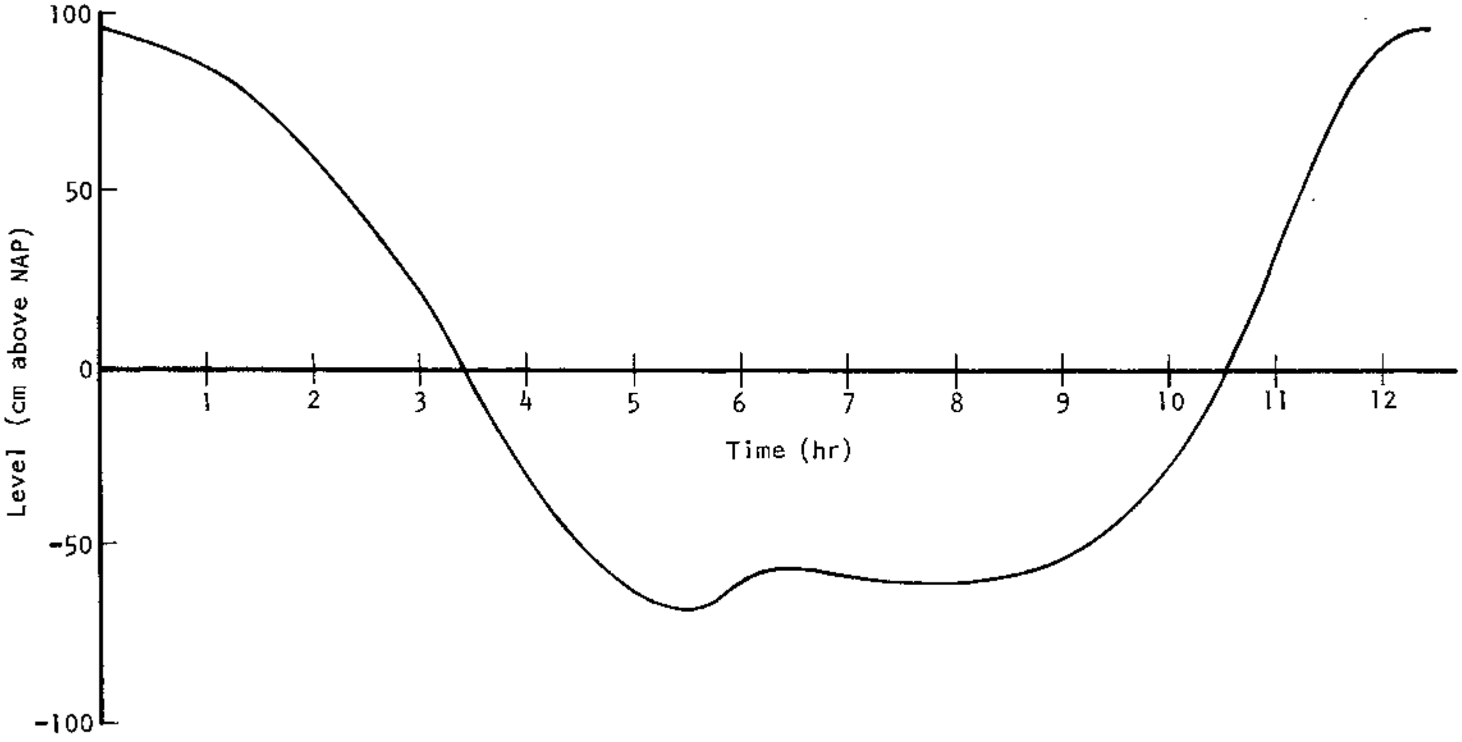


Fig. B.3--1971 average tide at Hoek van Holland

Table B.1 contains the flows produced by IMPLIC for the three sections of the Oude Maas and the predicted flows in these sections from the above equations.

Table B.1

OBSERVED VERSUS PREDICTED FLOWS IN OUDE MAAS SECTIONS
(All values are in m3/s)

