A RAND NOTE

Policy Analysis of Water Management for the Netherlands

Vol. XII, Model for Regional Hydrology, Agricultural Water Demands and Damages from Drought and Salinity

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April 1982

N-1500/12-NETH

Prepared for

The Netherlands Rijkswaterstaat

Rand
SANTA MONICA, CA. 90406

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

Published by The Rand Corporation

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 describes the District Hydrologic and Agriculture Model (DISTAG). DISTAG computes water demands by agriculture, the most important user of water in the Netherlands. Two other volumes are particularly closely related. Volume XI describes the Water Distribution Model, which uses DISTAG as a subroutine. Volume XIII describes various sprinkler models, some of which are used as subroutines by DISTAG.

Parts of this volume (Chaps. 1, 2, and 7) should be valuable for policymakers and others who are mainly interested in the results of the PAWN study and want to get an impression of the modeling effort behind the results. Chapters 3, 4, and 6 are directed toward readers more specifically interested in water management and hydrology. Details of the computer implementation of the model are given in Chap. 5.

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

This volume describes the District Hydrologic and Agriculture Model (DISTAG). It describes methodology only, and contains no results or conclusions about water management for the Netherlands--such results appear in other volumes.

DISTAG simulates the hydrologic cycle. It assumes that the amount of rain and conditions determining evaporation are known, as are hydrologic conditions (e.g., quantity of water stored in the soil) at the beginning of a time interval. It then determines:

- How much water actually evaporates, both directly and in the form of transpiration from plants.
- How much water and salt remain in the soil.
- How much water and salt drain out of the soil into the surface water system.
- The groundwater level.

In addition to these strictly hydrologic quantities, the model also computes:

- Quantity of water and operating cost of sprinkling.
- Drought and salt damage to crops.

This volume gives an overview of the problems to which DISTAG is applied, describes the model in detail, and shows how it is used by PAWN. It also describes the data used by DISTAG for the agricultural analysis and explains where they were obtained. Finally, it shows that the model gives results that are of adequate accuracy for PAWN.

ACKNOWLEDGMENTS

In developing the model described in this volume, we used many valuable suggestions from G. Miedema of the Delft Hydraulics Laboratory. He also provided much of the agricultural data.

We are also indebted to a number of officials of the Ministry of Agriculture and Fisheries. They provided information and expert opinions about the model and the analysis. We met with them many times to exchange ideas and discuss approaches. In particular, we would like to acknowledge H. Ton, J. M. L. Janssen, A. P. Hiddings, Th. de Vries of the Ministry of Agriculture and Fisheries, and R. A. Feddes and P. J. M. van Boheemen of the Institute of Land and Water Management Research.

Early in the study we visited some agricultural institutes to learn about problems and possible solutions. These visits proved to be very helpful, and we wish to thank the individuals with whom we met at these institutes.

The use of the great amount of data was only possible thanks to the kind collaboration of those who did the actual work in collecting it. We wish to thank H. Groen, W. Silva, H. J. Opdam, W. W. Zuiderveen, N. Borgesius, P. W. H. Buisman, D. R. Querner, A. W. van der Hoek, and B. P. C. Steenkamp, all of the Rijkswaterstaat, for their help.

The Dutch reviewer of this volume was H. J. Colenbrander of the Commission for Hydrologic Research-TNO, who made many suggestions that improved the first draft. Other constructive suggestions came from J. Wesseling and R. A. Feddes of the Institute of Land and Water Management Research and A. P. Hidding of the Ministry of Agriculture and Fisheries.

Finally, we wish to express our appreciation to the Rand reviewer, S. Wildhorn. In addition to suggesting a number of valuable improvements, he also helped us to incorporate the many suggestions received from the Netherlands in the final draft.

CONTENTS

FIGURES

TABLES

Chapter 1

THE CONTEXT

This chapter explains why agriculture causes water management problems and what some of the problems are. Then it outlines very briefly how the subject of this volume, the District Hydrologic and Agriculture Model, is used to analyze these problems.

The chapter is intended primarily for readers who are unfamiliar with water management in the Netherlands or with PAWN. A more complete discussion of PAWN is given in Vol. I.

1.1. THE MAJOR ELEMENTS OF THE WATER MANAGEMENT SYSTEM

The surface water system of the Netherlands, taken as a whole, is large and complicated. It includes the deltas of two large European rivers (the Rijn and the Maas), a large freshwater lake (the IJsselmeer), many smaller rivers, streams and canals, and a huge network of small ditches. If all of the details of the entire surface water system were contained in a single model, that model would be hopelessly complicated. For any modeling effort a distinction has to be made between that part of the surface water system whose details should be included, and that part that should be modeled in a much more aggregate way. We will call that part of the surface water system that we model in detail the distribution system. The distribution system is controlled by national and regional governments, while the rest is largely controlled by local authorities. The major elements of the distribution system are:

- The Rijn River and its distributaries--the Waal, the IJssel, etc.
- The Maas River.
- The Noordzeekanaal, the Amsterdam-Rijnkanaal, and other man-made waterways.
- The IJsselmeer and other big lakes.

Agriculture is the single most important "user" of water in the Netherlands. To get some idea of how much water is used by agriculture, we note that in the Netherlands there are more than 20,000 km^2 of land containing cultivated cash crops.[1] In an average summer month, approximately 100 mm of water will be transpired from each point on the surface of the cultivated area. Therefore, in that month, more than 2,000 million m^3 of water are transpired by this cropland (expressed as a flow, this amounts to 770 m^3/s). We can get an idea of how much water this is by comparing it with other large volumes:

- The Ijsselmeer has a surface area of approximately 2000 km^2, and an average depth of about 4 m. If the 2000 million m^3 required by agriculture in an average summer month were to be supplied from the IJsselmeer alone, it would draw down the level by at least a meter.
- A typical low summer discharge of the Rijn River is about 1000 m^3/s. At this rate, nearly the total discharge of the Rijn would be required to supply the needs of agriculture.
- The total production of all drinking water companies in the Netherlands is about 1000 million m^3 <u>per year</u>.

In addition to being the biggest user of water, agriculture suffers more damage than other users when water is scarce. Our models indicate that, one year in twenty, on the average, a drought will cause crop damage on the order of 1000 Dflm, whereas the costs to shipping are around 50 Dflm, and to power plants, 30 Dflm.

1.2. THE PROBLEM

The high consumption of water by agriculture does not usually pose a national water management problem because, most of the time, water needed by agriculture is supplied directly by rain or from moisture stored in the soil. Moreover, only a small fraction of the agricultural area can currently meet its demand by extracting water from the distribution system or from groundwater. First, not all areas have access to surface water or good quality groundwater. More importantly, the extent to which farmers have sprinkling equipment is still quite limited (only about 13 percent of the total agricultural area could be sprinkled from either surface water or groundwater in 1976).

However, the use of sprinkling has been rapidly increasing. If this growth continues, then agriculture will begin to experience new problems, and cause problems for other users of water. Increased extractions from surface water cause:

- Competition for water among farmers, and between farmers and other users.
- Increased salinity damage because of saline sprinkling water.

Water extracted from the ground for sprinkling can also become a problem. For example, in the Netherlands there are places where a lowering of the groundwater table could lead to the destruction of certain unique environmental areas.

There are a number of ways a nation can control the way in which water is allocated among various competing users. It can control water physically by building a canal or a sluice or other physical structure, or by managing an existing element of the system to favor one group or another. It can control water administratively by taxing a use, setting a price, or prohibiting an activity. In the present study, we call any combination of such options a water management policy.[2]

The problem addressed by PAWN is to determine the impacts of any proposed policy. By impacts, we mean the benefits or disbenefits to every "user" affected by the policy, as well as the costs of the policy itself.

1.3. THE MODEL

The District Hydrologic and Agriculture Model (DISTAG) is a model performs three functions. First, it estimates water and salt flows between the distribution system and the land. Second, it determines groundwater levels. Finally, it calculates agricultural costs and benefits affected by the availability or lack of water. To be explicit, it assumes that the amount of rain and conditions determining evaporation are known, as are hydrologic conditions (e.g., quantity of water stored in the soil), at the beginning of a time interval and then determines:

- How much water is actually evaporated, both directly and in the form of transpiration from plants.
- How much water and salt are retained in the soil.
- How much water and salt are drained out of the soil into the surface water system.
- The groundwater level.

In addition to these strictly hydrologic quantities, DISTAG also computes:

- Quantity and cost of sprinkling.
- Drought and salt damage to crops.

DISTAG is used by the principal tool of the PAWN analysis, the Distribution Model (DM), described in Vol. XI. DM simulates the major surface water system of the Netherlands. It computes water flows in the major rivers, canals, and lakes, the concentration of salt and some other pollutants in these waters, and what the impacts are for a number of user categories: shipping, power plants, agriculture, etc. In order to make these computations, DM needs to know how much water enters the country from rivers and from rain. It also needs to know how much water is extracted and/or discharged by the various user groups. DISTAG is used by DM to perform three functions. First, DISTAG computes:

- How much water and salt are discharged into and/or extracted from the distribution system.
- How much water is extracted by agriculture for sprinkling.
- Costs and benefits of sprinkling for agriculture.
- Crop damage.

Second, DM uses DISTAG's estimates of extractions and discharges, along with a specified management plan, to estimate water flows for the rivers, canals, and lakes of the national distribution system. Finally, it uses DISTAG's estimates of sprinkling costs and crop damage to compute the costs and benefits of the management plan.

NOTES

1. The Statistisch Zakboek of the Centraal Bureau voor de Statistiek reports over 25,000 km^2 of "cultured ground." In PAWN about 20,000 km^2 of land contained cash crops. The discrepancy is partly due to definitional differences, but also due to the fact that PAWN did not include the entire country (e.g., the islands in the North Sea were omitted from the analysis).
2. The term policy is defined more precisely in Vol. I.

Chapter 2

DEFINITIONS AND GENERAL DESCRIPTION OF THE MODEL

This chapter describes what DISTAG computes, and explains in some detail how it is related to DM. It begins by explaining a little of the specific hydrology of the Netherlands, and then continues with discussions of the hydrologic features that are included in the model.

The chapter is intended for readers who wish to get a general idea of what the model is, but may not need to know specifically how the model works. It is also used to define a large number of terms needed in subsequent chapters, and in other volumes.

2.1. THE HYDROLOGY OF THE NETHERLANDS

DISTAG is a general model, and could be used for many problems in many regions. For example, it could be used to study the benefits to agriculture and effects on groundwater levels of increased groundwater extractions in California. It could also be used to estimate the optimal size of a reservoir in a Nebraskan watershed. Nevertheless, we had only one problem in mind: water management in the Netherlands. We will begin our discussion by explaining general features of climate and geography of the Netherlands that dominated our thinking as the model was developed.

2.1.1. Rain and Evaporation

The Netherlands has a moderate climate, with approximately 750 mm of rain per year, of which about 500 mm is evaporated by plants. Neither rain nor evaporation is uniform over the year. Rain varies somewhat over the year, but evapotranspiration varies widely. As Fig. 2.1 shows, higher levels of precipitation occur in the autumn and winter, compared with spring and early summer. (The term "decade" used in Fig. 2.1 and elsewhere is defined in Sec. 2.4.) But the highest precipitation occurs in July and August. The level of evapotranspiration is very high in summer. In average years, evapotranspiration is greater than precipitation from April through September by about 100 mm [2.1]. The deficit is usually made up by drawing on water stored in the soil.

Although the Netherlands is a small country, there is a considerable variation in climate from one place to the next. Generally, there is less rain and more evapotranspiration along the coast than inland. For example, in the province of Zeeland, in the southwest corner of the country, about 320 mm of rain usually falls from April through September, while in the province of South Limburg, in the southeast, about 380 mm falls. Normal open water evaporation from April through September is 590 mm in Zeeland and 570 mm in the southern part of the province of Brabant.

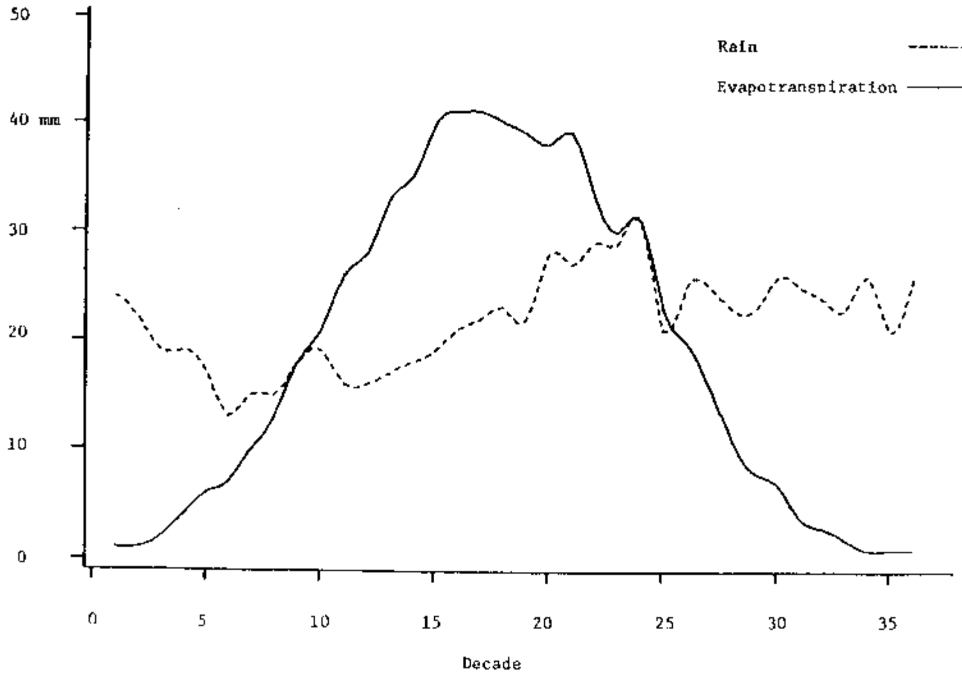

Fig. 2.1--Average rain and evapotranspiration per decade at De Bilt, 1911-1975

In a dry year, the discrepancy between rain and evaporation becomes much larger than in normal years. Whereas the normal discrepancy during the growing season, averaged over the whole country, is only around 100 mm, the discrepancy was closer to 375 mm during the drought year of 1976. During droughts, the moisture stored in the soil is inadequate, and crops are damaged. Because of regional differences, this damage can be quite different in different parts of the country.

2.1.2. Surface and Groundwater Systems

About 7 percent of the surface area[1] of the Netherlands consists of roads, buildings, and other hard surfaces that are impervious to moisture. Most of the rain that falls on such surfaces runs into the surface water system (a small fraction evaporates). Another 4 percent of the surface area consists of water that is not contained in the distribution system: ditches, small brooks, and the like. The remaining surface area is covered with vegetation. Except for a small part that evaporates immediately, rain falling on the vegetation-covered surfaces enters the soil, resides either in the root zone for a while before being evaporated by plants, infiltrates deeper into the groundwater (the saturated zone), or drains out into the surface water system. The hydrology of these vegetation-covered areas is complicated. It is necessary to distinguish two different landforms, called the lowlands and the highlands.

That part of the Netherlands where the elevation of the ground surface is less than 2 m above mean sea level is called the lowlands. The complement is called the highlands. These two regions are shown in Fig. 2.2. The lowlands contain about 60 percent of the total surface area of the country and lie largely in the northwestern part of the country. The terms highlands and lowlands need clarification in the context of the Netherlands, where the higher areas rarely exceed elevations of 30 to 40 m. The use of this terminology merely emphasizes the differences in hydrology between higher and lower parts of the country. These two landforms are discussed separately below.

The Hydrology of the Lowlands. Much of the lowlands lies below sea level--some parts even more than 6 m--and so excess water does not drain out naturally. To get rid of excess water, a system of ditches, polders, and boezems is used.

Ditches are straight and relatively shallow channels for water, which slice up the land into rectangular fields 50 to a few hundred meters on a side.

Polders are land areas surrounded by dikes. In polders the water level of the ditches is controlled independently of neighboring polders.

A boezem is a system of interconnected drainage canals and lakes surrounding the polders, having a single, controllable water level. When the water level in a polder gets too high, water is pumped into the boezem, which then drains it into the national distribution system (rivers, major canals, etc.), or temporarily stores it. In dry periods, the polders can be supplied with water from the boezem. In most places a considerable number of polders are connected to the same boezem. The water level in the boezem is generally substantially higher than those in the ditches of the connected polders. Water levels of both boezems and polders are normally maintained at a specified constant level.

In polders lying below sea level the considerable head difference between the ditches and the sea can cause a deep groundwater flow of saline water that penetrates the land and reaches the surface water. This phenomenon is called seepage. The rate of seepage and its salt content vary considerably from one area to another. In those places where the salinity of the seepage is very high, it is necessary to flush the ditches and boezems with fresh water to reduce the salinity and thus avoid crop damage.

Since the groundwater level in the lowlands is close to the surface, water can rise directly from the groundwater table to the root zone where it can be used by plants. This process is called capillary rise.

The Hydrology of the Highlands. Typically the elevation of the highlands ranges from 10 to 30 or 40 m above sea level. In most

Fig. 2.2--Lowlands and highlands of the Netherlands

places, the land surface is slightly sloped. Most of the rain falling on the land reaches the groundwater table, where it flows from places with higher groundwater levels to places with lower groundwater levels and eventually ends up in brooks or small rivers. We call the phenomenon of water flowing out of the groundwater table because of gravitational forces basic drainage.

The natural drainage capacity of the highlands is generally not sufficient to prevent problems associated with high groundwater levels and flooding in wet periods. To combat these problems, the Dutch have dug an extensive network of ditches in many places that drains water more quickly into the bigger brooks and streams, where it eventually flows into the main distribution system. These ditches do not usually contain water in dry periods.

Seepage, similar to that in the lowlands and caused by basic drainage from higher surrounding areas, may occur in some places. But as this seepage is not influenced by the sea, it is not saline, and causes no crop damage.

The groundwater level in the highlands typically ranges from somewhat less than a meter to a couple of meters below the surface. The shallow groundwater levels are found in those parts of the highlands of relatively low altitude and near beds of rivers and streams. In these places, the capillary action can cause some water to rise from the groundwater table to the root zone. Where the groundwater level is deeper, capillary rise supplies no significant quantities of water, especially during the growing season.

2.1.3. Districts

We can view the hydrologic system of the Netherlands from many levels of detail. At a broad level, we could think of one or two rivers, and rain and evaporation averaged over the entire surface area. At a detailed level, we could consider every ditch, and different rain and evaporation measurements for every square meter of land. But this broad picture is too crude to give useful insight into water management problems, and the detailed picture would be hopelessly complicated. We need to strike a compromise.

On the basis of geography and surface water hydrology, we have partitioned the Netherlands into 77[2] regions that we call districts. Every district contains some urban area, some surface water, and some vegetation-covered area. Some of the vegetation-covered area may be in the lowlands, and some may be in the highlands. We assume that within each district:

- There is a single, connected surface water system, with a constant level everywhere.
- There is no variation of rain and open water evaporation.

- All parts discharge into and extract from the surface water system in the same way.
- Salt mixes perfectly in the surface water.

Districts are the basic hydrologic entities of PAWN. The division of the country into districts is shown in Fig. 2.3.

2.1.4. Perspective on the Main Water Management Problem

Historically, the main water management problem in the Netherlands has been too much water in both lowlands and highlands. Throughout the years many improvements to the drainage systems have been made, such as digging ditches and building pumping stations. Due to these improvements, the problem of excess water is essentially under control. Because of increases in the demand for water, and the occurrence of some dry summers in recent years (most recently, 1976), attention has gradually shifted to problems associated with water shortages. Thus, PAWN focuses on water shortage problems and their possible solutions rather than problems of excess water. Of course it also pays major attention to problems of water quality.

2.2. THE HYDROLOGIC CYCLE IN GENERAL

The term <u>hydrologic cycle</u> can be applied to the simple notion that water falls to the earth in some form of precipitation (rain, snow) and eventually evaporates back into the atmosphere. The term can also be applied to a much more complicated process, containing many pathways along which water moves in solid, liquid, and vapor forms. Large flows can be distinguished, such as major ocean and atmospheric currents, and major rivers. But there are also many small-scale processes involved, such as rain dripping from the leaves of a tree, leakage from ditches, etc. In addition to the water pathways to be included in a hydrologic model, the geographic features of the real world play an important role.

Generally, various dissolved or suspended substances are carried with water (when it is in a liquid phase). This process is sometimes called the <u>geochemical cycle</u>. In this volume, we are concerned with only one such substance: chloride, for which we will simply use the term <u>salt</u>. A discussion of the movement of salt through the hydrologic system concludes this section.

2.2.1. Geographic Features

<u>Districts</u>, introduced in Sec. 2.1.3, are regions small enough that internal details of surface water movement can be regarded as unimportant from a water management standpoint. A district consists of three parts: surface water, urban areas, and vegetation-covered

Fig. 2.3--PAWN districts

areas. We discuss each part in turn. Table 2.1 shows the total area of each of these three regions in the Netherlands.

The Surface Water System. This part of a district includes canals, ditches, lakes, and other bodies of water, the surfaces of which are open to the sky. They may be connected in quite complicated ways, but we do not consider such complications in our model. Instead, we regard the surface water system as one, homogeneous body. We assume that there is exactly one place (the extraction point) in the surface water system where water enters from the distribution system, and one place (the discharge point) where it leaves. These two places may or may not coincide.

Urban Areas. Each district contains surfaces that are essentially impervious to the vertical flow of water. Such surfaces include roads, buildings, glasshouses, and other hard surfaces. After a rain, a small amount of water may evaporate from these surfaces, but most of the rain runs, via sewage systems, into the surface water system. Most of these surfaces are in cities, so we will call them urban areas.

Vegetation. The major part of any district is covered with vegetation. Such vegetation includes agricultural cash crops (the cultivated area) and "nature," i.e., woods, fallow land, marshes, verges, parks, playing fields, etc. In the areas covered with vegetation, water can be stored in the soil in two separate zones. The root zone consists of a relatively shallow top layer of soil (30 to 80 cm, depending on soil type and kind of vegetation). The subsoil consists of everything below the root zone. The soil moisture content in the subsoil varies with depth. It increases with increasing depth to a point, called the groundwater level, where there is a maximum amount of water per unit of volume. The region below this level is called the saturated zone.

Table 2.1

SURFACE WATER, URBAN, AND VEGETATION-COVERED AREAS IN THE NETHERLANDS

Category	Area (km^2)	Pct
Surface water	1450	4.4
Urban areas (roads, buildings, etc.)	2400	7.3
All vegetation-covered land	28910	88.2
"Nature" (see text for definition)	9100	27.8
Cash crops	19810	60.5
Open-air cash crops	19730	60.2
Glasshouse crops	80	0.2
Total area	32760	100.0

SOURCE: Estimated by authors from data supplied by the Centraal Bureau voor de Statistiek. See Chap. 6. Values may differ in other tables because of round-off.

2.2.2. Pathways for the Flow of Water

Figure 2.4 depicts the elements of the hydrologic cycle that are included in our model. In this section we will discuss the various water flows. These flows are also shown schematically in Fig. 2.5.

Rain and Evaporation. Rain falls on each of the three primary areas of a district, surface water, urban, and vegetation-covered areas. Water evaporates from each of the three areas, too. Water is lost from vegetation-covered areas by a process known as evapotranspiration. Direct evaporation continually takes place from the surface water. To a limited extent evaporation losses also occur in urban areas.

Urban Runoff. Since urban areas, by definition, are impervious to the vertical flow of water, such rain as does not evaporate flows into the surface water system, either directly via the sewage system, or after going through some form of treatment.

Sprinkling: Surface Water, Groundwater, and Losses. By effective sprinkling we mean the amount of sprinkled water that finds its way into the root zone, from which it may be evaporated by crops. Such water comes from two places: surface water sprinkling is drawn from the surface water system; groundwater sprinkling is drawn from the subsoil. During and immediately after sprinkling water is applied, there are losses into the atmosphere due to evaporation of the water.

Root Zone Loss and Capillary Rise. By root zone loss we mean the downward flow of water, under the force of gravity, from the root zone into the subsoil. When the groundwater level is close enough to the surface, and the root zone is dried out to some extent, water rises into the root zone by a process known as capillary rise.

Seepage and Leakage. Head differences in groundwater aquifers cause groundwater to flow from places with higher groundwater levels to places with lower groundwater levels. In the lower parts of the country, this may result in seepage flows entering the subsoil and surface water. In higher parts, water may leak from the subsoil for this reason. A particularly important phenomenon occurs in some lowland areas where saline seepage flows penetrate the subsoil and surface water, driven by relatively high sea level.

Drainage and Infiltration. When water moves from the subsoil into the surface water system under the force of gravity, the flow is called drainage. In low-lying areas, such water drains into the ditches, from which it is pumped up into the system of canals and lakes that surround polders called a boezem. Elsewhere, the elevation of the land is such that water drains out of the subsoil into naturally occurring streams and rivers, a phenomenon called basic drainage.

Not all drainage from a district flows into the surface water system of the district itself. Sometimes a portion of it flows out of the

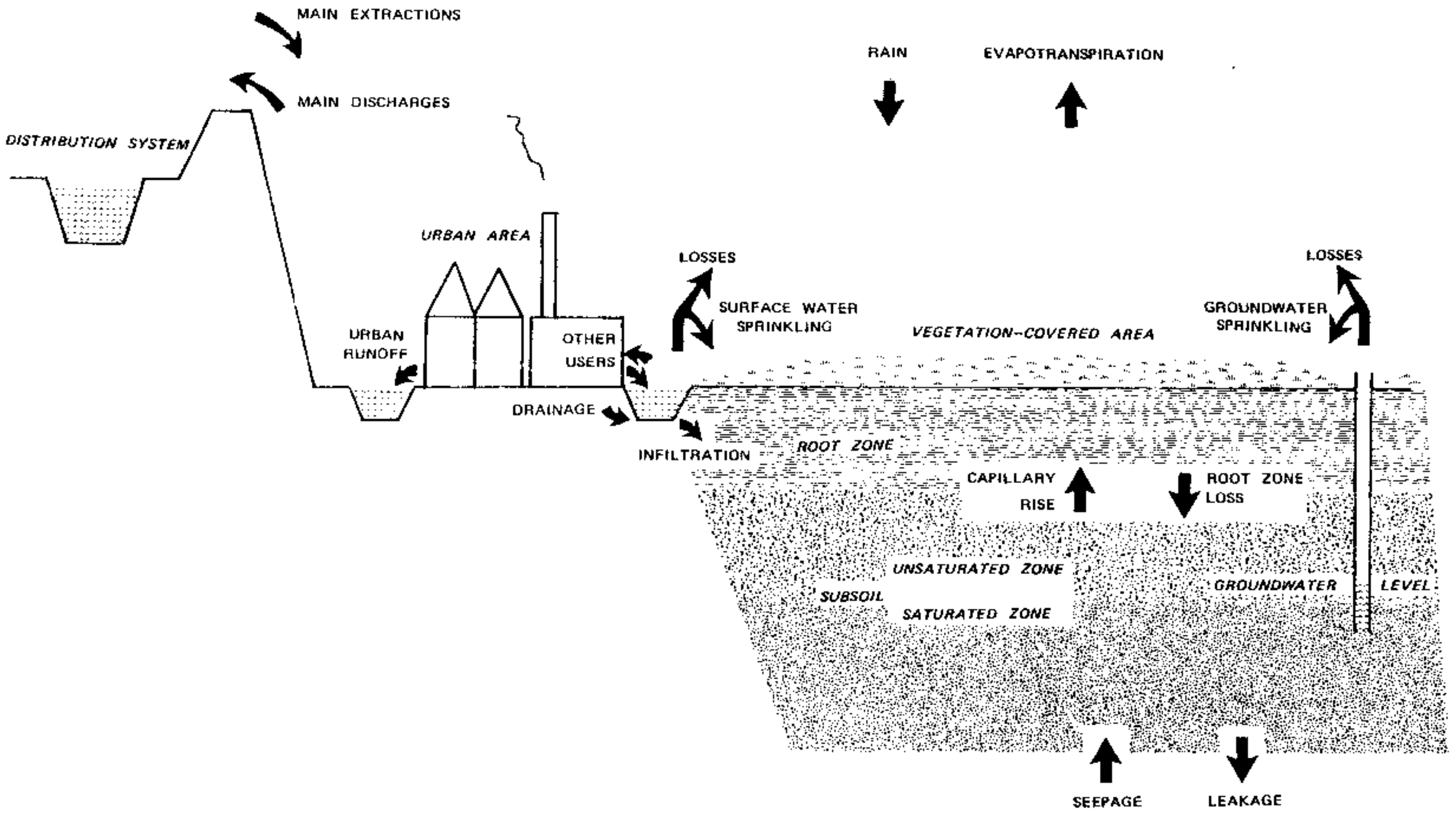

Fig. 2.4--Pathways for the flow of water

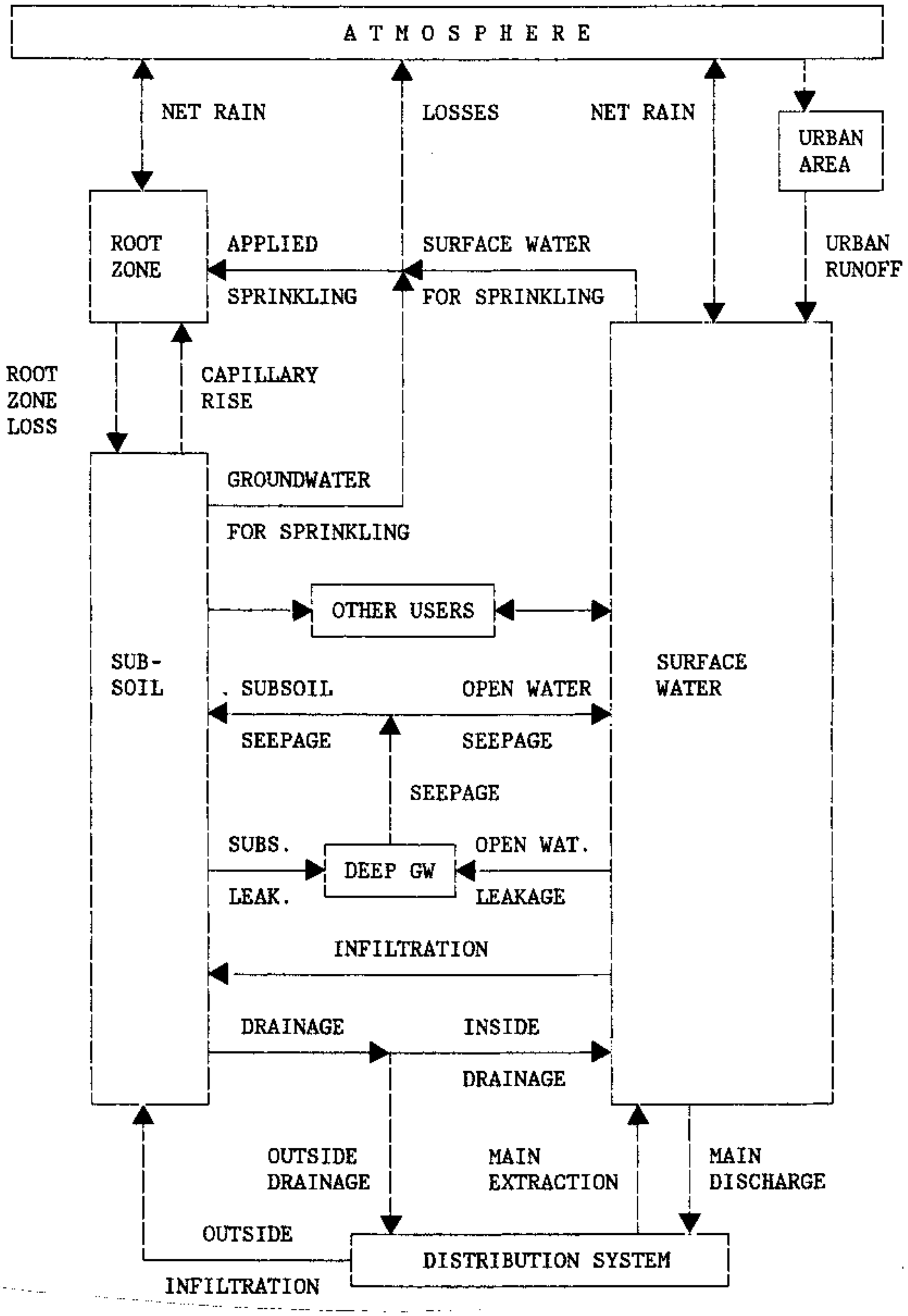

Fig. 2.5--Schematic showing district water flows

district into the surface water system of some other district or into the national distribution system; we call this total leakage to surrounding areas outside drainage. The drainage that remains entirely inside a district is called inside drainage.

Water can flow in the opposite direction, from ditches, canals, rivers, etc., directly into the subsoil. When this happens, the flow is called infiltration.

Other Users of Water. There may be other users of water in a district whose use of water is beyond the direct control of the water management system. Industries and drinking water companies are the most typical such users. They may extract groundwater and surface water, and they may discharge water into the surface water system.

Main Extractions and Discharges. Finally, the main discharge is the discharge of water from the surface water system of a district into the national distribution system, and the main extraction is the extraction of water from that place. Generally, these extractions and/or discharges are the result of managerial decisions, decisions made in order to control the level of the water in the canals and ditches of the district, to reduce the amount of salt, to provide adequate water for sprinkling, etc.

2.2.3. Pathways for the Transport of Salt

By salt we mean dissolved chloride. Only chloride is considered because it is by far the most prevailing salt component in Dutch surface waters and also the most harmful to crops. Salt is present in most naturally occurring bodies of water, and is transported along with the water wherever it flows (in liquid phase). Therefore, many water paths are also paths along which salt is transported. These paths are shown in Fig. 2.6.

Sources of Salt. Each of the three paths by which water enters a district can bring salt. Rain brings a small amount from the atmosphere, and more is washed into the surface water from urban areas by rain; the latter is mostly salt spread on roads in winter for controlling ice. In areas close to the ocean, seepage carries salt into the subsoil. Extractions from the national distribution system account for much salt. (The Rijn has a high salt concentration, due largely to industrial activity in Germany and France). Finally, fertilizers applied to agricultural land carry a certain amount of salt; this is a direct source not immediately connected to any inflow of water.

How Salt Leaves a District. Salt is not carried out of a district by evaporated water, and the only way to get rid of it is to discharge it into the national distribution system. In periods when no discharge

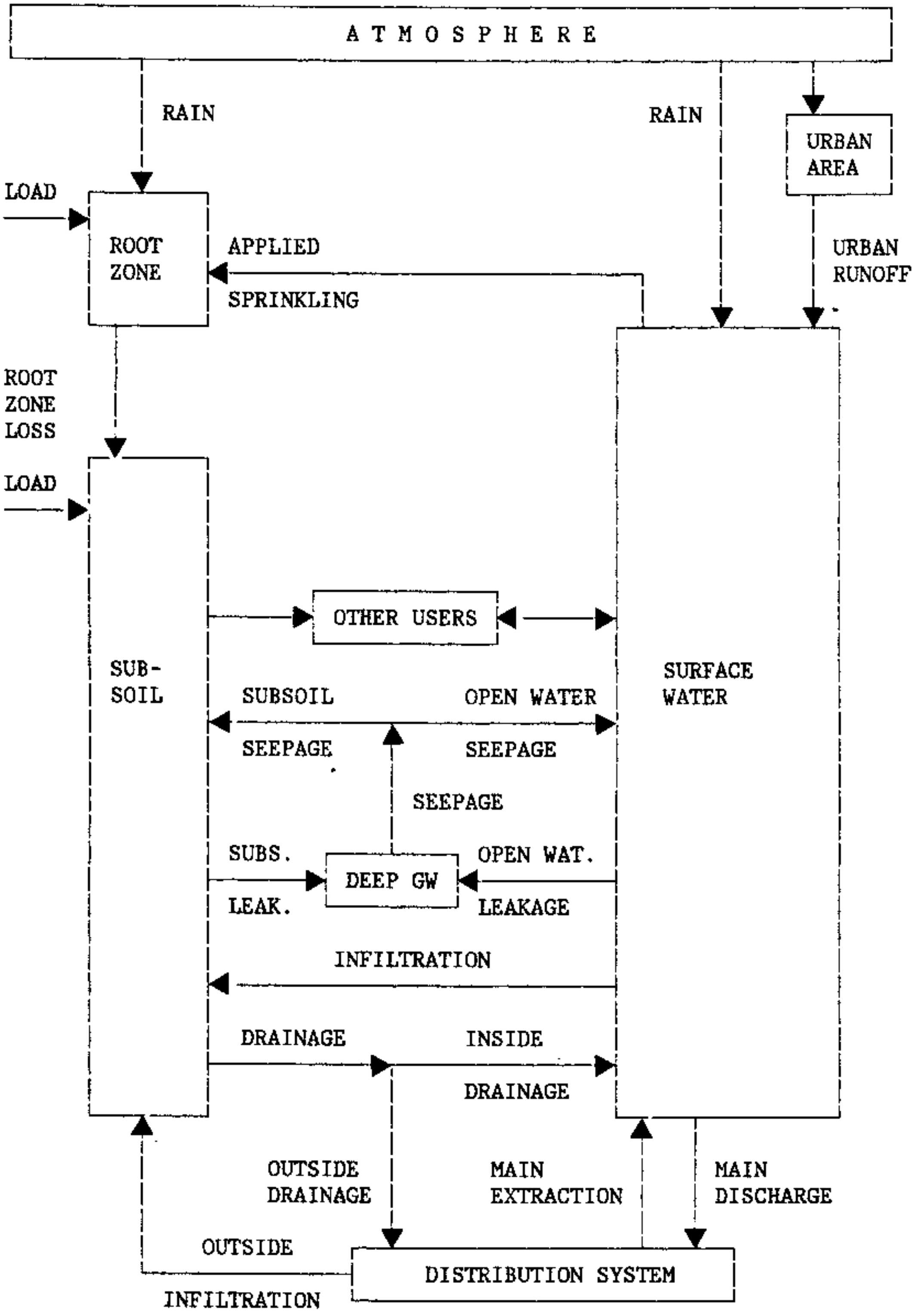

Fig. 2.6--Schematic showing district salt flows

takes place naturally, flushing may be needed, achieved by taking in and discharging water simultaneously. Reducing the amount of salt in the surface water can be a major reason to flush a district.

Internal Salt Flows. The flow of salt from urban areas into the surface water of a district has already been mentioned. Salt carried from the surface water system into the root zone by sprinkling causes the most trouble. Salt is also carried from the root zone into the subsoil by the water lost from the root zone, but this is a slow process, and so salt in the root zone can build up rather high concentrations and cause crop damage. Salt is transported from the subsoil into the open water system along with drainage water.