Nominal Rijn Disch.	Discharges			Extractions			Flows in Oude Maas Sections								
							X			Y			Z		
	Waal	Maas	Lek	I	II	V	Obs.	Pred.	Error	Obs.	Pred.	Error	Obs.	Pred.	Error
600	402	0	45	0	5	25	263	264	1	194	198	4	40	38	-2
600	402	0	45	19	5	25	261	261	0	193	195	2	39	35	-4
600	402	0	45	60	5	25	257	256	-1	189	189	0	35	29	-6
800	557	0	45	0	5	25	361	362	1	263	267	4	49	57	8
800	557	0	45	19	5	25	359	360	1	262	265	3	47	54	7
800	557	0	45	60	5	25	354	354	0	258	258	0	44	48	4
1000	730	95	45	0	5	25	531	534	3	382	388	6	50	60	10
1000	730	95	45	19	5	25	529	531	2	380	386	6	49	57	8
1000	730	95	45	60	5	25	525	525	0	376	380	4	45	50	5
2200	1495	260	395	30	517	25	841	840	-1	639	637	-2	277	271	-6
600	402	0	25	125	5	0	262	260	-2	191	187	-4	22	10	-12
600	402	0	25	125	5	150	163	163	0	130	122	-8	41	40	-1
600	402	0	100	0	5	0	289	288	-1	213	217	4	46	42	-4
600	402	0	100	0	5	150	188	190	2	155	152	-3	65	72	7
600	402	150	25	125	5	0	361	356	-5	256	254	-2	3	-18	-21
600	402	150	25	125	5	150	260	259	-1	198	190	-8	22	11	-11
600	402	150	100	0	5	0	386	383	-3	277	284	7	27	13	-14
600	402	150	100	0	5	150	288	286	-2	217	220	3	46	43	-3
1000	730	0	25	125	5	0	469	469	0	338	335	-3	46	50	4
1000	730	0	25	125	5	150	369	372	3	282	270	-12	71	80	9
1000	730	0	100	0	5	0	495	497	2	260	365	5	70	82	12
1000	730	0	100	0	5	150	396	399	3	300	300	0	94	111	17
1000	730	250	25	125	5	0	632	629	-3	445	448	3	8	2	-6
1000	730	250	25	125	5	150	532	531	-1	384	383	-1	30	32	2
1000	730	250	100	0	5	0	658	656	-2	467	477	10	33	34	1
1000	730	250	100	0	5	150	558	559	1	410	413	3	55	63	8
1700	1165	0	225	125	5	0	777	774	-3	567	561	-6	138	134	-4
1700	1165	0	100	0	5	150	667	677	10	499	497	-2	156	164	8
1700	1165	0	320	120	5	0	794	788	-6	582	576	-6	154	150	-4
1700	1165	0	320	0	5	150	707	707	0	533	529	-4	192	198	6
1700	1165	550	225	125	315	0	940	931	-9	673	681	8	90	87	-3
1700	1165	550	100	0	165	150	835	839	4	608	620	12	107	116	9
1700	1165	550	320	0	535	0	830	822	-8	610	622	12	156	164	8
1700	1165	550	320	120	285	150	775	765	-10	576	577	1	156	158	2
2200	1495	0	300	100	200	0	873	876	3	652	644	-8	236	227	-9
2200	1495	0	200	0	50	150	875	886	11	656	651	-5	227	224	-3
2200	1495	0	405	0	400	0	792	795	3	608	603	-5	299	292	-7
2200	1495	0	405	100	175	125	817	819	2	630	613	-17	276	265	-11
2200	1495	700	200	0	700	200	859	869	10	661	660	-1	226	231	5
2200	1495	700	300	100	775	125	879	880	1	668	666	-2	231	228	-3
2200	1495	700	405	100	850	150	839	836	-3	647	643	-4	267	262	-5
2200	1495	700	405	0	1100	0	808	805	-3	623	629	6	292	291	-1

Appendix C

THE POLLUTANT DIFFERENTIAL EQUATION

In the DM the amount of pollutant in any volume of water is assumed to be diminished over time by natural processes. For pollutants other than thermal the pollutant loss (or decay) is assumed to be proportional to the amount of pollutant in the volume (for salt the constant of proportionality is zero). For thermal pollution, the loss represents the transfer of excess heat from the water to air at the air/water interface and the transfer rate is assumed to be proportional to the water surface area and the concentration of excess heat in the water, i.e., the excess temperature (see Sec. 6.3). For storage volumes we make the additional assumption of instantaneous mixing with the storage volume of any water and pollutant being added. Other assumptions are implied by the definitions below (see Vol. V for a detailed discussion of these assumptions).
Define

$P(t)$ = the amount of pollutant in storage at time t (for thermal pollution the amount of pollutant is the excess heat),
$C(t)$ = the pollutant concentration at time t (for thermal pollution the concentration is measured by the temperature),
$V(t)$ = the storage volume at time t,
A = the surface area of the storage volume,
T = the length of the time period, i.e., $0 \le t \le T$,
D = the rate at which water is being discharged into storage plus precipitation on and minus evaporation from the storage area,
E = the rate at which water is being extracted from the storage volume (with concentration $C(t)$),
Q = the rate of change of the storage volume,
$= D - E$,
S = the rate at which new pollutant is being added to the storage volume, either discharged directly into storage or transported in the water being discharged into storage,
k = the pollution decay rate (k is zero for salt and thermal pollution),
R = the heat loss rate (R is zero for pollutants other than thermal).

Then

$$V(t) = V(0) + Qt \tag{C.1}$$

$$P(t) = C(t)V(t) \tag{C.2}$$

and, from our assumptions, the amount of pollutant in storage satisfies the differential equation

$$dP(t)/dt = S - EC(t) - kP(t) \tag{C.3}$$

for pollutants other than thermal, and

$$dP(t)/dt = S - EC(t) - RAC(t) \tag{C.4}$$

for thermal pollution. From Eqs. C.2 and C.1,

$$\begin{aligned} dP(t)/dt &= C(t)dV(t)/dt + V(t)dC(t)/dt \\ &= QC(t) + V(t)dC(t)/dt \end{aligned}$$

so that

$$dC(t)/dt = [dP(t)/dt - QC(t)]/V(t) \tag{C.5}$$

From Eqs. C.5, C.3, and C.2, the pollutant concentration satisfies the differential equation

$$\begin{aligned} dC(t)/dt &= [S - EC(t) - kP(t) - QC(t)]/V(t) \\ &= [S - DC(t)]/V(t) - kC(t) \end{aligned} \tag{C.6}$$

for pollutants other than thermal, and from Eqs. C.5 and C.4,

$$dC(t)/dt = [S - DC(t) - RAC(t)]/V(t) \tag{C.7}$$

for thermal pollution. Equations C.6 and C.7 may be written in combined form as the [pollutant differential equation],

$$dC(t)/dt = [S - DC(t) - RAC(t)]/V(t) - kC(t) \tag{C.8}$$

In discussing the solution of Eq. C.8, we may, without loss of generality, take $V(0) = 1$, $R = 0$, and $T = 1$. This may be shown by making the normalizing transformation, $t^* = t/T$, $C^*(t^*) = C(Tt^*)$,