2.3. AGRICULTURE

In this section, we discuss briefly special problems relating to Dutch agriculture. First, we mention why various crops, soils, and landforms need to be distinguished. Then we discuss problems involving sprinkling. Finally we touch upon problems involved with crop damage, and conclude by defining two new entities: the subdistrict and the plot.

2.3.1. Crops, Soils, and Landforms

What happens to agriculture in any particular place and time depends on three important factors: the kind of crop under cultivation, the soil type, and the landform. We discuss each of these three factors in turn.

Crops. The crops raised in the Netherlands differ in their need for water, their capacity to extract water from the soil, their susceptibility to drought and salt damage, and their economic value. To capture the most important differences, we have distinguished thirteen different crop types.

The vegetation-covered area that does not have cash crops we call "nature." This area represents a significant fraction of the vegetation of the country, and so its presence is important for water balance computations. Since the hydrology of nature is, in principle, identical to that of agricultural crops, we treat "nature" as a kind of crop in addition to the thirteen proper agricultural crops. "Nature" includes many kinds of vegetation: woods, marshes, parks, verges, etc.

We distinguish between the crops raised in the open air and crops raised in glasshouses. The latter represent a rather small fraction of the total area devoted to agriculture in the Netherlands, but they are extremely valuable. The hydrologic and geochemical processes of glasshouse crops are quite different from those of open-air crops.

Soil Type. The soil type of a region affects the amount of water that can be stored in it, the difficulty plants have in extracting this water, and the rates at which water infiltrates, or rises through capillary action. Sixteen root zone/subsoil combinations are distinguished in our model. Associated with each soil type is a set of soil parameters used to control computations dependent on soil type. These computations are discussed in Sec. 4.1.

Landforms. The major landforms, the lowlands and the highlands, were defined in Sec. 2.1.2. The distinction between these landforms is important for agriculture, because in the lowlands the groundwater level is usually close to the surface, so capillary rise can account for a significant supply of water for crops. In the low highlands the groundwater level is usually less than 1 m below the soil surface. Depending on root zone depth there may be a substantial contribution of capillary rise to the water needed by agriculture. In the high highlands the groundwater level is usually more than a meter from the soil surface. For deep-rooted crops at locations where the groundwater level is not much deeper than a meter, capillary rise might be of some value. In other cases, capillary rise will be almost negligible or will not occur at all. The areas of these two landforms for the entire Netherlands are given in Table 2.2.

2.3.2. Sprinkling

In the Netherlands, farmers obtain water to irrigate crops from one of two places: water is pumped either from a nearby source of surface water (a ditch or canal) or from a groundwater well. A relatively small amount of irrigation is applied by actually flooding the crop land. This is called surface irrigation and it is almost only used for grass. Most irrigation is applied by various types of sprinklers. PAWN assumes that all irrigation is of the latter sort, so the term sprinkling is used to denote all forms of artificial irrigation. The term groundwater sprinkling denotes the situation where the source of the water is from the ground, and the term surface water sprinkling denotes the case where the source of the water is a ditch or canal.

The amount of water consumed by sprinklers in any district during a particular time period depends on four factors:

- How much of the cultivated land has sprinklers.
- How much the sprinklers are used, provided there is enough water.
- Water requirement of crops that are sprinkled, and sprinkling losses.
- The amount of water available.

The area of land sprinkled in a district does not change from one timestep to another, so, from DISTAG's perspective, this amount is an aspect of the geography of the district, just like the amount of

Table 2.2

VEGETATION-COVERED AREA, BY LANDFORM, IN THE NETHERLANDS

Landform	Area (km²)	Pct
Lowlands	17070	59.0
Highlands	11850	41.0
Low highlands	2700	9.3
High highlands	9150	31.6
Total vegetation-covered area	28920	100.0

SOURCE: Estimated by authors from data supplied by Stichting voor Bodemkartering. See Chap. 6. Values may differ in other

Table 2.3

NETHERLANDS AGRICULTURAL LAND AREA, BY SPRINKLING CATEGORY

Sprinkling category	Area (km²)	Pct
Unsprinkled	17170	86.7
Surface water	1930	9.7
Groundwater	710	3.6
Total land containing cash crops	19810	100.0

SOURCE: Estimated by authors from data supplied by the Instituut voor Cultuurtechniek en Waterhuishouding. See Chap. 6. Values may differ in other tables because of round-off.

any particular crop growing there. In Table 2.3, the area of land sprinkled in the nation for 1976 is given. For some PAWN analyses, estimates of future amounts of sprinklers have been made. These are discussed in Vol. XIV.

2.3.4. Crop Damage

In PAWN, only two types of crop damage are studied. Drought damage is the reduction in crop production due to water shortages. Salt damage is the reduction due to excessive salt concentration of the water in the root zone. Other kinds of damage, such as that caused by frost, excessive rain, or plant diseases, are not explicitly considered.

In any timestep (most often 10 days), DISTAG estimates the fraction of the total crop production that is lost due to drought or salt damage, both the damage in that particular timestep and the cumulative damage up to that point. The survival fraction is defined as the complement of the total cumulative damage fraction (both drought and salt); i.e., the survival fraction is 1 minus the cumulative damage fraction. Crop production can be estimated in money terms by multiplying the survival fraction by the total value of the crop.

In dry years, crop prices may rise considerably because drought damages reduce market supply. This offsetting effect is treated by estimating crop prices as a function of how dry the year is. How these crop prices are estimated is described in App. A. Estimates for crop prices for an average year and for 1976 (an extremely dry year) are given in Chap. 6.

2.3.5. Definition of Subdistricts

Many districts contain more than one soil type and/or include more than one of the three landforms: lowlands, low highlands, or high highlands. That part of each district that is covered with vegetation has been divided further into subdistricts by first partitioning the district into landform types and then, if still necessary, partitioning the landform types by soil type. In districts where there is only one soil type and one landform, we call the entire vegetated region a single subdistrict. There are 143 subdistricts; each of the 77 districts contains from 1 to 6 subdistricts.

2.3.6. Definition of Plots

A mixture of crops is found in each subdistrict. Generally, each crop may be unsprinkled in some parts of the subdistrict, yet sprinkled from groundwater or surface water in other places. The two-way split of a subdistrict, first into crop types, then into type of sprinkling (if any), partitions each subdistrict into areas that we call plots.

We treat fourteen different crops and three different categories of sprinkling (no sprinkling, surface water sprinkling, and groundwater sprinkling), so each subdistrict could contain as many as 42 plots. However, not every crop occurs in every subdistrict, nor is every type of sprinkling applied to every crop. In practice the number of plots in a subdistrict is rarely greater than 12, and averages around 9. There are 1259 plots in the data that describe the agricultural situation of the Netherlands for 1976.

The plot is the smallest geographic unit of analysis used in DISTAG for the computation of water flows, salt flows, crop damage, and sprinkling costs. Three important submodels, the plot water model, the plot salt model, and the plot damage model operate solely at the level of the plot. They are all described in Chap. 4.

2.4. TIME

The overall PAWN analysis is carried out for a calendar year (January 1 through December 31). We divide each month of the year into three timesteps which the Dutch call decades; the first two decades of each month contain exactly 10 days, and the third decade contains as many days as are needed to fill in the month (8, 9, 10, or 11 days). We compute what happens for each decade, and then put together results for an entire year.

2.5. THE DISTRICT HYDROLOGIC AND AGRICULTURE MODEL (DISTAG)

Inputs to DISTAG can be segregated into three general classes:

- Geographic conditions define properties of the district itself, e.g., area of the district.
- Initial conditions indicate the state of the district at the beginning of the time period, e.g., salinity of the surface water in the district, amount of water stored in the root zone.
- Step conditions give time-varying conditions that occur during the time period, e.g., amount of rain, salinity of water in the distribution system, amount of water available for sprinkling.

Outputs from DISTAG fall into two classes:

- Final conditions indicate the state of the district at the end of the time period, to be carried forward and become the initial conditions for the next period.
- Impacts are the major quantities determined by the

model for a given decade and district. They include:

Water Flows

Extractions from the distribution system.
Discharges to the distribution system.
Amount of water required by agriculture for sprinkling.

Salt Transport

Salt concentration of the water discharged from the district.

Agriculture Costs and Benefits

Operating cost for sprinkling.
Crop damage due to drought.
Crop damage due to salt.

DISTAG uses three submodels to describe the more specific agricultural aspects within the district. These submodels all make computations for plots.

- The plot water model (PLOTWAT) computes water requirements by agriculture.
- The plot salt model (PLOTSLT) determines the salt concentration in the root zone and subsoil.
- The plot damage model (PLOTDAM) computes agricultural damages.

These models are described in more detail in Chap. 4.

2.6. THE DISTRIBUTION MODEL (DM)

The water distribution system studied by PAWN is a network of rivers, canals, and lakes, into which water comes from rivers, rain, and drainage from the land. The Distribution Model (DM) is a simulation model of the water distribution system, and it uses DISTAG as a subroutine to estimate discharges from or extractions by districts. DM is described in Vol. XI. To place DISTAG in context, we summarize DM briefly:

- DM considers details of the surface water system, such as flows in rivers, water levels, etc.
- It makes computations for a calendar year or longer.
- It considers regional differences.
- It includes a number of impact categories, such as

agriculture, shipping, power plants, etc.
- It can implement managerial decisions, such as allocating water when demand exceeds supply.

The relationship between DM and DISTAG is illustrated in Fig. 2.7. There are four main steps.

- Using the plot water model, DISTAG determines agricultural water requirements.
- DISTAG aggregates the agricultural demand and combines it with demands of other users, resulting in a total district demand.
- DM weighs the demands from all the districts and the various national users and then allocates water to the districts according to a specified managerial strategy.
- DISTAG allocates the water each district receives among its various users, and computes impacts on agriculture.

The first two of these steps are called the "request" phase; the last two are called the "delivery" phase.

A single "run" of DM simulates a water management policy and determines its impact for a single calendar year. In doing so, DM uses DISTAG many times, because it makes computations for many districts, for each of the 36 decades in the year.

DM must treat two interactions among districts. First, districts may demand more water than available. When this happens, DM must reduce the amount of water some district gets, either by reducing the amount of sprinkling allowed there or by reducing the amount of flushing. In either case, agricultural damages may increase: drought damages will increase if sprinkling is cut back, while salt damages will increase if flushing is reduced. If sprinkling is cut back, sprinkling costs will be reduced, too.

Second, districts exchange salt. DM must indicate to DISTAG the salinity of each district's extraction point. But this salinity is affected in part by what is discharged from other districts.

In a single decade, DM uses DISTAG twice for each district. The first time, the "request," DISTAG computes the previously listed impacts, first, assuming that there are no constraints on the amount of water available to each district and, second, using some initial estimate for the salinity of the water in the distribution system. After DISTAG has made its "request" computations, DM allocates water to the districts. Some districts may get less then requested.

Then, with updated estimates of salinities, DM uses DISTAG a second time, the "delivery," possibly constraining some water some districts get. DISTAG determines the impacts of this allocation. In Fig. 2.8, we diagram this two-step procedure.

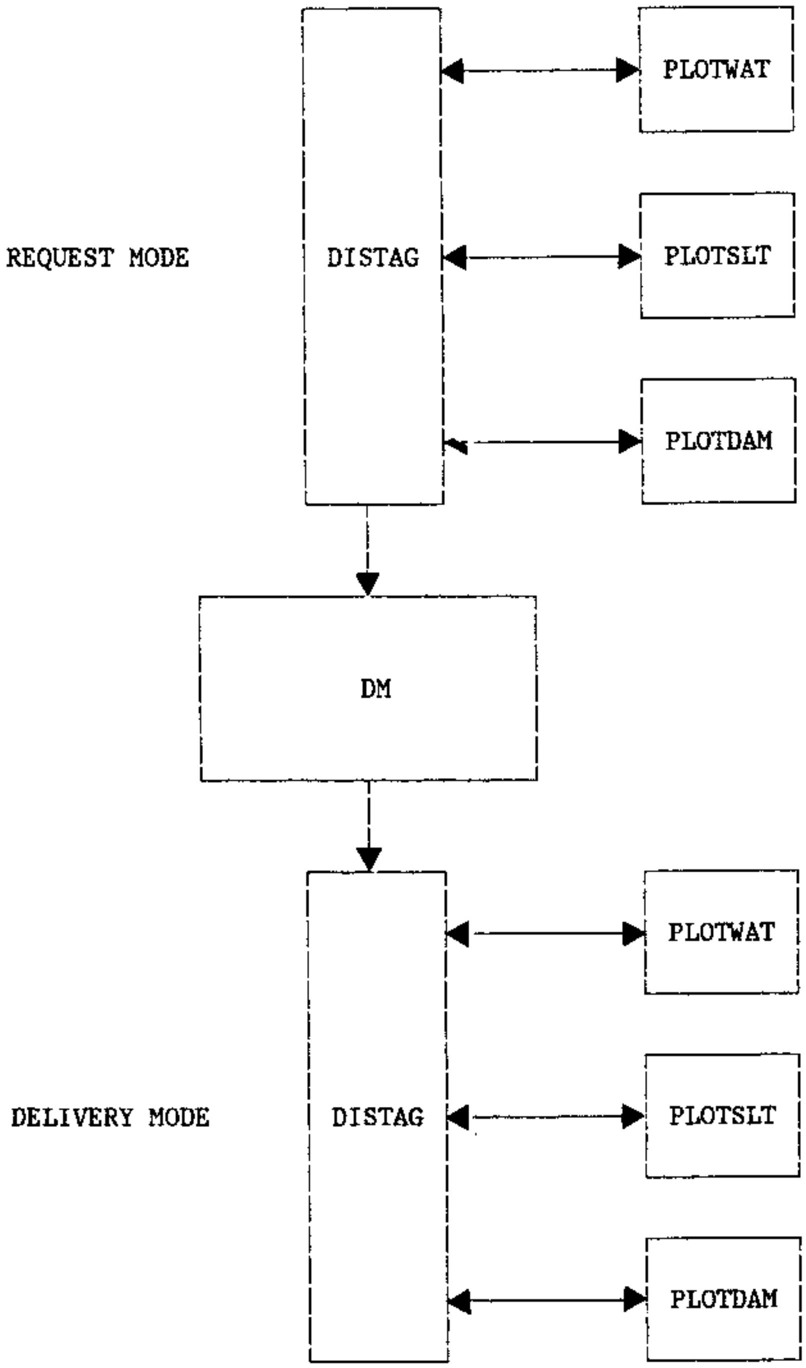

Fig. 2.7--Relationship between DM, DISTAG, and the plot models

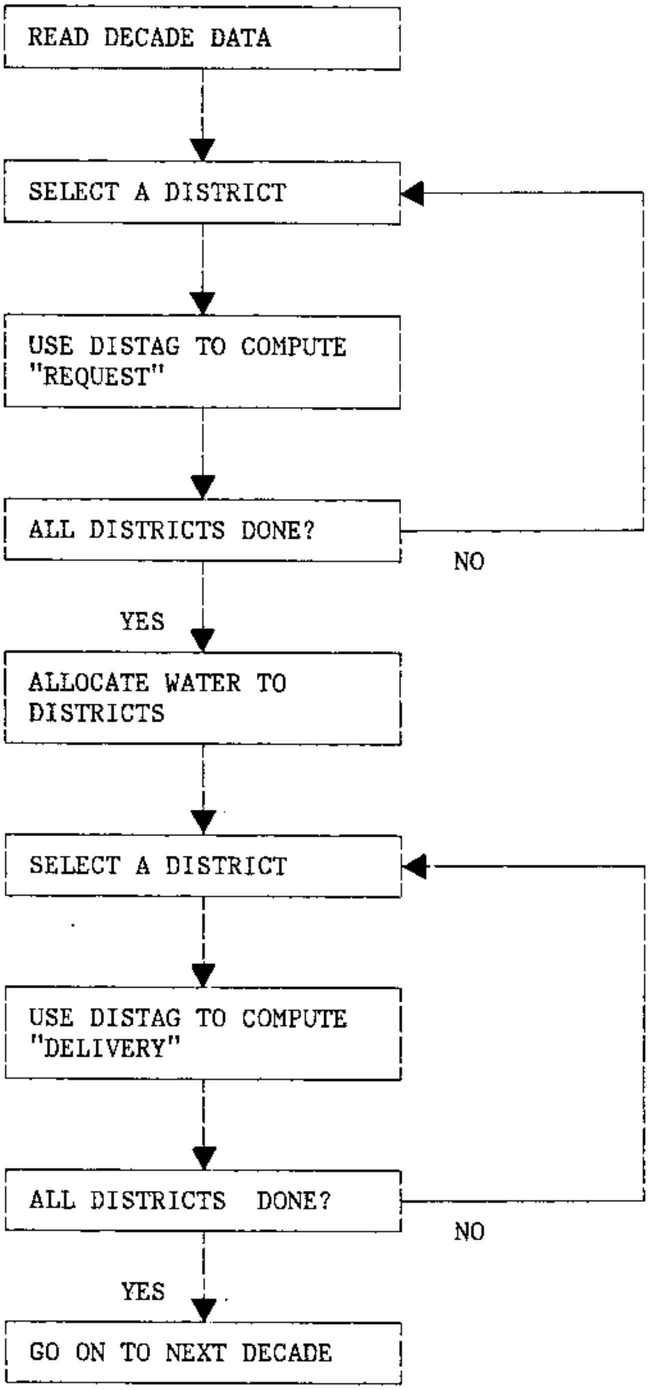

Fig. 2.8--Overview showing how DM uses DISTAG in a single timestep

Every time DISTAG is used by DM, it computes a set of final conditions that can be used as the initial conditions for the next timestep. Since DISTAG is used twice by DM, only the final conditions computed during the second call (the "delivery") are actually carried forward. Fig. 2.9 illustrates this logic.

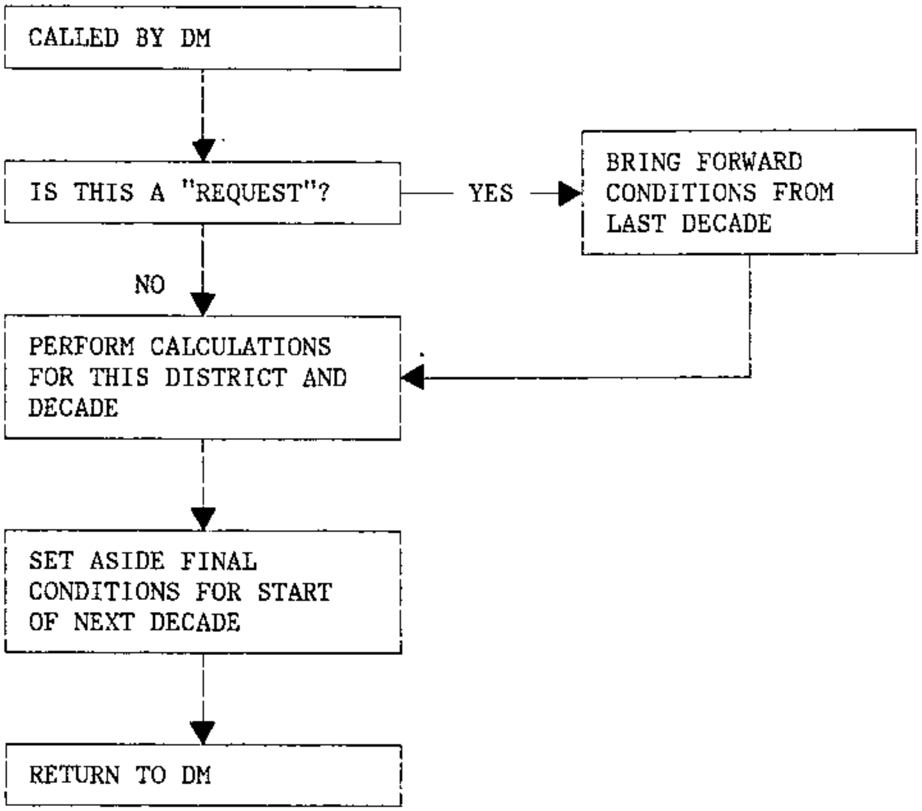

Fig. 2.9--Overview of DISTAG logic

NOTES

1. For this discussion, we exclude the surface area of the waters contained in the distribution system.
2. We also defined a 78th district corresponding to the proposed Markerwaard polder.

REFERENCE

2.1. Koninklijk Nederlands Meteorologisch Instituut, De Droogte van 1976, Publicatie No. 154, De Bilt, December 1976.

Chapter 3

INPUTS AND OUTPUTS

Chapter 2 gave an overview of what is included in DISTAG. The present chapter, in which we describe its inputs and outputs, will be important to readers interested in the technical details of the model. In the next two chapters, we explain how the model works. Chapter 6 describes the data base used by PAWN, including the specific values of the inputs.

Inputs to the model fall into three classes. First, there are rain and evaporation data. Second, there are the geographic and location-dependent data that characterize the soils, crops, districts, and other features of the system. Finally, there are computed input data: variables passed to DISTAG from DM, and initial conditions computed in a previous timestep. In what follows, we discuss each of these classes of input data in turn. In the final section, we discuss the outputs of the model.

3.1. RAIN, EVAPORATION, AND LENGTH OF TIMESTEP

In any decade, the amount of rain and evaporation that occurs during the decade must be supplied as input data to the district agriculture model. In reality, there is day-to-day variation in both rain and evaporation, and there is spatial variation as well. Our model does not resolve this day-to-day variation, but assumes a constant rate of both rain and evaporation for the entire decade. While we do treat the spatial variation to some extent by assigning different districts to different weather stations, no variation of rain or evaporation is assumed within a district.

Evaporation is the change of phase of water from a liquid to a vapor. We use the term to denote the amount of water that evaporates from open water. Transpiration is the evaporation of water from plants. Evapotranspiration is the mixture of evaporation and transpiration from a vegetation-covered region. Open water evaporation is considered to be a process that depends mainly on climatological conditions. It is affected by radiation, temperature, humidity, wind conditions, and other factors. Since controlling the weather is not part of any policy studied by PAWN, evaporation is specified as an input to the model. Once evaporation is given, evapotranspiration is computed by the model.

Transpiration is limited by the physiological processes within the plant, the external plant characteristics (shape, height, degree of soil covering), and the availability of water to the plant. The term potential evapotranspiration denotes the amount of water that will evaporate from a vegetation-covered surface in a given period of time, as long as the ability of plants to transpire water is not constrained by the lack of it. Actual evapotranspiration is what is actually evaporated from vegetation.

Not every decade is exactly ten days long. The last decade in each month may be 8, 9, 10, or 11 days long. The length of each decade is read in as data along with rain and evaporation.

3.2. GEOGRAPHIC AND LOCATION-DEPENDENT DATA

The inputs described in this section are read from data files once, stored in memory, and never changed. They define the nature of the system being modeled. We have grouped these data into classes that depend on how large a geographical area the elements represent. First, we discuss the "constants" of the model: numbers that remain fixed throughout the whole country. Then, we introduce in turn data that characterize districts, subdistricts, and finally, plots.

3.2.1. Constants

Some characteristics are assumed to remain the same throughout the entire nation. The most important ones are listed in Table 3.1, but it is more convenient to discuss these data in other places in this volume.

3.2.2. Data Characterizing Districts

Where a district is connected to the distribution system, i.e., where it extracts and/or discharges surface water, depends on management decisions made by the national government. Such connections are not treated by DISTAG, but rather by DM. The reader is referred to Vol. XI for further information about the connection of districts to the national distribution system.

Data characterizing districts may be classified into four groups. First, we note characteristics that a district may share with its immediate neighbors by virtue of its location: the weather station, which determines rain and evaporation, and the drainage region, which determines the groundwater aquifer characteristics. Second, there are data characterizing the urbanized part of the district. Third, there are data describing the surface water part. Finally, there is an extensive collection of data related to the vegetation-covered part of the district, including all the parameters characterizing agriculture. This last class of data elements is discussed in subsequent sections. The first three classes are discussed in what immediately follows. The district-specific data elements described in this section are listed in Table 3.2.

Weather Station and Drainage Region. In any particular decade, rain and evaporation may be different in different parts of the nation. We have used a standard division of the Netherlands into fourteen weather stations. Each district is assigned to one of them. These stations are discussed in more detail in Sec. 6.5.

Table 3.1

DATA THAT ARE CONSTANT OVER NATION

Name	Units	Description
<u>Constant over time</u>		
DRAIN_MAXOUT	mm/year	Maximum amount of drainage that can flow directly into distribution system
DRAIN_UG	mm/year	Amount of root zone flushing for crops grown under glass
LOAD_RZ	$(mg/m^2)/day$	Salt load in root zone
LOAD_SS	$(mg/m^2)/day$	Salt load in subsoil
RAIN_CONC	mg/l	Salt concentration of rain
RAIN_SURP	mm	Average annual rain surplus
SPR_EFF	mm/mm	Sprinkling efficiency, amount of sprinkling actually reaching soil divided by amount of water sent through sprinkling system
URBAN_CF	mm/mm	"Urban crop factor," potential evaporation from urban surface divided by open water evaporation
URB_CONC	mg/l	Salt concentration of urban runoff
VOLRZ_UG	mm	Volume of root zone for crops under glass
VOLSS_UG	mm	Volume of subsoil for crops under glass
<u>Varying over time</u>		
BARE_CF	mm/mm	"Bare soil crop factor," amount of water that evaporates from bare soil, divided by open water evaporation

Table 3.2

DISTRICT DATA

Name	Units	Description
Constant over Time		
DRAIN_REG	--	Index of drainage region
FLUSH_MIN	m^3/s	Default flushing minimum
INDUST_EXT	m^3/s	Industrial extraction from surface water
INDUST_DIS	m^3/s	Industrial discharge into surface water
INDUST_SALT	mg/l	Salt concentration of discharge
URBAN_AREA	ha	Area of urban part of district
WATER_AREA	ha	Area of surface water of district
WATER_VOL	$1000 \times m^3$	Volume of surface water of district
WEA_STA	--	Index of weather station
Time Varying		
NDAYS	day	Number of days in timestep
EVAP	mm	Open water evaporation
RAIN	mm	Rain

In the highlands, there is an appreciable drainage from the subsoil into the rivers and streams of the region. The nature of this drainage is complicated, but an important factor is the geological nature of the underlying aquifers. To treat such drainage, the highlands has been partitioned into seventeen hydrologically homogeneous drainage regions, each of which is judged to be more or less homogeneous with respect to the geological factors affecting drainage. Each district that contains part of the highlands has been assigned to one of the drainage regions. The model that computes this drainage is described in Sec. 4.1.

Urban Area. The urbanized part of a district is characterized solely by its surface area. Two other parameters are relevant, though they remain constant throughout the nation. The so-called "urban crop factor" determines how much water can potentially evaporate from the urban surfaces. The salt concentration of the urban runoff determines how much salt is discharged from cities.

Surface Water. The area of the district containing surface water (lakes, canals, ditches, etc.) determines the increase due to rain and the decrease due to evaporation of the amount of such water. The total volume of the surface water is used to determine the salt concentration. In some places, high salt concentration of the surface water is controlled by requiring a minimum amount of water to flow out of the district at all times. We call this flow the flushing minimum. In some places, there is a constant extraction or discharge into or out of the surface water of a district, e.g., industrial extractions. When these flows are regarded as beyond the control of the managerial strategy and other decision rules built into DM, they are taken as input data to DISTAG. Industrial discharges may contain salt, so its concentration must be specified.

3.2.3. Data Characterizing Subdistricts

As explained in Chap. 2, a subdistrict is defined as a part of a district that has a unique landform and soil characteristic. Additional data that are associated with subdistricts are described in this section and displayed in Table 3.3.

Agricultural Region. For statistical purposes, the Landbouw Economisch Instituut (Agriculture Economic Institute, or LEI) divided the country into 14 agricultural regions; in some places the distinctions follow our division based on soil type and landform. Data assembled with respect to these 14 regions have been used to estimate sprinkling costs, and so each subdistrict has been assigned to one of these regions. Associated with each agricultural region is a set of numbers used to compute sprinkling costs for each kind of sprinkling and each crop type. These computations are discussed in Sec. 4.5.

Drainage and Infiltration Coefficients and Ditch Level. In the lowlands, the drainage rate is assumed to be proportional to the head

Table 3.3

SUBDISTRICT DATA

Name	Units	Description
AGRI_REG	--	Index of agricultural region
BD_COEF	/day	Coefficient of basic drainage model
BD_CONST	mm/day	Constant of basic drainage model
DRAIN_COEF	/day	Drainage coefficient
DIST_INDEX	--	Index of district
DITCH_LEVEL	mm	Level of ditches
GWL_INDUST	mm/day	Industrial groundwater withdrawals
GWL_DRINK	mm/day	Drinking water groundwater withdrawals
HILO_CODE	--	Landform code (0 = lowlands, 1 = low highlands, 2 = high highlands)
INITIAL_GWL	mm	Groundwater level at first of year
INFIL_COEF	/day	Infiltration coefficient
INF_RATE	mm/day	Loss from surface water to subsoil due to infiltration from ditches
RZ_SOIL	--	Index of root zone soil type
SATCAP_RZ	mm/mm	Saturation capacity of root zone
SATCAP_SS	mm/mm	Saturation capacity of subsoil
SEEP_FRAC	mm/mm	Amount of seepage into surface water divided by total seepage
SEEP_RATE	mm/day	Seepage rate
SEEP_SALT	mg/l	Salt concentration of seepage
SSDEPTH	mm	Effective depth of subsoil
SS_SOIL	--	Index of subsoil
SUP_FRAC	ha/ha	Fraction of subdistrict that is suppliable from ditches
WILTPT	mm/mm	Wilting point (of root zone)

difference between the groundwater level and the ditch level. The ditch level is held constant, while the groundwater level changes from one decade to the next. The constant of proportionality depends on such factors as the soil type and the spacing between ditches, and has been empirically determined for all places in the lowlands. Infiltration is the reverse of drainage. Normally infiltration takes place at a slower rate than drainage, so a different coefficient has to be specified. The ditch level, the drainage coefficient, and the infiltration coefficient are irrelevant in the highlands, because drainage is treated using a different model for basic drainage.

Basic Drainage Coefficients. In the highlands, the basic drainage rate has been assumed to be a function of the groundwater level. The two constants determining this function have been determined for each drainage region, for the high highlands and for the low highlands, by a statistical analysis of measured groundwater levels. This analysis is described in Sec. 6.4. The coefficients are irrelevant in the lowlands, because basic drainage does not occur there.

Seepage Rate and Open Water Seepage Fraction. In some places in the lowlands, there is a constant flow of water upward due to pressure differences between the groundwater level or surface water and deeper aquifers. The seepage rate is the rate at which this flow occurs and is assumed to be constant over the year. The open water seepage fraction indicates the fraction of the total seepage that flows directly to the open water. The rest of the seepage flows into the subsoil.

Seepage Salt Concentration. In those places where there is seepage into the region and the seepage water contains salt, the concentration of the seepage water must be specified.

Infiltration Rate. The drainage process in the highlands is modeled by means of the basic drainage functions. In some places in the highlands, however, water also infiltrates from canals and ditches into the subsoil. The infiltration rate specifies the rate at which this flow occurs. This rate, which is assumed to be a constant, is used only in those highlands subdistricts that have access to surface water.

Suppliable Fraction. This quantity is the fraction of the subdistrict that can be supplied with water from the national distribution system. It indicates in what fraction of the subdistrict the level of the ditches can be controlled. For highlands subdistricts this is the fraction of the area to which the above infiltration rate is applied in order to compute the infiltration flow.

Subsoil Depth. This is an empirically determined value needed for calculating salt concentrations in the subsoil. It is discussed in more detail in Sec. 4.3.2.

Industrial and Drinking Water Extractions. In some places, industries and drinking water companies extract groundwater. These extractions are assumed to be constant demands and are supplied as data to our model.

Root Zone Soil and Subsoil Type. Soil types affect the amount of water that can be stored and the difficulty plants have in extracting this water. Associated with each soil type is a set of soil parameters used to control computations dependent on soil type. These parameters are discussed in Sec. 4.1.

Landform. The three landform types were defined in Sec. 2.3.1.

3.2.4. Data Characterizing Plots

A plot is characterized by the subdistrict in which it lies, its crop, the kind of sprinkling installed (if any), and its area. Data characterizing plots are listed in Table 3.4.

Several data elements characterizing a plot depend on the crop type. For open-air crops, the potential evapotranspiration is determined by multiplying the open water evaporation by a factor. This constant factor, the crop factor, is approximately 0.8 for most crops during the growing season and somewhat less during the rest of the year. For glasshouse crops, potential evapotranspiration is specified as data. The crop value is just the value of the crop, in guilders per hectare. The root depth, which also depends on the soil type of the root zone, is important for the amount of water that can be stored in the root zone. Energy and labor costs of sprinkling depend on the crop type, as well as the type of sprinkling and the agricultural region in which the plot lies. Finally, associated with each plot is a large number of parameters controlling some of the submodels: the plot damage model, the plot salt model, etc. These parameters are more easily introduced when the models themselves are discussed.

3.3. COMPUTED INPUT DATA

Computed input data are not read from data files, but are supplied either by DM or were computed for a previous decade by DISTAG and carried forward. The latter are called initial conditions.

To each initial condition there corresponds, at the end of the decade, a final condition, which is used as the initial condition for subsequent computations. However, there must be supplied an "initial" initial condition to be used the very first time the model is applied.

In this section, we discuss each group of computed input data in turn. A summary of the data is given in Table 3.5.

Table 3.4

PLOT DATA

Name	Units	Description
Constant over Time		
COST_ENERGY	(Dflm/mm)/ha	Energy cost of sprinkling
COST_LABOR	(Dflm/mm)/ha	Labor cost of sprinkling
CROP_VALUE	Dfl/ha	Value of crop
IRR_CODE	--	Irrigation code (0 = unsprinkled, 1 = surface water sprinkled, 2 = groundwater sprinkled)
PLOTAREA	ha	Area of plot
PSI_REDUCE	mm	Evaporation reduction parameter
ROOTDEPTH	mm	Root depth of crop
SUBD_INDEX	--	Index of subdistrict
Time Varying		
CROPFACTOR	mm/mm	For open-air crops, potential evapotranspiration divided by open water evapotranspiration
	mm/day	For glasshouse crops, potential evapotranspiration per day

Table 3.5

COMPUTED INPUTS

Name	Units	Description
<u>Initial Condition for District</u>		
SWSALT_OLD	g	Quantity of salt in surface water
<u>Initial Condition for Each Plot in District</u>		
GWL_OLD	mm	Groundwater level
RZDEF_OLD	mm	Root zone moisture deficit
SSDEF_OLD	mm	Subsoil moisture deficit
RZSALT_OLD	mg/l	Root zone salt concentration
SSSALT_OLD	mg/l	Subsoil salt concentration
SURVFRAC_OLD	ha/ha	Survival fraction
<u>Provided by DM</u>		
IDIST		Index of district
CUTBACK	mm/mm	For "request": 1.0 For "delivery": sprinkling to be delivered to open-air crops sprinkled from surface water divided by amount requested by such crops
FLUSH_RED	m^3/s	Reduction from default flushing minimum
SALTCONC	mg/l	Salt concentration of water extracted by district from distribution system

3.3.1. Initial Conditions

There is one "districtwide" initial condition for each district. For each plot in the district, there are six initial "plot" conditions.

Salt Concentration. The districtwide condition is the salt concentration of the surface water changes from decade to decade and depends on the amount of salt present at the start of the decade.

Root Zone and Subsoil Deficits. Because the subsoil has no definite bottom, we do not know how much water it contains. Therefore, we find it convenient to measure the amount of water in the subsoil in terms of a deficit, so that, when the deficit is zero, the subsoil is full. The root zone does have a finite capacity, but to remain consistent, we have chosen to measure the water in the root zone as a deficit too.

Groundwater Level. The groundwater level depends on the subsoil deficit and the rate of capillary rise. The rate of capillary rise is not retained from one timestep to the next.

Root Zone and Subsoil Salt Concentrations. There is salt in both the root zone and the subsoil, and they both change from one decade to the next.

Survival Fraction. The survival fraction is a parameter needed in the damage calculation and indicates the history of the crop, i.e., which part of the original crop still survives at the beginning of the decade. The survival fraction also affects potential evapotranspiration.

3.3.2. Control Variables Supplied by DM

DM controls DISTAG with four parameters. DISTAG has the characteristics of all districts available but uses them only one district at a time. DM supplies a district index to indicate the district being considered.

Second, DM indicates the salt concentration of the water in the distribution system at the point where the given district extracts water.

Third, it indicates whether the computations are to be done in the request mode or the delivery mode. It indicates the request mode by setting a number, called the cutback fraction, equal to unity. It indicates the delivery mode by setting the cutback fraction equal to some value less than unity. When the cutback fraction is less than unity, sprinkling of certain crops is reduced so that the total amount of actual sprinkling, divided by the amount requested, is equal to the cutback fraction.

Finally, DM can change the amount of flushing using a parameter called the flushing reduction. When the flushing reduction is not zero, the amount of flushing in the district is reduced by an amount equal to it.

3.4. OUTPUTS

Outputs from DISTAG include variables returned directly to DM, final conditions that are retained internally and carried forward to the next decade where they are used as initial conditions, and a groundwater level that is written on a file for later analysis. These outputs are listed in Table 3.6.

3.4.1. Outputs Returned to DM

The model computes three water flows between the district and the distribution system. It computes a discharge from the surface water into the distribution system and an extraction from the distribution system into the surface water. These two numbers may both be nonzero, because of the necessity to flush water through the district for quality control. In addition, an amount representing drainage directly from the subsoil into the distribution system is computed.

DISTAG also gives DM some sprinkling quantities: the total amount sprinkled, the amount of sprinkling drawn from the surface water, and the amount of sprinkling drawn from the surface water that is applied to open-air cash crops. This last term represents the amount that DM can reduce if the extractions requested by a district are too great. The model also computes the average salt concentration of the water discharged to the distribution system.

Two other types of agricultural impacts are passed to DM. The first type consists of the amount of agricultural damage that occurred, due to salt, and the total agricultural damage (salt and drought). The second consists of the labor and energy costs of sprinkling, for each crop type.

3.4.2. Final Conditions

For each initial condition described in Sec. 3.3.1, the district agriculture model computes a final condition. This value is retained internally until the beginning of the next decade, when it becomes the initial condition for the new decade. There is one initial condition for the whole district (the amount of salt in the surface water), and there are six initial conditions for each plot in the district.

3.4.3. Groundwater

The groundwater level is not used in any way by the distribution model. Nevertheless, for some PAWN issues it is important to know the groundwater level. DISTAG computes the average groundwater level for each subdistrict and writes it on an output file at the end of each decade. Subsequently, these calculations can be studied to determine the effect of the policy.

Table 3.6

DISTRICT AGRICULTURE MODEL OUTPUTS

Name	Units	Description
Water Flows		
DISCHARGE	m^3/s	Discharge by district into distribution system
DRAIN_OUT	m^3/s	Drainage from subsoil of district that flows directly into distribution system
EXTRACTION	m^3/s	Extraction by district from distribution system
SPRINK_CUT	m^3/s	Total surface water sprinkling that can be cut back in case of water shortages
SPRINK_SW	m^3/s	Total sprinkling from surface water
SPRINK_TOT	m^3/s	Total amount of water consumed for sprinkling
Salt		
AVCONC_SW	mg/l	Average salt concentration of water discharged from district into distribution system
Crop Damage		
SALTDAM	Dfl	Total salt damage in district
TOTDAM	Dfl	Total damage (salt and drought)
Sprinkling Costs		
LABOR_COST	Dfl	Labor costs of sprinkling, per crop
ENERGY_COST	Dfl	Energy costs of sprinkling, per crop
Groundwater Levels		
AV_GWL	mm	Average groundwater level, per subdistrict

NOTE: DISTAG also computes a final condition, corresponding to each initial condition mentioned in Table 3.5. In the documentation, these outputs are referred to by the same prefix used in Table 3.5, followed by the suffix "_NEW." For example, SWSALT_NEW, the quantity of salt in the surface water at the end of the decade, becomes SWSALT_OLD at the beginning of the next decade.

Chapter 4

HOW DISTAG WORKS

In this chapter we explain the theoretical background and mathematics of DISTAG, that is, how the model works. We will not discuss details of the computer implementation of the model. This explanation is given in Chap. 5.

4.1. AN OVERVIEW

In this section, we show how DISTAG is used by DM, and then we outline its main computational steps.

4.1.1. How DISTAG Is Used by DM

The operation of DM is shown in Fig. 4.1., a figure that emphasizes the role of DISTAG. We outline here the eight major steps shown in that figure.

Read Geographic Data. By geographic data we mean the data that remain constant from one decade to the next. These data describe the districts, and control some of the submodels.

Read Timestep Data. DM reads rain and evaporation data for a particular timestep.

Make Initial Estimates of Salt Concentrations. DM makes an estimate of the salt concentration of the waters of the national distribution system. An estimate of the salt concentration of the water extracted by the districts for agriculture is needed in order to, first, compute how much salt damage will occur and, second, to compute the concentration of the water discharged by the districts. The estimate made at this point is a temporary one, however, because the actual salt concentration may be affected by salt from districts whose discharges have not yet been computed.

Use DISTAG in "Request" Mode. For every district, DISTAG determines how much water is needed by agriculture to prevent additional damage during the timestep. DISTAG also computes salt discharges, based on the initial estimate described in the previous step.

Is There Enough Water? It may happen that, initially, more water is requested than is available. If this happens, then DM must invoke some previously specified managerial plan either to increase the supply of water where the shortage exists or to decrease the demand there. DM has two ways to reduce water demand by districts. First, DM can reduce the amount of water demanded for flushing out salt. Second, it can reduce the demand for surface water sprinkling by

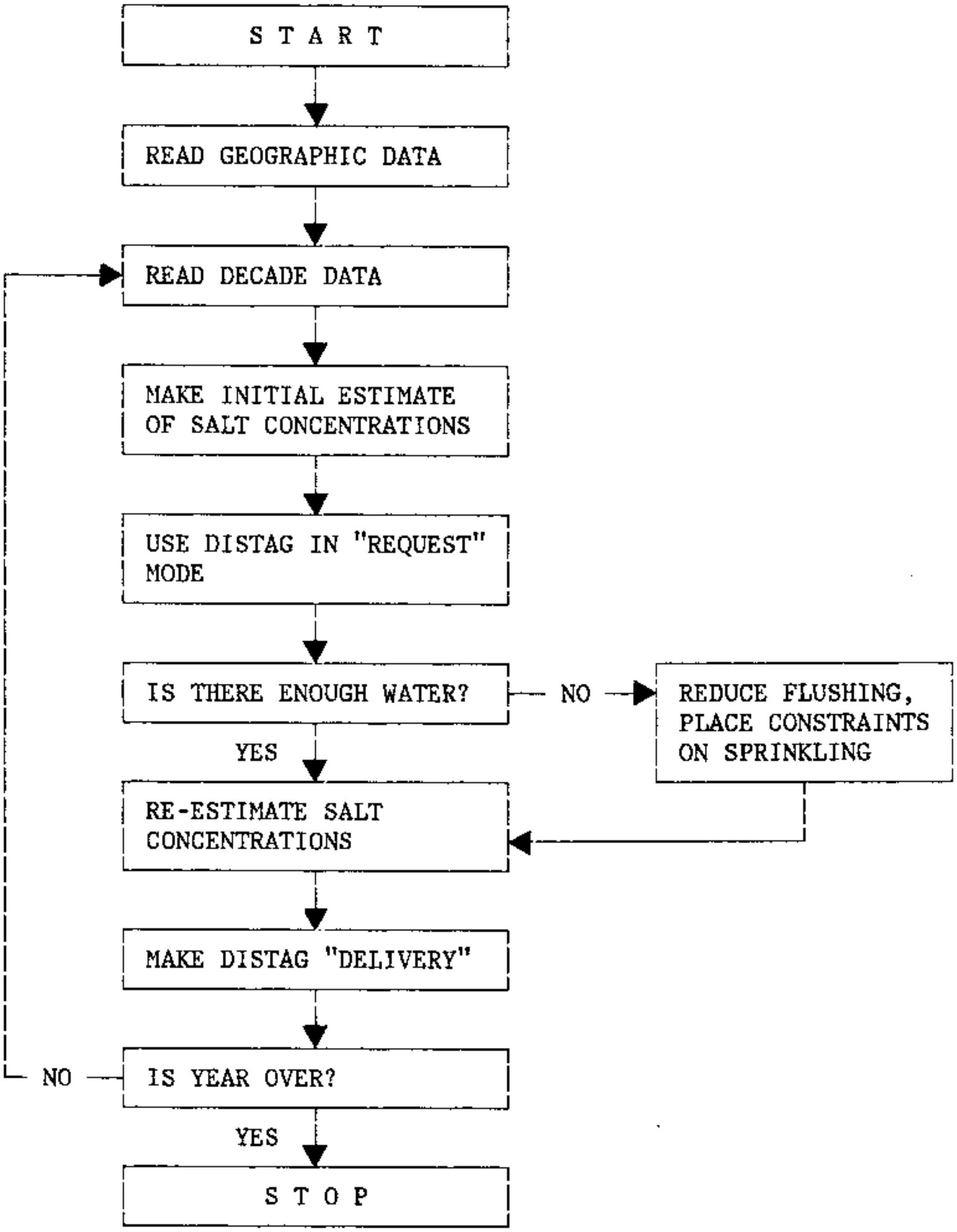

Fig. 4.1--How DM uses DISTAG

imposing a constraint on it. This constraint is applied only to sprinkling on open-air crops. (We assume that the demands of glasshouse crops will not be cut back, because these crops are much more valuable than open-air crops and depend totally on irrigation. The benefits of saving a relatively small amount of water by constraining water delivered to these crops would be far outweighed by the costs.) The constraint is applied only to sprinkling from surface water, of course. DM applies this constraint by specifying a "cutback fraction." The total amount of surface water sprinkled on open-air crops is then set equal to the amount originally requested, multiplied by this cutback fraction.

Reestimate Salt Concentrations. At this point, DM has better information about what extractions and discharges the districts are making, and so it can make a better estimate of the salt concentrations in the national distribution system.

Use DISTAG to "Deliver." With updated estimates of salt concentrations, and possibly some constraints on agricultural extractions for sprinkling, DM uses DISTAG a second and last time to compute impacts. Agricultural damages and costs of sprinkling may change in this step: the damages may be higher and the costs of sprinkling lower than previously because of the constraints that may have been imposed on sprinkling by DM.

Is Year Over? If the year for which computations are being made is not completed, then DM returns to the point where data for the next timestep is read in, and repeats the above described steps for the new timestep.

4.1.2. The Main Computational Phases of DISTAG

DISTAG carries out its computations in eight main steps, summarized here and shown in Fig. 4.2.

If a Request: Bring Forward Last Decade's Conditions. As described in Sec. 3.2, there are a number of time-varying quantities required at the beginning of each timestep. Since DISTAG is used twice during each timestep, it must retain the correct initial conditions until they are no longer needed. When DISTAG is used for a "request," it carries forward from the previous timestep the final state conditions computed for that timestep, and uses them as the initial state conditions for the present timestep, destroying the old initial state conditions. When DISTAG is used to "deliver," it is not necessary to do this again.

If a Delivery: Constrain Flushing and Sprinkling, If Necessary. If DISTAG is being used to deliver water, then because of some conflict between supply and demand, DM may have decided to constrain the amount of water available for flushing and sprinkling. If DM has constrained flushing, it passes a variable to DISTAG indicating the amount by which flushing should be reduced. If DM has constrained sprinkling, it informs DISTAG of this decision by setting the cutback fraction.

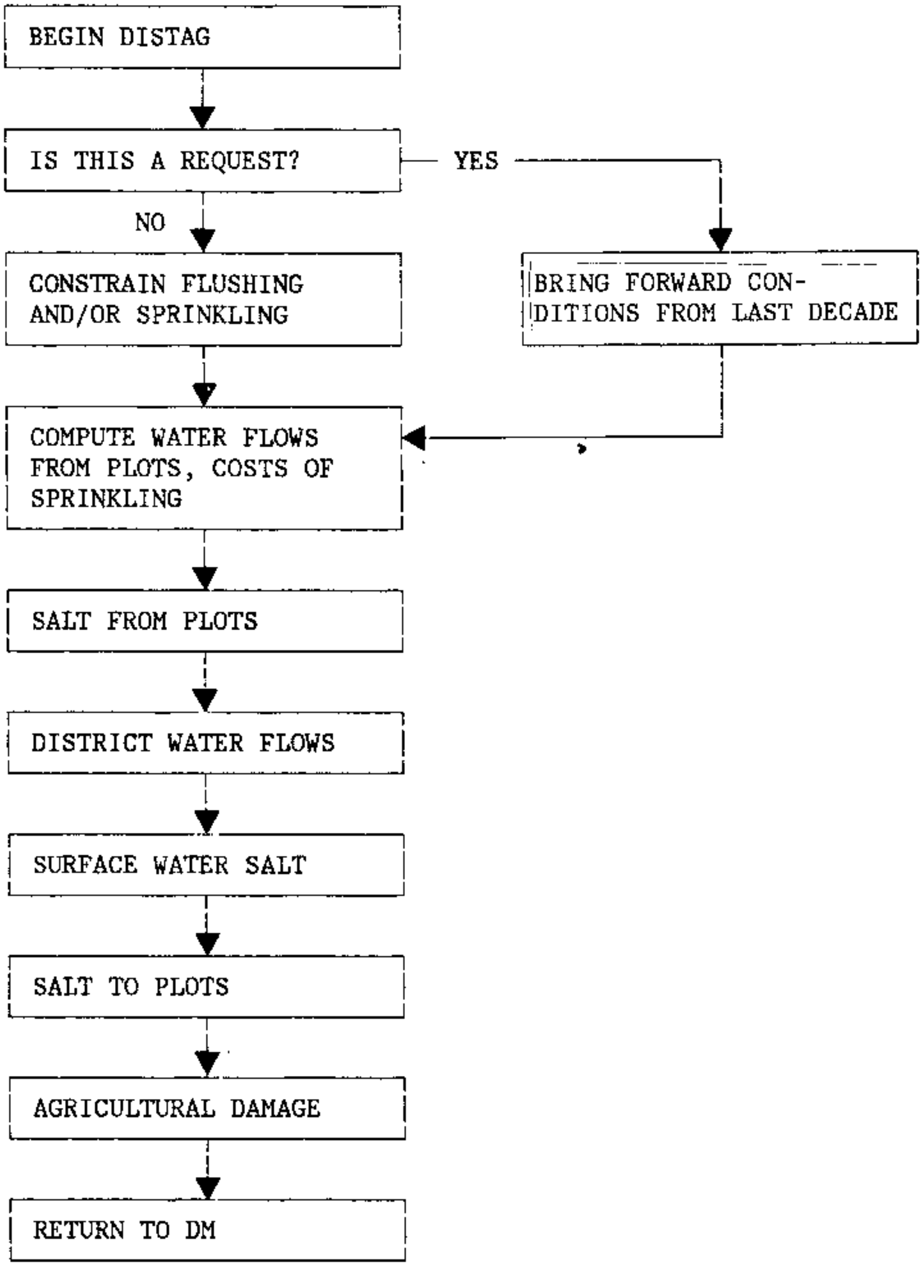

Fig. 4.2--Overview of DISTAG

The cutback fraction is the total amount of sprinkling that is to be delivered to all open-air surface water sprinkled crops, divided by the total amount of sprinkling actually requested by such crops. Generally, there are several plots containing such crops. Each of these plots receives what it originally requested, multiplied by the cutback fraction.

Discharges and Extractions from Plots, Sprinkling Costs. As described in Sec. 2.3.6, each district contains a number of plots, and these plots comprise all the agriculture and nature in the district. DISTAG first computes what extractions and discharges of water occur between these plots and the surface water system of the district. If DISTAG is being used in the "delivery" mode, some of the requests for sprinkling water may be constrained. If it is being used in the "request" mode, no such constraints are applied. The computation of water discharges, extractions, and sprinkling requests are carried out by the plot water model (PLOTWAT), described in much more detail in Sec. 4.2. After computing the amount of water sprinkled, DISTAG computes the operating cost of sprinkling.

Salt Flows from Discharging Plots. In the same timestep, some plots can discharge water at the same time that other plots extract water. In order to accurately determine the salinity of the extracted water, the amount of salt dumped into the district water by the discharging plots must be known. Salt discharged from plots is computed by the plot salt model (PLOTSLT), a model that is used again (see below) for plots that extract water.

District Water Flows. DISTAG determines the remaining water flows within the surface water system: urban runoff, rain into and evaporation from surface water, extractions from the main system, etc.

Salt Concentration of the Surface Water. Given all water and salt flows, DISTAG determines the salt concentration of the surface water and, hence, the salt concentration of the water taken in by plots that are extracting water and of the water that is being discharged into the national distribution system.

Salt Flows to Extracting Plots. Using the salt concentration mentioned in the previous step, DISTAG uses PLOTSLT again--this time for the remaining plots--to update the amount of salt contained in the soil of the plots that are extracting water from the district.

Agricultural Damage. At this point, all water and salt quantities have been computed, so the plot damage model (PLOTDAM) is used to determine what agricultural damage may have occurred due to salt or drought.

4.2. COMPUTATION OF WATER FLOWS

In this section, we explain how water flows are calculated. The main role of DISTAG here is to compute flows (i.e., discharges and extractions) between the district and the national distribution system, and to indicate to DM how much water is demanded for sprinkling. When DISTAG is used to formulate a request, DM needs to know how much water is used for sprinkling open-air crops with surface water, since this water may be constrained by DM if there are water shortages.

In Sec. 4.2.1 through Sec. 4.2.5 we will explain the theory underlying the water flow computations for open-air plots. In Sec. 4.2.6 we discuss the glasshouse crops, and we conclude this section with a discussion of the water flow computations carried out on a district level.

4.2.1. Definitions and Schematization for an Open-Air Plot

For the present purposes, it helps to think of a plot as a vertical column of soil. The surface area is not important, so to make matters precise, let us assume the area is 1 m^2. Suppose we take a slice Δz cm thick, containing Δw cm of water. If this water is removed and placed in a container of cross-sectional area 1 m^2, then the *moisture content* Θ of the slice is the ratio $\Theta = \Delta w/\Delta z$. Depending on the soil type, there is a maximum moisture content, called the *saturation capacity* ω. Generally, the moisture content is different at different depths; it usually increases with increasing depth, until a point is reached where the moisture content just equals the saturation capacity. This point is called the *groundwater level*. Below the groundwater level lies the *saturated zone*. Above the groundwater level lies the *unsaturated zone*.

Schematization of the Soil Profile. The ideas in this section are illustrated in Fig. 4.3. The *effective root zone* is defined as the top layer of soil in which the roots of plants withdraw 80 percent of their water. Water is stored in the root zone; the actual amount at any one time is equal to the average soil moisture content of the root zone multiplied by the depth of the root zone.

The part of the soil profile below the effective root zone is called the *subsoil*. It consists of the saturated zone and the part of the unsaturated zone between the bottom of the root zone and the saturated zone. It is impossible to estimate the amount of water stored in the subsoil, because its depth is unknown. Instead, we consider the *subsoil deficit*, defined as the amount of water that could be added to the unsaturated zone in order to bring the groundwater level up to the top of the subsoil.

Any place water does not completely fill the soil pores, so that the moisture content is less than the saturation capacity, surface tension causes a negative pressure, called *suction*. Where the soil is saturated, suction is zero; as the soil becomes drier, suction increases.

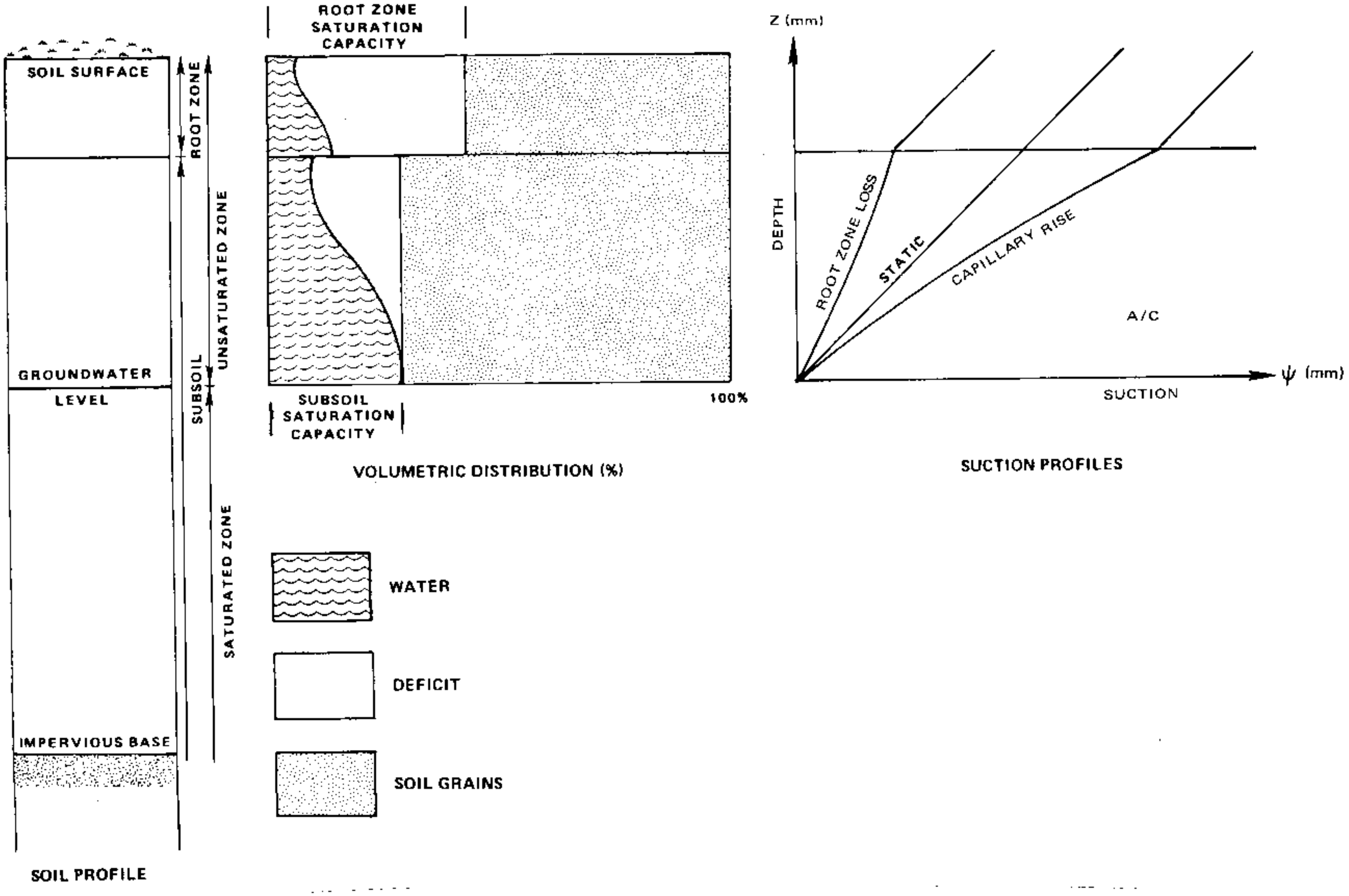

Fig. 4.3 Soil profile, volumetric distribution and suction profile below a plot

Generally, the driest soil can be found in the root zone in dry periods, when the suction may become so high that plants can no longer absorb water from the soil. This limit on suction is around 16,000 cm, for almost all kinds of plants and soils. The moisture content of the soil when the suction is 16,000 cm is called the wilting point of the soil. In Fig. 4.3 we give an example of a suction profile in the unsaturated zone. (From this point on, we express suction in mm, since this unit is standard in the computer applications of our equations.)

We assume the suction profile in the root zone is linear and follows the hydrostatic pressure slope, that is,

$$\Psi_x = \Psi_i + x$$

where

Ψ_x: Suction (mm) at a distance of x mm from bottom of root zone

Ψ_i: Suction (mm) at bottom of root zone

It follows that if the depth of the root zone is ρ mm, then

$$\Psi_i = \Psi - \rho/2$$

where Ψ is the average suction (mm) in the root zone.

The field capacity of a soil is the maximum moisture it can hold against the force of gravity. When the soil is at field capacity, there is by definition no capillary flow and the soil moisture tension curve follows the hydrostatic pressure line as shown in Fig. 4.3. This implies that the field capacity is different at different depths and the corresponding suction depends on the distance from the groundwater level.

Water Flows in an Open- Air Plot. The flows identified in this section are shown in Fig. 4.4. Since we consider a plot with a fixed cross-sectional area, the quantity of water in any given flow over a fixed interval of time can be expressed as a depth.

In our model, we will use as input two quantities that depend on atmospheric and climatic conditions:

- Rain, from atmosphere into root zone.
- Potential evapotranspiration, from root zone to atmosphere.

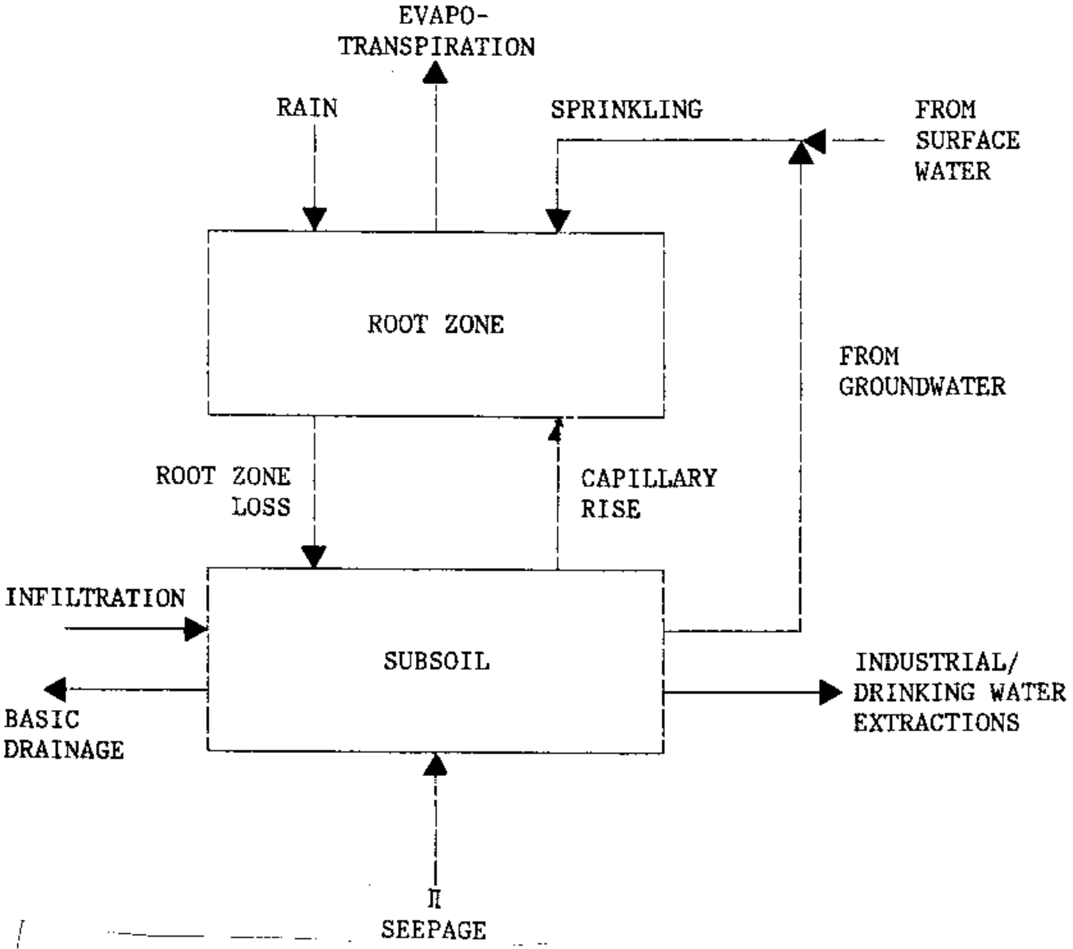

Fig. 4.4--Water flows in a plot

The remaining flows are determined by the physical processes occurring within the plot:

- Actual evapotranspiration, from root zone into atmosphere.
- Capillary rise, from subsoil into root zone.
- Drainage, from subsoil into surface water.

Evapotranspiration, of course, always represents a flow out of the plot. Water can flow from the root zone into the subsoil, in the opposite direction of capillary rise. When this happens, we call the flow root zone loss. Similarly, water can flow from the surface water system into the subsoil, in the opposite direction of drainage. When this happens, we call the flow infiltration.

In the "real" world, all of the quantities mentioned change continuously with time. In addition, the rate of vertical flow of water throughout the soil column is different at different depths, and the rate at which the moisture content of each "slice" of the soil column changes is different at different depths. A complete mathematical description of this system, if one were possible, would involve a complex system of partial differential equations whose variables are dependent on time and depth below the soil surface. Such a formulation is too complex for practical applications. In the next section, we describe a much simpler situation, called the steady state.

4.2.2. Steady State Flows in Open-Air Plots

If during a fixed interval of time all the quantities discussed in the previous section remain constant, we say the system is in a steady state condition. While such a situation probably never occurs in the "real" world, it is a useful approximation for short intervals when quantities change slowly.

We specify two atmospheric conditions:

R: Rain (mm/day)

E_P: Potential evapotranspiration (mm/day)

Other flows depend on the physical situation:

E_A: Actual evapotranspiration (mm/day)

V: Capillary rise (mm/day)

D: Drainage (mm/day)

Finally, the "state" of the plot is determined by:

Θ: Soil moisture content of root zone (mm/mm)

Ψ: Average suction in root zone (mm)

Δ: Moisture deficit in subsoil (mm)

γ: Groundwater level (mm)

In the "real" world, everything depends on everything else. In our model, we make some simplifying assumptions about certain causal relationships between the basic variables of our model. In what follows, we state these assumptions by writing some functional relationships between our variables. The exact nature of these relationships will be described in the next section.

Actual Evapotranspiration. Evapotranspiration depends on climatological conditions (the potential evapotranspiration), and on the difficulty that plants have extracting moisture from the soil (average suction in the root zone):

$$E_A = E_P \times F_{EVAP}(\Psi).$$

Drainage. Drainage depends on the groundwater level:

$$D = F_{DRAIN}(\gamma).$$

Suction-Moisture (pF-curve). Suction depends on soil moisture:

$$\Psi = F_{PSI}(\Theta).$$

Groundwater Level and Capillary Rise. Darcy's law (see, e.g., Ref. 4.1) relates the groundwater level, the soil moisture profile in the subsoil, and capillary rise. Two functions can be derived from this theory:

$$\gamma = F_{GWL}(\Delta,v)$$

and

$$V = F_{CAPRISE}(\Psi,\gamma).$$

4.2.3. Using Steady State Conditions

We consider an interval δ days long. Suppose that during this time rain falls at a constant rate equal to R mm/day, and that the potential evapotranspiration is E_P mm/day. At the beginning of the interval, we know

θ^0: The initial root zone soil moisture (mm/mm))

Δ^0: The initial subsoil deficit (mm)

γ^0: The initial groundwater level (mm)

Our problem is to determine three water flows:

E_A: The actual evapotranspiration (mm/day)

V: The capillary rise during the interval (mm/day)

D: The drainage (mm/day)

and three final conditions:

θ^1: The final root zone soil moisture (mm/mm))

Δ^1: The final subsoil deficit (mm)

γ^1: The final groundwater level (mm)

Finally, we will need two parameters that describe the plot itself:

ρ: The root depth (mm)

ω: The saturation capacity of the root zone (mm/mm)

Mass balances and one of the functions introduced in the previous sections allow us to calculate the final conditions from the initial conditions and all of the water flows:

$$\theta^1 = \theta^0 + (R + V - E_A)\delta/\rho \tag{1}$$

$$\Delta^1 = \Delta^0 + (V + D)\delta \tag{2}$$

and

$$\gamma^1 = F_{GWL}(\Delta^1, V). \tag{3}$$

We now assume that the water flows match those of a steady state system in which the state conditions (root zone soil moisture, subsoil deficit, and groundwater level) are set equal to averages. That is, we let

$$\theta = (\theta^0 + \theta^1)/2$$

$$\gamma = (\gamma^0 + \gamma^1)/2$$

denote the average root zone soil moisture and groundwater level, respectively. We then assume that if the plot had been in a steady state condition, with constant value of the root zone soil moisture equal to Θ and groundwater level equal to γ, then the same water flows would have been observed. If we let

$$\Psi = F_{PSI}(\Theta),$$

then under such steady state conditions:

$$E_A = E_P \times F_{EVAP}(\Psi) \tag{4}$$

$$V = F_{CAPRISE}(\Psi,\gamma) \tag{5}$$

and

$$D = F_{DRAIN}(\gamma). \tag{6}$$

Our problem is therefore converted to that of solving simultaneously the six equations Eq. (1) through Eq. (6).

4.2.4. Specifying the Functions

In Sec. 4.2.2 we introduced five functional relationships between the steady state quantities in a plot, and in Sec. 4.2.3 we showed how the functions will be used. We now explain how these functions are actually defined.

Actual Evapotranspiration. Water is lost from the top of the soil column to the atmosphere by evaporation directly from the soil surface and by transpiration from plants. The sum of these two flows is called *evapotranspiration*. The amount of *actual evapotranspiration* cannot exceed the *potential evapotranspiration*. The latter quantity is computed from input data, by multiplying the open water evaporation rate by a time-dependent crop factor. (A correction factor used when plants have suffered damage is explained in Sec. 5.3.1.) The actual evapotranspiration depends on the amount of water available in the root zone. If the suction is low enough, the rate of actual evapotranspiration will equal the rate of potential evapotranspiration. But as the suction becomes higher, the actual rate will become lower than the potential rate. Evapotranspiration totally ceases at the wilting point, corresponding to a root zone suction of around 16,000 cm. An important question is what the functional relationship between the actual evapotranspiration (E_A), the potential evapotranspiration (E_P), and the average soil moisture suction (Ψ) looks like. As indicated by Minhas et al. [4.2], the results of various studies in this field differ considerably, so there does not seem to be a clear answer to this question. We made the following assumptions:

- Up to a certain value of the suction (Ψ_{reduce}), E_A equals E_P.
- Between Ψ_{reduce} and the wilting point ($\Psi = 16000$ cm), E_A decreases linearly with the pF value of the soil moisture (which is the logarithm of the suction in cm).
- At the wilting point, $E_A = 0$.

To express these assumptions in functional form, we write

$$E_A = E_P \times F_{EVAP}(\Psi)$$

where

E_A: Actual evapotranspiration (mm/day)

E_P: Potential evapotranspiration (mm/day)

Ψ: Average suction in the root zone (mm)

and the function F_{EVAP} is defined by the expression

$$\begin{aligned} F_{EVAP}(\Psi) &= 1 && \Psi \le \Psi_{reduce} \\ &= X && \Psi_{reduce} \le \Psi \le 160000 \\ &= 0 && 160000 \le \psi \end{aligned}$$

where

X: $\log(\Psi/160000)/\log(\Psi_{reduce}/160000)$

Ψ_{reduce}: A specified parameter

Figure 4.5 shows the relationship between E_A/E_P and the pF value of the soil moisture.

Drainage and Infiltration. The force of gravity acts on water in the saturated zone, causing it to flow from places with a higher piezometric head to places with a lower one. When this flow moves water from the subsoil into the surface water, it is called drainage. When it causes water to leave the surface water and enter the subsoil, it is called infiltration. In either case, the flow is governed by a differential equation called Darcy's law (Fig. 4.6):

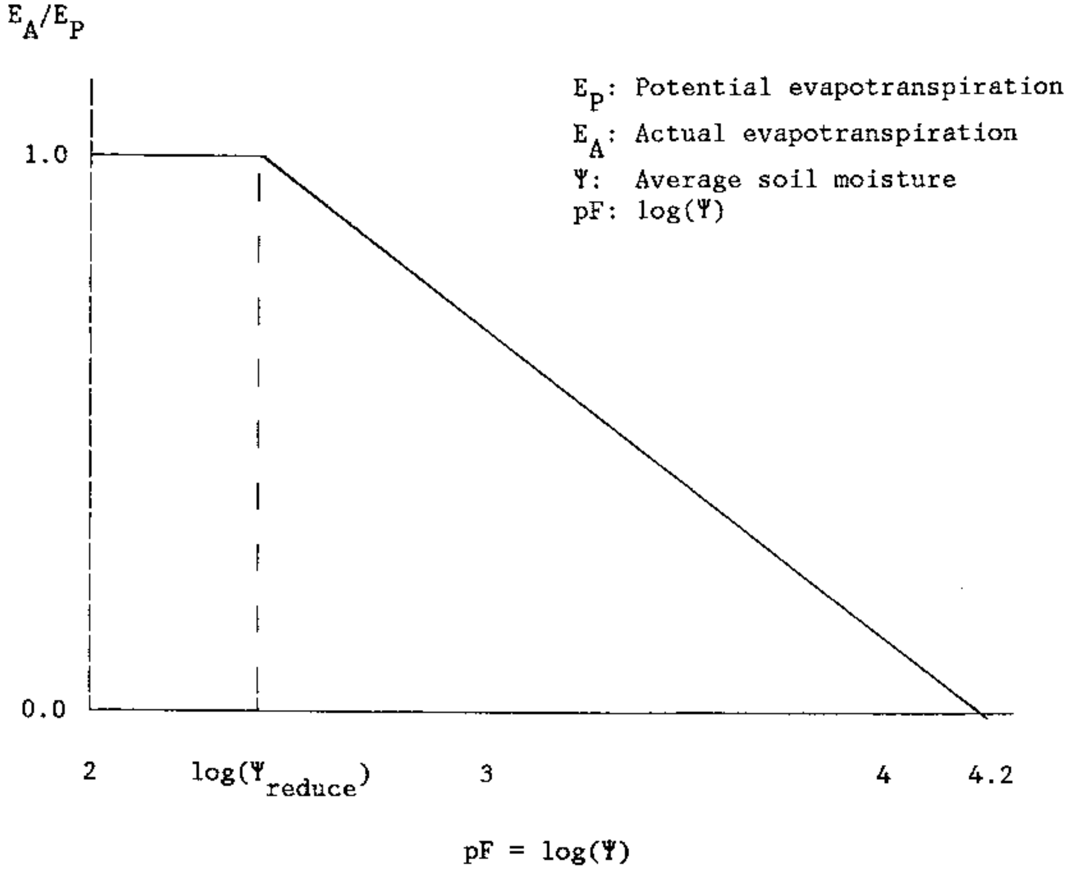

Fig. 4.5--E_A/E_P as a function of pF

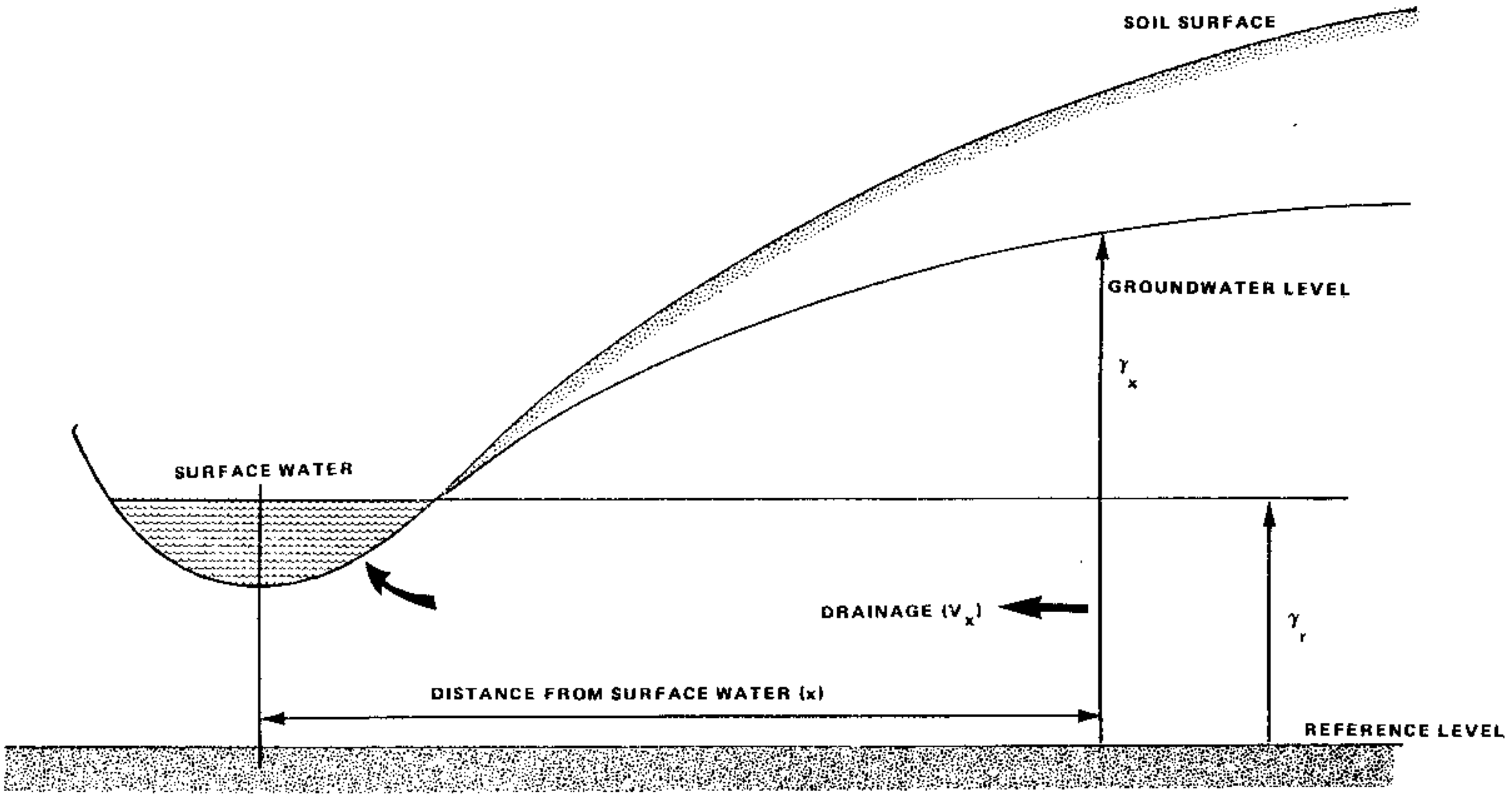

Fig. 4.6--Soil profile illustrating water flows due to drainage

$$V_x = \gamma'_x/K_x \tag{7}$$

where

x: Vertical distance from an arbitrary datum (mm)

V_x: Drainage velocity (mm/day)

K_x: Drainage resistance (days)

γ_x: Hydraulic potential (groundwater level) in (mm)

γ'_x: Derivative with respect to x

Solutions to Eq. (7) define the drainage function:

$$D = F_{DRAIN}(\gamma)$$

where

D: Drainage (if positive) or infiltration (if negative) (mm/day)

γ: Groundwater level (mm)

When drainage occurs, the resistance consists of a horizontal component caused by the horizontal flow and a radial component when the flow enters the surface water system. When infiltration occurs, there is an additional entrance resistance when water from the surface water system enters the subsoil. We can assume that otherwise these two resistances are constant. The steady state solution to Eq. (7) then becomes:

$$\begin{aligned} D &= (\gamma - \gamma_r)/k^+ && \gamma > \gamma_r \\ &= (\gamma - \gamma_r)/k^- && \gamma \le \gamma_r \end{aligned}$$

where

k^+: Drainage resistance (1/day)

k^-: Infiltration resistance (1/day)

γ_r: Reference level (e.g., level of the surface water system) (mm)

This form of the drainage function is used for plots lying in the lowlands, where the reference level is set equal to the ditch level. The values used for resistances can be estimated on the basis of such factors as soil type, ditch spacing, etc.