$V^*(t^*) = V(Tt^*)/V(0)$, $S^* = ST/V(0)$, $k^* = kT$, $D^* = (D + RA)T/V(0)$, $E^* = (E + RA)T/V(0)$, in Eq. C.8 and then dropping the superscripts. Then Eq. C.8 reduces to

$$dC(t)/dt = [S - DC(t)]/V(t) - kC(t) \qquad 0 \le t \le 1 \qquad (C.9)$$

This differential equation is in a standard form that has a solution satisfying

$$C(t)\ \exp\left(\int_0^t x(s)ds\right) = C(0) + \int_0^t y(s)\ \exp\left(\int_0^s x(u)du\right)ds \qquad (C.10)$$

where

$$x(t) = k + D/V(t), \qquad y(t) = S/V(t),$$

$$\int_0^t x(s)ds = kt + (D/Q)\ \ln(V(t))$$

so that the general solution of Eq. C.9 is

$$C(t) = V(t)^{-D/Q}\, e^{-kt}\ [C(0) + S\int_0^t V(s)^{E/Q}\, e^{ks}\ ds] \qquad (C.11)$$

We need C(t) evaluated at the end of the time period and the average of C(t) over the time period, $\bar{C}$. Defining

$$f(t) = V(t)^{-D/Q}\, e^{-kt}$$

$$g(t) = V(t)^{E/Q}\, e^{kt}, \qquad G(t) = \int_0^t g(s)ds$$

we have, from Eq. C.11,

$$C(t) = f(t)[C(0) + SG(t)]$$

$$C(1) = C(0)f(1) + Sf(1)G(1) \tag{C.12}$$

$$\bar{C} = \int_0^1 C(t)dt$$

$$= \int_0^1 f(t)[C(0) + SG(t)]dt \tag{C.13}$$

In general, Eqs. C.12 and C.13 must be evaluated by numerical integration of the indicated integrals (see Vol. VA), and this is done in the DM. However, analytic solutions of Eqs. C.12 and C.13 exist for the following special cases:

(1) $D = E,\ D + k \neq 0,$

$$C(1) = C(0)e^{-D-k} + S(1 - e^{-D-k})/(D + k)$$

$$\bar{C} = [C(0)(1 - e^{-D-k}) + S[1 - (1 - e^{-D-k})/(D + k)]]/(D + k)$$

(2) $D \neq E,\ S = 0,$

$$C(1) = C(0)e^{-k}\ V(1)^{-D/Q}$$

(3) $D = 0,\ S = 0,$

$$C(1) = C(0)e^{-k}$$

$$\bar{C} = C(0)(1 - e^{-k})/k \qquad k \neq 0$$

$$\bar{C} = C(0) \qquad k = 0$$

(4) $E = 0,\ k \neq 0,$

$$C(1) = C(0)e^{-k}/V(1) + S(1 - e^{-k})/(kV(1))$$

(5) $D \neq E,\ D \neq 0,\ k = 0,$

$$C(1) = C(0)V(1)^{-D/Q} + S[1 - V(1)^{-D/Q}]/D$$

$$\bar{C} = [C(0) - S/D]\ [1 - V(1)^{-E/Q}]/E + S/D \qquad E \neq 0$$

$$= [C(0) - S/D]\ \ln(V(1)) + S/D \qquad E = 0$$

(6) $D \neq E,\ D = 0,\ k = 0,$

$$C(1) = C(0) - (S/E)\ \ln(V(1))$$

$$\bar{C} = C(0) + (S/E^2)[V(1)\ \ln(V(1)) + E]$$

(7) $D = 0,\ E = 0,\ k = 0,$

$$C(1) = C(0) + S$$

$$\bar{C} = C(0) + S/2$$

Equations C.3 and C.4 can be interpreted so as to yield Eqs. 6.1 and 6.2, which are used for pollution concentration decay on links. Let the link have surface area A and volume V. Consider a small element of water with surface area A0, volume V0, and depth equal to the average depth of the waterway represented by the link. Then A0/V0 = A/V. From Eqs. C.3 and C.4, the pollutant concentration in the element satisfies the differential equation,

$$dC(t)/dt = -kC(t) \tag{C.14}$$

for pollutants other than thermal, and for thermal, the differential equation

$$\begin{aligned} dC(t)/dt &= -RC(t)A0/V0 \\ &= -RC(t)A/V \end{aligned} \tag{C.15}$$

The solutions of Eqs. C.14 and C.15 are

$$C(t) = Cb\ \exp(-kt)$$

$$C(t) = Cb\ \exp(-RAt/V)$$

where Cb is the concentration at the beginning of the link. The time it takes the element of water to travel from the beginning of the link to the end is V/Q, where Q is the flow in the link, so that the concentration, Ce, when the element reaches the end of the link is

$$Ce = Cb\ \exp(-kV/Q) \tag{C.16}$$

for pollutants other than thermal, and for thermal

$$Ce = Cb\ \exp(-RA/Q) \tag{C.17}$$

Appendix D

DISTRIBUTION MODEL INPUTS AND OUTPUTS

The following is a brief description of the inputs and outputs of the distribution model. This description is introductory and not intended to be a user's manual. In particular, neither formats nor units are included for either inputs or outputs.