When no specific reference level can be distinguished, the steady state solution to Eq. (7) can be written in the form:

$$D = \alpha + \beta \gamma$$

where

α: Constant term of the drainage function (mm/day)

β: Coefficient term of the drainage function (1/day)

This form of the drainage function is used for plots in the highlands, where the coefficients are determined on the basis of measured groundwater levels.

Infiltration losses from the surface water system in the highlands are treated differently. These losses are assumed to come from that part of the surface water system in the highlands that is suppliable from the national system, and they are assumed to take place at a constant rate. Hence, they are determined only by the suppliable part of the highlands district and the infiltration rate. They are included as a part of the constant term of the drainage function. (See Sec. 5.3.2.)

Suction-Moisture (pF-Curve). For any suction value Ψ there corresponds a unique value of the soil moisture θ. This relationship depends strongly on the soil type, and in general it must be empirically determined. We will denote this empirical relationship generically by the functional notation

$$\Psi = F_{PSI}(\theta).$$

The relationship is monotonic, and so can be inverted. We will denote the inverse by the notation

$$\theta = F_{THETA}(\Psi).$$

The Ψ-θ relation has been empirically determined for twenty soil types [4.3]. It is called the pF-curve of the soil (pF is $\log_{10}\Psi$). Figure 4.7 is an example.

The Groundwater Relation. Darcy's law states that when steady state conditions hold, capillary rise is governed by the differential equation

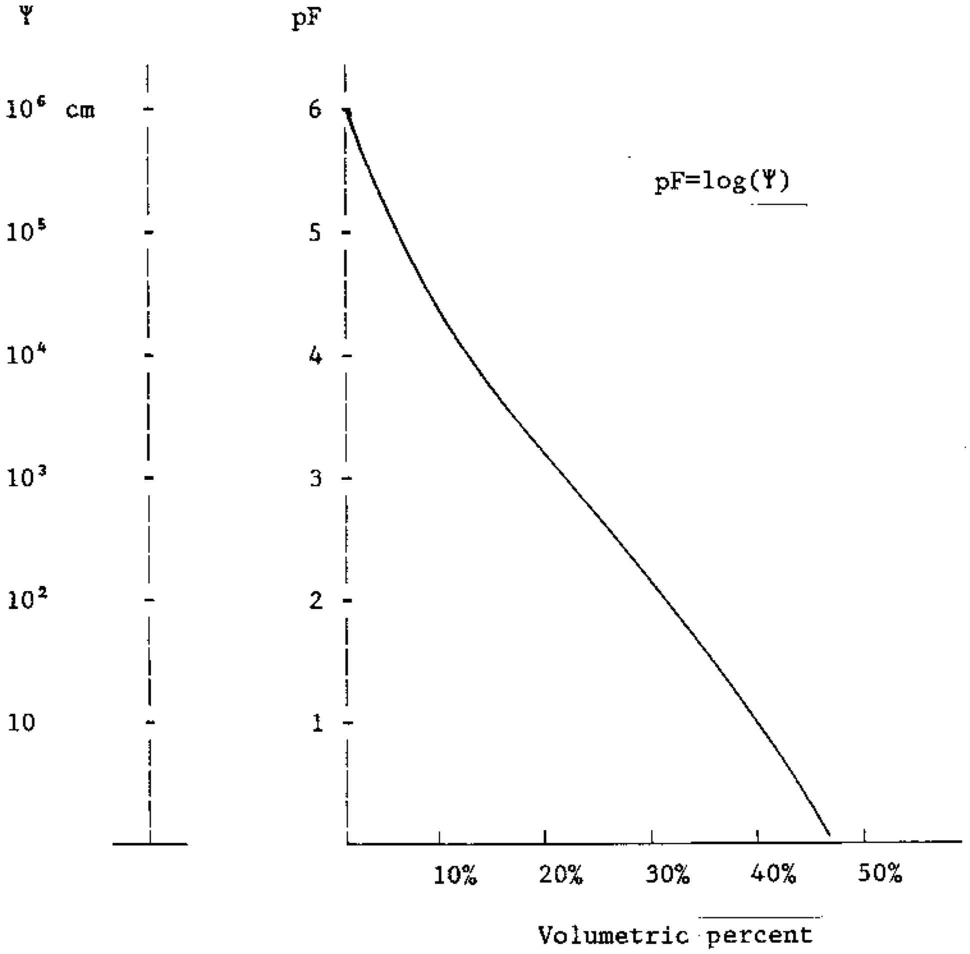

Fig. 4.7--Typical soil moisture-soil tension curve (pF-curve)

$$V = k(\Psi(z))(\Psi'(z) - 1) \qquad 0 \le z \le \gamma \tag{8}$$

where

γ: Groundwater level (mm) measured downward from base of root zone

$\Psi(z)$: Suction (mm) z mm above the groundwater level

$k(\psi)$: Capillary conductivity as an empirically determined function of suction ψ (mm/day)

V: Rate of capillary rise (mm/day) in unsaturated zone (assumed constant)

If the capillary rise V is known, and a particular value for suction, Ψ, is specified, let $z(\Psi,V)$ denote the distance above the groundwater level where the suction Ψ is found. In the steady state situation, Darcy's equation gives the following expression for $z(\Psi,V)$:

$$z(\Psi,V) = \int_0^{\Psi} k(\psi)/(k(\psi)+V)d\psi. \tag{9}$$

Expressions for $k(\psi)$ take the following forms [4.3]. For each soil type, four empirically determined parameters k_0, α, Ψ_a, and Ψ_{max} are given. Then,

$$\begin{aligned} k(\psi) &= k_0 && 0 \le \psi \le \Psi a \\ &= k_0 \exp(-\alpha(\psi-\Psi_a)) && \Psi_a \le \psi \le \Psi_{max} \\ &= a\psi^{-1.4} && \Psi_{max} \le \psi \end{aligned}$$

where a is the constant that makes the last two expressions equal when $\psi = \Psi_{max}$.

For this "k" function, explicit expressions can be given for $z(\Psi,V)$:

$$\begin{aligned} z(\Psi,V) &= \Psi k_0/(k_0+V) && 0 \le \Psi \le \Psi_a \qquad (10) \\ &= z(\Psi_a,V)+\ln(R)/\alpha && \Psi_a \le \Psi \le \Psi_{max} \end{aligned}$$

$$= z(\Psi_{max})+b \int 1/(1+u^{1.4})du \qquad \Psi_{max} < \Psi$$

where

$$R = [V+k_0]/[V+k_0\exp(-\alpha(\Psi-\Psi_a))]$$

$$b = (a/V)^{1/1.4}$$

and the integral is evaluated from Ψ_{max}/b to Ψ/b.

It can be seen from Eq. (9) that for a fixed value of capillary rise V, $z(\Psi,V)$ is a monotonic function of the suction Ψ. Therefore, given a distance Z above the groundwater level, and a capillary rise V, the equation

$$z(\Psi,V) = Z$$

can be solved for the suction Ψ. We will denote this solution by the expression $\Psi(Z,V)$.

As explained above, the soil moisture Θ can be determined from the suction Ψ. Therefore, once we know the suction $\Psi(Z,V)$ corresponding to a specified distance Z and capillary rise V, we know the soil moisture too, which we could denote as $\Theta(Z,V)$. This defines the function F_{THETA}:

$$\Theta(Z,V) = F_{THETA}(\Psi(Z,V)).$$

For a fixed value V of capillary rise and a given groundwater level γ, the moisture function $\Theta(Z,V)$ can be integrated to obtain an estimate of the total amount of water in the subsoil between the bottom of the root zone and the groundwater level:

$$\Theta_{subsoil} = \int_{0}^{\gamma} \Theta(z,V)dz.$$

An expression for the subsoil deficit Δ can therefore be written

$$\Delta(V,\gamma) = \gamma\omega_{subsoil} - \Theta_{subsoil}$$

where $\omega_{subsoil}$ is the saturation capacity of the subsoil. For a fixed value of capillary rise, V, this expression is monotonic in the groundwater level γ. Therefore, if a subsoil deficit Δ is specified, the equation

$$\Delta(V,\gamma) = \Delta$$

can be solved to find that groundwater level γ which, for a specified capillary rise V, yields the specified subsoil deficit Δ. We denote the solution to this equation by the expression

$$\gamma = F_{GWL}(\Delta,V)$$

where

γ: Groundwater level (mm)

Δ: Subsoil deficit (mm)

V: Capillary rise (mm/day)

The Capillary Rise Relation. From Eq. (8), capillary rise is zero when the slope of the suction curve is equal to one everywhere, and in this case it follows the hydrostatic curve:

$$\Psi(z) = z \qquad 0 \leq z \leq \gamma.$$

Thus, capillary rise is zero if and only if the suction at the base of the root zone is equal to the groundwater level, and is therefore positive when the suction at the base of the root zone is greater than the groundwater level.

If the suction at the base of the root zone is equal to the groundwater level, the moisture in the root zone is at field capacity. If the suction decreases even more (e.g., because rain exceeds evapotranspiration), the excess must flow from the root zone into the subsoil. We call this flow *root zone loss*. We do not introduce an additional term for this flow. Instead, we will use the variable associated with capillary rise, but we let it take a negative value equal in magnitude to the rate of root zone loss.

Suppose Ψ is the average suction in the root zone, and let

$$\Psi_i = \Psi - \rho/2$$

denote the suction at the interface between the root zone and the subsoil. As the foregoing discussion indicates, if V denotes the capillary rise (in the extended sense just introduced), then

$$\begin{aligned} V &> 0 && \text{if } \Psi_i > \gamma \\ &\leq 0 && \text{otherwise.} \end{aligned}$$

Since $z(\Psi, V)$, defined in Eq. (9), is monotonic, the equation

$$z(\Psi_i, V) = \gamma \tag{11}$$

can be solved to obtain the capillary rise associated with the tension Ψ_i and groundwater level γ.

In principle, solutions can result in positive <u>or</u> negative values for capillary rise. To simplify our calculations, however, we assume that negative capillary rise (root zone loss) is instantaneous. This means that the root zone soil moisture never exceeds field capacity. The rate of root zone loss is then just the difference between rain and evapotranspiration. Hence, in this case

$$V = -(R - E_A).$$

These two expressions define our capillary rise function,

$$V = F_{CAPRISE}(\Psi, \gamma)$$

where

V: Capillary rise (mm/day)

Ψ: Average suction in the root zone (mm)

γ: Groundwater level (mm)

That is, V is the solution to Eq. (10) when $\Psi_i > \gamma$, and is given by Eq. (11) otherwise.

4.2.5. Sprinkling

In order to simplify the discussion, we have so far ignored the fact that some plots are sprinkled. We will discuss first how the overview presented in Sec. 4.2.2 could be modified to include sprinkling, and then we will discuss the ways in which sprinkling was modeled.

<u>Overview</u>. When a plot is sprinkled, four additional water flows need to be considered.

First of all, water that is sprinkled represents an additional input of water into the root zone. Second, because of cracks in the soil surface, or because sprinkled water is not uniformly distributed over the field, some of the sprinkled water may flow directly into the subsoil. Third, when water is sprinkled, part of it evaporates into the air before it ever reaches the root zone. The sum of these three flows represents the fourth flow: the total amount of water that is extracted, either from the groundwater or from the surface water system, for the purpose of sprinkling.

To modify our overview discussion to include sprinkling, we need to introduce two additional terms:

I:	Rate at which sprinkled water effectively enters the root zone (mm/day)
I_NET:	Net withdrawal from subsoil, including a part that is extracted if the plot is sprinkled from groundwater, minus the part that flows directly back into the subsoil (mm/day). (Negative when sprinkled from surface water.)

The discussion in Sec. 4.2.2 can be modified to include sprinkling by adding the sprinkling term I to the rain term R in Eq. (1), and the subsoil flow term I_NET to the capillary rise term V in Eq. (1) and Eq. (2).

<u>Sprinkling Open- Air Crops</u>. DISTAG contains two different sprinkling procedures. Either can be used.

The simpler procedure uses two soil moisture levels, a critical level and a target level, and an upper bound on the rate at which sprinkling can occur. It first computes what the soil moisture would be if no sprinkling occurs. If this soil moisture is above the critical level, no sprinkling occurs. If this soil moisture level is below the critical level, then sprinkling is assumed to take place at such a rate as to bring the soil moisture up to the target level by the end of the timestep, unless this rate exceeds the upper bound. If it does exceed the upper bound, the sprinkling rate is set equal to the upper bound. To be precise, we let

$$\Theta_{unspr} = \Theta^{0} + (R + V - E_{p})\delta/\rho$$

denote what the soil moisture would be if no sprinkling occurs. Then we set

$$\begin{aligned} \text{AMOUNT} &= 0 && \Theta_{critical} \leq \Theta_{unspr} \\ &= \min(\text{I\_MAX},(\Theta_{target} - \Theta_{unspr})\times\rho/\delta) && \text{otherwise} \end{aligned}$$

where

AMOUNT:	Rate at which sprinkled water effectively enters the root zone (mm/day)
δ:	Length of interval (days)

R: Rain (mm/day)

E_p: Potential evapotranspiration (mm/day)

V: Capillary rise (mm/day)

θ^0: Initial root zone soil moisture (mm/mm))

$\theta_{critical}$: Critical soil moisture level (mm/mm)

θ_{target}: Target soil moisture level (mm/mm)

I_MAX: Maximum sprinkling rate possible (mm/day)

ρ: Depth of root zone (mm)

We then define

$$\text{LOSS} = \text{AMOUNT} \times (1-\varepsilon)/\varepsilon$$

$$\text{DOWN} = \text{LOSS} \times \varepsilon'$$

where

LOSS: Total rate at which water extracted for sprinkling is lost to atmosphere or subsoil

DOWN: Rate at which sprinkled water flows directly into subsoil (mm/day)

ε: Water effectively applied to root zone divided by total water withdrawn for sprinkling

ε': Fraction of "lost" water that flows into subsoil

Finally, we let

$$\text{REQUEST} = \text{AMOUNT} + \text{LOSS}$$

denote the total amount withdrawn for sprinkling.

These quantities are related to the symbols I and I_NET introduced above:

- For all sprinkled plots,

  I = AMOUNT.

- In addition, if the plot is sprinkled from groundwater,

  I_NET = REQUEST - DOWN.

- However, if the plot is sprinkled from surface water,

  I_NET = - DOWN.

This simple procedure does not take into account certain practical considerations concerning irrigation. A farmer lacks perfect knowledge about rain and evapotranspiration, and since it takes quite a while to irrigate his entire field, he must decide when to start sprinkling based on weather forecasts of a week or more. Moreover, he is constrained by the technical capabilities of an irrigation system that requires him to move it around his field in steps (sprinkling relatively small sections at a time) and that limits it to a certain capacity. The simple irrigation model treats the plot as a single, simultaneously irrigated field owned by a farmer who knows everything about the weather in that timestep. This procedure tends to underestimate the amount of irrigation, the drought damage that still occurs, and the amount of water lost from root zone to subsoil because of rainfall shortly after irrigation.

We have developed a more complicated sprinkling procedure that takes these problems into account. This procedure reproduces a detailed model that simulates the behavior of farmers whose activities are based on daily weather information and are constrained by practical considerations concerning the operations of irrigation systems. This detailed procedure is described in Chap. 5 of Vol. XIII. This more complicated procedure produces the same kinds of outputs as the simpler one described above (e.g., it computes I and I_NET). The more complicated procedure was the one actually used by PAWN.

4.2.6. Water Flow Computations for Glasshouse Plots

Plots with glasshouse crops differ considerably from those with open-air crops. The climate of the glasshouses is carefully controlled. Temperature, the supply of water, and sometimes even light are controlled in such a way that optimal growing conditions for the plants are created. The soil moisture in the glasshouses is kept high, and capillary rise from the subsoil never occurs. To prevent salt buildup, farmers tend to sprinkle more water than is required for evapotranspiration, and so they flush salt from the root zone into the subsoil.

To model the flow of water in the glasshouse plots, we made the following assumptions:

- All rain flows directly into the surface water.
- Potential evapotranspiration does not depend on the "natural"

climate, but is predetermined.

- The actual evapotranspiration is always equal to the potential evapotranspiration.
- Capillary rise never occurs.
- Root zone loss (flushing) is fixed and constant over the year.
- The moisture in the root zone is constant over the year.
- The moisture in the subsoil and the groundwater level are constant over the year.

These assumptions lead to a series of simple mass balance equations.

4.2.7. Flows in and out of the Surface Water of a District

We now turn to water flows in a district other than those computed by PLOTWAT.

Flows from Vegetation-Covered Area. In the previous section, we showed how water flows are calculated for a single plot. These flows are computed in units of millimeters per unit of area for the entire timestep, and the area of a given plot does not affect the calculations. To compute flows between the entire vegetation-covered region, which is made up of a number of plots of different sizes, and the surface water system, DISTAG must use PLOTWAT for each of these plots, then convert the relevant flows provided by PLOTWAT on the basis of a millimeter per unit of area to a volume of water (cubic meters per second), and sum these flows over all the plots in the district.

How DISTAG works depends on whether it is formulating a "request" or a "delivery." For a "request," there are no constraints on the amount of water that can be withdrawn from the surface water for sprinkling. For a "delivery," there may be a constraint, supplied by DM, on the amount of water that can be withdrawn from the surface water for sprinkling open-air crops. This constraint is expressed in the form of a so-called cutback fraction, set equal to the total amount of such sprinkling that DM is willing to allow, divided by the amount of such sprinkling originally requested. DISTAG "delivers" this reduced amount of water only to the plots that sprinkle open-air crops from surface water. When this happens, PLOTWAT simply adds the reduced amount of sprinkling to the rain, and makes computations as though the plot were an unsprinkled one. Cutting back sprinkling has no effect on the water flow computations of the unsprinkled plots, the plots with crops under glass, and the plots sprinkled from groundwater. For computing total water flows from the plots, DISTAG can use the flows from these plots that were calculated during the "request" phase.

In both the "request" and the "delivery" phases, DISTAG accumulates the relevant water flows for all the plots. In the "request" phase, PLOTWAT is used for each plot in the district to determine these flows. In the "delivery" phase, PLOTWAT is used again to recompute these flows only for the plots whose sprinkling can be cut back. For the other plots, such flows are "remembered" from the time the "request" was formulated, and used again.

Urban Runoff. The amount of rain falling on the urban area is obtained by multiplying the surface area of the urban region by the amount of rain and converting to cubic meters per second. A small amount of evaporation is assumed to occur from the urban surfaces. It is calculated by multiplying the open water evaporation by what we call the urban crop factor, typically set equal to 0.2, and converting to a volume quantity as we did for rain. Urban runoff is the amount of rain minus this amount of urban evaporation, or the runoff is zero if urban evaporation exceeds the rain.

Change in Surface Water Volume Due to Rain and Evaporation. The rain falling on the surface water and the evaporation from the surface are converted to cubic meters per second.

Main Extraction and Discharge. The computation of the main discharge from the district to the national distribution system and of the main extraction in the reverse direction is based on three principles. First, the total water volume in the district must remain fixed: this is called the principle of absolute level control. Second, the discharge must not be less than a fixed constraint imposed by DM for flushing. Finally, the discharge should be minimized, as long as these first two principles are not violated.

The amount of flushing is governed by two quantities. First, there is a minimum flushing rate associated with each district. Second, DM can increase or reduce this amount with a control parameter.

All of the flows to and from the surface water system are combined to yield a preliminary change in water volume due to all causes other than flows between the district and the national distribution system. The main discharge is then the minimum of that required to discharge any excess water and meet the flushing minimum. The main extraction is what is required to keep the water volume constant.

4.3. COMPUTATION OF SALT FLOWS

When a district extracts water from the national distribution system, salt is usually found in the extracted water. The concentration of this salt is given to DISTAG by DM. In addition, a district has other sources of salt: rainwater, urban discharge, seepage, etc. This salt may be stored in the surface water for some time. It may also enter the plots, either with water withdrawn from the surface water for sprinkling or with water that infiltrates from the surface water directly into the subsoil. Eventually, however, salt returns to the national distribution system when the district discharges water, and so DISTAG must give to DM the salt concentration of the discharged water. In this section, we discuss how this salt concentration is computed.

Salt is stored in both the root zone and the subsoil of the plots, and the plot salt model, PLOTSLT, is used to estimate the salt content in these two places for each plot in the district. A simple model is used to calculate salt quantities in the surface water system. It turns out that an essentially identical mathematical formulation is used for both the salt computations for plots and for the surface water. We call this formulation the basic salt model, and we describe it first. Then we show how it is applied to plots and, finally, to the surface water system.

4.3.1. The Basic Salt Model

We consider a closed body of water over a fixed interval of time. We suppose there is a constant flow of water into the system carrying with it some salt at a fixed concentration, which mixes instantaneously and perfectly with the salt originally there. Some water may leave the system carrying no salt, say as evaporation; the rest flows out carrying some salt with it. We wish to know how much salt leaves and how much salt is left in the system at the end of the time interval.

The basic salt model takes as inputs the following six variables:

W_IN	Water entering the system
W_UP	Water leaving the system with no salt
W_OLD	Amount of water in system at start of interval
W_NEW	Amount of water in system at end of interval
S_IN	Salt entering the system
S_OLD	Amount of salt in system at start of interval

It determines the following two quantities:

S_NEW	Amount of salt in system at end of interval
AVCONC	Average concentration of water leaving system

It is sufficient to determine the salt concentration $C(1)$ at the end of the timestep, because then:

$$S\_NEW = C(1) \times W\_NEW$$

$$AVCONC = (S\_IN + S\_OLD - S\_NEW)/W\_OUT$$

where

$$W\_OUT = W\_OLD - W\_NEW + W\_IN - W\_UP.$$

The Basic Differential Equation. Let t be the variable denoting time, with $t = 0$ at the beginning of the time interval, and $t=1$ at the end. The following intermediate variables will be used:

$C(t)$: Salt concentration at time t

$V(t)$: Water volume at time t
$S(t)$: Amount of salt at time t, $C(t)\times V(t)$
W_DEL: Change in water volume, $\text{W\_NEW} - \text{W\_OLD}$
W_NET: Net volume entering, $\text{W\_IN} - \text{W\_UP}$

We know the initial salt concentration,

$$C(0) = \text{S\_OLD}/\text{W\_OLD}.$$

Because water flows are constant, we can write

$$V(t) = \text{W\_OLD} + \text{W\_DEL}\times t.$$

Perfect mixing implies that salt leaves the system at time t at a rate equal to

$$(\text{W\_NET} - \text{W\_DEL})\times C(t).$$

Hence, the rate of change of the volume of salt is given by the differential equation

$$S'(t) = \text{S\_IN} - (\text{W\_DEL} - \text{W\_NET})\times C(t).$$

Now, since

$$S'(t) = V'(t)\times C(t) + V(t)\times C'(t)$$

it follows that

$$C'(t)\times V(t) = \text{S\_IN} - (\text{W\_DEL}-\text{W\_NET})\times C(t) - \text{W\_DEL}\times C(t).$$

This gives us our basic equation

$$C'(t) = [\text{S\_IN} - \text{W\_NET}\times C(t)]/[\text{W\_OLD} + \text{W\_DEL}\times t].$$

The equation is separable and the solution is elementary. There are four cases to consider, and we give the solution in each case.

Case 1: $\text{W\_NET} \neq 0$, $\text{W\_DEL} \neq 0$.

$$C(t) = B(t)\times C(0) + (1-B(t))\times \text{S\_IN}/\text{W\_NET}$$

where

$$B(t) = [\text{W\_OLD}/V(t)]^{(\text{W\_NET}/\text{W\_DEL})}.$$

Case 2: $\text{W\_NET} = 0$, $\text{W\_DEL} \neq 0$.

$$C(t) = C(0) - \ln(V(t)/\text{W\_OLD})\times \text{S\_IN}/\text{W\_DEL}.$$

Case 3: $W\_NET \neq 0 \quad W\_DEL = 0$.

$$C(t) = E(t)\times C(0) + (1-E(t))\times S\_IN/W\_NET$$

where

$$E(t) = \exp(-t\times W\_NET/W\_OLD).$$

Case 4: $W\_NET = 0$, $W\_DEL = 0$.

$$C(t) = C(0) + t\times S\_IN/W\_OLD.$$

A Simple Expression for C(1). For our purposes, we need only the value for C(1), the concentration at the end of the timestep. The four solutions above can be combined in a fairly simple way to obtain the following.

Define X by

$$\begin{aligned} X &= \ln(W\_NEW/W\_OLD)/W\_DEL && \text{if } W\_DEL \neq 0 \\ &= 1/W\_OLD && \text{otherwise.} \end{aligned}$$

Define Y by

$$\begin{aligned} Y &= [1 - \exp(-X\times W\_NET)]/W\_NET && \text{if } W\_NET \neq 0 \\ &= X && \text{otherwise.} \end{aligned}$$

Then

$$C(1) = Y\times S\_IN + (1-Y\times W\_NET)\times C(0).$$

4.3.2. Salt Computations for Plots: PLOTSLT

The plot salt model, PLOTSLT, is a model of the salt flows for a particular plot. It uses the water flow computations of PLOTWAT with various salt inputs, described in more detail below, and computes salt concentrations of:

- The water in the root zone
- The water in the subsoil
- The water that drains from the subsoil

PLOTSLT is used by DISTAG twice. First, it is used to compute discharges of salt from plots that are discharging water into the surface water system. Second, after DISTAG has computed the salt concentration of the surface water system, PLOTSLT is used to compute the salt concentrations in the soil for plots that are extracting water from the surface water system. It sometimes happens that a plot extracts and discharges water at the same time. In such a case, PLOTSLT is used twice for the same plot. The results of the computations of

PLOTSLT are also used by the plot damage model, discussed later, to determine salt damage.

PLOTSLT proceeds in two steps. First, it computes salt flows to and from the root zone, and then it computes salt flows to and from the subsoil. In principle, salt can flow from the subsoil to the root zone with capillary rise. Because generally a substantial freshwater layer builds up in the winter season, the salt in the subsoil (e.g., because of seepage) will hardly ever reach the root zone. The assumption therefore is that capillary rise carries no salt. This means that for most plots salt cannot be transported from the subsoil to the root zone, and the two-step computation, first for the root zone, then for the subsoil, is perfectly valid. The one exception involves plots that are sprinkled by using groundwater: the water extracted from the ground in fact carries salt with it, so there is an interaction going both ways between the root zone and the subsoil. However, in places where groundwater sprinkling takes place, the salt concentration of the subsoil is low relative to concentrations that cause damage to crops; therefore this contribution to the salt in the root zone is neglected.

PLOTSLT treats glasshouse crops quite differently from open-air crops--in fact, PLOTSLT is actually two different models, one for each of these two groups of crops.

Open-Air Crops. For crops grown in open air we assume that the water volumes in the root zone and the subsoil are completely mixed and that therefore the basic salt model described in Sec. 4.3.1 can be used. PLOTSLT uses it twice, first for the root zone, then for the subsoil.

For the root zone, the water flows are those computed by PLOTWAT. Salt enters the root zone along three paths. First, rainwater has a mild salt concentration. Second, there are exogenous sources of salt not connected directly to any inflow of water (e.g., from fertilizer and pesticides). Finally, if the plot is sprinkled using surface water, salt enters with this water at a concentration provided by DISTAG.

The basic salt model determines the amount of salt in the root zone at the end of the timestep and the average concentration of the salt leaving the root zone. The former value is used to compute the final root zone salt concentration, and the latter to compute the concentration of the root zone loss, which is used subsequently in the calculation of salt flows in the subsoil.

PLOTWAT computes water flows in the subsoil, just as it did for the root zone. Consistent with the assumption implicit in the root zone calculation that no salt is introduced when sprinkling from groundwater, we assume that no salt is carried from the subsoil by the water for this kind of sprinkling. Salt enters the subsoil from the root zone via root zone loss, at the concentration calculated during the root zone phase of PLOTSLT. Salt enters the subsoil via infiltration from surface water of the district at a concentration equal to that determined by

DISTAG. Salt also enters in seepage and as an exogenous load. The exogenous load that goes directly to the subsoil accounts for diffuse loads like salt used for ice abatement on roads. Eventually such salt ends up in the surface water system via verges alongside the road and from drainage out of the subsoil. Our way of handling the load ensures that the real phenomena are represented reasonably, although there is no actual physical meaning to it.

In order to compute salt concentrations, the model must assume a subsoil volume. Based on empirical findings with respect to the response time of the system, a limited top layer of the subsoil was specified to represent the "active" volume, i.e., that part of the subsoil where salt is stored.

The basic salt model determines the amount of salt in the subsoil at the end of the timestep and gives the average salt concentration of the water draining into the surface water system.

Glasshouse Crops. There are several reasons why a more accurate modeling of the salt flows in the glasshouse plots is required:

- Glasshouse crops are sprinkled continuously throughout the year.
- They are more sensitive to salt.
- They have a higher value (per unit of area) than open air crops.
- Most are located in lowland areas with rather high salt concentrations in the surface water.

Glasshouse crops get their total water supply from sprinkling, the most important source of salt for the root zone. This leads to an accumulation of salt in the root zone. Farmers try to prevent this accumulation by flushing the root zone, i.e., by sprinkling more water than is required for evapotranspiration by the plants. The simple approach described in the previous section that we adopted for open-air crops would lead to a very high concentration of salt in the root zone of glasshouse crops. This high concentration would be caused by the assumption that the outflowing water of the root zone takes with it salt at a concentration equal to the average concentration of the root zone. In fact, there exists a distinct gradient of salt in the soil profile. The concentration is low at the top and equal to that of the sprinkling water. It is up to several times higher at the bottom. The concentration of the outflowing water is actually that of the bottom of the root zone.

We assume that the salt profile in the root zone of glasshouse crops is of the form (see Fig. 4.8):

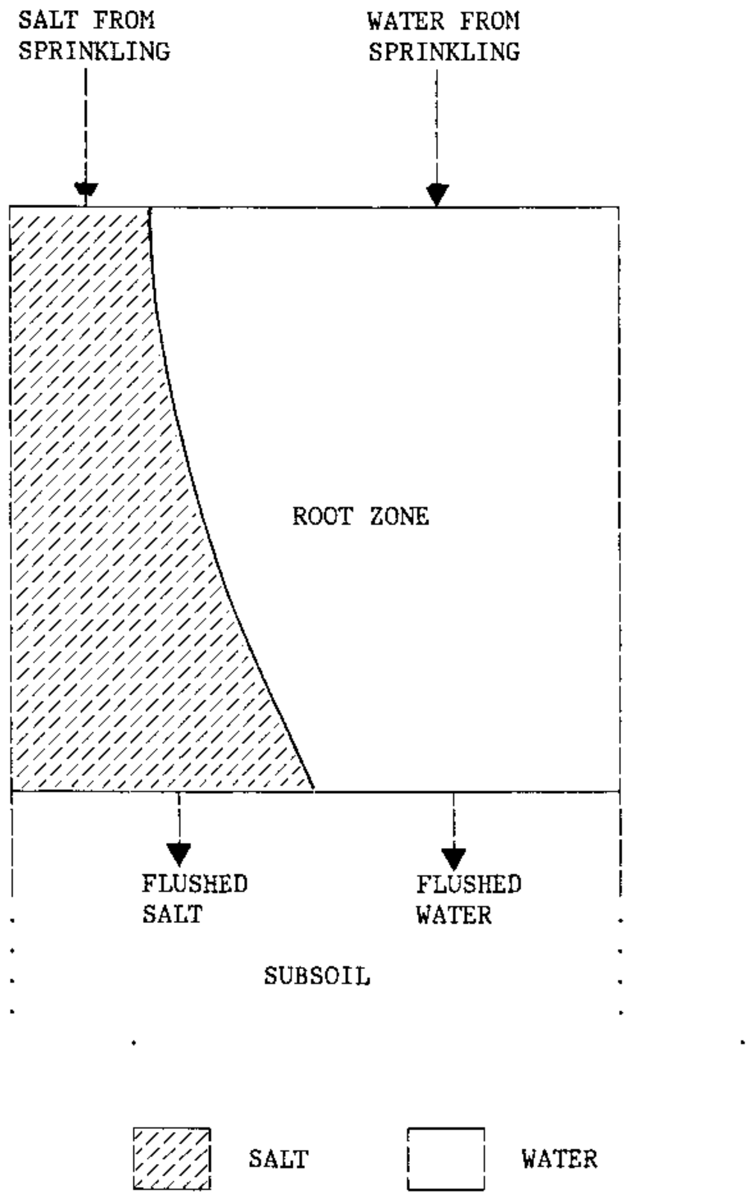

Fig. 4.8--Water and salt flows, with the root zone salt profile for crops grown under glass

$$S_x = S_0/(1-x(1-LF)) \tag{12}$$

where

S_x: The salt concentration at a fraction x of the depth of the root zone below the soil surface, in mg/l

LF: A leaching fraction

The leaching fraction is defined as the amount of flushing water (flowing from the root zone to the subsoil) divided by the total amount of water applied. We assume that the amount of flushing water is constant over the year, while the amount of irrigation water changes considerably.

By integrating Eq. (12) over the root zone, it follows that

$$\text{Average salt concentration} = S_0 \times \ln(LF)/(LF-1).$$

This expression gives a more realistic estimate of the outflowing salt from the root zone of glasshouse crops.

4.3.3. Salt Flows in the Surface Water

The basic task of DISTAG described here is to take the amount of salt in the surface water at the beginning of the timestep and to compute the amount of salt in the surface water at the end of the timestep, as well as the average concentration of any water extracted from the district. This concentration is required by DM so that it can estimate the salinity of the water of the national distribution system.

In computing salt flows in the surface water system, DISTAG uses PLOTSLT twice, first to determine discharges of salt from the vegetation-covered area, and last to allow PLOTSLT to compute the salt concentrations in the soil of plots that are extracting water. Between these two applications of PLOTSLT, DISTAG uses the basic salt model described in Sec. 4.3.1 to determine the salt concentration of the district's surface water. We organize our discussion around these three tasks.

Discharges of Salt from Plots. The drainage from plots into the district's surface water system may contain salt. The amount of salt coming from a particular plot depends on the salt concentration of the subsoil of that plot. DISTAG uses PLOTSLT for each plot actually draining into the surface water system to determine this concentration.

In some districts, water seeps directly into the surface water system of the district, without first passing through the subsoil of any plot. The input data to DISTAG includes a fraction that indicates what part of the total seepage into the district flows directly into the surface water of that district. Since seepage typically contains salt, we use this fraction to estimate the amount of salt that is so carried into the surface water system of the district.

In the exceptional case where a plot both extracts and discharges water in the same timestep, we assume that within this timestep the salt concentration of the extracted water does not affect the salt concentration of the drainage.

Salt Concentration of the Surface Water. Having determined how much salt is entering the surface water from the plots, DISTAG uses the basic salt model to determine the average concentration of any water that is flowing out of the surface water system; it also determines the amount of salt left there, which is carried forward to the next timestep.

Extractions of Salt by Plots. Having determined the average salt concentration of any withdrawals of water from the surface water system, DISTAG then goes through those plots in the district that are extracting water from the district, and uses PLOTSLT to update the salt concentration of the root zone and the subsoil. For this use of PLOTSLT, the salt concentration of the district water is important, but it has just been calculated. These calculations are not relevant to the salt concentration of the district water for the immediate timestep. They are important for subsequent timesteps, and they are also needed to determine salt damage.

4.4. AGRICULTURAL DAMAGE

DISTAG determines two types of crop damage: that due to drought and that due to excess salt in the root zone. In this section, we will discuss how these crop damages are calculated. We first discuss PLOTDAM, which computes damages for a particular plot. We then discuss how PLOTDAM is used by DISTAG to accumulate damages for a whole district.

We need to define two terms. On any plot, the potential annual yield is the annual yield that would be realized on that plot if there were no salt or drought damage. As most crop types are aggregates of many individual crops, physical units do not necessarily have a logical interpretation, so the potential annual yield for any plot is expressed as a crop value, in Dutch guilders.

In any particular timestep, the crop at risk is defined as the crop that can potentially still be damaged sometime before the end of the growing season. The value of the crop at risk may be less than the potential annual yield, for two reasons.

First, crops grow over time, and in any timestep, especially late in the growing season, a fraction of the crop may have already been formed; hence a fraction of the potential annual yield may have already been earned. A good example is grass. During the growing season grass is formed continuously. Halfway through the growing season, half the grass has already been produced, and hence only half the annual yield can possibly be damaged. To account for the time-dependent production of each crop, a time series of potential yield fractions is supplied as data for each crop. For each timestep, the potential yield fraction corresponding to a given crop is the fraction of the crop that normally remains to be produced, assuming no damage occurs.

Second, the value of the crop at risk may be less than the potential annual yield because in some previous timestep some part of it was lost, due to drought or excess salt.

4.4.1. Computing the Drought Damage Fraction

Drought damage on a plot is estimated by computing a drought damage fraction--the fraction of the crop at risk that is damaged because of drought, independent of any salt damage that might also occur.

We assume that the drought damage fraction depends on the ratio of actual evapotranspiration to the potential evapotranspiration:

$$\text{RATIO} = E_A/E_P.$$

This ratio is always between 0 and 1. When it is equal to 1, we assume that the crop gets all the water it needs, so that production is optimal and damage is zero. As the ratio decreases, the crop receives less and less of the water it requires, and production decreases, so damage increases. We assume that the drought damage fraction is a piecewise linear function of RATIO, given by the following expression:

$$\begin{aligned} \text{DDF} &= 0 && \text{RATIO} = 1 \\ &= \text{RD}*(1-\text{RATIO})/(1-\text{RP}) && \text{RP} \le \text{RATIO} < 1 \\ &= \text{RD} + (\text{DD}-\text{RD})*(\text{RP}-\text{RATIO})/(\text{RP}-\text{DP}) && \text{DP} \le \text{RATIO} < \text{RP} \\ &= \text{DD} && \text{RATIO} < \text{DP} \end{aligned}$$

where

DDF: Drought damage fraction

RD, RP, DD, DP: Input parameters, defined below.

The nature of the drought damage fraction is different over three different ranges for RATIO (see Fig. 4.9). We discuss each in turn.

Moderate Damage. When RATIO is less than 1, but greater than the input parameter RP, called the *reduction point*, we assume the damage is moderate. The damage fraction is set equal to zero when RATIO is one, and it is set equal to the input parameter RD when RATIO equals RP. When RATIO is between 1 and RP, the damage fraction is linearly interpolated between 0 and RD. The damage is only "moderate" because the damage does not lead to additional production losses in subsequent timesteps, provided there is enough water during those timesteps. The parameter RD is called the *reduction damage*.

Maximum Damage. When RATIO is less than the input parameter DP, called the *death point*, maximum damage occurs. The drought damage fraction is set equal to the input parameter DD, called the *death damage*. The crop is damaged to such an extent that no further production can take place, if the timestep considered is long enough.

Severe Damage. When RATIO is between RP and DP, the damage fraction is linearly interpolated between RD and DD.

The Parameters. Different crop types are susceptible to damage in different ways; therefore we can specify a different set of damage parameters for each crop type.

The drought damage fraction is computed each timestep. The susceptibility of a particular crop to drought changes over time. A crop has a specific growing season, so it cannot be damaged outside of that season. Some crops have specific drought sensitive periods, and during these periods the same degree of drought will have more severe consequences than at other times of the year. Because of the time-varying nature of crop damage, different damage model parameters can be provided for each timestep.

4.4.2. Computing the Salt Damage Fraction

Salt damage on a plot is estimated by computing a salt damage fraction--the fraction of the crop at risk that is damaged because of excess salt, independent of any drought damage that might also occur.

We assume that the salt damage fraction is a piecewise linear function of the salt concentration in the root zone. It is given by the following expression (see Fig. 4.10):

$$\begin{array}{lll} \mathrm{SDF} & = 0 & \mathrm{RZSALT} < \mathrm{MIN} \\ & = \mathrm{SD} * (\mathrm{RZSALT} - \mathrm{MIN}) & \mathrm{MIN} \le \mathrm{RZSALT} < \mathrm{MAX} \\ & = 1 & \mathrm{MAX} \le \mathrm{RZSALT} \end{array}$$

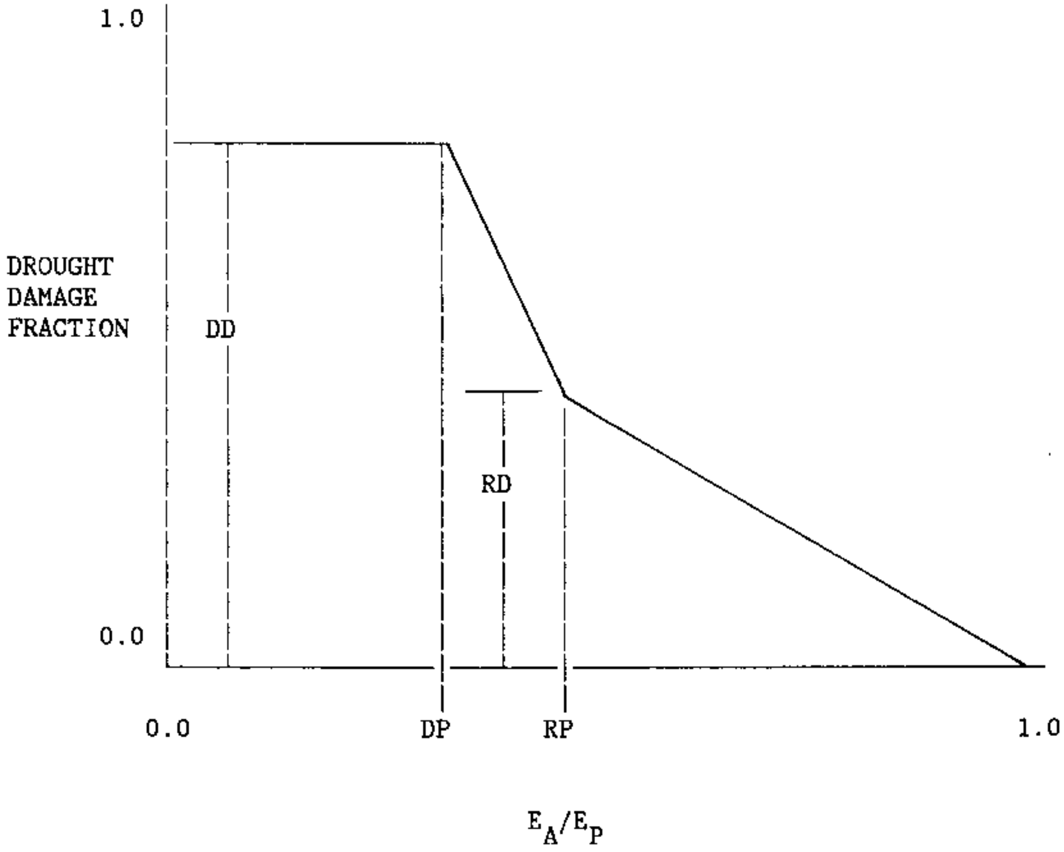

Fig. 4.9--Drought damage fraction as a function of E_A/E_P

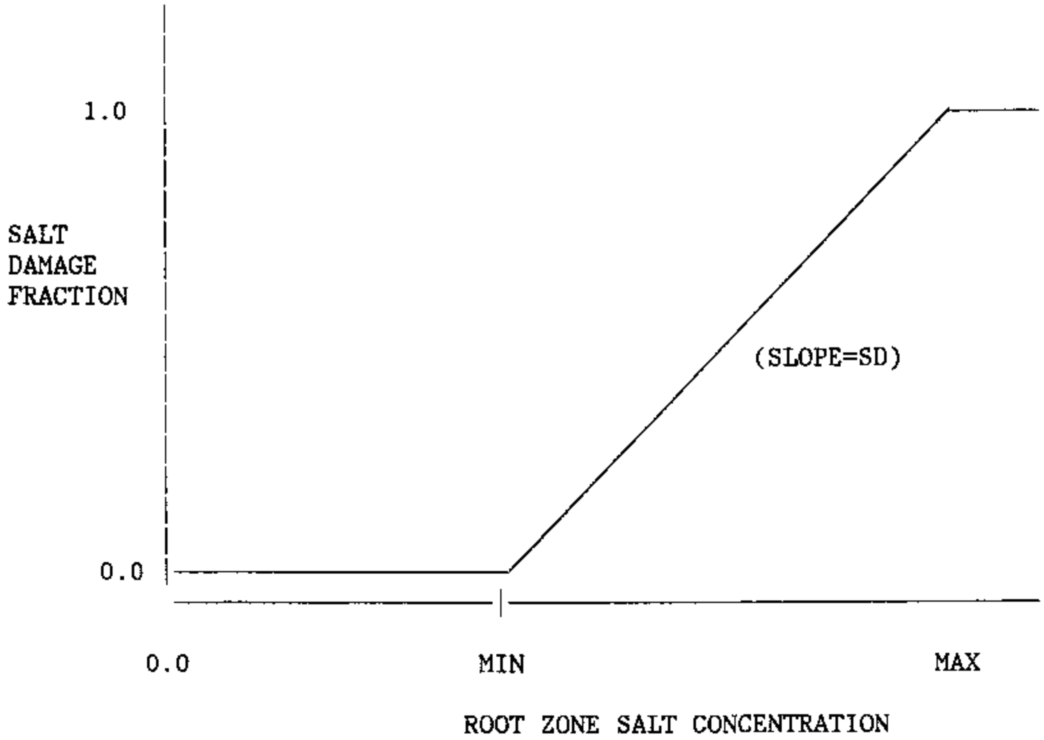

Fig. 4.10--Salt damage fraction as a function of the root zone salt concentration

where

SDF: Salt damage fraction

RZSALT: Concentration of salt in root zone

MIN, SD: Specified parameters

MAX = MIN + 1/SD.

The model is based on the notion that no damage occurs as long as the concentration of salt in the root zone is below some critical level (MIN), but that damage increases linearly with this concentration for higher values.

Only two parameters, MIN and SD, are required to specify the above function. They depend on crop type, but are assumed not to depend on the timestep, since the susceptibility of a plant to salt damage does not depend on the stages of growth of the plant.

4.4.3. Computing the Total Damage Fraction

In the model, the part of a crop damaged by salt cannot be damaged by drought, and vice versa. Therefore, damages computed for drought and salt cannot be simply added. Instead, the salt damage fraction is applied to the total crop "at risk" to compute salt damage, and then the drought damage fraction is applied to the remainder (the part of the crop "at risk" that was not damaged by salt). Total damage is the sum of these two damages. Of course, the order in which the two damage models are applied is irrelevant with respect to total damage. However, it should be remarked that the simultaneous occurrence of salt and drought damage is rare. Typically, drought damage occurs if a crop is unsprinkled, and because sprinkling from surface water is the major source of salt in the root zone, unsprinkled crops are rarely damaged by salt. Conversely, sprinkled crops are rarely damaged by drought.

The total damage fraction is derived from the drought damage fraction and the salt damage fraction by the formula:

$$\text{TDF} = \text{SDF} + (1-\text{SDF})*\text{DDF}$$

where TDF represents the total damage fraction.

4.4.4. Applying the Damage Fractions

Information about the cumulative damage to each plot is carried forward from one timestep to the next. This information is contained in the so-called survival fraction, set equal to the fraction of the total crop that still survives at the end of each timestep. For each timestep, we determine the crop at risk by multiplying the potential annual yield by the survival fraction, then by the current value of the potential yield fraction.

Using the outputs of the plot water and salt models, the salt, drought, and total damage fractions are computed as described above. The value of the crop at risk is then multiplied by the salt damage fraction and the total damage fraction to obtain the salt damage and the total damage. The survival fraction is then updated and carried forward to the next timestep.

4.4.5. Computing Agricultural Damage in a District

PLOTDAM computes salt and total damage for each plot, in terms of guilders per hectare. It uses output from PLOTWAT and PLOTSLT. DISTAG computes district agricultural damage after it has used PLOTWAT to compute water flows, and PLOTSLT to compute salt concentrations. By using PLOTDAM to compute damages for each plot and summing the plot damages over all plots in the district, DISTAG computes total salt damage in the district (in guilders), and the total agricultural damage due to both salt and drought.

4.5. COST OF SPRINKLING

DISTAG computes the total amount of money spent sprinkling each crop in the district, broken into two cost components, labor and energy. The costs of sprinkling depend on the sprinkling system that is used, which in turn depends on a number of other factors such as crop type, area of the sprinkled field, source of the sprinkling water, etc. In a separate analysis, described in Vol. XIII, sprinkling cost parameters have been determined for each plot to take into account these various factors. DISTAG uses two coefficients for each plot. The first is the labor cost of sprinkling, in units of guilders per millimeter of sprinkling, per hectare of land. The second is the energy cost of sprinkling water, in the same units. DISTAG simply multiplies the amount of sprinkling on each plot by these numbers, then by the area of the plot, and sums over all sprinkled plots in the district.

4.6. GROUNDWATER LEVELS

DM does not use groundwater levels, but for some PAWN purposes, it is desirable to be able to analyze what happened to groundwater levels, after a DM run has been completed. To make such analyses, DISTAG writes a file of groundwater levels. Records are written on this file at the end of each timestep, when DISTAG is used in the "delivery" mode.

Groundwater levels are computed by the plot water model, PLOTWAT, and a separate groundwater level is retained for each plot. DISTAG computes the average groundwater level in each subdistrict. This average is the weighted average of the groundwater level in each plot in each subdistrict, weighted by the area of the plot.

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Chapter 5

COMPUTER IMPLEMENTATION OF DISTAG

Before a mathematical theory can be programmed into a computer, it has to be translated into mathematics that is compatible with what the computer can do. For example, if the theory contains a differential equation, a numerical technique must be devised that allows the computer to solve the equation. We call this step implementation, and we distinguish it from programming, which involves translating the implementation into some computer language (e.g., FORTRAN or PL/I). The present chapter is devoted to discussing the implementation, in the sense just described, of the theory presented in Chap. 4.

This chapter will be of interest to readers concerned with the general problem of implementing mathematical theories, particularly hydrologic ones, and to those who need to understand the models described here at the source code level, either because they plan to modify these programs or because they are writing similar ones.

We begin by reviewing the models and their interrelationships. We then discuss how the models communicate, and in particular, we outline how the data were structured internally and how certain variables are carried forward from one timestep to the next. Then, we discuss each of the models in turn.

5.1. THE MODELS IN CONTEXT

The four models described in this volume are:

- The District Hydrologic and Agriculture Model (DISTAG), which computes water and salt balances, crop damage, sprinkling costs, etc., for single districts.
- The plot water model (PLOTWAT), which computes water flows for a single plot.
- The plot salt model (PLOTSLT), which computes salt flows for a single plot.
- The plot damage model (PLOTDAM), which computes crop damages due to drought or salinity for a single plot.

DISTAG does not stand by itself, but is used as a subroutine by other programs. In particular, it is used by the Distribution Model (DM), which simulates the surface water distribution system for the entire nation and is described in Vol. XI. DISTAG is also used by the demand generator (DEMGEN), described in Sec. 5.6.3. New programs could be written that use DISTAG as well.

DISTAG uses the three plot models as subroutines. The interactions between the district and its plots, across time and within a decade, are controlled by DISTAG, and the data elements and other variables required by the plot models are provided by DISTAG. In the next section, we will briefly describe some aspects of the flow of data between DISTAG and the plot models.

5.2. DATA FILES AND COMMUNICATION BETWEEN THE MODELS

5.2.1. Input Files

DISTAG requires 16 input files, containing all the climatologic, geographic, and location-dependent data, and the parameters of the various submodels. No data have been permanently built into the programs themselves. The 16 files are:

FILE NAME	DESCRIPTION
CFACFIL	Crop factors
COEFFIL	Parameters for soil moisture relationships
COSTFIL	Sprinkling costs
DAMFIL	Parameters of the damage model
DISTFIL	District data
DRANFIL	Parameters of the basic drainage functions
ESFILE	External supply
PLOTFIL	Plot data
PSIFIL	Soil moisture tension values
RDEPFIL	Root depths
SCAPFIL	Capillary rise function parameters
SOILFIL	Soil parameters
SPRFIL	Sprinkling model parameters
SUBDFIL	Subdistrict data
SUB2FIL	Infiltration data
VALUFIL	Crop values

These files are described more thoroughly in Chap. 6.

5.2.2. Data Element Associations

Many of the variables contained in these files have been given names in Chap. 3, particularly in Tables 3.1 through 3.4. We will use these names consistently in this chapter, to show logically how computations flow from one model to the next.

In Chap. 3, we grouped the data according to geographical levels. For example, since subdistricts were defined partly on the basis of soil types, we associated soil parameters with subdistricts. In the computer implementation of the model, however, the situation is somewhat more complicated.

For example, only 16 root zone/subsoil combinations are used by PAWN, even though there are 143 subdistricts. While it would have been possible to associate a different set of soil parameters with each subdistrict, because only 16 combinations were actually used, many of these combinations would have been repeated. We found it easier to handle the data, and we saved space, by associating soil type indexes with each subdistrict. We then read in the soil parameters from separate files that contained one record for each soil type. When we needed to know the value of some soil parameter for a particular subdistrict, we used the soil type index associated with that subdistrict to "look up" the desired parameter in the row of the matrix containing the parameters of the corresponding soil type.

This feature is not essential for an understanding of our models. We mention it here for the benefit of readers who may wish to consider such fine details, and inspect the source code itself.

Associated with a district is one variable (the salt concentration of the surface water) that must be carried forward at the end of each decade's computation, to be used as an initial condition at the beginning of the next. Associated with each plot are six such variables (see Table 3.5 and the note to Table 3.6). In our discussions, we denote each initial condition by adding the suffix "OLD"; thus, the initial surface water salt concentration is denoted by the symbol SWSALT_OLD. The final condition is likewise denoted by adding the suffix "NEW"; thus, the final surface water salt concentration is denoted SWSALT_NEW.

At the beginning of each decade, the final conditions from the previous decade must be carried forward. The salt concentration of the surface water of a district is carryed forward by executing the instruction:

```
SWSALT_OLD = SWSALT_NEW.
```

Instructions are included in DISTAG to correctly carry forward these district and plot variables at the appropriate time. To make the discussion that follows easier to understand, we will not mention this fact every time it might be appropriate to do so.

5.3. THE PLOT WATER MODEL (PLOTWAT)

In this section, we explain the implementation of the plot water model. We list the inputs to PLOTWAT in Table 5.1. Two of these inputs are specified by DISTAG to indicate whether sprinkling is to be calculated (the "request" mode) or has already been specified (the "delivery" mode). The interpretation of these variables is given in Table 5.2. The outputs from PLOTWAT are displayed in Table 5.3, and subsequent sections of this report will show how these outputs are used by DISTAG and the other models.

Table 5.1

INPUTS TO THE PLOT WATER MODEL

Name	Units	Description
Fixed Data		
BARE_CF	mm/mm	Bare soil "crop factor"
BD_COEF	/day	Basic drainage coefficient
BD_CONST	mm/day	Basic drainage constant
CROPFACTOR	mm/mm,mm/day	Crop factor
DITCH_LEVEL	mm	Level of ditches
DRAIN_COEF	/day	Drainage coefficient
DRAIN_UG	mm/year	Drainage from glasshouse crop subsoil
DRAIN_MAXOUT	mm/year	Maximum drainage to distribution system
EVAP	mm	Open water evaporation
GWL_DRINK	mm/day	Drinking water withdrawals
GWL_INDUST	mm/day	Industrial withdrawals
INF_RATE	mm/day	Infiltration rate
INFIL_COEF	/day	Infiltration coefficient
INITIAL_GWL	mm	First-of-year groundwater level
NDAYS		Number of days in decade
PSI_REDUCE	mm	Evapotranspiration reduction parameter
RAIN	mm	Rain
ROOTDEPTH	mm	Root depth
SATCAP_RZ	mm/mm	Saturation capacity of root zone
SEEP_RATE	mm/day	Seepage
SEEP_FRAC	mm/mm	Fraction of seepage to surface water
SPR_EFF	mm/mm	Sprinkling efficiency
SPR_EVAP	mm/mm	Fraction lost due to evaporation
SUP_FRAC	ha/ha	Suppliability fraction
WILTPT	mm/mm	Wilting point
Passed by DISTAG		
SPRINK_ALLOW	mm	Sprinkling applied if "delivery"
SPRINK_INDEX		Sprinkling code
Computed Previous Decade by PLOTWAT		
GWL_OLD	mm	Initial groundwater level
RZDEF_OLD	mm	Initial root zone deficit
SSDEF_OLD	mm	Initial subsoil deficit
Computed Previous Decade by PLOTDAM		
SURVFRAC_OLD	mm/mm	Initial survival fraction

Table 5.2

HOW DISTAG CONTROLS PLOTWAT

Name	Units	Description
SPRINK_ALLOW	mm	Set to zero for "request." Set to CUTBACK × SPRINKLE for "delivery." (CUTBACK supplied by DM, SPRINKLE previously computed by PLOTWAT during "request.")
SPRINK_INDEX	--	Set to sprinkling code for "request." (0 if unsprinkled, 1 if sprinkled from surface water, 2 if sprinkled from groundwater.) Set to zero for "delivery."

Table 5.3

OUTPUTS FROM THE PLOT WATER MODEL

Name	Units	Description
Water Flows		
AVAP	mm	Actual evapotranspiration
CAPRISE	mm	Capillary rise
DRAINAGE	mm	Total drainage from subsoil
DRAIN_SW	mm	Drainage to surface water
DRAINOUT	mm	Drainage to distribution system
INFILT	mm	Infiltration into subsoil
RZLOSS	mm	Downward flow, root zone to subsoil
PVAP	mm	Potential evapotranspiration
SEEPAGE_SS	mm	Seepage to subsoil
SEEPAGE_SW	mm	Seepage to surface water
SPRINKLE	mm	Sprinkling
SPRINK_LOSS	mm	Total sprinkling losses
Initial Conditions for Next Decade		
GWL_NEW	mm	Final groundwater level
RZDEF_NEW	mm	Final root zone deficit
SSDEF_NEW	mm	Final subsoil deficit

PLOTWAT contains two submodels. The first computes water flows for plots containing crops grown in open air (including "nature"), the second for crops grown under glass. The submodel used for crops grown in open air is explained in Secs. 5.3.1 through 5.3.4. The submodel used for crops grown under glass is explained in Sec. 5.3.5.

The plot water model for open-air crops is complicated. To make it easier to understand, we treat in a separate discussion what we call the core computations. By describing these computations as a separate model, we isolate the mathematical complications from the hydrologic ones.

To make the formulas used by the core computations easier to read, we adopt a more compact notation. In Sec. 5.3.1 we explain how the "input" variables of the core computations are defined using the plot water model inputs displayed in Table 5.1, and then how the results of the core computations are translated into the outputs from the plot water model, displayed in Table 5.3.

The core computations use six functions introduced in Sec. 4.2. We will call these the core functions. They are:

- The evaporation function F_{EVAP}
- The drainage function F_{DRAIN}
- The suction function F_{PSI}
- The moisture function F_{THETA}
- The groundwater function F_{GWL}
- The capillary rise function $F_{CAPRISE}$

The core computations also use outputs from the sprinkling procedure. In Sec. 5.3.2 we explain how these six functions are implemented, and how the sprinkling procedure is used. In Sec. 5.3.3 we give an overview of the core computations, and in Sec. 5.3.4 we go into the details.

5.3.1. Variables Used by the Core Computations

Among the variables used by the core computations are those that can be called inputs, and those that can be called outputs. These variables are listed in Table 5.4. The inputs are derived from the inputs to the plot water model, the outputs are converted into outputs of the plot water model.

Inputs. Table 5.5 shows how the inputs to the core computations are set. The core computations use the root zone soil moisture content. PLOTWAT keeps track of the soil moisture by retaining the root zone moisture deficit (equal to the capacity of the root zone minus the actual root zone soil moisture content).

Table 5.4

"CORE" COMPUTATIONS: INPUTS AND OUTPUTS

Name	Units	Description
		Inputs
Fixed Data		
ρ	mm	Depth of root zone
ω	mm/mm	Saturation capacity of root zone
γ_i	mm	Groundwater level at start of year
Initial Conditions		
γ^0	mm	Groundwater level
Θ^0	mm/mm	Root zone soil moisture content
Δ^0	mm	Subsoil deficit
Other Inputs		
δ	days	Length of interval
R	mm/day	Rainfall
E_P	mm/day	Potential evapotranspiration
From Sprinkling Model		
I	mm/day	Sprinkling applied root zone
I_NET	mm/day	Net subsoil extraction due to sprinkling
		Outputs
Final Conditions		
γ^1	mm	Groundwater level
Θ^1	mm/mm	Root zone soil moisture content
Δ^1	mm	Subsoil deficit
Flows		
E_A	mm/day	Actual evapotranspiration
V	mm/day	Capillary rise
D	mm/day	Drainage

Table 5.5

SETTING INPUTS TO "CORE" COMPUTATIONS

Equations:

Initial Conditions

γ^0 = GWL_OLD

θ^0 = SATCAP - (RZDEF_OLD - BARE_EVAP × NDAYS)/ROOTDEPTH

Δ^0 = SSDEF_OLD

Other Variables

δ = NDAYS

ω = SATCAP_RZ

Flows

R = RAIN/NDAYS

E_P = EVAP × CROPFACTOR × SURVFRAC_OLD / NDAYS

I,I_NET are obtained from sprinkling model

We adjust the potential evapotranspiration to account for the fact that when crops die, they evaporate less water. We multiplied the potential evapotranspiration by the survival fraction to estimate the evapotranspiration from plants, and then assumed that the land covered with dead plants would evaporate water at a rate defined by the "bare soil crop factor," a data element built into the program. We treat the computations as though this evaporation occurs at the beginning of the timestep, rather than attempting to calculate it simultaneously with other factors (which would involve a "feedback" because the amount of water affects the amount of damage, and vice versa). Because the amount of evaporation from bare soil is small when potential evaporation is large, the error incurred is small.

Outputs. Table 5.6 summarizes how the outputs from the core computations are used. We make a distinction between drainage that goes directly to the national distribution system (DRAINOUT) and drainage that flows into the surface water system of the district (DRAIN_SW). The former flow represents a deep groundwater flow that eventually ends up in the bigger streams and rivers.

5.3.2. Implementation

In Sec. 4.2.1 we outlined the theory behind the functions needed by our model. We now describe how these functions are implemented.

Actual Evapotranspiration. The evapotranspiration function is implemented exactly as it is described in Sec. 4.2.4. Table 5.7 gives details.

The Drainage Function. Because of some added hydrologic complications, the drainage function described in Sec. 4.2.4 contains some extra details. It is displayed in Table 5.8. A different expression is used for the lowlands from the one used in the highlands. From the point of view of the core computations, drainage is considered to consist of all water leaving or entering the saturated zone except for flows between the subsoil and the root zone (capillary rise, root zone loss, water withdrawn for sprinkling, etc.). Flows added to the "real" drainage are

- The fraction of seepage that goes into the subsoil.
- Groundwater extractions for drinking water companies and industry.
- Infiltration from surface water (in the highlands).

In contrast to the "real" drainage, these added flows are all constant over time and are determined only by data inputs. They are explained in Sec. 3.2.3.

The Moisture Function. For any particular soil type, the soil moisture content at a given place is related to a corresponding value

Table 5.6

COMPUTATION OF PLOTWAT OUTPUTS FOR OPEN-AIR CROPS

Equations:

Water Flows

AVAP = E_A

CAPRISE = V if $V > 0$
= 0 if $v \leq 0$

DRAINAGE = D

DRAINOUT = min(DRAINAGE,NDAYS × DRAIN_MAXOUT/365)

DRAIN_SW = DRAINAGE - DRAINOUT

INFILT = NDAYS × INF_RATE × SUP_FRAC

PVAP = E_P

RZLOSS = 0 if $V > 0$
= V iv $V \leq 0$

SEEPAGE_SS = NDAYS × SEEP_RATE × SEEP_OW_FRAC

SEEPAGE_SW = NDAYS × SEEP_RATE × (1-SEEP_OW_FRAC)

SPRINKLE = I

SPRINK_LOSS = I × (1-SPR_EFF)/SPR_EFF

Final Conditions

GWL_NEW = γ^1

RZDEF_NEW = (SATCAP - θ^1) × ROOTDEPTH

SSDEF_NEW = Δ^1

Table 5.7

IMPLEMENTATION OF THE CORE FUNCTION $E_A = E_P \times F_{EVAP}(\Psi)$

Equations:

AVAP = PVAP if PSI ≤ PSI_REDUCE

= PVAP × log (PSI-160000)/log(PSI_REDUCE-160000) otherwise

Name	Units	Description
PVAP	mm	Potential evapotranspiration (E_P)
PSI	mm	Average suction in root zone (Ψ)
AVAP	mm	Actual evapotranspiration (E_A)

Table 5.8

IMPLEMENTATION OF THE CORE FUNCTION $D = F_{DRAIN}(\gamma)$

Equations:

Lowlands

DRAINAGE = COEF × (GWL_REF - GWL)
+ GWL_INDUST + GWL_DRINK
- SEEP_RATE × (1-SEEP_OW_FRAC)

where

GWL_REF = DITCH_LEVEL - ROOTDEPTH

COEF = DRAIN_COEF if GWL > GWL_REF
= INFIL_COEF × SUP_FRAC otherwise

Highlands

DRAINAGE = BD_CONST + BD_COEF × GWL
+ GWL_INDUST + GWL_DRINK
- SEEP_RATE × (1-SEEP_OW_FRAC)
- INF_RATE × SUP_FRAC

Name	Units	Description
GWL	mm	Groundwater level (γ)
DRAINAGE	mm/day	Drainage (D)

for suction in a unique way. Using empirical data [5.1] for each of twenty soil types, we estimated a formula that gave the moisture content Θ as a function of suction Ψ.

There were two values that we wanted the formula to give exactly:

- Θ = saturation capacity ω when $\Psi = 0$
- Θ = wilting point ν when Ψ = 160000 mm

To obtain such a function, we note first that the expression

$$g(x) = \omega\nu/(\nu + (\omega-\nu)x)$$

satisfies the property

$$g(0) = \omega,\ g(1) = \nu.$$

Next, we note that the expression

$$x(\Psi) = \log(\Psi+1)/\log(160001)$$

satisfies

$$x(0) = 0,\ x(160000) = 1.$$

Finally, if A and B are any two constants, if we define

$$X(\Psi) = A\times x(\Psi)^{B} + (1-A)\times x(\Psi)^{2B}$$

then also

$$X(0) = 0,\ X(160000) = 1.$$

It follows that the compound expression

$$\Theta(\Psi) = g(X(\Psi))$$

has the desired properties

$$\Theta(0) = \omega,\ \Theta(160000) = \nu$$

whatever the constants A and B. Taking the above expression, we used a nonlinear least squares estimating procedure to determine those values of A and B for which the above expression gave a best fit to the data. The function so derived is described in Table 5.9.

The Suction Function. The moisture function described above can be inverted to obtain a formula that gives the value for suction corresponding to a given moisture level. This expression is described in Table 5.10.

Table 5.9

IMPLEMENTATION OF THE CORE FUNCTION $\Theta = F_{THETA}(\Psi)$

Equations:

$$\mathrm{THETA} = \mathrm{SATCAP\_RZ} \times \mathrm{WILTPT}/(\mathrm{WILTPT}+(\mathrm{SATCAP\_RZ}-\mathrm{WILTPT}) \times \mathrm{X})$$

where

$$\mathrm{X} = \mathrm{PF\_A} \times \mathrm{Y}^{\mathrm{PF\_B}} + (1-\mathrm{PF\_A}) \times \mathrm{Y}^{2\mathrm{PF\_B}}$$

and

$$\mathrm{Y} = \ln(\mathrm{PSI}+1)/\ln(160001)$$

Name	Units	Description
PSI	mm	Suction in root zone
THETA	mm/mm	Soil moisture corresponding to this suction

Table 5.10

IMPLEMENTATION OF THE CORE FUNCTION $\Psi = F_{PSI}(\Theta)$

Equations:

$PSI = 160001^{X} - 1$

where

$X = ((-PF\_A+Y)/(2(1-PF\_A)))^{(1/PF\_B)}$

and

$Y = sqrt(PF\_A^{2}+4(1-PF\_A)Z)$

$Z = WILTPT(SATCAP-THETA)/THETA(SATCAP-THETA)$

Name	Units	Description
THETA	mm/mm	Soil moisture in root zone (Θ)
PSI	mm	Suction (Ψ)

The Groundwater Function. It is not impossible to implement the groundwater function described in Sec. 4.2.4 in a computer program directly from its definition, but the implementation would involve inverting a function ($\Delta(V,\gamma)$) that would itself be computed by means of a numeric integration. Therefore we developed a formula that we use to calculate this function.

To explain the formula, we refer to Fig. 4.3. We note that the region corresponding to the subsoil deficit (marked with a Δ) is roughly rectangular at the top, roughly triangular at the bottom. It seems plausible that as the groundwater level γ increases (gets deeper), the widths of the rectangle and the triangle increase, the height of the rectangle increases, but the height of the triangle remains about the same. If this in fact happens, the area of the rectangle would depend on the square of the groundwater level, while the area of the triangle would depend only on the groundwater level itself. Therefore, we would have roughly:

$$\Delta = A\times\gamma + B\times\gamma^2.$$

Inverting this formula, we would obtain something like:

$$\gamma = a\times\mathrm{sqrt}(\Delta) + b\times\Delta.$$

Our formula is of this form, except that the "coefficient" b is made dependent on capillary rise, and the expression is truncated at the vertex of the parabola relating Δ to γ.

Equation (9) of Sec. 4.2.4 shows how the groundwater level can be expressed in terms of the tension Ψ at the top of the subsoil and the rate of capillary rise V. We used these formulas and the relationship between tension and moisture described above to compute, for each of the twenty soil types [5.1], a large table giving the relationship between groundwater level, capillary rise, and soil moisture content. To make these computations, we estimated the inegral of Eq. (9) using the expression:

$$\int_0^x 1/(1+u^{1.4})\ du = A(x)P(x)/Q(x)$$

where

$$A(x) = 1.82721\arctan(x)$$

$$P(x) = 1 + 1.90222x^{-0.699262}$$

and

$$Q(x) = 1 + 4.41712x^{-0.63754}.$$

This formula was obtained by first evaluating the integral using a very accurate numerical method, and then estimating the coefficients of the formulas for A(x), P(x), and Q(x) to fit these values.

From our tables expressing the groundwater level as a function of capillary rise and soil moisture content, we derived a table expressing the subsoil deficit as a function of groundwater level and capillary rise. We used this final table to explore various relationships. Eventually, we found that the expression given in Table 5.11 worked well. The coefficients were estimated from our data using a nonlinear least squares procedure.

The Capillary Rise Function. The capillary rise function is defined for two cases. When $\Psi > \gamma + \rho/2$, where ρ is the depth of the root zone in mm, the associated capillary rise V is positive. Otherwise, V is negative, and the resulting flow from the root zone to the subsoil is called root zone loss.

We implement the capillary rise formula only for positive capillary rise. It is easier to discuss root zone loss as a separate case when we discuss the core computations.

When suction at the interface between the root zone and the subsoil is greater than the groundwater level, the corresponding capillary rise is obtained by solving Eq. (11) in Sec. 4.2.4. We have implemented the solution of this equation using a binary search technique. Since the search may involve quite a number of evaluations of the left-hand side of Eq. (11), this method of deriving the capillary rise can be computationally costly.

To reduce costs, we developed an easily evaluated formula for the capillary rise function. For each soil type used in the PAWN analysis, we generated a table containing many combinations of capillary rise, groundwater levels, and soil suction values. After some experimentation, we obtained the formula displayed in Table 5.12. The coefficients were estimated using ordinary least squares regression on the logarithms of both sides of the expression.

Either the binary search technique or the simple formula can be used. If the coefficients of the simple formula are set equal to zero, the binary search technique is used.

The Sprinkling Procedures. The outputs from the sprinkling procedures are listed in Table 5.13. The "simple" sprinkling procedure described in Sec. 4.2.5 was not used in the PAWN analysis, so we will not describe it further. The more realistic sprinkling procedure actually used is described in Chap. 5 of Vol. XIII, where a discussion of the inputs will be found.

The sprinkling procedure is used only in the "request" mode, in which case the core computations use it to compute the two variables described in Table 5.14. In the "delivery" mode, these variables are

Table 5.11

IMPLEMENTATION OF THE CORE FUNCTION $\gamma = F_{GWL}(\Delta,V)$

Equations:

If SSDEF > SSDEF_CR then

$$\mathrm{GWL} = \mathrm{DEF\_A} \times \mathrm{sqrt(SSDEF)}$$

otherwise

$$\mathrm{GWL} = \mathrm{DEF\_A} \times \mathrm{sqrt(SSDEF)} + (\mathrm{DEF\_B} - \mathrm{DEF\_C} \times \mathrm{CAPRISE}^{\mathrm{DEF\_D}}) \times \mathrm{SSDEF}$$

where

$$\mathrm{SSDEF\_CR} = -(\mathrm{DEF\_A}/(2 \times (\mathrm{DEF\_B} - \mathrm{DEF\_C} \times \mathrm{CAPRISE}^{\mathrm{DEF\_D}})))^2$$

Name	Units	Description
SSDEF	mm	Subsoil deficit (Δ)
CAPRISE	mm/day	Capillary rise (V)
GWL	mm	Groundwater level (γ)

Table 5.12

IMPLEMENTATION OF THE CORE FUNCTION $V = F_{CAPRISE}(\Psi,\gamma)$

Equation:

$$CAPRISE = \exp(A1) \times GWL^{A2}(\log(PSI - GWL))^{A3}$$

Name	Units	Description
GWL	mm	Groundwater level (γ)
PSI	mm	Suction at top of subsoil (Ψ)
CAPRISE	mm/day	Corresponding capillary rise (V)

NOTE: This formula is used only when A1 > 0. Otherwise a binary search technique is used.

Table 5.13

OUTPUTS FROM THE SPRINKLING PROCEDURES

Name	Units	Description
SPRINK_AMOUNT	mm	Water effectively applied to root zone
SPRINK_REQUEST	mm	Water extracted (from surface or ground) for sprinkling
SPRINK_LOSS	mm	Extracted water that is not effectively applied
SPRINK_DOWN	mm	Water that is not effectively applied that flows to the subsoil

Table 5.14

SPRINKLING QUANTITIES IN THE CORE MODEL

Equations:

"Request" Mode:

I = SPRINK_AMOUNT

I_NET = SPRINK_REQUEST - SPRINK_DOWN   if plot sprinkled from groundwater

= -SPRINK_DOWN   otherwise

"Delivery" Mode:

I = SPRINK_ALLOW × SPR_EFF

I_NET = SPRINK_ALLOW × (1-FRAC_DOWN)   if plot sprinkled from groundwater

= -SPRINK_ALLOW × FRAC_DOWN   otherwise

where

FRAC_DOWN = (1-SPR_EVAP) × (1-SPR_EFF)

---

computed using the inputs passed to PLOTWAT by DISTAG, as is also described in Table 5.14. The distinction between the "request" mode and the "delivery" mode affects only the way in which the sprinkling variables of the core computations are defined.