D.1. INPUTS

To facilitate the task of preparing inputs for a computer run of the DM, most of the data inputs are placed in data files that are read into the computer at the start of a run. These inputs are described in Sec. D.1.1. However, certain parameters may be changed on a cycle-by-cycle basis, and the changes are read in each cycle during execution of the run. They are described in Sec. D.1.2. Certain values which are "wired" into the program may also be considered as inputs since they may be changed to reflect altered assumptions or new information.

As a further aid in the preparation of run inputs, a computer program (actually, three programs run in sequence) was written that prepares input data files for a run as a function of keyword inputs that define certain scenario variables--the set of waterboard plans to be implemented, the level and intensity of surface water sprinkling, the level and intensity of groundwater sprinkling, and groundwater quota and priority variables (see Secs. 1.5 and D.1.2). This program is described in Vol. XIV. Most of the data files prepared by this program are inputs to DISTAG (see Vol. XII) and will not be discussed further here. However, three data files are prepared by this program as inputs to the DM, as distinct from DISTAG: costs of (implemented) waterboard plans (see Sec. D.1.1.4); costs of (new) sprinkler equipment (see Sec. D.1.1.4); and district distribution keys (see Sec. D.1.1.1). When waterboard plans are implemented and/or sprinkling levels and intensity are increased, additional costs may be incurred; these costs are provided by the cost files. When waterboard plans are implemented, larger areas are supplied by water inlet works, and capacities of existing inlet works may be expanded and/or new inlet works created; this leads to changes in the district distribution keys from those given in Table 3.8, that represent the current situation.

In screening and impact assessment, the above-described program was run as a separate job step at the beginning of the DM run to create temporary input files that were discarded at the end of the run. In the following, the number of the Fortran dataset containing each input or output file is indicated by a dataset number in parentheses, e.g., (FT50).

D.1.1. Inputs from Data Files

D.1.1.1. Distribution System Infrastructure. The complete PAWN network consisting of 92 nodes and 154 links is always input (see Link Inputs and Node Inputs below). However, the "effective" network is made smaller by "zeroing out" inactive links, i.e., by setting the flow constraints (the values of Cap.1, Cap.2, and FLCT; see Sec. 2.1.1) on those links equal to zero.

Link Inputs (FT12). For each link: link name, names of the nodes at each end of the link, the values for Cap.1, Cap.2, and FLCT, and the surface area and volume of the waterway(s) represented by the link (see Table 2.1).

Node Inputs (FT10). For each node: node name, initial storage level, storage area, storage volume at initial level, initial salinity, heat input at node (see Sec. 2.1.2).

Node Distribution Keys (FT11). For each regional node (i.e., for node numbers greater than 50): node extraction and discharge distribution keys (see Sec. 4.2.3).

District Distribution Keys (FT13). For each district: extraction and discharge distribution keys (see Sec. 3.4).

D.1.1.2. External Supply Files

River Discharges (FT20). By decade: Rijn, Maas, Overijsselsche Vecht, Roer, Niers, and Swalm discharges and discharge salinities.

Rain and Evaporation. By decade: rain and evaporation at each of 16 weather stations (part of input to DISTAG and passed to the DM internal to the program).

D.1.1.3. Pollutant Parameter Files

River Salinities. See river discharges in Sec. D.1.1.2.

Phosphate Concentrations in the Major Rivers (FT51). For each month: phosphate concentrations in discharges of Rijn, Overijsselsche Vecht, Maas, Roer, Niers, Swalm, and Ur (for discharges at PANHEEL) (see Sec. 6.4.2).

BOD Concentrations in the Major Rivers (FT52). For each month: BOD concentrations in discharges of Rijn, Overijsselsche Vecht, Maas, Roer, Noers, Swalm, and Ur (for discharges at PANHEEL) (see Sec. 6.4.2).

Nitrogen Concentrations in the Major Rivers (FT53). For each month: nitrogen concentrations in discharges of Rijn, Overijsselsche Vecht, Maas, Roer, Niers, Swalm, and Ur (for discharges at PANHEEL). Since the DM has not been calibrated for nitrogen, these values have been input as zero.

Chromium Concentrations in the Major Rivers (FT54). For each month: chromium concentrations in discharges of Rijn, Overijsselsche Vecht, Maas, Roer, Niers, Swalm, and Ur (for discharges at PANHEEL) (see Sec. 6.4.2).

Node and District Pollutant Parameters (FT55). For each node and district: initial pollutant concentrations and pollutant discharges for phosphate, BOD, nitrogen, and chromium (see Secs. 6.4.1 and 6.4.3).

Decay Rates and Bottom Release Rates at Nodes (FT58). For each node and each pollutant (i.e., phosphate, BOD, nitrogen, and chromium): pollutant decay rate and bottom release rate from storage at node (see Sec. 6.4.5).