5.3.3. An Overview of the Core Computation Scheme

In this section, we outline briefly the overall logic of the core computations. Details of the calculations are given in the next section.

Capillary Rise vs. Root Zone Loss. We follow different computational paths, one if capillary rise occurs, the other is root zone loss occurs.

Computations If Capillary Rise Occurs. If capillary rise occurs, we use a computation scheme, repeated three times. To begin, we make a preliminary estimate of capillary rise and of actual evapotranspiration. Then, we compute water balances for both the root zone and the subsoil.

- A root zone water balance computes Θ^1 and E_A.
- A subsoil water balance computes Δ^1, γ^1, and D.

Next, we estimate the actual capillary rise, V.

Unless the actual estimate of capillary rise is nearly equal to the preliminary estimate, we make new preliminary estimates, and repeat the two water balance calculations and the estimation of actual capillary rise. We conclude by once again making new preliminary estimates, and repeating the two water balance calculations.

Computations If Root Zone Loss Occurs. If root zone loss occurs, a water balance is computed exactly once, first for the root zone, then for the subsoil

- A root zone water balance computes Θ^1, E_A, and V.
- A subsoil water balance computes Δ^1, γ^1, and D.

The subsoil scheme is the same as the one used when capillary rise occurs.

5.3.4. Details of the Core Computations

We now fill in the calculational details of the core computations.

Capillary Rise vs. Root Zone Loss. We assume root zone loss will occur if the initial root zone soil moisture, the rain, and the potential evapotranspiration are such that without additional extractions of water the root zone soil moisture would exceed field capacity at the end of the timestep.

Field capacity is defined by the following expressions:

Suction at Field Capacity

$$\Psi_{FC} = \min(1000,\max(\gamma^0+\rho/2,\gamma_i-\rho/2))$$

Moisture at Field Capacity

$$\Theta_{FC} = F_{THETA}(\Psi_{FC})$$

The symbol γ_i represents the groundwater level at the beginning of the growing season. Its presence in this formula is explained in Sec. 5.3.6.

Deciding whether capillary rise or root zone loss occurs involves the following:

Estimate Moisture

$$\Theta_{est} = \Theta^0 + (\Theta - E_P)\delta$$

Condition for Root Zone Loss

$$\Theta_{est} > \Theta_{FC}$$

Condition for Capillary Rise

$$\Theta_{est} < \Theta_{FC}$$

Computations If Capillary Rise Occurs. In Sec. 5.3.3, we explained that when capillary rise occurs the core computations involve iterations among four computational parts:

1. Preliminary estimates of capillary rise and actual evapotranspiration.
2. A root zone water balance.
3. A subsoil water balance.
4. A new estimate of capillary rise.

Here we will discuss each of these parts separately.

1. Preliminary estimates V^0 and A^0 of capillary rise and evapotranspiration, respectively, are

   V^0: Capillary rise from previous timestep
   A^0: Potential evapotranspiration

2. A root zone water balance, shown below, estimates the final root zone soil moisture θ^1 and the actual evapotranspiration E_A:

   Sprinkling

   Use sprinkling procedure to compute I and I_NET

   Soil Moisture

   $$\theta^1 = \max(0,\min(\omega,\theta^0+(R+I+V^0-A^0)/\rho))$$

   Evapotranspiration

   $$E_A = E_P \times F_{EVAP}(\Psi)$$

   where

   $$\Psi = F_{PSI}((\theta^0+\theta^1)/2)$$

   If the actual evapotranspiration differs from the preliminary estimate by more than a specified tolerance, the preliminary estimate is replaced by the estimate, and the root zone water balance calculations are repeated, until either the estimate is close enough to the preliminary one, or the calculations have been repeated more than a specified number of times.

3. A subsoil balance equation uses the preliminary estimate V^0 of capillary rise estimated by the root zone calculations. The net extraction from the subsoil due to sprinkling, I_NET was calculated in the process of computing the root zone water balance. We compute the final subsoil deficit Δ^1, the final groundwater level γ^1, and the rate of drainage, D.

   The computation is complicated by the fact that drainage is a very fast process (especially in the lowlands) and so steady state conditions do not approximate the actual situation for long timesteps. Rather than break the whole core computations into many short intervals, we break up only the subsoil computations.

   We begin by setting γ' equal to γ^0, and we let D = 0 to accumulate the drainage. We then compute a daily subsoil water balance, shown below, for each day in the timestep. When finished, we let γ^1 be the groundwater level γ' observed at the end of the last day of computation. We divide D by the length of the interval, to convert it to a rate of flow.

Daily Drainage

$$D' = F_{DRAIN}(\gamma')$$

Subsoil Deficit

$$W' = W' + V^0 + D' + I\_NET$$

Groundwater Level

$$\gamma' = FGWL\ (\Psi, V^0)$$

where

$$\Psi = F_{PSI}((\theta^0+\theta^1)/2)$$

Accumulate Drainage

$$D = D + D'$$

4. To calculate actual capillary rise, we use the formulas displayed below. Notice the calculations involve one term associated with the root zone (average suction), and one term associated with the subsoil (average groundwater level). The capillary rise is also constrained so that the final moisture in the root zone does not exceed field capacity.

Average Suction

$$\Psi = F_{PSI}((\theta^0+\theta^1)/2)$$

Average Groundwater Level

$$\gamma = (\gamma^0+\gamma^1)/2$$

Maximum Capillary Rise

$$V_{max} = (\theta_{FC}-\theta^0)/w - R - I + E_A$$

Capillary Rise

$$V = \min(V_{max}, F_{CAPRISE}(\Psi,\gamma))$$

Computations If Root Zone Loss Occurs. When root zone loss occurs, we assume capillary rise is equal in magnitude to just that flow necessary to cause the final root zone soil moisture to be at field capacity. These calculations follow. The subsoil calculations in this case are identical to those used when capillary rise occurs, with V^0 set equal to the root zone loss.

Evapotranspiration

$$E_A = E_P$$

Root Zone Loss

$$V = -\ (R-E_A) + (\theta_{FC}-\theta^0)\rho/\delta$$

Root Zone Soil Moisture

$$\theta^1 = \theta_{FC}$$

5.3.5. The Computation Scheme for Glasshouse Crops

The computations for water flows in plots containing crops grown under glass are displayed in Table 5.15. Potential and actual evapotranspiration are specified as data, capillary rise is zero, root zone loss is a fixed quantity, the amount sprinkled includes the evapotranspiration plus the root zone loss, and the state variables (root zone and subsoil deficits, groundwater level) never change. The other flows are computed in the same way as for open-air plots.

5.3.6. Some Additional Details

In this section we will discuss two small details that were passed over in the preceding discussion. The details are:

- The "practical" definition of field capacity.
- Groundwater level corrections for non-steady state conditions.

A "Practical" Definition of Field Capacity. In Sec. 4.2.1 we defined the field capacity of the soil at a particular depth as a function of the distance from that point to the groundwater level. When we speak of the field capacity of the entire root zone, we mean the total amount of water the root zone is able to hold against the force of gravity. To calculate this quantity we should integrate the soil moisture curve over the root zone when each point is at field capacity, but to simplify our calculations we assume that the field capacity of the root zone is the field capacity in the middle of the root zone multiplied by the root depth.

Table 5.15

WATER FLOW COMPUTATIONS FOR CROPS GROWN UNDER GLASS

Equations:

Water Flows

AVAP = NDAYS × CROPFACTOR

CAPRISE = 0

DRAINAGE = RZLOSS + RAIN

DRAINOUT = min(DRAINAGE,NDAYS × DRAIN_MAXOUT/365)

DRAIN_SW = DRAINAGE - DRAINOUT

INFILT = 0

PVAP = AVAP

RZLOSS = NDAYS × DRAIN_UG/365

SEEPAGE_SS = NDAYS × SEEP_RATE × SEEP_OW_FRAC

SEEPAGE_SW = NDAYS × SEEP_RATE × (1-SEEP_OW_FRAC)

SPRINKLE = AVAP + RZLOSS

SPRINK_LOSS = SPRINKLE × (1-SPR_EFF)/SPR_EFF

Final Conditions

GWL_NEW = GWL_OLD

RZDEF_NEW = RZDEF_OLD

SSDEF_NEW = SSDEF_OLD

The use of this definition of field capacity gives reasonable results when the groundwater level is from about 300 to 1000 mm under the root zone. When the groundwater level is deeper than 1000 mm, this assumption leads to incorrect computations of soil moisture levels, because the steady state conditions cannot really be said to hold during the short timesteps used. Therefore, we constrained the suction at field capacity to lie between 1000 mm and the groundwater level γ_i at the beginning of the growing season. This constraint leads to the formula given in Sec. 5.3.4. One-half the root depth is added or subtracted where appropriate, to make all terms consistent with a depth measured from the bottom of the root zone.

Groundwater Level Corrections for Non-steady State Conditions. When the climatological conditions change rapidly from a rain surplus to a rain deficit (as is often the case in the spring), the steady state conditions assumed by our calculations do not apply. Our model then gives unrealistic "jumps" (up to a meter or more) in estimated groundwater levels. To avoid these jumps, we keep groundwater levels constant during periods where unsteady state conditions are likely to be more realistic. To detect such conditions, at the end of each timestep we check if the subsoil deficit and the groundwater level both increased or decreased in the same direction. If they did not, we kept the groundwater level fixed at its initial value.

We also constrained the change in groundwater level so that it never exceeded 20 times the increase in subsoil deficit (expressed as a water depth). When the subsoil deficit decreased, we computed how much of that decrease was due to flows from the subsoil other than those to and from the root zone (infiltration, seepage, etc). We then assumed that the groundwater level would decrease at least 20 times the decrease in the subsoil deficit (in mm) caused by these flows. In both of these cases, the number "20" was arbitrarily chosen.

5.4. THE PLOT SALT MODEL (PLOTSLT)

The computer implementation of the plot salt model is a relatively straightforward translation of the discussion in Sec. 4.3.2.

5.4.1. Inputs and Outputs

A list of the inputs and outputs of PLOTSLT is given in Table 5.16. There are only three output variables. The final concentrations of root zone and subsoil are used by PLOTSLT as the initial conditions for the next timestep. The concentration of the drainage is used by DISTAG to compute the salt flow to the district surface water. The plot damage model computes an average root zone salt concentration based on the initial and final root zone salt concentrations for the timestep.

Table 5.16

PLOT SALT MODEL INPUTS AND OUTPUTS

Name	Units	Description
		Inputs
Fixed Data		
NDAYS	days	Number of days in decade
RAIN	mm	Rainfall
RAIN_CONC	mg/l	Salt concentration of rainwater
ROOTDEPTH	mm	Root depth of crop
LOAD_RZ	$(mg/m^2)/day$	Constant salt flow into root zone
SATCAP_RZ	mm/mm	Saturation capacity of root zone
SATCAP_SS	mm/mm	Saturation capacity of subsoil
SEEP_CONC	mg/l	Salt concentration of seepage
SSDEPTH	mm	Effective depth of subsoil
LOAD_SS	$(mg/m^2)/day$	Constant salt flow into subsoil
VOLRZ_UG	mm	Root zone volume for crops under glass
VOLSS_UG	mm	Subsoil volume for crops under glass
Passed by DISTAG		
AVCONC_SW	mg/l	Salt concentration of district water
Computed by PLOTWAT		
AVAP	mm	Actual evapotranspiration
CAPRISE	mm	Capillary rise
DRAINAGE	mm	Drainage from subsoil
INFILT	mm	Infiltration from surface water
RZDEF_NEW	mm	Final root zone moisture deficit
RZDEF_OLD	mm	Initial root zone moisture deficit
RZLOSS	mm	Root zone loss
SEEPAGE_SS	mm	Seepage to subsoil
SPRINKLE	mm	Total water withdrawn for sprinkling
SPRINK_LOSS	mm	Sprinkling water lost
SSDEF_NEW	mm	Final subsoil moisture deficit
SSDEF_OLD	mm	Initial subsoil moisture deficit
Computed Previous Decade by PLOTSLT		
RZSALT_OLD	mg/l	Initial root zone salt concentration
SSSALT_OLD	mg/l	Initial subsoil salt concentration
		Outputs
AVCONC_OUT	mg/l	Average concentration of drainage
RZSALT_NEW	mg/l	Final root zone salt concentration
SSSALT_NEW	mg/l	Final subsoil salt concentration

5.4.2. Basic Equations

Open-Air Crops. PLOTSLT uses the basic salt model described in Sec. 4.3.1. It uses this model twice, first for the root zone, second for the subsoil. There are six inputs and two outputs associated with the basic salt model listed in Sec. 4.3.1.

In Tables 5.17 and 5.18 we show how the basic salt model is used by PLOTSLT for the root zone and subsoil salt balances, respectively. We will briefly explain some of these formulas.

For the root zone, the water flows are computed by PLOTWAT. The variable SPRINKLE is zero if the plot is not sprinkled. Since PLOTWAT computes the deficit in the root zone, we subtract this deficit from the total capacity of the root zone to find the total amount of water. The capacity is just the root depth multiplied by the saturation capacity of the root zone soil.

The inflow of salt to the root zone comprises three terms: the contribution of rain, an exogenous load, and salt from sprinkled surface water, if there is any.

The subsoil equations are not very different from those of the root zone. We assumed that groundwater sprinkling adds no salt to the root zone, so no salt is taken out of the subsoil if this kind of sprinkling is present. This fact explains why the term SPRINKLE is added to W_UP.

The inflow of salt to the subsoil comprises four terms: root zone loss, seepage, infiltration from surface water, and the (artificial) subsoil load.

Glasshouse Crops. The computation of salt flows in plots with glasshouse crops is based on the root zone salt profile that we described in Sec. 4.3.2. The shape of this profile is fixed by specifying two parameters:

- Average salt concentration
- Leaching fraction

The leaching fraction does not change very much from one timestep to the next, and to make computations simpler, we use the leaching fraction of the current timestep instead of the more logical leaching fraction of the previous timestep.

Table 5.19 shows the computations. First, we determine the leaching fraction and the salt concentration at the top of the root zone. It is important to realize that this concentration is not the "real" concentration (which will be about equal to the concentration of the

Table 5.17

SALT FLOWS IN ROOT ZONE OF OPEN-AIR PLOTS

How Inputs to the Basic Salt Model Are Defined:

W_IN = RAIN + CAPRISE	if plot is unsprinkled
= RAIN + CAPRISE + SPRINKLE	otherwise
W_UP = AVAP	if plot is unsprinkled
= AVAP + SPRINK_LOSS	otherwise
W_OLD = SATCAP_RZ × ROOTDEPTH - RZDEF_OLD	
W_NEW = SATCAP_RZ × ROOTDEPTH - RZDEF_NEW	
S_IN = RAIN × RAIN_CONC + LOAD_RZ × NDAYS	if plot is not sprinkled from surface water
= RAIN × RAIN_CONC + LOAD_RZ × NDAYS + AVCONC_SW × SPRINKLE	otherwise
S_OLD = W_OLD × RZSALT_OLD	

How Outputs (S_NEW and AVCONC) from Basic Salt Model Are Used:

RZSALT_NEW = S_NEW/W_NEW

RZ_CONC = AVCONC

NOTE: See Sec. 4.3.1 for description of inputs and outputs for the basic salt model.

Table 5.18

SALT FLOWS IN SUBSOIL OF OPEN-AIR PLOTS

How Inputs to the Basic Salt Model Are Defined:

W_IN = INFILT + RZLOSS + SEEPAGE_SS

W_UP = CAPRISE if plot is not sprinkled from groundwater
= CAPRISE + SPRINKLE otherwise

W_OLD = max(1,SATCAP_SS × SSDEPTH - SSDEF_OLD)

W_NEW = max(1,SATCAP_SS × SSDEPTH - SSDEF_NEW)

S_IN = RZLOSS × RZ_CONC + SEEPAGE_SS × SEEP_SALT
+ INFILT × AVCONC_SW + LOAD_SS × NDAYS

S_OLD = W_OLD × SSSALT_OLD

How Outputs (S_NEW and AVCONC) from Basic Salt Model Are Used:

SSSALT_NEW = S_NEW/W_NEW

AVCONC_OUT = AVCONC

NOTE: See Sec. 4.3.1 for description of inputs and outputs for the basic salt model.

Table 5.19

SALT FLOWS IN GLASSHOUSE PLOTS

Equations:

Root Zone

LEACHFRAC = -CAPRISE/SPRINKLE

SALT_TOP = RZSALT_OLD × (1-LEACHFRAC)/(-ln(LEACHFRAC))

X_DRAIN = 1+CAPRISE/(2 × VOLRZ_UG)

RZ_CONC = SALT_TOP/(1-X_DRAIN × (1-LEACHFRAC))

TOT_RZ_SALT = -CAPRISE × RZ_CONC

TOT_SALT_IN = SPRINKLE × AVCONC_SW

RZSALT_NEW = RZSALT_OLD + (TOT_SALT_IN - TOT_RZ_SALT)/VOLRZ_UG

Subsoil

SSSALT_NEW = SSSALT_OLD + (TOT_RZ_SALT+SEEPAGE_SS × SEEP_CONC -(INFILT+DRAINAGE) × SSSALT_OLD)/VOLSS_UG

AVCONC_OUT = SSSALT_OLD

Name	Units	Description
LEACHFRAC	mm/mm	Leaching fraction
SALT_TOP	mg/l	Salt concentration at top of root zone
X_DRAIN	mm/mm	Fraction of the root zone depth whose average concentration is that of the outflowing water
RZ_CONC	mg/l	Average concentration of outflowing water
TOT_RZ_SALT	mg/l	Total salt flowing out of the root zone
TOT_SALT_IN	g	Total salt flowing into the root zone

sprinkling water), but is just an aid to determining the salt concentration of the outflowing water. Next we determine the size of the slice of water that will leave the root zone during the timestep. The middle of this slice is assumed to have the average salt concentration of the slice. This concentration is calculated using Eq. (6) of Sec. 4.2.3. A mass balance equation for salt in the root zone then gives us the average concentration at the end of the timestep.

To compute salt concentrations in the subsoil, we invoke the mass balance equation.

5.5. THE PLOT DAMAGE MODEL (PLOTDAM)

The computer implementation of the plot damage model is a relatively straightforward translation of the formulas discussed in Sec. 4.4.

5.5.1. Inputs and Outputs

The inputs and outputs of PLOTDAM are given in Table 5.20. Four of the inputs are constant over time and describe the damage curves drought and salt as explained in Sec. 4.4.1 and 4.4.2, respectively. Three other damage parameters depend on the timestep. The remaining inputs to PLOTDAM are generated by PLOTWAT, PLOTSLT, and PLOTDAM itself (in a previous timestep.) The outputs of PLOTDAM are the salt damage, the total damage, and the survival fraction that is used in the next timestep.

5.5.2. Basic Equations

PLOTDAM consists of a drought damage calculation, a salt damage calculation, and a way to combine these two calculations into total damage. The drought and salt damage computation procedure was described in Sec. 4.4. These computations are summarized in Table 5.21.

5.6. DISTAG

5.6.1. Inputs and Outputs

The inputs to DISTAG that are read from data files are listed in Chap. 3. DISTAG uses outputs from the three plot models that have already been described. DISTAG outputs were listed in Table 3.6.

5.6.2. Basic Equations

DISTAG first computes a district water balance, then a district salt balance, and finally it aggregates damage and sprinkling costs.

Table 5.20

PLOT DAMAGE MODEL INPUTS AND OUTPUTS

Name	Units	Description
		Inputs
Fixed Data		
CROP_VALUE	Dfl/ha	Money value of crop
NDAYS		Number of days this decade
Parameters That Depend Only on Crop Type		
SD	/(mg/l)	Slope of salt damage curve
DP		Point of maximum drought damage
MIN	mg/l	Point where salt damage begins
RP		Point where slope of drought damage curve changes
Parameters That Depend on Crop and Timestep		
DD		Drought damage fraction at point DP
RD		Drought damage fraction at point RP
REMAIN_YIELD		Fraction of crop that remains to be produced
Computed by PLOTWAT		
AVAP	mm	Actual evapotranspiration
PVAP	mm	Potential evapotranspiration
Computed by PLOTSLT		
RZSALT_OLD	mg/l	Initial root zone salt concentration
RZSALT_NEW	mg/l	Final root zone salt concentration
Computed Previous Decade by PLOTDAM		
SURVFRAC_OLD	ha/ha	Initial survival fraction
		Outputs
SALT_DAM	Dfl/ha	Salt damage
SURVFRAC_NEW	ha/ha	Final survival fraction
TOT_DAM	Dfl/ha	Total damage

Table 5.21

PLOT DAMAGE MODEL

Equations:

Drought Damage

$$\mathrm{RATIO} = \mathrm{AVAP}/\mathrm{EVAP}$$

$$\mathrm{DD\_FRAC} = \begin{cases} 0 & \text{when } 1 = \mathrm{RATIO} \\ \mathrm{RD} \times (1-\mathrm{RATIO})/(1-\mathrm{RP}) & \mathrm{RP} < \mathrm{RATIO} < 1 \\ \mathrm{RD} + (\mathrm{DD}-\mathrm{RD}) \times (\mathrm{RP}-\mathrm{RATIO})/(\mathrm{RP}-\mathrm{DP}) & \mathrm{DP} < \mathrm{RATIO} < \mathrm{RP} \\ \mathrm{DD} & \mathrm{RATIO} < \mathrm{DP} \end{cases}$$

Salt Damage

$$\mathrm{RZSALT} = (\mathrm{RZSALT\_OLD} + \mathrm{RZSALT\_NEW})/2$$

$$\mathrm{SD\_FRAC} = \begin{cases} 0 & \text{when } \mathrm{MIN} > \mathrm{RZSALT} \\ \mathrm{SD} \times (\mathrm{RZSALT}-\mathrm{MIN}) & \mathrm{MIN} < \mathrm{RZSALT} < \mathrm{MAX} \\ 1 & \mathrm{MAX} < \mathrm{RZSALT} \end{cases}$$

Total Damage

$$\mathrm{POT\_YIELD} = \mathrm{REMAIN\_YIELD} \times \mathrm{SURVFRAC\_OLD} \times \mathrm{CROP\_VALUE}$$
$$\mathrm{SALT\_DAM} = \mathrm{SD\_FRAC} \times \mathrm{POT\_YIELD}$$
$$\mathrm{TOT\_DAM} = \mathrm{SALT\_DAM} + (\mathrm{POT\_YIELD}-\mathrm{SALT\_DAM}) \times \mathrm{DD\_FRAC}$$
$$\mathrm{SURVFRAC\_NEW} = \mathrm{SURVFRAC\_OLD} \times (1-\mathrm{SD\_FRAC}) \times (1-\mathrm{DD\_FRAC})$$

Name	Units	Description
RATIO	--	Potential evapotranspiration ratio
DD_FRAC	--	Drought damage fraction
SD_FRAC	--	Salt damage fraction
POT_YIELD	Dfl/ha	Potential financial yield, taking previous damage and normal production patterns into account
RZSALT	mg/l	Average salt in root zone

The District Water Balance. We distinguish two major steps:

- Compute flows from plots.
- Compute flows within the district.

DISTAG uses PLOTWAT to calculate the plot flows in millimeters per unit of area for each plot. It converts these flows into a rate (m^3/s) and adds them up. The equations are given in Table 5.22.

Computations differ depending on whether DISTAG is formulating a "request" or a "delivery." For a "request" there are no constraints on the amount of surface water that may be withdrawn for sprinkling crops, but for a "delivery," DM may impose a constraint for open-air crops. When this happens, DM passes to DISTAG a so-called cutback fraction that equals the total amount of open-air surface water sprinkling that DM is willing to allow, divided by the total amount of such sprinkling originally requested. DISTAG indicates to PLOTWAT the fact that sprinkling is to be cut back by setting two "switches," SPRINK_ALLOW and SPRINK_INDEX. Table 5.2 describes how this is done.

The computation of flows with the district are shown in Table 5.23.

The District Salt Computation. The district salt computation determines two quantities: the average concentration of the water extracted from the district by DM or flowing into the soil, and the amount of salt in the surface water of the district to be carried forward to the next timestep.

The basic salt model described in Sec. 4.3.1 is used for the district salt balance. One of the salt inflows to the district surface water is salt from draining plots, either because they are draining into the surface water system or because there is a positive seepage flow of which a part directly enters the surface water. The other possible contributions to the amount of salt in the district are extractions from the national distribution system, industrial discharges, rain, and urban runoff. Table 5.24 shows how the basic salt model is used to compute the district salt balance.

Damages and Sprinkling Costs. Finally, DISTAG aggregates crop damages and sprinkling costs for all the plots in the district. After the "request" and "delivery" modes have been completed, DISTAG computes the final results for the timestep using the formulas in Table 5.25.

5.6.3. The Demand Generator

DISTAG is a subroutine of DM. However, there are some useful applications of DISTAG that do not require computing interactions between districts:

Table 5.22

WATER FLOWS BETWEEN PLOTS AND THE SURFACE WATER SYSTEM

Equations:

$SPRINK\_TOT = \Sigma^0\ \lambda \times SPRINKLE$

$SPRINK\_SW = \Sigma^1\ \lambda \times SPRINKLE$

$SPRINK\_CUT = \Sigma^2\ \lambda \times SPRINKLE$

$SEEP\_SW = \Sigma^0\ \lambda \times SEEPAGE\_SW$

$INFILT\_SW = \Sigma^0\ \lambda \times INFILT$

$DRAIN\_TOT = \Sigma^0\ \lambda \times DRAINAGE$

$DRAIN\_OUT = \Sigma^0\ \lambda \times DRAINOUT$

$DRAIN\_SW = DRAIN\_TOT - DRAIN\_OUT$

where

$\lambda = PLOTAREA/(NDAYS \times 8640)$

Σ^0: Sum over all plots in district

Σ^1: Sum over all plots that use surface water

Σ^2: Sum over all plots with open-air crops that use surface water

Name	Units	Description
SEEP_SW	m^3/s	Total seepage that flows directly into the surface water system
INFILT_SW	m^3/s	Infiltration from surface water to subsoil
DRAIN_TOT	m^3/s	Drainage from subsoil
DRAIN_SW	m^3/s	Drainage that flows into the surface water system

Table 5.23

DISTRICT WATER BALANCE COMPUTATIONS

Equations:

URBAN_RAIN = URBAN_AREA × RAIN/(NDAYS × 8640)

URBAN_EVAP = URBAN_AREA × EVAP × URBAN_CF/(NDAYS × 8640)

URBAN_RUNOFF = max(0,URBAN_RAIN - URBAN_EVAP)

RAIN_SW = WATER_AREA × RAIN/(NDAYS × 8640)

EVAP_SW = WATER_AREA × EVAP/(NDAYS × 8640)

FLUSH = max(0,FLUSH_MIN - FLUSH_RED)

INFLOW = URBAN_RUNOFF + RAIN_SW + INDUST_DIS + SEEP_SW + DRAIN_SW

OUTFLOW = EVAP_SW + SPRINK_SW + INDUST_EXT + INFILT_SW

DISCHARGE = max(FLUSH,INFLOW - OUTFLOW)

EXTRACTION = DISCHARGE - INFLOW + OUTFLOW

Name	Units	Description
URBAN_RAIN	m^3/s	Rain falling on urban area
URBAN_EVAP	m^3/s	Potential evaporation from urban area
URBAN_RUNOFF	m^3/s	Water running off urban area
RAIN_SW	m^3/s	Rain falling on surface water
EVAP_SW	m^3/s	Evaporation from surface water
FLUSH	m^3/s	Actual (minimum) flushing requested
INFLOW	m^3/s	Total flow except for extraction from distribution system
OUTFLOW	m^3/s	Total flow except for discharge to distribution system

Table 5.24

SALT CONCENTRATION OF SURFACE WATER

How Inputs to the Basic Salt Model Are Defined:

W_IN = (INFLOW + EXTRACTION) × NDAYS × 86400

W_UP = EVAP_SW × NDAYS × 86400

W_OLD = WATER_VOLUME

W_NEW = WATER_VOLUME

S_IN = (SALTCONC × EXTRACTION + INDUST_SALT × INDUST_DIS
+ RAIN_CONC × RAIN_SW + URB_CONC × URBAN_RUNOFF) × NDAYS × 86400
+ Σ^0 AVCONC_OUT × DRAINAGE × PLOTAREA × 10
+ Σ^1 SEEP_CONC × SEEPAGE_SW × PLOTAREA × 10

where

Σ^0: sum over all plots that drain into district

Σ^1: sum over all plots where seepage is positive

S_OLD = SWSALT_OLD

How Outputs (S_NEW and AVCONC) from Basic Salt Model Are Used:

SWSALT_NEW = S_NEW

AVCONC_SW = AVCONC

NOTE: See Sec. 4.3.1 for description of inputs and outputs for the basic salt model.

Table 5.25

AGRICULTURAL DAMAGE AND COSTS OF SPRINKLING

Equations:

Damage:

$\mathrm{SALTDAM} = \Sigma^0\ \mathrm{SALT\_DAM} \times \mathrm{PLOTAREA}$

$\mathrm{TOTDAM} = \Sigma^0\ \mathrm{TOT\_DAM} \times \mathrm{PLOTAREA}$

Sprinkling Costs:

$\mathrm{LABOR\_COST} = \Sigma^1\ \mathrm{SPRINKLE} \times \mathrm{PLOTAREA} \times \mathrm{COST\_LABOR}$

$\mathrm{ENERGY\_COST} = \Sigma^1\ \mathrm{SPRINKLE} \times \mathrm{PLOTAREA} \times \mathrm{COST\_ENERGY}$

where

Σ^0: Sum over all plots in district.

Σ^1: Sum over all sprinkled plots. (Separate summation for each crop.)

- Estimating district water requirements, given a certain amount of installed sprinklers.
- Determining what crop damages can be prevented if sprinkling is applied and the plots get all the water they request.
- Analyzing the conditions and status (water and salt flows, damages) of specific plots.

Neither DISTAG nor the plot models can stand alone. All four require a calling program to handle certain housekeeping functions, such as reading data, writing results, etc. These housekeeping functions are normally taken care of by DM. Occasionally (for example, in designing sprinkling scenarios) we needed to make water balance computations for isolated plots, but we did not need to compute the associated flows in the national distribution system. To enable us to make computations of this sort, without using DM, we created a stand-alone computer program called the demand generator (DEMGEN). DEMGEN handles the housekeeping necessary to call DISTAG (which in turn calls the plot models) and to write results of DISTAG and plot computations on files that can be used for subsequent analysis. DEMGEN can be thought of as a replacement for DM; however, it is not able to make any "distribution" computations, such as constraining delivery of water for sprinkling due to low river discharges.

Inputs and Outputs. DEMGEN uses the same 16 files as DISTAG (see Sec. 5.2). The other inputs are essentially the same as those described in Chap. 3. The parameters that are normally passed to DISTAG by DM (the flushing reduction, the cutback fraction, and the salt concentration of the extracted water) are specified as control variables to DEMGEN, and these specified values are used for all districts and all timesteps. It is also possible to control which districts and which timesteps are actually used. We can specify:

- The first and last district; any consecutive subset of districts can be specified in a single run (e.g., districts 13 through 58).
- The first and last year to be run (e.g., 1959 through 1964).

DEMGEN writes results from the district and plot models on two files. An output file called DSTCOMP contains the district results, and a file called PLTCOMP contains the plot results. Tables 5.26 and 5.27 give an overview of the values written on these files. These results can be processed by various analysis programs (e.g., standard statistical analytic packages such as SPSS or SAS) to generate results in a form that is useful to the analysis being carried out.

We might remark at this point that since DISTAG is not a stand-alone program, anyone can write a "main" program that uses it. Thus it would be possible to write another version that eliminates some of the

Table 5.26

VARIABLES WRITTEN ON FILE PLTCOMP

Name	Units	Description
RUN_ID	--	An integer identifying the run
YEAR	--	Year of record
TIMESTEP	--	Timestep (decade) of record
PLOT	--	Index of plot
IRR_CODE		Irrigation code of plot
CROP_INDEX		Index of crop contained in plot
RAIN	mm	Amount of rain
PVAP	mm	Potential evapotranspiration
RZDEF_NEW	mm	Final root zone deficit
SSDEF_NEW	mm	Final subsoil deficit
RZSALT_NEW	mg/l	Final root zone salt concentration
SSSALT_NEW	mg/l	Final subsoil salt concentration
SURVFRAC_NEW	ha/ha	Final survival fraction
AVAP	mm	Actual evapotranspiration
DRAINAGE	mm	Total drainage from subsoil
CAPRISE	mm	Capillary rise
SEEPAGE_SS	mm	Seepage to subsoil
SPRINKLE	mm	Sprinkling
PSI	mm	Suction in root zone
AVCONC_OUT	mg/l	Average concentration of drainage

Table 5.27

VARIABLES WRITTEN ON FILE DSTCOMP

Name	Units	Description
RUN_ID	--	An integer identifying the run
YEAR	--	Year of record
TIMESTEP	--	Timestep (decade) of record
IRR_CODE		Irrigation code of plot
CROP_INDEX		Index of crop contained in plot
RAIN	mm	Amount of rain
PVAP	mm	Potential evapotranspiration
RZDEF_NEW	mm	Final root zone deficit
SSDEF_NEW	mm	Final subsoil deficit
RZSALT_NEW	mg/l	Final root zone salt concentration
SSSALT_NEW	mg/l	Final subsoil salt concentration
SURVFRAC_NEW	ha/ha	Final survival fraction
AVAP	mm	Actual evapotranspiration
DRAINAGE	mm	Total drainage from subsoil
CAPRISE	mm	Capillary rise
SEEPAGE_SS	mm	Seepage to subsoil
SPRINKLE	mm	Sprinkling
PSI	mm	Suction in root zone
AVCONC_OUT	mg/l	Average concentration of drainage
DIST	--	Index of district
URBAN_RUNOFF	m^3/s	Water running off urban area
RAIN_SW	m^3/s	Rain falling on surface water
EVAP_SW	m^3/s	Evaporation from surface water
DRAIN_TOT	m^3/s	Drainage from subsoil
LEAK_TOT	m^3/s	Leakage into subsoil
SPRINK_TOT	m^3/s	Total water consumed for sprinkling
SPRINK_CUT	m^3/s	Surface water sprinkling that can be cut back in case of shortage
SALT_TODIST	g	Total salt discharged into district
SALT_FRDIST	g	Total salt discharged by district
TOTDAM	Dflm	Total damage to all plots
SALTDAM	Dflm	Salt damage to all plots
DISCHARGE	m^3/s	Discharge to national system
EXTRACTION	m^3/s	Extraction from national system
AVCONC_SW	mg/l	Average salt concentration of water discharged from district
SALT_OUT	g	Total salt discharged to national system

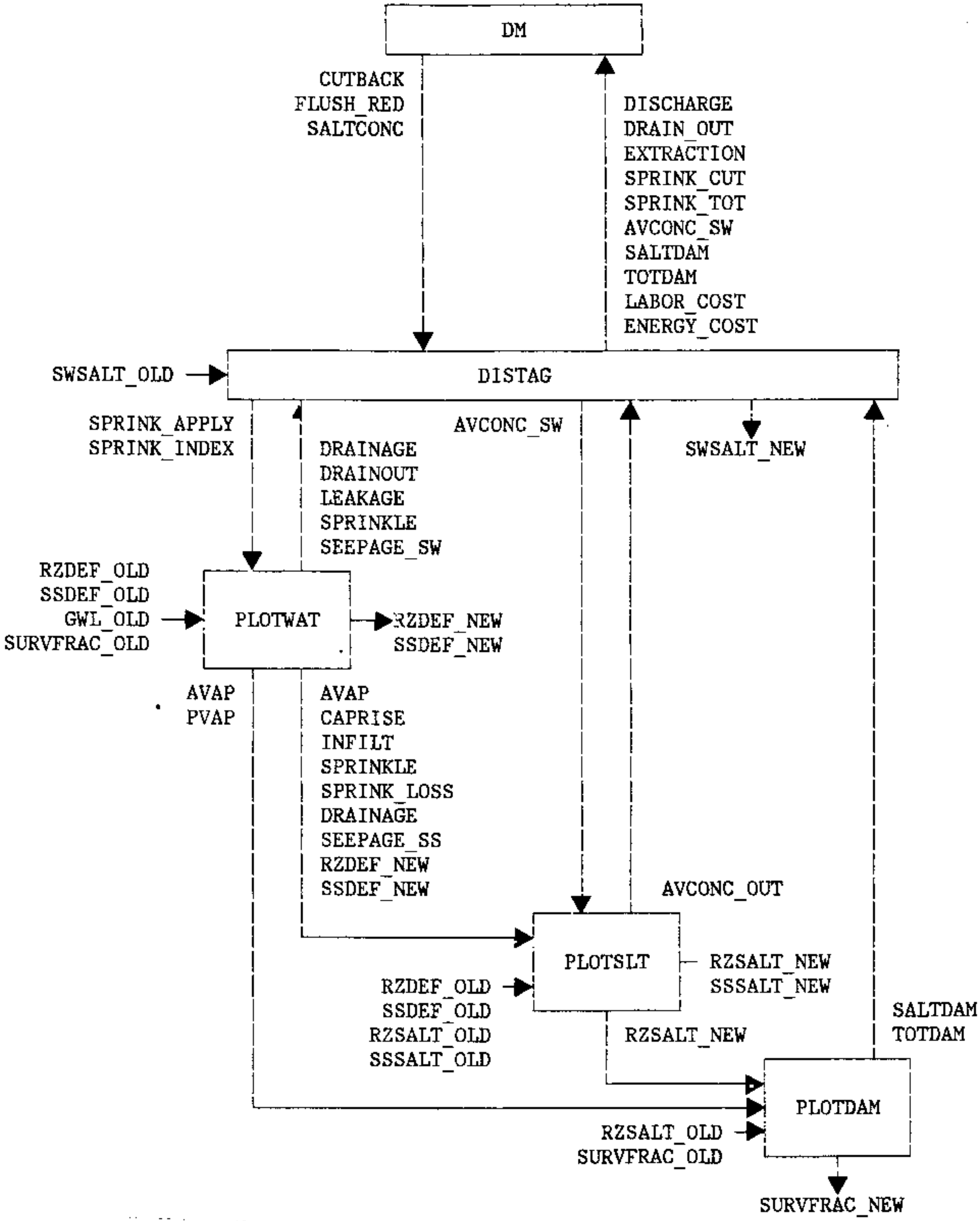

Fig. 5.1--Overview showing variables passed between DM, DISTAG, and the three PLOT models

limitations of DEMGEN (e.g., the fact that the salt concentration of the surface water must be a single constant specified in advance).

5.7. OVERVIEW OF DATA FLOWS AMONG THE MODELS

In describing the models in Secs. 5.3 through 5.6, we used many variables that were passed from one model to the next. Figure 5.1 presents an overview of these variables. It shows only the variables that control interactions among the models in either the "request" or "delivery" modes, and none of the fixed input data.

REFERENCE

5.1. Rijtema, P. E., Soil Moisture Forecasting, Report 513, ICW, Wageningen, 1969.

Chapter 6

DATA

In this chapter we describe the data files needed by DISTAG, and the data base assembled in order to use DISTAG for the PAWN analysis. All of the data are listed in conveniently formatted tables.

The description of the data files will be consulted by readers who are using DISTAG and need to develop new data files or modify current ones. The description and listings of the data are needed by those interested in examining detailed assumptions upon which the PAWN results are based. The data give a rather detailed picture of the agriculture and hydrology of the Netherlands, and may be useful for purposes other than PAWN altogether. On the other hand, this chapter is not essential to those who read the present volume to get an understanding of the theoretical basis for the models described.

We begin by describing those data that characterize the geography of the Netherlands, that is, the various characteristics of districts, subdistricts, and plots. Next we discuss parameters associated with various submodels--those associated with soils and crops, those that are used by the sprinkling models, and those used to compute basic drainage. We then discuss external supply data (rain, evaporation), and conclude with a discussion of many miscellaneous data, most of them single numbers, which are difficult to classify.

6.1. DISTRICTS, SUBDISTRICTS, AND PLOTS

The data that describe districts, subdistricts, and plots comprise the basic geographical description of the Netherlands used by DISTAG. In this section, we will first describe the basic input files containing these data, and then we will discuss the data themselves. We will explain how districts and subdistricts were chosen, and then describe how the data were obtained.

6.1.1. Input Data Files

There are four data files, one containing district data, two containing subdistrict data, and one containing plot data. These files are described in Table 6.1.

6.1.2. The Data

The District File. DISTFIL contains 13 data elements. An overview of these data for the situation treated by PAWN is given in Table 6.2. The district index and name are used only for administrative reasons and identification; the districts were numbered from 1

Table 6.1

DISTRICT, SUBDISTRICT, AND PLOT DATA FILES

File	Field	Column	Format	Description	Source Code Identifier	Documentation
DISTFIL				DISTRICT GEOGRAPHY		
	1	1- 2	F(2)	District index	IDIST	
	2	4-11	A(8)	District name		
	3	12-14	F(3)	Index of weather station	DIST.DATA.WEATHER_STATION (IDIST)	
	4	15-17	F(3)	Index of drainage region	DIST.DATA.DRAINAGE_REGION (IDIST)	
	5	18-24	F(7)	Total area (ha)		
	6	25-31	F(7)	Urban area (ha)	DIST.DATA.URBAN_AREA (IDIST)	URBAN_AREA
	7	32-38	F(7)	Open water area (ha)	DIST.DATA.WATER_AREA (IDIST)	WATER_AREA
	8	39-45	F(7)	Water volume (1000 m^3)	DIST.DATA.WATER_VOLUME (IDIST)	WATER_VOL
	9	46-49	F(4,1)	Flushing minimum (m^3/s)	DIST.DATA.FLUSHING_MINIMUM (IDIST)	FLUSH_MIN
	10	50-54	F(5)	Initial salt concentrationn (mg/l)	DIST.DATA.INITIAL_SALT (IDIST)	
	11	55-58	F(4,1)	Industrial extraction (m^3/s)	DIST.DATA.INDUST_EXTRACT (IDIST)	INDUST_EXT
	12	59-62	F(4,1)	Industrial discharge (m^3/s)	DIST.DATA.INDUST_DISCH (IDIST)	INDUST_DIS
	13	63-67	F(5)	Discharge salt (mg/l)	DIST.DATA.INDUST_SALT (IDIST)	INDUST_SALT
SUBDFIL				SUBDISTRICT GEOGRAPHY		
	1	1- 3	F(3)	Index of subdistrict	ISUBD	
	2	4- 6	F(3)	Index of district	SUBD.DATA.DISTRICT_INDEX (ISUBD)	
	3	7- 9	F(3)	Index of agricultural region	SUBD.DATA.AGRI_REGION (ISUBD)	
	4	10-12	F(3)	Index of root zone soil	SUBD.DATA.RZ_SOIL_INDEX (ISUBD)	
	5	13-16	F(4)	Index of subsoil	SUBD.DATA.SS_SOIL_INDEX (ISUBD)	
	6	17-18	F(2)	Highlands/lowlands code	SUBD.DATA.HILO_CODE (ISUBD)	
	7	19-22	F(4,2)	Fraction of district		
	8	23-27	F(5,4)	Infiltration coefficient	SUBD.DATA.INFILTRATION_COEF (ISUBD)	INFIL_COEF
	9	28-33	F(6,5)	Drainage coefficient	SUBD.DATA.DRAINAGE_COEF (ISUBD)	DRAIN_COEF
	10	34-38	F(5)	Initial groundwater level (mm)	SUBD.DATA.INITIAL_GWL (ISUBD)	
	11	39-44	F(6)	Ditch level (mm)	SUBD.DATA.DITCH_LEVEL (ISUBD)	DITCH_LEVEL
	12	45-48	F(4,2)	Seepage amplitude (mm/day)	SUBD.DATA.SEEP_RATE (ISUBD)	SEEP_RATE
	13	49-54	F(6)	Salt concentration (ppm)	SUBD.DATA.SEEP_SALT (ISUBD)	SEEP_SALT
	14	55-58	F(4,2)	Industrial GW withdrawal (mm/day)	SUBD.DATA.GWL_INDUST (ISUBD)	GWL_INDUST
	15	59-63	F(4,2)	DW GW withdrawal (mm/day)	SUBD.DATA.GWL_DRINK (ISUBD)	GWL_DRINK
	16	64-69	F(6)	GW constraint (mm)	SUBD.DATA.GWL_CONSTR (ISUBD)	
SUB2FIL				SUBDISTRICT INFILTRATION DATA		
	1	1- 3	F(3)	Index of subdistrict	ISUBD	
	2	6- 9	F(4)	Fraction suppliable	SUB2.DATA.INF_FRAC (ISUBD)	SUPP_FRAC
	3	10-14	F(5)	Infiltration rate (mm/day)	SUB2.DATA.INF_RATE (ISUBD)	INF_RATE
	4	15-18	F(4)	Open water seepage fraction	SUB2.DATA.SEEP_OW_FRAC (ISUBD)	OW_FRAC
PLOTFIL				PLOT GEOGRAPHY		
	1	1- 3	F(3)	Index of subdistrict	PLOT.DATA.SUBDISTRICT_INDEX (IPLOT)	
	2	4- 5	F(2)	Irrigation code	PLOT.DATA.SPRINK_CODE (IPLOT)	IRR_CODE
	3	6- 7	F(2)	Index of crop	PLOT.DATA.CROP_INDEX (IPLOT)	
	4	8-13	F(6)	Area (ha)	PLOT.DATA.PLOT_AREA (IPLOT)	PLOTAREA

Table 6.2

DISTRICT DATA

PAWN Region 1: North

DISTRICT	DESCRIPTION	WEATHER	DRA	------------AREAS (ha)------------					WATER	FLUSH	INIT	--INDUSTRIAL--		
		STATION	REG	TOTAL	CROPS	NATURE	URBAN	WATER	VOL	MIN	SALT	EXT	DIS	SALT
1 FRIELAND	Friesland	Leeuward	1	289896	217889	46690	12708	12609	188530	3.0	175	.	.	.
2 HETBILDT	Het Bildt	Leeuward	.	15997	10948	3928	438	683	6085	2.0	175	.	.	.
3 LAUWMEER	Area around Lauwersmeer	Eelde	.	75320	48578	18896	2460	5386	70025	3.8	175	.	.	.
4 UITHUIZN	Uithuizen	Eelde	.	12623	8240	3602	349	432	4860	.	175	.	.	.
5 EEMSKANN	Eemskanaal Boezem--North	Eelde	.	36923	28927	3457	2425	2114	24535	2.5	175	.	.	.
6 OLDAMBT	Oldambt	Eelde	.	39376	30885	5040	2105	1346	14125	0.7	175	.	.	.
7 WESTWOLD	Area around the Westerwoldse A	Eelde	2	53759	43629	4082	4074	1974	19710	.	175	.	.	.
8 NWDRENTE	Northwest Drenthe	Eelde	2	57946	35846	16844	3336	1920	27172	.	175	.	.	.
9 WESKWART	Westerkwartier	Eelde	1	52921	29579	17730	3623	1989	21412	.	175	.	.	.
13 VOLENHOV	Land van Vollenhove	Dedemsv	1	52636	30282	16461	1419	4474	72125	.	175	.	.	.
14 NEPOLDER	Northeast Polder	Lelystad	.	48017	39332	5862	837	1986	25320	4.5	400	.	.	.
15 MASTBROK	Mastenbroek	Dedemsv	.	42960	32453	6787	1958	1762	17915	.	175	.	.	.
Total for region				778374	556588	149379	35732	36675						

PAWN Region 2: Northeast Highlands

DISTRICT	DESCRIPTION	WEATHER	DRA	------------AREAS (ha)------------					WATER	FLUSH	INIT	--INDUSTRIAL--		
		STATION	REG	TOTAL	CROPS	NATURE	URBAN	WATER	VOL	MIN	SALT	EXT	DIS	SALT
10 NEDRENTE	Northeast Drenthe	Eelde	2	29301	21214	4988	1929	1170	14610	.	175	.	.	.
11 SEDRENTE	Southeast Drenthe	Dedemsv	3	45587	32428	9377	2505	1277	15295	.	175	.	0.1	.
12 SWDRENTE	Southwest Drenthe	Dedemsv	3	91104	65039	20459	3167	2439	28320	.	175	.	0.4	.
16 OVIJVECT	Area around the Overijsselsche Vecht	Dedemsv	4	42995	28597	11303	1562	1533	17760	0.1	175	.	.	.
17 DINKEL	Area around the Dinkel	Dedemsv	5	24409	13808	8926	1268	407	4450	.	175	.	.	.
18 TWENTHE	Twenthe	Dedemsv	5	82475	46823	28372	5815	1465	16955	.	175	.	0.3	.
19 SALLAND	Salland	Dedemsv	5	47081	33249	10067	2483	1282	15080	.	175	.	.	.
20 TWENTKAN	Catchment area of Twenthe Canal	Dedemsv	5	59499	28790	26889	2890	930	9705	.	175	.	0.4	.
21 SHIPBEEK	Schipbeek	Dedemsv	5	27761	14099	11323	1882	457	4940	.	175	.	.	.
24 BERKEL	Berkel	Winters	6	73787	53424	16338	2870	1155	12045	.	175	.	0.3	.
25 OUDEIJSL	Area around the Oude IJssel	Winters	6	70429	47790	16521	4615	1503	19485	.	175	.	.	.
Total for region				594428	385261	164563	30986	13618						

PAWN Region 3: Flevoland & Veluwe

DISTRICT	DESCRIPTION	WEATHER	DRA	------------AREAS (ha)------------					WATER	FLUSH	INIT	--INDUSTRIAL--		
		STATION	REG	TOTAL	CROPS	NATURE	URBAN	WATER	VOL	MIN	SALT	EXT	DIS	SALT
22 IJSELGEB	Area around the IJssel River	De Bilt	9	25648	11076	12432	1648	492	5985	.	175	.	.	.
23 NEVELUWE	Northeast Veluwe	De Bilt	9	52861	19787	28549	3615	910	10310	.	175	.	.	.
26 ARNHEM	Area around Arnhem	De Bilt	9	7690	2349	4142	1024	175	2330	.	175	.	.	.
27 SEVELUWE	Southeast Veluwe	De Bilt	9	18656	5539	10581	2247	289	2960	.	175	.	.	.
28 SWVELUWE	Southwest Veluwe	De Bilt	8	93517	34386	49064	8256	1811	15235	1.0	175	.	.	.
29 NWVELUWE	Northwest Veluwe	De Bilt	7	58206	19350	33583	4152	1121	12175	.	175	.	.	.
30 FLEVLAND	Flevoland	Lelystad	.	97806	54562	38325	2255	2664	38610	4.0	600	.	.	.
Total for region				354384	147049	176676	23197	7462						

Table 6.2 (continued)

PAWN Region 4: North Holland

DISTRICT	DESCRIPTION	WEATHER	DRA	-----------AREAS (ha)-----------					WATER	FLUSH	INIT	--INDUSTRIAL--		
		STATION	REG	TOTAL	CROPS	NATURE	URBAN	WATER	VOL	MIN	SALT	EXT	DIS	SALT
31 WIERGMER	Wieringermeer Polder	Hoorn NH	.	19938	15406	3476	263	793	9725	2.2	2000	.	.	.
32 AMSTLMER	Amstelmeer	Hoorn NH	.	25057	18427	3108	1412	2110	28850	0.6	175	.	.	.
33 MEDMBLIK	Area of W.Friesland around Medemblik	Hoorn NH	.	23916	17653	2854	1834	1575	18862	0.3	175	.	.	.
34 HOORN	Area of W.Friesland around Hoorn	Hoorn NH	.	9032	5723	1746	1048	515	5672	0.4	175	.	.	.
35 SCHERMER	Schermerboezem	Hoorn NH	.	75265	46742	16494	7227	4802	41472	1.9	175	.	.	.
36 WATRLAND	Waterland	Hoorn NH	.	7526	4849	1405	320	952	13948	0.4	175	.	.	.
37 NZKANGEB	Area around Noordzeekanaal	Hoorn NH	.	24643	7100	7917	7039	2587	37115	0.3	175	.	.	.
Total for region				185377	115900	37000	19143	13334						

PAWN Region 5: Midwest and Utrecht

DISTRICT	DESCRIPTION	WEATHER	DRA	-----------AREAS (ha)-----------					WATER	FLUSH	INIT	--INDUSTRIAL--		
		STATION	REG	TOTAL	CROPS	NATURE	URBAN	WATER	VOL	MIN	SALT	EXT	DIS	SALT
38 RIJNLAND	Rijnland	Naaldwyk	.	95287	49251	24434	15082	6520	60000	2.8	175	.	.	.
39 AMSTLAND	Amstelland	Naaldwyk	.	24689	14173	5034	3000	2482	26368	1.0	175	.	.	.
40 GOOI	Gooi	De Bilt	.	25977	11260	9080	4179	1458	43805	.	175	.	.	.
41 KROMRIJN	Area around Kromme Rijn	De Bilt	8	38683	16948	15272	5622	841	4618	.	175	.	.	.
42 LEIDRIJN	Area around Leidsche Rijn	Naaldwyk	.	11546	5944	3763	1278	561	5490	.	175	.	.	.
43 WOERDEN	Woerden	Naaldwyk	.	18505	11264	4520	1701	1020	8497	0.5	175	.	.	.
44 LOPIKWAR	Lopikerwaard	Naaldwyk	.	15931	9444	4650	1088	749	5117	.	175	.	.	.
45 KRIMPWAR	Krimpenerwaard	Naaldwyk	.	15012	9012	2520	2091	1389	16440	.	175	.	.	.
46 SCIELAND	Schieland	Naaldwyk	.	16400	9463	3656	2263	1018	11975	1.0	175	.	.	.
47 DELFLAND	Delfland	Naaldwyk	.	27502	16850	3741	5910	1001	6138	0.7	175	.	.	.
Total for region				289532	153609	76670	42214	17039						

PAWN Region 6: Large Rivers & Northern Delta

DISTRICT	DESCRIPTION	WEATHER	DRA	-----------AREAS (ha)-----------					WATER	FLUSH	INIT	--INDUSTRIAL--		
		STATION	REG	TOTAL	CROPS	NATURE	URBAN	WATER	VOL	MIN	SALT	EXT	DIS	SALT
48 VOORNE	Voorne-Putten, part of Hoeksche Waard	Naaldwyk	.	30740	19566	7093	1617	2464	32577	2.0	175	.	.	.
49 GOEREE	Northern part of Goeree-Overflakkee	Vliss	.	10493	6221	3253	399	620	6805	0.4	175	.	.	.
50 IJSLMOND	Ijsselmond	Naaldwyk	.	17633	11985	3208	1511	929	10487	1.0	175	.	.	.
52 DORDRECT	Area around Dordrecht	Andel	.	12355	6537	2584	2621	613	7685	0.8	175	.	.	.
53 ABLASWAR	Alblasserwaard	Andel	.	29261	19873	5168	2600	1620	16650	0.6	175	.	.	.
55 TIELWARD	Tielerwaard	Andel	10	49219	33870	10406	2842	2101	20787	.	175	.	.	.
57 BETUWE	Betuwe	Andel	10	35644	22570	9053	2852	1169	12670	.	175	.	.	.
59 RECMAASN	Area on Right Bank of Maas--North	Andel	16	10103	5900	2320	1438	445	6530	.	175	.	.	.
Total for region				195448	126522	43085	15880	9961						

Table 6.2 (continued)

PAWN Region 7: West Brabant & Southern Delta

DISTRICT	DESCRIPTION	WEATHER STATION	DRA REG	----------AREAS (ha)---------- TOTAL	CROPS	NATURE	URBAN	WATER	WATER VOL	FLUSH MIN	INIT SALT	--INDUSTRIAL-- EXT	DIS	SALT
51 HOLNDIEP	Area around Hollandsch Diep	Oudenbos	.	41154	29041	8311	2078	1724	19900	0.4	175	.	.	.
54 BIESBOSH	Biesbosch	Oudenbos	11	30436	22680	3614	2446	1696	17720	.	175	.	.	.
74 MARK	Area around the Mark	Oudenbos	11	52774	31349	15824	4738	863	8590	.	175	.	.	.
75 ROSENDAL	Steenbergse and Roosendaalse Vliet	Oudenbos	11	30838	21371	5768	2666	1033	11390	.	175	.	.	.
76 ZOOM	Area around the Zoommeer	Vliss	11	65962	45075	16357	2416	2114	27470	2.0	175	.	.	.
77 SCHOUWEN	Schouwen	Vliss	.	25911	18610	5158	971	1172	14500	5.0	175	.	.	.
Total for region				247075	168126	55032	15315	8602						

PAWN Region 8: Southeast Highlands

DISTRICT	DESCRIPTION	WEATHER STATION	DRA REG	----------AREAS (ha)---------- TOTAL	CROPS	NATURE	URBAN	WATER	WATER VOL	FLUSH MIN	INIT SALT	--INDUSTRIAL-- EXT	DIS	SALT
56 DENBOSCH	Area southwest of 's-Hertogenbosch	Gemert	12	43658	27282	10084	4066	2226	25155	.	175	.	.	.
58 MAASWAAL	Area between Maas and Waal	Andel	10	22773	15171	4139	2318	1145	16000	.	175	.	.	.
60 RECMAASM	Area on Right Bank of Maas--Middle	Venlo	16	11861	5830	4420	1323	288	3975	.	175	.	.	.
61 MASKANTE	Maaskant East	Gemert	13	42777	26934	12635	2398	810	9810	.	175	.	.	.
62 MASKANTW	Maaskant West	Gemert	13	25350	14756	7387	2597	610	8390	1.0	175	.	.	.
63 AA	Area around the Aa	Gemert	13	88811	45662	35010	6602	1537	1740	1.5	175	.	0.3	.
64 DEPEEL	dePeel	Venlo	15	48494	27000	17853	2993	648	5700	0.2	175	.	.	.
65 RECMAASS	Area on Right Bank of Maas--South	Venlo	16	26087	11986	10876	2727	498	6045	.	175	.	.	.
66 ROERMOND	Area around Roermond	Beek ZL	16	17919	9347	6809	1190	573	8760	.	175	.	.	.
67 SLIMBURG	South Limburg	Beek ZL	17	71345	36548	21619	11796	1382	16945	.	175	.	.	.
68 MLIMBURG	Middle Limburg	Venlo	15	40516	22035	15018	2329	1134	16620	.	175	.	0.2	.
69 EDOMMEL	Dommel--East	Gemert	14	31073	16338	11374	2628	733	9980	.	175	.	.	.
70 MDOMMEL	Dommel--Middle	Gemert	14	33812	17767	10374	5001	670	8245	.	175	.	0.1	.
71 WDOMMEL	Dommel--West	Gemert	14	36967	19061	14770	2482	654	7515	.	175	.	0.2	.
72 NDOMMEL	Dommel--North	Gemert	12	34356	17401	13355	2864	736	9590	.	175	.	0.4	.
73 DONGE	Area around the Donge	Oudenbos	12	30786	14967	11576	3780	463	4625	.	175	.	0.3	.
Total for region				606585	328085	207299	57094	14107						

PAWN Region 9: Markerwaard (Proposed)

DISTRICT	DESCRIPTION	WEATHER STATION	DRA REG	----------AREAS (ha)---------- TOTAL	CROPS	NATURE	URBAN	WATER	WATER VOL	FLUSH MIN	INIT SALT	--INDUSTRIAL-- EXT	DIS	SALT
78 MARKWARD	Markerwaard	Lelystad	.	50000	28500	19000	1150	1350	19203	2.0	175	.	.	.
Total for region				50000	28500	19000	1150	1350						

through 77 and given a name that in most cases relates to their geographic location. Twenty-one different weather stations have been considered, and each district has been associated with one of these stations, as will be described in Sec. 6.5. Similarly, each district containing any part of the highlands has been assigned to one of 17 drainage regions, as will be explained in Sec. 6.4.

We will describe how the various areas and the volume of water were determined in Sec. 6.1.4. The flushing minimum reflects the minimum desired discharge for quality control in the districts. With a few exceptions only the districts with saline seepage are flushed. The desired flushing rates for a number of districts were derived from an inquiry by the Union of Waterboards [6.1]. For the districts with saline seepage for which no flushing rate was given, a flushing rate was estimated based on the total salt load.

The initial salt concentration of each district was arbitrarily set to 175 mg/l, except for a few districts with very high salt concentrations. For these districts, a higher initial concentration was specified based on observations. The industrial extraction or discharge reflects a constant flow out of or into the district waters because of actions of users other than agriculture. These extractions and discharges are set equal to zero in most places; in some highlands districts the industrial discharge entry was used to account for water flows into the district because of losses from adjacent highlands canals.

In the district files reflecting future scenarios, the industrial extraction or discharge entry is used to reflect changes in discharges to the surface water because of changes in groundwater withdrawals by industry or drinking water companies. (Except for some small losses, the groundwater withdrawn for these purposes eventually ends up in the surface water system.) The last data element, the salt concentration of the industrial discharge, allows for the specification of the salt flow into the surface water system because of users other than agriculture. It is used only in connection with the incremental discharges in future scenarios.

The Subdistrict Files. SUBDFIL and SUB2FIL contain 19 data elements. A listing of these data for the situation treated by PAWN is given in Table 6.3. The subdistricts were numbered from 1 through 143, and the district index associated with each subdistrict indicates the district to which the subdistrict belongs. The index of the agricultural regions indicates which of the 14 agricultural regions contains the subdistrict, as described in Sec. 6.1.5. Associated with each subdistrict is a root zone soil type and a subsoil type. Soil types were selected from a list of 20 standard soils as described in Sec. 6.2.1. The highlands/lowlands code indicates the landform of the district; the value 0 indicates a lowlands subdistrict, the value 1 indicates a low highlands subdistrict, and a value 2 indicates a high highlands subdistrict.

The fraction of the subdistrict is the area of the subdistrict divided by the area of the district containing the subdistrict; this number is not actually used by DISTAG.

Table 6.3

SUBDISTRICT DATA

PAWN Region 1: North

DISTRICT	SUBD	LANDFORM	ROOTZONE SOILTYPE	SUBSOIL TYPE	AGRICULTURE REGION	--AREAS (ha)- CROP	NATURE	PCT DST	INFIL COEF	DRAIN COEF	INIT GWL	DTCH LEVL	SEEP AMP	SEEP CONC	SUPP FRAC	INFL RATE	OW SEEP
1 FRIELAND	1	Lowland	LoMeCoS*	LoMeCoSa	North Sand	65408	14007	30	0.0025	0.00375	500	1000	0.09	3860	0.50	0.90	.
	2	Lowland	BasnCla*	BasinCla	NorthPasture	55000	11673	25	0.0001	0.00015	700	1250	0.06	500	1.00	0.90	.
	3	Lowland	LiteCla*	(HuLMCS)	NorthSeaClay	32481	7003	15	0.0017	0.00255	900	1250	0.13	3450	1.00	0.90	.
	4	Lowland	Peat	Peat	NorthPasture	28000	6069	13	0.0025	0.00375	500	1000	0.14	300	1.00	0.90	.
	5	Lowland	BasnCla*	Peat	NorthPasture	26000	5603	12	0.0025	0.00375	500	1000	0.14	420	1.00	0.90	.
	6	Hi High	LoMeCoS*	LoMeCoSa	North Sand	11000	2335	5	.	.	1800	.	.	.	.	0.90	.
2 HETBILDT	7	Lowland	Loam	(LiLMCS)	NorthSeaClay	10948	3928	100	0.0025	0.00375	900	1250	0.11	6000	1.00	0.90	.
3 LAUWMEER	8	Lowland	LiteCla*	(HuLMCS)	NorthSeaClay	48578	18896	100	0.0017	0.00255	900	1250	0.29	9300	0.60	0.90	.
4 UITHUIZN	9	Lowland	Loam	(LiLMCS)	NorthSeaClay	8240	3602	100	0.0025	0.00375	900	1250	0.08	13400	.	0.90	.
5 EEMSKANN	10	Lowland	LiteCla*	(HuLMCS)	NorthSeaClay	16678	2420	59	0.0017	0.00255	900	1250	0.37	3000	0.91	0.90	.
	11	Lowland	HuLoMCS*	LoMeCoSa	Peat	12249	1037	41	0.0005	0.00075	800	1000	0.08	1600	0.87	0.90	.
6 OLDAMBT	12	Lowland	SandCla*	SandClay	NorthSeaClay	23380	4032	76	0.0006	0.00090	900	1250	0.12	2000	0.20	0.90	.
	13	Lowland	HuLoMCS*	LoMeCoSa	NorthSeaClay	7505	1008	24	0.0005	0.00075	800	1000	.	.	.	0.90	.
7 WESTWOLD	14	Lowland	HuLoMCS*	LoMeCoSa	Peat	43629	4082	100	0.0005	0.00075	800	1000	.	.	0.52	0.90	.
8 NWDRENTE	15	Lowland	LoMeCoS*	LoMeCoSa	North Sand	19658	9264	55	0.0025	0.00375	800	1000	.	.	0.10	0.90	.
	16	Hi High	LoMeCoS*	LoMeCoSa	North Sand	16188	7580	45	.	.	1700	.	.	.	.	0.90	.
9 WESKWART	17	Lowland	LoMeCoS*	LoMeCoSa	North Sand	22188	13297	75	0.0025	0.00375	800	1000	.	.	0.70	0.90	.
	18	Hi High	LoMeCoS*	LoMeCoSa	North Sand	7391	4433	25	.	.	1800	.	.	.	0.30	0.90	.
13 VOLENHOV	24	Lowland	Peat	Peat	NorthPasture	20646	11523	69	0.0025	0.00375	400	750	.	.	0.90	0.90	.
	25	Lowland	LoMeCoS*	LoMeCoSa	North Sand	4503	2469	15	0.0025	0.00375	800	1000	.	.	0.50	0.90	.
	26	Hi High	LoMeCoS*	LoMeCoSa	North Sand	5133	2469	16	.	.	1800	.	.	.	0.30	0.90	.
14 NEPOLDER	27	Lowland	SaClLoam	(HuLMCS)	H-IJ Polder	39332	5862	100	0.0025	0.00375	900	1250	1.10	900	0.17	0.90	0.70
15 MASTBROK	28	Lowland	LoMeCoS*	LoMeCoSa	NorthPasture	12940	2715	40	0.0025	0.00375	800	1000	.	.	0.30	0.90	.
	29	Lowland	LiteCla*	(HuLMCS)	NorthPasture	13000	2715	40	0.0017	0.00255	600	1250	.	.	1.00	0.90	.
	30	Lowland	Peat	Peat	NorthPasture	6513	1357	20	0.0025	0.00375	400	750	.	.	1.00	0.90	.
Total for region						556588	149379										

Table 6.3 (continued)

PAWN Region 2: Northeast Highlands

DISTRICT	SUBD	LANDFORM	ROOTZONE SOILTYPE	SUBSOIL TYPE	AGRICULTURE REGION	--AREAS (ha)- CROP	NATURE	PCT DST	INFIL COEF	DRAIN COEF	INIT GWL	DTCH LEVL	SEEP AMP	SEEP CONC	SUPP FRAC	INFL RATE	OW SEEP
10 NEDRENTE	19	Lowland	HuLoMCS*	LoMeCoSa	Peat	21214	4988	100	0.0005	0.00075	800	1000	.	.	0.42	0.90	.
11 SEDRENTE	20	Lo High	LoMeCoS*	LoMeCoSa	Peat	13022	3751	40	.	.	800	.	.	.	1.00	0.90	.
	21	Hi High	LoMeCoS*	LoMeCoSa	North Sand	19406	5626	60	.	.	1900	.	.	.	0.20	0.90	.
12 SWDRENTE	22	Lowland	LoMeCoS*	LoMeCoSa	North Sand	26086	8184	40	0.0025	0.00375	800	1000	.	.	0.50	0.90	.
	23	Hi High	LoMeCoS*	LoMeCoSa	North Sand	38953	12275	60	.	.	1900	.	.	.	0.20	0.90	.
16 OVIJVECT	31	Lo High	LoMeCoS*	LoMeCoSa	North Sand	7154	2826	25	.	.	800	.	.	.	0.80	0.90	.
	32	Hi High	LoMeCoS*	LoMeCoSa	North Sand	21443	8477	75	.	.	2300	.	.	.	0.25	0.90	.
17 DINKEL	33	Lo High	LoMeCoS*	LoMeCoSa	East Sand	3500	2232	25	.	.	800	.	.	.	.	0.90	.
	34	Hi High	LoMeCoS*	LoMeCoSa	East Sand	10308	6694	75	.	.	2100	.	.	.	.	0.90	.
18 TWENTHE	35	Lo High	LoMeCoS*	LoMeCoSa	East Sand	16230	9930	35	.	.	800	.	.	.	0.01	0.90	.
	36	Hi High	LoMeCoS*	LoMeCoSa	East Sand	30593	18442	65	.	.	2100	.	.	.	.	0.90	.
19 SALLAND	37	Lowland	LoMeCoS*	LoMeCoSa	River Clay	21670	6544	65	0.0025	0.00375	800	1000	.	.	0.85	0.90	.
	38	Hi High	LoMeCoS*	LoMeCoSa	East Sand	11579	3523	35	.	.	2100	.	.	.	.	0.90	.
20 TWENTKAN	39	Lowland	LiLoMCS*	(LiLMCS)	East Sand	20206	18822	70	0.0011	0.00165	800	1250	.	.	0.02	0.90	.
	40	Lo High	LoMeCoS*	LoMeCoSa	East Sand	2864	2689	10	.	.	800	.	.	.	.	0.90	.
	41	Hi High	LoMeCoS*	LoMeCoSa	East Sand	5720	5378	20	.	.	2100	.	.	.	.	0.90	.
21 SHIPBEEK	42	Lowland	LiLoMCS*	(LiLMCS)	East Sand	14099	11323	100	0.0011	0.00165	800	1250	.	.	0.40	0.90	.
24 BERKEL	47	Lo High	LoMeCoS*	LoMeCoSa	East Sand	13224	4084	25	.	.	800	.	.	.	.	0.90	.
	48	Hi High	LoMeCoS*	LoMeCoSa	East Sand	40200	12254	75	.	.	1700	.	.	.	.	0.90	.
25 OUDEIJSL	49	Lowland	LiteCla*	(HuLMCS)	River Clay	16842	5782	35	0.0017	0.00255	800	1250	.	.	.	0.90	.
	50	Hi High	LoMeCoS*	LoMeCoSa	East Sand	30948	10739	65	.	.	1700	.	.	.	.	0.90	.
Total for region						385261	164563										

PAWN Region 3: Flevoland & Veluwe

DISTRICT	SUBD	LANDFORM	ROOTZONE SOILTYPE	SUBSOIL TYPE	AGRICULTURE REGION	--AREAS (ha)- CROP	NATURE	PCT DST	INFIL COEF	DRAIN COEF	INIT GWL	DTCH LEVL	SEEP AMP	SEEP CONC	SUPP FRAC	INFL RATE	OW SEEP
22 IJSELGEB	43	Lowland	LiteCla*	(HuLMCS)	River Clay	11076	12432	100	0.0014	0.00210	600	1250	.	.	0.29	0.90	.
23 NEVELUWE	44	Lowland	LiteCla*	(HuLMCS)	River Clay	6865	7137	29	0.0017	0.00255	600	1250	.	.	0.09	0.90	.
	45	Lo High	LoMeCoS*	LoMeCoSa	Central Sand	4257	7137	24	.	.	800	.	.	.	0.45	0.90	.
	46	Hi High	LoMeCoS*	LoMeCoSa	Central Sand	8665	14275	47	.	.	6700	.	.	.	.	0.90	.
26 ARNHEM	51	Lowland	LiteCla*	(HuLMCS)	Central Sand	2349	4142	100	0.0017	0.00255	800	1250	.	.	.	0.90	.
27 SEVELUWE	52	Lo High	LoMeCoS*	LoMeCoSa	Central Sand	1700	3174	30	.	.	800	.	.	.	.	0.90	.
	53	Hi High	LoMeCoS*	LoMeCoSa	Central Sand	3839	7407	70	.	.	6700	.	.	.	.	0.90	.
28 SWVELUWE	54	Lo High	LoMeCoS*	LoMeCoSa	Central Sand	20579	29439	60	.	.	800	.	.	.	0.30	0.90	.
	55	Hi High	LoMeCoS*	LoMeCoSa	Central Sand	13807	19625	40	.	.	3900	.	.	.	.	0.90	.
29 NWVELUWE	56	Lo High	LoMeCoS*	LoMeCoSa	Central Sand	13623	23508	70	.	.	800	.	.	.	0.50	0.90	.
	57	Hi High	LoMeCoS*	LoMeCoSa	Central Sand	5727	10075	30	.	.	1400	.	.	.	.	0.90	.
30 FLEVLAND	58	Lowland	SaClLoam	(HuLMCS)	H-IJ Polder	54562	38325	100	0.0025	0.00375	900	1250	1.20	845	0.75	0.90	0.70
Total for region						147049	176676										

Table 6.3 (continued)

PAWN Region 4: North Holland

DISTRICT	SUBD	LANDFORM	ROOTZONE SOILTYPE	SUBSOIL TYPE	AGRICULTURE REGION	--AREAS (ha)- CROP	NATURE	PCT DST	INFIL COEF	DRAIN COEF	INIT GWL	DTCH LEVL	SEEP AMP	SEEP CONC	SUPP FRAC	INFL RATE	OW SEEP
31 WIERGMER	59	Lowland	LiteCla*	(HuLMCS)	H-IJ Polder	15406	3476	100	0.0017	0.00255	900	1250	1.34	3800	0.10	0.90	0.80
32 AMSTLMER	60	Lowland	LiteCla*	(HuLMCS)	H-IJ Polder	18427	3108	100	0.0017	0.00255	700	1000	0.20	1700	1.00	0.90	.
33 MEDMBLIK	61	Lowland	LiteCla*	(HuLMCS)	Rest of NH	17653	2854	100	0.0017	0.00255	700	1000	0.11	1560	1.00	0.90	.
34 HOORN	62	Lowland	LiteCla*	(HuLMCS)	Rest of NH	5723	1746	100	0.0017	0.00255	700	1000	0.11	1560	1.00	0.90	.
35 SCHERMER	63	Lowland	Peat	Peat	West Pasture	14009	4948	30	0.0025	0.00375	500	750	0.03	2470	1.00	0.90	.
	64	Lowland	Peat	Peat	West Pasture	14009	4948	30	0.0025	0.00375	500	750	-0.25	.	1.00	0.90	.
	65	Lowland	BasnCla*	BasinCla	West Pasture	9339	3299	20	0.0001	0.00015	500	1000	0.68	1700	1.00	0.90	.
	66	Lowland	LiLoMCS*	(HuLMCS)	West Pasture	9385	3299	20	0.0011	0.00165	700	1000	0.04	6120	1.00	0.90	.
36 WATRLAND	67	Lowland	Peat	Peat	West Pasture	4849	1405	100	0.0025	0.00375	400	600	0.30	2000	1.00	0.90	.
37 NZKANGEB	68	Lowland	SandCla*	(HuLMCS)	H-IJ Polder	4600	5146	65	0.0006	0.00090	900	1250	0.25	2360	0.50	0.90	.
	69	Lowland	Peat	Peat	West Pasture	2500	2771	35	0.0025	0.00375	500	750	.	.	0.50	0.90	.
Total for region						115900	37000										