Phosphate Diffuse-Source Parameters (FT56). For each district: constant load and drainage concentration (see Sec. 6.4.4).

Nitrogen Diffuse-Source Parameters (FT57). For each district: constant load and drainage concentration (see Sec. 6.4.4).

D.1.1.4. Cost Files.

Tactic Cost Table (FT16). Cost parameters for each technical tactic (see Sec. 7.3).

Costs of Waterboard Plans (FT14). For each district: cost of waterboard plan (if implemented for run).

Costs of Sprinklers (FT15). Annualized fixed costs of sprinklers for newly sprinkled areas in each district and each crop in the district.

D.1.2. Inputs Read in with the Run JCL

These inputs are read in as data along with the JCL (Job Control Language) inputs defining the run (but may be read from a separate Fortran dataset FT05, if desired). They are read as a card-image data file (i.e., as 80-character logical records).

D.1.2.1. Run Title. A 3-card (240 characters) description of the run that is printed on three lines at the top of a number of output pages for run identification. The first 80 characters are arbitrary. The remaining 160 characters are divided into 20 8-character fields whose entries are keywords that define various aspects of the input scenario for the run. The list below describes each of the 20 fields and the options for the keyword values in those fields. Unless otherwise indicated, the first listed keyword alternative is the default value; i.e., if the keyword field is left blank, the first listed keyword is implied.

1. Context. CON76 and CON85 indicate 1976 and 1985 context, respectively. For a DM run, the content implies 1976 or 1985 values for shipping losses and for extractions by industry, drinking-water companies, and Belgium.

2. External supply. DEX is the "extremely" dry year defined in Sec. 1.4; D05 is actual 1959; D10 is actual 1943; D50 is actual 1967; and WEX (for "extremely" wet year) is actual 1965 (see Sec. 1.4).

3. Surface water sprinkling. SPRLOW, SPRMED, and SPRHI indicate low, medium, and high levels of surface water sprinkling intensity, respectively (see Vols. II and XIV).

4. Waterboard plans implemented. RNONE indicates no waterboard plans are implemented; R1 through R8 indicate waterboard plans implemented only in regions 1 to 8, respectively (excluding district 77); R9 indicates a fresh Grevelingen and the waterboard plan implemented that takes water from the fresh Grevelingen to district 77; RALL indicates all waterboard plans are implemented, exclusive of the one for district 77; RALL9 indicates all waterboard plans are implemented, including the one for district 77.

5. Groundwater sprinkling (e.g., GWLOW, GWMEDI00, GWHII00, GWHII20, GWHIA20, GWHIA00, GWHIQ150). The first characters indicate low, medium, and high levels of groundwater extractions; the remaining refer to groundwater priority, quota, and use charge (see Sec. 1.5). See Vol. XIV for a complete description of the allowable keywords.

6. Number of cycles. Default is 36; any nonblank input sets the number of cycles equal to 12.

7. Flag for DISTAG. Default is to use DISTAG. Any nonblank input indicates that DISTAG inputs to DM are to be read from FT30 (used for test purposes only).

8, 9, and 10. (not used)

11. Rijn salt dump. RSDLOW, RSDINT, RSDMED, and RSDHI indicate values for the Rijn salt dump of 251, 305, 311, and 365 kg/s, respectively (see Sec. 6.2.1).

12. Maas. MAASREF indicates no Maas Treaty; MAASYES indicates that the Maas Treaty is implemented. (Under MAASYES the DM takes the larger of the input Maas discharge and 50 m^3/s for each decade.)

13. Zoommeer. ZOOMREF indicates a fresh Zoommeer; ZOOMSLT indicates a salt Zoommeer.

14. Grevelingen. GREVREF indicates a salt Grevelingen. GREVFR indicates a fresh Grevelingen.

15. Markerwaard. MARKREF indicates no Markerwaard; MARKYES indicates a Markerwaard.

16. Thermal standard (intended to be used for thermal standards, but is not actually used).

17. Tiel. TIELREF indicates dredging of Waal is allowed; TIELNO indicates no dredging.

18. Pollutants. POLL76 and POLL85 indicate 1976 and 1985 scenario values for pollutants in the major river discharges, respectively (see Sec. 6.4.2); default (i.e., a blank input) indicates no pollutant calculations are to be made by the DM.

19. Management strategy. RWPOLICY, SDPOLICY, DNPOLICY, and EXPOLICY indicate the RWS strategy, the MSDM strategy, the Velsen strategy, and the current strategy, respectively (see Sec. 5.4).

20. (not used)

D.1.2.2. Cycle-by-Cycle Inputs. The first field on each card (or on the first card for those inputs that take more than one card) is the decade at which the parameter changes indicated on the card are to take effect, and the second field is an 8-character (or less) keyword identifier for the card. The entire set of cards must be arranged in order of increasing time (i.e., decade number); otherwise the ordering is arbitrary. The following is a list of the permissible keywords and a description of the contents of the remainder of the card image, including the parameter values affected.

ARKANAL5. Two values: flow in ARKANAL5 is increased to first value (if not already larger) whenever Rijn discharge is greater than the second value.

BELGMIN. The minimum value to which the extraction by Belgium at Lozen may be reduced (see Sec. 5.3.1).

CAPTABLE. Link name (SCHERMIN, STONTEL, or MARGKAN); values for extraction capacities as function of lake level (see Secs. 4.3.2 and 4.3.3).

DECAY. Four values: decay rates in districts for the four pollutants: phosphate, BOD, nitrogen, and chromium.

DEXTKEY. District name; new extraction distribution key for the named district (see Sec. 3.4).

DDISKEY. District name; new discharge distribution key for the named district (see Sec. 3.4).

DISCH. Node name; an (arbitrary) number for discharge type; discharge at named node by industry, drinking-water companies, etc., for 1976 context; same for 1985 context; salinity of the discharge.

EMERG1. Number of the Midwest emergency plan selected for the run plus 5-character identifiers for each of 6 plans.

EMERG2. Link name; capacity of link (i.e., the Cap.2 value; see Sec. 2.1.1) for each of the six plans named on the EMERG1 card (one card for each link connected with any of the plans). (The EMERG1 and EMERG2 inputs are included as a convenience to the user; they need not be used.)

EXTRACT. Node name; an (arbitrary) number for extraction type; extraction at named node by industry, drinking-water companies, etc., for 1976 context; same for 1985 context.

FLUSHD. District name; new value for the amount of flushing for named district.

FLUSHL. Two following card images indicate by a "1" in the column corresponding to link number (i.e., columns 1-80 on the first card correspond to links 1-80; columns 1-74 on the second card correspond to links 81-154) those links whose FLCT value represents a desired flow that may be cut back to the Cap.1 value for the link (see Table 2.1).

GOUDA. The salinity from the Rotterdam salt wedge at the Gouda inlet that triggers emergency action in the Midwest (see Sec. 5.3.6).

GREV. Indicator for use of bubble screens at locks at Bruinisse in the Grevelingen (1 indicates use of bubble screens; 0 is default).

HEAT. Indicator that temperatures at nodes are to be calculated (1 indicates that temperature calculations are to be made; 0 indicates no temperature calculations).

LEVEL. Node name; target, emergency (both flushing and sprinkling for the IJssel lakes), and minimum levels for storage at the node.

LINK. Link name; Cap.1, Cap.2, and FLCT values for the named link (see Table 2.1).

LOCK. Lock name (KREEKRAK or PHILIPS, for Kreekrak or Philipsdam locks), value indicating use of regain feature at the named locks (0 is default and indicates no regain; 1 indicates regain) (see Sec. 6.2.4).

MAAS. Three values for ratios to apportion Maas discharges (ZUIDWLM1:JULCANL1:MAAS1; see Sec. 5.3.1).

NEXTKEY. Node name; new extraction distribution key for the named node (see Sec. 4.2.3).

NDISKEY. Node name; new discharge distribution key for the named node (see Sec 4.2.3).

NODE. Node name; new storage area for the named node.

NORTH. The following card image indicates by a "1" in columns corresponding to district numbers those districts in the North whose flushing and sprinkling extractions may be cut back when the IJsselmeer drops below emergency levels (see Sec. 5.3.14).

N/S CONN. Indicator for the mode of operation of the North-South Connection (see Sec. 5.3.7.2). Values of 0, 1, 2 (0 is default) indicate alternatives 1, 2, 3, respectively, in Sec. 5.3.7.2. A value of 10 indicates that the North-South Connection is to be used to provide only a flow north.

PARM. Miscellaneous parameters. First four values are salt intrusion rates for lock at Bruinisse (without bubble screens, summer and winter; with bubble screens, summer and winter) (see Sec. 6.2.4); and the fifth value is an indicator for the use of outside drainage (1 indicates that outside drainage is to be discarded; 0 is default and indicates that outside drainage is to be added to the district discharge (see Sec. 3.3.2).

PUMP. Node name; pumping capacity at the named node (used only for node 16, BORN, and node 18, LINNE, to represent pumping capacity at Maasbracht and at Linne, respectively).

RIJNSALT. Value of Rijn salt load (overrides keyword input value indicated by keyword on title card).

SWPARM. The value of the coefficient SDPARM for use when the MSDM strategy is used (see Sec. 5.4).

TACTIC. Eight-character technical tactic identifier (see Sec. 7.3), indicating to the DM that the tactic is included in the run and that the annualized fixed and variable costs of the tactic are to be included in the technical tactic cost output (see Sec. D.2.3).

WEIR. Weir schedules: the number 1 or 2 (for IJsselmeer above or below target level); values for Min NR/Des IJssel/Min IJssel/Des NR/Des Waal (see Sec. 5.3.2).

D.2. OUTPUTS

D.2.1. Initialization Output

At the beginning of the run, data are read from data files (see Sec. D.1.1) defining the initial status of the network. These data are immediately printed in several tables. The Link Data Table contains, for each link, the link number and name, the nodes the link connects, the values for Cap.1, Cap.2, and FLCT (see Table 2.1), and the link surface area and volume. The Node Data Table contains, for each node, the node name and (if a storage node) the storage level, depth, and surface area; and for each pollutant, its initial concentration and discharge rate at the node. The District Pollution Data Table contains, for each district, its surface water volume and, for each pollutant, the initial concentration and discharge rate into the district. The Discharge and Extraction Parameter Table contains the node and district extraction and discharge keys for each regional node and each district.

D.2.2. Cycle-by-Cycle Output

Several types of output are printed as the model is performing the calculations for each decade. As input cards that change the parameter values are read at the beginning of each decade, they are listed (see Sec. D.1.2.2). As certain actions occur during the decade calculations, messages are printed describing the action (e.g., the schedule selected for the weir at Driel, a switch to emergency supply facilities in the Midwest, a reduction in flushing on links whose extractions come from the IJsselmeer, etc.). And a list is printed of all link flows that are greater than the maximum flows specified for the links.

D.2.3. Summary Output

At the end of the computer run, various summary tables are printed. Except where noted, the structure of each of these tables is the same--there is a column for each decade and a final column that is either the total or the average of the decade entries. The following is a list of these tables with descriptions of their row entries (the descriptions are ordered as the tables appear in the printed output).

District Summary. For each district: discharge, target extraction, target extraction for sprinkling of open-air crops, actual extraction for sprinkling of open-air crops, other sprinkling (i.e., sprinkling from groundwater plus surface water sprinkling of glasshouse crops), salinity of district discharge.

Node Summary. For each node: discharges minus extractions at the node, rain minus evaporation on storage at the node, salinity at the node.

Link Flows. For each link: flow in the link.

Net Rain Summary. For each weather station: rain minus evaporation.

IJssel Lakes Storage Summary. For each lake: level, rate water is being stored or extracted from lake, rate at which storage is being changed by rain and evaporation, salinity of the lake.

Flow Summary (all values are expressed in m^3/s). Flows for the Rijn, Waal, Neder-Rijn, IJssel, Overijsselsche Vecht, Maas, Roer, Niers, and Swalm plus external drainage; total river flows plus external drainage; total rain minus evaporation; total district discharges; total district extractions; change in the amount stored at nodes; total discharged to the North Sea; total miscellaneous extractions minus discharges.

Salinity Summary. Salinity at selected locations: Rijn, Maas, IJsselmeer, Markermeer, IJsselmonde, Gouda, Wilemstad, Zoommeer, and Grevelingen.

Temperature Summary. Temperatures of the Rijn at PANDNKOP, the Maas at MASTRICT and at each node with a power plant (see Sec. 6.3.6).

Shipping Depths. For each major river section[1] (Upper Rijn, Lower Rijn, Waal, IJssel, Maas): shipping depth.

Low Water Shipping Losses. For each shipping route[1] (Upper Rijn-Waal, Lower Rijn-Waal, Waal-Maas, Lower Rijn-IJssel, Maas-IJssel, Upper Rijn-IJssel, and Waal-IJssel): low water shipping losses; and storage costs for the Waal and IJssel (see Sec. 7.2.1).

Shipping Delay Losses. For canals in the Southeast Highlands (Julianakanaal, Lateraalkanaal, Wessem-Nederweert, Wilhelminakanaal, and Zuid-Willemsvaart): shipping delay losses (see Sec. 7.2.2).

Dredging Costs. For withdrawals at Tiel and St. Andries: single values for the depth of the sandbar, volume to be dredged, and the cost of dredging (see Sec. 7.2.3).

Annualized Fixed and Variable Costs for Tactics. For each technical tactic included in the run (see TACTIC in Sec. D.1.2.2): annualized fixed and variable costs of the tactic (see Sec. 7.3).

Agriculture Costs. For each district: agricultural losses due to salinity, agricultural losses due to water shortage, costs of surface water sprinkling, costs of groundwater sprinkling, total costs exclusive of costs of groundwater sprinkling; single entries for the costs of (implemented) waterboard plans and the annualized fixed costs of new sprinklers.

Agricultural Losses by Crop Type. For each district and each crop: losses due to water salinity and water shortage for entire year.

Regional Discharge and Extraction Summary. Total for all districts in each region: water discharges, extractions, target extractions, surface water sprinkling, other sprinkling (i.e., sprinkling from groundwater and sprinkling of glasshouse crops); single entries for total costs of (implemented) waterboard plans and total costs of new sprinklers.

Overall Cost Summary. Decade and yearly values of variable costs and losses: shipping losses, agriculture losses due to water shortage, agriculture losses due to water salinity, surface water sprinkling costs, total costs to agriculture, variable costs of technical tactics, and total variable costs. Single entries for yearly totals for annualized fixed costs of new sprinklers, waterboard plans, and technical tactics; single entries for annualized variable costs of shipping losses, agriculture costs and losses, and technical tactics. Single entries for total annualized fixed costs, total variable costs and losses, and grand total of costs and losses.

Phosphate Pollution Summary. For each node: phosphate concentration.

BOD Pollution Summary. For each node: BOD concentration.

Nitrogen Pollution Summary. For each node: nitrogen concentration.

Chromium Pollution Summary. For each node: chromium concentration.

Fraction of Total Node-Decades Not Meeting Specified Concentration Values. For a division of the nodes into provinces, on the Rijn, on the Maas, on the Amsterdam-Rijnkanaal and Noordzeekanaal, on the IJssel lakes, and on the Grevelingen and Zoommeer, two tables are output: (1) the fractions of the total node-decades in each division with concentrations greater than values for phosphate, BOD, nitrogen, chromium, and salt of 0.9 mg/l, 15 mg/l, 9 mg/l, 0.15 mg/l, and 300 mg/l, respectively; and (2) the fractions with concentrations greater than 0.6 mg/l, 10 mg/l, 6 mg/l, 0.1 mg/l, and 250 mg/l, respectively.

Fraction of Total Node-Decades Not Meeting Proposed Water Quality Standards. The same format as the above table except using old IMP provisional limits and target values for the concentrations.

Average Concentrations at Regional Nodes. With the same division of nodes as above, the average concentrations at all nodes in the divisions for the year.

Total Pollutant Loads at Various Storage Nodes. Increase in the amount of phosphate, BOD, nitrogen, and chromium in the storage at selected nodes during the year (IJSLMEER, MARKMEER, IJMEER, VELUWMER, GOOIMEER, LITH, WILEMSTD, ZOOMMEER, FRIELAND, and RIJNLAND).

D.2.4. Output Data Files for Use by Other Programs

Agriculture Costs (FT91). For each decade and each district: cost of waterboard plan, cost of new sprinklers, water shortage cost to agriculture, water salinity cost to agriculture, variable sprinkler costs.

Shipping Depths (FT92). For each decade[1]: shipping depths for the Upper Rijn, Lower Rijn, Waal, Maas, and IJssel.

Temperatures (FT80). For each decade and each node with a power plant (plus PANDNKOP and MASTRICT): decade number, node number, temperature.

BENCOMP (FT90). Title cards; low water shipping losses for the 7 shipping routes and storage costs for the Waal and IJssel (see Low Water Shipping Losses in D.2.3); shipping delay losses (see Shipping Delay Losses in D.2.3); dredging costs for withdrawals at Tiel and St. Andries; annualized fixed and variable costs for each technical tactic included in the run; costs of (implemented) waterboard plans for each district; for each district and each crop type: sprinkling energy and labor costs, annualized fixed costs for new sprinklers, water shortage and salinity damage, and crop price.

NOTE

1. In the printed output of the DM, the terms Upper Rijn and Lower Rijn have been replaced by S.Rijn and N.Rijn, respectively.

Appendix E

MODIFICATIONS TO THE DM SINCE DECEMBER 1979

This note describes the distribution model as it existed at the RAND Corporation in July 1980. DM runs made during the PAWN study and reported on in other volumes of the PAWN series used versions of the model that existed in December 1979, or earlier. A number of modifications were made to the DM between December 1979 and July 1980--to correct errors, to make the model more closely represent the actual water distribution system, to incorporate new managerial rules, and to provide additional options to some of the existing managerial rules. The following is a list of these modifications, ordered according to the sections of the report where the current versions of the modified components are described:

Sec. 3.1.1.3. External Drainage. Certain of the equations for external drainage in this section have been modified to correct errors in the original equations.

Sec. 4.3.2. Managerial Rules for the North Holland Regional System. The dependency of the extraction capacities of the STONTEL and SCHERMIN links upon the levels of the Markermeer and IJsselmeer, respectively, as given in Table 4.3, has been added.

Sec. 4.3.3. Managerial Rules for the North Regional System. The entries in Table 4.4, giving the capacity of link 78, MARGKAN, as a function of the level of the IJsselmeer, have been revised. The earlier version of this table contained larger values of the capacities. In addition, an error in the computer implementation of the cutback rule when the MARGKAN capacity is exceeded was corrected.

Sec. 4.3.5. Managerial Rules for the Midwest and Utrecht Regional System. The restriction on the combined capacity of the JUTGEMAL and MERWKAN2 links due to the capacity of 8 m^3/s in the Doorslaag was added.

Sec. 4.3.7. Managerial Rules for the South Regional System. An error was corrected in the cutback rule when the supply south on the Zuid-Willemsvaart is exceeded and either of the tactics pumping water south on the Zuid-Willemsvaart or Wilhelminakanaal is implemented.

Sec. 5.3.1.4. Flows at Low Maas Discharges. The managerial rule increasing the flow on the Zuid-Willemsvaart to meet the (final) demand after all demand cutbacks have been made was added. Earlier versions of the model could produce negative extractions at Lozen under certain conditions.

Sec. 5.3.7.2. North-South Connection Flow South. Two of the three options described in this section were added. Earlier versions of the DM brought water south only to reduce the salt wedge salinity to the specified maximum value.

Sec. 5.4. A Set of Alternative Managerial Strategies. The Current Strategy was added to the set of alternative strategies. (The current strategy was the original strategy included in the DM but had been dropped since it was not being used in the PAWN runs).

Sec. 6.2.4. Salt Intrusion at Salt-Fresh Locks. New salt intrusion values (Table 6.5) were calculated for the Philipsdam and Kreekrak locks, based on revised information about the lock complexes.

Sec. 6.2.6. Zoommeer and Grevelingen. Salt intrusion values to the (fresh) Grevelingen from the North Sea, Oosterschelde, and the locks at Bruinisse were added.

Sec. 7.1.3.2. Losses to Salt Intrusion at Salt-Fresh Locks. The term in Eq. 7.4 that decreases the flow at Spaarndam by 2 m^3/s was added.

Sec. 7.2.2. Shipping Delay Losses. An error in a conversion coefficient was corrected.

Sec. 7.2.3. Cost of Dredging Sediment from the Waal. Improved estimates of the sediment volume created by withdrawals at Tiel and the cost of removing the sediment were incorporated.

RAND/N-1500/11-NETH POLICY ANALYSIS OF WATER MANAGEMENT FOR THE NETHERLANDS VOL. XI