PAWN Region 5: Midwest and Utrecht

DISTRICT	SUBD	LANDFORM	ROOTZONE SOILTYPE	SUBSOIL TYPE	AGRICULTURE REGION	--AREAS (ha)- CROP	NATURE	PCT DST	INFIL COEF	DRAIN COEF	INIT GWL	DTCH LEVL	SEEP AMP	SEEP CONC	SUPP FRAC	INFL RATE	OW SEEP
38 RIJNLAND	70	Lowland	SandCla*	(HuLMCS)	H-IJ Polder	24687	12217	50	0.0006	0.00090	900	1250	0.34	1370	1.00	0.90	.
	71	Lowland	Peat	Peat	West Pasture	18956	9773	39	0.0025	0.00375	400	600	0.10	880	1.00	0.90	.
	72	Lowland	LoMeCoS*	LoMeCoS*	Rest of SH	3108	1222	6	0.1000	0.15000	400	500	.	.	1.00	0.90	.
	73	Lowland	BasnCla*	Peat	West Pasture	2500	1222	5	0.0025	0.00375	400	600	1.08	200	1.00	0.90	.
39 AMSTLAND	74	Lowland	Peat	Peat	West Pasture	9194	3272	65	0.0025	0.00375	400	600	.	.	1.00	0.90	.
	75	Lowland	BasnCla*	Peat	West Pasture	4979	1762	35	0.0025	0.00375	400	600	2.14	1000	1.00	0.90	.
40 GOOI	76	Lowland	Peat	Peat	West Pasture	11260	9080	100	0.0025	0.00375	400	600	-0.25	.	1.00	0.90	.
41 KROMRIJN	77	Hi High	LoMeCoS*	LoMeCoSa	Central Sand	8410	9164	55	.	.	3900	.	.	.	0.20	0.90	.
	78	Lowland	LiteCla*	(HuLMCS)	River Clay	8538	6108	45	0.0017	0.00255	800	1250	.	.	1.00	0.90	.
42 LEIDRIJN	79	Lowland	BasnCla*	(SanCla)	West Pasture	5944	3763	100	0.0001	0.00015	500	1250	.	.	1.00	0.90	.
43 WOERDEN	80	Lowland	Peat	Peat	West Pasture	11264	4520	100	0.0025	0.00375	400	600	-0.25	.	1.00	0.90	.
44 LOPIKWAR	81	Lowland	BasnCla*	(SanCla)	West Pasture	3798	1860	40	0.0001	0.00015	500	1250	.	.	1.00	0.90	.
	82	Lowland	BasnCla*	Peat	West Pasture	2850	1395	30	0.0025	0.00375	400	600	.	.	1.00	0.90	.
	83	Lowland	LiteCla*	(HuLMCS)	West Pasture	2796	1395	30	0.0017	0.00255	800	1250	.	.	1.00	0.90	.
45 KRIMPWAR	84	Lowland	Peat	Peat	West Pasture	7275	2016	81	0.0025	0.00375	400	600	-0.25	.	1.00	0.90	.
	85	Lowland	Loam	(LiLMCS)	SW Sea Clay	1737	504	19	0.0025	0.00375	600	1000	.	.	1.00	0.90	.
46 SCIELAND	86	Lowland	Peat	Peat	West Pasture	4618	1828	49	0.0025	0.00375	400	600	0.57	800	1.00	0.90	.
	87	Lowland	SandCla*	(BasCla)	H-IJ Polder	4845	1828	51	0.0006	0.00090	700	1000	0.23	800	1.00	0.90	.
47 DELFLAND	88	Lowland	BasnCla*	Peat	West Pasture	11430	2431	67	0.0025	0.00375	400	600	0.08	1850	1.00	0.90	.
	89	Lowland	LiLoMCS*	(LiLMCS)	Rest of SH	4301	936	25	0.0011	0.00165	500	750	.	.	1.00	0.90	.
	90	Lowland	SandCla*	(BasCla)	West Pasture	1119	374	7	0.0006	0.00090	700	1000	0.31	450	1.00	0.90	.
Total for region						153609	76670										

Table 6.3 (continued)

PAWN Region 6: Large Rivers & Northern Delta

DISTRICT	SUBD	LANDFORM	ROOTZONE SOILTYPE	SUBSOIL TYPE	AGRICULTURE REGION	--AREAS (ha)-		PCT DST	INFIL COEF	DRAIN COEF	INIT GWL	DTCH LEVL	SEEP AMP	SEEP CONC	SUPP FRAC	INFL RATE	OW SEEP
						CROP	NATURE										
48 VOORNE	91	Lowland	Loam	(LiLMCS)	SW Sea Clay	19566	7093	100	0.0025	0.00375	600	1000	0.40	5500	1.00	0.90	.
49 GOEREE	92	Lowland	Loam	(LiLMCS)	SW Sea Clay	6221	3253	100	0.0025	0.00375	600	1000	0.50	1300	1.00	0.90	.
50 IJSLMOND	93	Lowland	Loam	(LiLMCS)	SW Sea Clay	11985	3208	100	0.0025	0.00375	600	1000	0.20	700	1.00	0.90	.
52 DORDRECT	95	Lowland	Loam	(LiLMCS)	SW Sea Clay	6537	2584	100	0.0025	0.00375	600	1000	0.60	1000	1.00	0.90	.
53 ABLASWAR	96	Lowland	BasnCla*	Peat	West Pasture	10896	2842	55	0.0025	0.00375	400	600	0.30	1000	1.00	0.90	.
	97	Lowland	BasnCla*	(SanCla)	West Pasture	4993	1292	25	0.0001	0.00015	500	1250	0.30	1000	1.00	0.90	.
	98	Lowland	Peat	Peat	West Pasture	3984	1034	20	0.0025	0.00375	400	600	0.30	1000	1.00	0.90	.
55 TIELWARD	102	Lowland	LiteCla*	(HuLMCS)	River Clay	17064	5203	50	0.0017	0.00255	800	1250	.	.	1.00	0.90	.
	103	Lowland	BasnCla*	(SanCla)	River Clay	16806	5203	50	0.0001	0.00015	500	1250	.	.	1.00	0.90	.
57 BETUWE	107	Lowland	LiteCla*	(HuLMCS)	River Clay	22570	9053	100	0.0017	0.00255	800	1250	.	.	1.00	0.90	.
59 RECMAASN	109	Lowland	LiteCla*	(HuLMCS)	River Clay	1772	696	30	0.0017	0.00255	800	1250	.	.	.	0.90	.
	110	Hi High	LoMeCoS*	LoMeCoSa	South Sand	4128	1624	70	.	.	3500	.	.	.	.	0.90	.
Total for region						126522	43085										

PAWN Region 7: West Brabant & Southern Delta

DISTRICT	SUBD	LANDFORM	ROOTZONE SOILTYPE	SUBSOIL TYPE	AGRICULTURE REGION	--AREAS (ha)-		PCT DST	INFIL COEF	DRAIN COEF	INIT GWL	DTCH LEVL	SEEP AMP	SEEP CONC	SUPP FRAC	INFL RATE	OW SEEP
						CROP	NATURE										
51 HOLNDIEP	94	Lowland	Loam	(LiLMCS)	SW Sea Clay	29041	8311	100	0.0025	0.00375	600	1000	0.20	700	1.00	0.90	.
54 BIESBOSH	99	Lowland	Loam	(LiLMCS)	SW Sea Clay	9067	1446	40	0.0025	0.00375	600	1000	.	.	1.00	0.90	.
	100	Lowland	LoMeCoS*	LoMeCoSa	River Clay	6779	1084	30	0.0025	0.00375	900	1250	.	.	0.60	0.90	.
	101	Lowland	LiteCla*	(HuLMCS)	River Clay	6834	1084	30	0.0017	0.00255	800	1250	.	.	1.00	0.90	.
74 MARK	137	Lo High	LoMeCoS*	LoMeCoSa	South Sand	4700	2374	15	.	.	900	.	.	.	.	0.90	.
	138	Hi High	LoMeCoS*	LoMeCoSa	South Sand	26649	13450	85	.	.	2300	.	.	.	.	0.90	.
75 ROSENDAL	139	Lowland	Loam	(LiLMCS)	SW Sea Clay	9321	2019	42	0.0025	0.00375	600	1000	.	.	0.10	0.90	.
	140	Hi High	LoMeCoS*	LoMeCoSa	South Sand	12050	3749	58	.	.	2300	.	.	.	.	0.90	.
76 ZOOM	141	Lowland	Loam	(LiLMCS)	SW Sea Clay	42049	15315	93	0.0025	0.00375	600	1000	0.30	1700	0.02	0.90	.
	142	Lowland	LoMeCoS*	LoMeCoSa	South Sand	3026	1042	7	0.0025	0.00375	900	1000	.	.	.	0.90	.
77 SCHOUWEN	143	Lowland	Loam	(LiLMCS)	SW Sea Clay	18610	5158	100	0.0025	0.00375	600	1000	0.70	10000	.	0.90	.
Total for region						168126	55032										

Table 6.3 (continued)

PAWN Region 8: Southeast Highlands

DISTRICT	SUBD	LANDFORM	ROOTZONE	SUBSOIL	AGRICULTURE	--AREAS	(ha)-	PCT	INFIL	DRAIN	INIT	DTCH	SEEP	SEEP	SUPP	INFL	OW
			SOILTYPE	TYPE	REGION	CROP	NATURE	DST	COEF	COEF	GWL	LEVL	AMP	CONC	FRAC	RATE	SEEP
56 DENBOSCH	104	Lowland	LiteCla*	(HuLMCS)	River Clay	13667	5043	50	0.0017	0.00255	800	1250	.	.	1.00	0.90	.
	105	Lowland	LoMeCoS*	LoMeCoSa	South Sand	4085	1512	15	0.0025	0.00375	900	1250	.	.	1.00	0.90	.
	106	Hi High	LoMeCoS*	LoMeCoSa	South Sand	9530	3529	35	.	.	1700	.	.	.	0.05	0.90	.
58 MAASWAAL	108	Lowland	LiteCla*	(HuLMCS)	River Clay	15171	4139	100	0.0017	0.00255	800	1250	.	.	1.00	0.90	.
60 RECMAASM	111	Hi High	LoMeCoS*	LoMeCoSa	South Sand	5830	4420	100	.	.	3500	.	.	.	.	0.90	.
61 MASKANTE	112	Lo High	LoMeCoS*	LoMeCoSa	South Sand	5291	2527	20	.	.	900	.	.	.	.	0.90	.
	113	Hi High	LoMeCoS*	LoMeCoSa	South Sand	21643	10108	80	.	.	1800	.	.	.	.	0.90	.
62 MASKANTW	114	Lowland	LiteCla*	(HuLMCS)	West Pasture	7490	3694	51	0.0017	0.00255	800	1250	.	.	1.00	0.90	.
	115	Lo High	LoMeCoS*	LoMeCoSa	South Sand	2950	1477	20	.	.	900	.	.	.	0.50	0.90	.
	116	Hi High	LoMeCoS*	LoMeCoSa	South Sand	4316	2216	29	.	.	1800	.	.	.	.	0.90	.
63 AA	117	Lo High	LoMeCoS*	LoMeCoSa	South Sand	11481	8753	25	.	.	900	.	.	.	0.80	0.90	.
	118	Hi High	LoMeCoS*	LoMeCoSa	South Sand	34181	26257	75	.	.	1800	.	.	.	0.20	0.90	.
64 DEPEEL	119	Lo High	LoMeCoS*	LoMeCoSa	South Sand	4032	2678	15	.	.	900	.	.	.	0.70	0.90	.
	120	Hi High	LoMeCoS*	LoMeCoSa	South Sand	22968	15175	85	.	.	2700	.	.	.	.	0.90	.
65 RECMAASS	121	Lo High	LoMeCoS*	LoMeCoSa	South Sand	3000	2719	25	.	.	900	.	.	.	0.30	.	.
	122	Hi High	LoMeCoS*	LoMeCoSa	South Sand	8986	8157	75	.	.	3500	.	.	.	.	0.90	.
66 ROERMOND	123	Lo High	LoMeCoS*	LoMeCoSa	South Sand	941	681	10	.	.	900	.	.	.	.	0.90	.
	124	Hi High	LoMeCoS*	LoMeCoSa	South Sand	8406	6128	90	.	.	3500	.	.	.	.	0.90	.
67 SLIMBURG	125	Hi High	Loam	Loam	Loess	36548	21619	100	.	.	8500	.	.	.	0.02	.	.
68 MLIMBURG	126	Lo High	LoMeCoS*	LoMeCoSa	South Sand	4380	3003	20	.	.	900	.	.	.	0.30	0.90	.
	127	Hi High	LoMeCoS*	LoMeCoSa	South Sand	17655	12015	80	.	.	2700	.	.	.	0.10	0.90	.
69 EDOMMEL	128	Lo High	LoMeCoS*	LoMeCoSa	South Sand	4105	2844	25	.	.	900	.	.	.	0.50	0.90	.
	129	Hi High	LoMeCoS*	LoMeCoSa	South Sand	12233	8530	75	.	.	1400	.	.	.	0.10	0.90	.
70 MDOMMEL	130	Lo High	LoMeCoS*	LoMeCoSa	South Sand	3537	2074	20	.	.	900	.	.	.	.	0.90	.
	131	Hi High	LoMeCoS*	LoMeCoSa	South Sand	14230	8300	80	.	.	1400	.	.	.	.	0.90	.
71 WDOMMEL	132	Hi High	LoMeCoS*	LoMeCoSa	South Sand	19061	14770	100	.	.	1400	.	.	.	.	0.90	.
72 NDOMMEL	133	Lo High	LoMeCoS*	LoMeCoSa	South Sand	2592	2003	15	.	.	900	.	.	.	.	0.90	.
	134	Hi High	LoMeCoS*	LoMeCoSa	South Sand	14809	11352	85	.	.	1700	.	.	.	.	0.90	.
73 DONGE	135	Lo High	LoMeCoS*	LoMeCoSa	South Sand	3760	2894	25	.	.	900	.	.	.	.	0.90	.
	136	Hi High	LoMeCoS*	LoMeCoSa	South Sand	11207	8682	75	.	.	1700	.	.	.	.	0.90	.
Total for region						328085	207299										

PAWN Region 9: Markerwaard (Proposed)

DISTRICT	SUBD	LANDFORM	ROOTZONE	SUBSOIL	AGRICULTURE	--AREAS	(ha)-	PCT	INFIL	DRAIN	INIT	DTCH	SEEP	SEEP	SUPP	INFL	OW
			SOILTYPE	TYPE	REGION	CROP	NATURE	DST	COEF	COEF	GWL	LEVL	AMP	CONC	FRAC	RATE	SEEP
78 MARKWARD	144	Lowland	SaClLoam	(HuLMCS)	H-IJ Polder	28500	19000	100	0.0025	0.00375	900	1250	0.30	900	.	0.90	.
Total for region						28500	19000										

NOTE: Asterisks denote substitution soils. See note to Table 6.5.

The infiltration and drainage coefficients are used in the formulas relating the flow from surface water to subsoil (infiltration) or vice versa (drainage) to groundwater and ditches. Estimates of these parameters were obtained from contacts with the Instituut voor Cultuurtechniek en Waterhuishouding (Institute for Land and Water Management Research, or ICW). Initial groundwater levels and ditch levels (the latter is assumed to be constant within a subdistrict) were obtained from maps [6.2], various reports on reallotment, and contacts with the Studiecommissie Waterbehoefte Land- en Tuinbouw (Study Committee for Water Demands of Agriculture and Horticulture, or SWLT). (Infiltration, drainage coefficients, and ditch levels are only relevant for the lowlands.) Seepage rates and seepage salt concentrations came from several reports [6.3,6.4].

The industrial and drinking water withdrawals in the subdistrict file have been set to zero for the files described here, because these discharges and extractions are accounted for by the parameters of the basic drainage model, described in Sec. 6.4; they can be used to account for changes from the current situation. The groundwater constraint was never used.

The fraction suppliable indicates what part of the subdistrict has a surface water system that can be supplied from the main system. Estimates for these fractions were obtained from the above-mentioned inquiry of the Union of Waterboards [6.1]. The infiltration rate is used to compute the infiltration losses from the highlands ditches and canals to the subsoil. It is expressed in mm/day and is applied to the part of the highlands that is suppliable from the surface water system. It is based on some very crude estimates of infiltration losses per unit of open water area and the open water area itself. The open water seepage fraction indicates what part of the seepage immediately flows into the surface water system. The general assumption is that all seepage flows to the subsoil and only indirectly to the surface water. So in most places this fraction is equal to zero. In the new polders in the IJsselmeer this assumption does not seem to be a good one, and so for these polders an open water seepage fraction was empirically determined, by using DISTAG to reproduce observed salt concentrations in the IJsselmeer.

The Plot File. PLOTFIL contains four data elements per record. These data are listed in Table 6.4. The subdistrict index specifies the subdistrict containing the plot; the irrigation code indicates whether the plot is unsprinkled (set equal to zero), or sprinkled from surface water (set equal to one) or groundwater (set equal to two). The index of the crop indicates the crop type. Finally, the area of each plot is given. In Sec. 6.1.5 we describe how these plots were defined.

6.1.3. Selection of Districts and Subdistricts

Districts were defined as hydrologic entities in the sense that all parts of a district discharge water to or extract water from the

Table 6.4

PLOT DATA

```
******************************
PAWN Region 1:
North
******************************

------------------------------
Dist: 1 FRIELAND       Subd:  1
Lowland        LoMeCoS*/LoMeCoSa

CROP    UNSP     SW     GW   TOTAL
Nat    14007      .      .   14007
Gra    57741   4259      .   62000
Mil      547      .      .     547
Sed      733      .      .     733
Sug      484      .      .     484
Cer     1283      .      .    1283
Cut      361      .      .     361

TOT    75156   4259      .   79415
------------------------------
Dist: 1 FRIELAND       Subd:  2
Lowland        BasnCla*/BasinCla

CROP    UNSP     SW     GW   TOTAL
Nat    11673      .      .   11673
Gra    48430   6570      .   55000

TOT    60103   6570      .   66673
------------------------------
Dist: 1 FRIELAND       Subd:  3
Lowland        LiteCla*/(HuLMCS)

CROP    UNSP     SW     GW   TOTAL
Nat     7003      .      .    7003
Gra    18669   4023      .   22692
Con      519    224      .     743
Sed      795   1214      .    2009
Sug     2467      .      .    2467
Cer     3759      .      .    3759
Blb       74     29      .     103
Vgo      344    162      .     506
Fru      127     42      .     169
Vgg        .     20      .      20
Flr        .     13      .      13

TOT    33757   5727      .   39484
------------------------------
```

```
------------------------------
Dist: 1 FRIELAND       Subd:  4
Lowland        Peat/Peat

CROP    UNSP     SW     GW   TOTAL
Nat     6069      .      .    6069
Gra    28000      .      .   28000

TOT    34069      .      .   34069
------------------------------
Dist: 1 FRIELAND       Subd:  5
Lowland        BasnCla*/Peat

CROP    UNSP     SW     GW   TOTAL
Nat     5603      .      .    5603
Gra    20920   5080      .   26000

TOT    26523   5080      .   31603
------------------------------
Dist: 1 FRIELAND       Subd:  6
Hi High        LoMeCoS*/LoMeCoSa

CROP    UNSP     SW     GW   TOTAL
Nat     2335      .      .    2335
Gra    10672      .    328   11000

TOT    13007      .    328   13335
------------------------------
Dist: 2 HETBILDT       Subd:  7
Lowland        Loam/(LiLMCS)

CROP    UNSP     SW     GW   TOTAL
Nat     3928      .      .    3928
Gra     3061   1257      .    4318
Con      307     37      .     344
Sed        .   1573      .    1573
Sug     1725      .      .    1725
Cer     2387      .      .    2387
Vgo      483      .      .     483
Fru      100      .      .     100
Vgg        .     13      .      13
Flr        .      5      .       5

TOT    11991   2885      .   14876
------------------------------
```

```
------------------------------
Dist: 3 LAUWMEER       Subd:  8
Lowland        LiteCla*/(HuLMCS)

CROP    UNSP     SW     GW   TOTAL
Nat    18896      .      .   18896
Gra    22623   1962      .   24585
Con     1276      .      .    1276
Sed     2591    500      .    3091
Sug     4728      .      .    4728
Cer    14250      .      .   14250
Cut      160      .      .     160
Vgo      464      .      .     464
Vgg        .     16      .      16
Flr        .      8      .       8

TOT    64988   2486      .   67474
------------------------------
Dist: 4 UITHUIZN       Subd:  9
Lowland        Loam/(LiLMCS)

CROP    UNSP     SW     GW   TOTAL
Nat     3602      .      .    3602
Gra     2176      .      .    2176
Con      343      .      .     343
Sed      794      .      .     794
Sug     1210      .      .    1210
Cer     3585      .      .    3585
Vgo      126      .      .     126
Vgg        .      4      .       4
Flr        .      2      .       2

TOT    11836      6      .   11842
------------------------------
Dist: 5 EEMSKANN       Subd: 10
Lowland        LiteCla*/(HuLMCS)

CROP    UNSP     SW     GW   TOTAL
Nat     2420      .      .    2420
Gra     6580    603      .    7183
Con      401      .      .     401
Sed      750    122      .     872
Sug     1572      .      .    1572
Cer     6303      .      .    6303
Cut      131      .      .     131
Vgo      216      .      .     216

TOT    18373    725      .   19098
------------------------------
```

```
------------------------------
Dist: 5 EEMSKANN       Subd: 11
Lowland        HuLoMCS*/LoMeCoSa

CROP    UNSP     SW     GW   TOTAL
Nat     1037      .      .    1037
Gra     3113    273      .    3386
Mil     3224      .      .    3224
Sug      647      .      .     647
Cer     4985      .      .    4985
Vgg        .      4      .       4
Flr        .      3      .       3

TOT    13006    280      .   13286
------------------------------
Dist: 6 OLDAMBT        Subd: 12
Lowland        SandCla*/SandClay

CROP    UNSP     SW     GW   TOTAL
Nat     4032      .      .    4032
Gra     4131      .      .    4131
Con      118      .      .     118
Sed      315      .      .     315
Sug     2220      .      .    2220
Cer    15044      .      .   15044
Cut      858      .      .     858
Vgo      694      .      .     694

TOT    27412      .      .   27412
------------------------------
Dist: 6 OLDAMBT        Subd: 13
Lowland        HuLoMCS*/LoMeCoSa

CROP    UNSP     SW     GW   TOTAL
Nat     1008      .      .    1008
Mil     4015      .      .    4015
Sug      750      .      .     750
Cer     2600      .      .    2600
Tre      133      .      .     133
Vgg        .      2      .       2
Flr        .      5      .       5

TOT     8506      7      .    8513
------------------------------
```

Table 6.4 (continued)

Dist: 7 WESTWOLD Subd: 14
Lowland HuLoMCS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	4082	.	.	4082
Gra	5469	705	111	6285
Mil	17235	342	.	17577
Sed	319	.	.	319
Sug	5557	.	.	5557
Cer	13252	.	.	13252
Cut	268	.	.	268
Vgo	110	.	.	110
Tre	236	.	.	236
Vgg	.	12	.	12
Flr	.	13	.	13
TOT	46528	1072	111	47711

Dist: 8 NWDRENTE Subd: 15
Lowland LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	9264	.	.	9264
Gra	16162	.	413	16575
Mil	2571	.	.	2571
Cut	464	.	.	464
Tre	42	.	.	42
Vgg	.	6	.	6
TOT	28503	6	413	28922

Dist: 8 NWDRENTE Subd: 16
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	7580	.	.	7580
Con	179	.	.	179
Mil	6335	.	122	6457
Sed	561	.	.	561
Sug	3623	.	.	3623
Cer	5192	.	.	5192
Vgo	66	.	110	176
TOT	23536	.	232	23768

Dist: 9 WESKWART Subd: 17
Lowland LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	13297	.	.	13297
Gra	20282	679	.	20961
Con	137	.	.	137
Sed	279	.	.	279
Cer	811	.	.	811
TOT	34806	679	.	35485

Dist: 9 WESKWART Subd: 18
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	4433	.	.	4433
Gra	4208	.	.	4208
Mil	1395	.	.	1395
Sug	754	.	.	754
Cer	811	.	.	811
Cut	214	.	.	214
Vgg	.	.	3	3
Flr	.	.	6	6
TOT	11815	.	9	11824

Dist:13 VOLENHOV Subd: 24
Lowland Peat/Peat

CROP	UNSP	SW	GW	TOTAL
Nat	11523	.	.	11523
Gra	17414	3223	.	20637
Vgg	.	7	.	7
Flr	.	2	.	2
TOT	28937	3232	.	32169

Dist:13 VOLENHOV Subd: 25
Lowland LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	2469	.	.	2469
Gra	3525	978	.	4503
TOT	5994	978	.	6972

Dist:13 VOLENHOV Subd: 26
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	2469	.	.	2469
Gra	2194	.	425	2619
Mil	1161	.	.	1161
Sug	155	.	.	155
Cer	731	.	.	731
Cut	467	.	.	467
TOT	7177	.	425	7602

Dist:14 NEPOLDER Subd: 27
Lowland SaClLoam/(HuLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	5862	.	.	5862
Gra	2003	5048	.	7051
Con	692	2793	.	3485
Sed	.	5334	.	5334
Sug	9333	.	.	9333
Cer	7538	.	.	7538
Cut	441	.	.	441
Blb	508	120	.	628
Vgo	3202	879	.	4081
Fru	1175	237	.	1412
Vgg	.	5	.	5
Flr	.	24	.	24
TOT	30754	14440	.	45194

Dist:15 MASTBROK Subd: 28
Lowland LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	2715	.	.	2715
Gra	10932	330	997	12259
Cer	153	.	.	153
Cut	528	.	.	528
TOT	14328	330	997	15655

Dist:15 MASTBROK Subd: 29
Lowland LiteCla*/(HuLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	2715	.	.	2715
Gra	5420	7580	.	13000
TOT	8135	7580	.	15715

Dist:15 MASTBROK Subd: 30
Lowland Peat/Peat

CROP	UNSP	SW	GW	TOTAL
Nat	1357	.	.	1357
Gra	6500	.	.	6500
Vgg	.	10	.	10
Flr	.	3	.	3
TOT	7857	13	.	7870

****

Summary for region
North

CROP	UNSP	SW	GW	TOTAL
Nat	149379	.	.	149379
Gra	320225	42570	2274	365069
Con	3972	3054	.	7026
Mil	36483	342	122	36947
Sed	7137	8743	.	15880
Sug	35225	.	.	35225
Cer	82684	.	.	82684
Cut	3892	.	.	3892
Blb	582	149	.	731
Vgo	5705	1041	110	6856
Fru	1402	279	.	1681
Tre	411	.	.	411
Vgg	.	99	3	102
Flr	.	78	6	84
TOT	647097	56355	2515	705967

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Table 6.4 (continued)

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PAWN Region 2:
Northeast Highlands
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------------------------------
Dist:10 NEDRENTE      Subd: 19
Lowland       HuLoMCS*/LoMeCoSa

CROP    UNSP    SW    GW   TOTAL
Nat     4988     .     .    4988
Gra     2083   406     .    2489
Mil     9128   211     .    9339
Sed      142     .     .     142
Sug     3694     .     .    3694
Cer     5118     .     .    5118
Cut      134     .     .     134
Vgo      251     .     .     251
Vgg        .    35     .      35
Flr        .    12     .      12

TOT    25538   664     .   26202
------------------------------
Dist:11 SEDRENTE      Subd: 20
Lo High       LoMeCoS*/LoMeCoSa

CROP    UNSP    SW    GW   TOTAL
Nat     3751     .     .    3751
Gra    11211   956     .   12167
Sed      228   384     .     612
Vgo      243     .     .     243

TOT    15433  1340     .   16773
------------------------------
Dist:11 SEDRENTE      Subd: 21
Hi High       LoMeCoS*/LoMeCoSa

CROP    UNSP    SW    GW   TOTAL
Nat     5626     .     .    5626
Gra      725     .   533    1258
Con      155     .     .     155
Mil     8937     .   117    9054
Sug     3427     .     .    3427
Cer     4933     .     .    4933
Cut      555     .     .     555
Vgg        .     .    18      18
Flr        .     .     6       6

TOT    24358     .   674   25032
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------------------------------
Dist:12 SWDRENTE      Subd: 22
Lowland       LoMeCoS*/LoMeCoSa

CROP    UNSP    SW    GW   TOTAL
Nat     8184     .     .    8184
Gra    24149   779     .   24928
Sed      813   208     .    1021
Vgo      137     .     .     137

TOT    33283   987     .   34270
------------------------------
Dist:12 SWDRENTE      Subd: 23
Hi High       LoMeCoS*/LoMeCoSa

CROP    UNSP    SW    GW   TOTAL
Nat    12275     .     .   12275
Gra    17592     .  1514   19106
Con      362     .     .     362
Mil     9287     .   294    9581
Sug     3203     .     .    3203
Cer     5408     .     .    5408
Cut     1290     .     .    1290
Vgg        .     .     1       1
Flr        .     .     2       2

TOT    49417     .  1811   51228
------------------------------
Dist:16 OVIJVECT      Subd: 31
Lo High       LoMeCoS*/LoMeCoSa

CROP    UNSP    SW    GW   TOTAL
Nat     2826     .     .    2826
Gra     6189   733     .    6922
Con       63    40     .     103
Sed       29   100     .     129

TOT     9107   873     .    9980
------------------------------
Dist:16 OVIJVECT      Subd: 32
Hi High       LoMeCoS*/LoMeCoSa

CROP    UNSP    SW    GW   TOTAL
Nat     8477     .     .    8477
Gra    12080     .   579   12659
Mil     3775     .     .    3775
Sug     1137     .     .    1137
Cer     2260     .     .    2260
Cut     1608     .     .    1608
Vgg        .     .     1       1
Flr        .     .     3       3

TOT    29337     .   583   29920
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------------------------------
Dist:17 DINKEL        Subd: 33
Lo High       LoMeCoS*/LoMeCoSa

CROP    UNSP    SW    GW   TOTAL
Nat     2232     .     .    2232
Gra     3500     .     .    3500

TOT     5732     .     .    5732
------------------------------
Dist:17 DINKEL        Subd: 34
Hi High       LoMeCoS*/LoMeCoSa

CROP    UNSP    SW    GW   TOTAL
Nat     6694     .     .    6694
Gra     8008     .   316    8324
Mil      250     .     .     250
Cer      385     .     .     385
Cut     1348     .     .    1348
Flr        .     .     1       1

TOT    16685     .   317   17002
------------------------------
Dist:18 TWENTHE       Subd: 35
Lo High       LoMeCoS*/LoMeCoSa

CROP    UNSP    SW    GW   TOTAL
Nat     9930     .     .    9930
Gra    15843   387     .   16230

TOT    25773   387     .   26160
------------------------------
Dist:18 TWENTHE       Subd: 36
Hi High       LoMeCoS*/LoMeCoSa

CROP    UNSP    SW    GW   TOTAL
Nat    18442     .     .   18442
Gra    22129     .  1055   23184
Con      303     .    72     375
Mil      691     .    89     780
Sug      355     .     .     355
Cer     1282     .     .    1282
Cut     4492     .     .    4492
Tre      120     .     .     120
Vgg        .     .     1       1
Flr        .     .     4       4

TOT    47814     .  1221   49035
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------------------------------
Dist:19 SALLAND       Subd: 37
Lowland       LoMeCoS*/LoMeCoSa

CROP    UNSP    SW    GW   TOTAL
Nat     6544     .     .    6544
Gra    18873  2074     .   20947
Con      133   146     .     279
Sug      172    79     .     251
Fru      188     .     .     188
Vgg        .     3     .       3
Flr        .     2     .       2

TOT    25910  2304     .   28214
------------------------------
Dist:19 SALLAND       Subd: 38
Hi High       LoMeCoS*/LoMeCoSa

CROP    UNSP    SW    GW   TOTAL
Nat     3523     .     .    3523
Gra     7351     .  1363    8714
Mil      332     .     .     332
Cer      570     .     .     570
Cut     1963     .     .    1963

TOT    13739     .  1363   15102
------------------------------
Dist:20 TWENTKAN      Subd: 39
Lowland        LiLoMCS*/(LiLMCS)

CROP    UNSP    SW    GW   TOTAL
Nat    18822     .     .   18822
Gra    15410   708   707   16825
Con      201   124     .     325
Sug      206    61     .     267
Cer      887     .     .     887
Cut     1900     .     .    1900
Flr        .     2     .       2

TOT    37426   895   707   39028
------------------------------
Dist:20 TWENTKAN      Subd: 40
Lo High       LoMeCoS*/LoMeCoSa

CROP    UNSP    SW    GW   TOTAL
Nat     2689     .     .    2689
Gra     2664   200     .    2864

TOT     5353   200     .    5553
------------------------------
```

Table 6.4 (continued)

Dist:20 TWENTKAN Subd: 41
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	5378	.	.	5378
Gra	4106	.	300	4406
Mil	416	.	.	416
Cut	898	.	.	898
TOT	10798	.	300	11098

Dist:21 SHIPBEEK Subd: 42
Lowland LiLoMCS*/(LiLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	11323	.	.	11323
Gra	11157	387	504	12048
Mil	208	.	.	208
Cer	443	.	.	443
Cut	1399	.	.	1399
Flr	.	1	.	1
TOT	24530	388	504	25422

Dist:24 BERKEL Subd: 47
Lo High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	4084	.	.	4084
Gra	11928	1296	.	13224
TOT	16012	1296	.	17308

Dist:24 BERKEL Subd: 48
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	12254	.	.	12254
Gra	25333	.	4924	30257
Con	331	.	90	421
Mil	273	.	40	313
Sug	440	.	65	505
Cer	2575	.	115	2690
Cut	5728	.	.	5728
Vgo	76	.	91	167
Tre	57	.	55	112
Vgg	.	.	3	3
Flr	.	.	4	4
TOT	47067	.	5387	52454

Dist:25 OUDEIJSL Subd: 49
Lowland LiteCla*/(HuLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	5782	.	.	5782
Gra	11528	.	1631	13159
Sug	550	.	.	550
Cer	1000	.	.	1000
Cut	1500	.	.	1500
Vgo	142	.	159	301
Fru	195	.	137	332
TOT	20697	.	1927	22624

Dist:25 OUDEIJSL Subd: 50
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	10739	.	.	10739
Gra	19619	.	4000	23619
Con	217	.	177	394
Sed	.	.	117	117
Sug	361	.	134	495
Cer	2174	.	215	2389
Cut	3914	.	.	3914
Vgg	.	.	15	15
Flr	.	.	5	5
TOT	37024	.	4663	41687

Summary for region
Northeast Highlands

CROP	UNSP	SW	GW	TOTAL
Nat	164563	.	.	164563
Gra	251478	7926	17426	276830
Con	1765	310	339	2414
Mil	33297	211	540	34048
Sed	1212	692	117	2021
Sug	13545	140	199	13884
Cer	27035	.	330	27365
Cut	26729	.	.	26729
Vgo	849	.	250	1099
Fru	383	.	137	520
Tre	177	.	55	232
Vgg	.	38	39	77
Flr	.	17	25	42
TOT	521033	9334	19457	549824

PAWN Region 3:
Flevoland & Veluwe

Dist:22 IJSELGEB Subd: 43
Lowland LiteCla*/(HuLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	12432	.	.	12432
Gra	8218	732	521	9471
Con	161	.	.	161
Sug	142	.	.	142
Cer	491	.	.	491
Cut	699	.	.	699
Fru	102	.	.	102
Vgg	.	4	.	4
Flr	.	6	.	6
TOT	22245	742	521	23508

Dist:23 NEVELUWE Subd: 44
Lowland LiteCla*/(HuLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	7137	.	.	7137
Gra	4641	271	658	5570
Con	74	197	.	271
Cer	250	.	.	250
Cut	447	.	.	447
Vgo	36	72	81	189
Fru	51	41	46	138
TOT	12636	581	785	14002

Dist:23 NEVELUWE Subd: 45
Lo High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	7137	.	.	7137
Gra	3526	731	.	4257
TOT	10663	731	.	11394

Dist:23 NEVELUWE Subd: 46
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	14275	.	.	14275
Gra	6526	.	394	6920
Mil	70	.	30	100
Sug	198	.	87	285
Cer	671	.	.	671
Cut	673	.	.	673
Vgg	.	.	6	6
Flr	.	.	10	10
TOT	22413	.	527	22940

Dist:26 ARNHEM Subd: 51
Lowland LiteCla*/(HuLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	4142	.	.	4142
Gra	1638	.	.	1638
Mil	102	.	.	102
Cer	377	.	.	377
Cut	230	.	.	230
Vgg	.	1	.	1
Flr	.	1	.	1
TOT	6489	2	.	6491

Dist:27 SEVELUWE Subd: 52
Lo High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	3174	.	.	3174
Gra	1700	.	.	1700
TOT	4874	.	.	4874

Dist:27 SEVELUWE Subd: 53
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	7407	.	.	7407
Gra	2725	.	.	2725
Mil	191	.	.	191
Cer	458	.	.	458
Cut	462	.	.	462
Vgg	.	.	1	1
Flr	.	.	2	2
TOT	11243	.	3	11246

Table 6.4 (continued)

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------------------------------
Dist:28 SWVELUWE        Subd: 54
Lo High       LoMeCoS*/LoMeCoSa

CROP   UNSP     SW     GW  TOTAL
Nat   29439      .      .  29439
Gra   19295    888      .  20183
Con     198      .      .    198
Fru      73    125      .    198

TOT   49005   1013      .  50018
------------------------------
Dist:28 SWVELUWE        Subd: 55
Hi High       LoMeCoS*/LoMeCoSa

CROP   UNSP     SW     GW  TOTAL
Nat   19625      .      .  19625
Gra    9448      .   1081  10529
Mil     237      .      .    237
Cer     679      .      .    679
Cut    2124      .      .   2124
Tre     224      .      .    224
Vgg       .      .      4      4
Flr       .      .     10     10

TOT   32337      .   1095  33432
------------------------------
Dist:29 NWVELUWE        Subd: 56
Lo High       LoMeCoS*/LoMeCoSa

CROP   UNSP     SW     GW  TOTAL
Nat   23508      .      .  23508
Gra   12958    547      .  13505
Con     118      .      .    118

TOT   36584    547      .  37131
------------------------------
Dist:29 NWVELUWE        Subd: 57
Hi High       LoMeCoS*/LoMeCoSa

CROP   UNSP     SW     GW  TOTAL
Nat   10075      .      .  10075
Gra    4298      .      .   4298
Cer     386      .      .    386
Cut    1039      .      .   1039
Vgg       .      .      2      2
Flr       .      .      2      2

TOT   15798      .      4  15802
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------------------------------
Dist:30 FLEVLAND        Subd: 58
Lowland       SaClLoam/(HuLMCS)

CROP   UNSP     SW     GW  TOTAL
Nat   38325      .      .  38325
Gra    3666   1443    151   5260
Con    4181    917     98   5196
Sed    1495    867     93   2455
Sug    8335      .      .   8335
Cer   29059      .      .  29059
Cut     257      .      .    257
Vgo    2812     70      .   2882
Fru     948      .      .    948
Tre     169      .      .    169
Vgg       .      1      .      1

TOT   89247   3298    342  92887
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Summary for region
Flevoland & Veluwe

CROP   UNSP     SW     GW  TOTAL
Nat  176676      .      . 176676
Gra   78639   4612   2805  86056
Con    4732   1114     98   5944
Mil     600      .     30    630
Sed    1495    867     93   2455
Sug    8675      .     87   8762
Cer   32371      .      .  32371
Cut    5931      .      .   5931
Vgo    2848    142     81   3071
Fru    1174    166     46   1386
Tre     393      .      .    393
Vgg       .      6     13     19
Flr       .      7     24     31

TOT  313534   6914   3277 323725
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PAWN Region 4:
North Holland
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------------------------------
Dist:31 WIERGMER        Subd: 59
Lowland       LiteCla*/(HuLMCS)

CROP   UNSP     SW     GW  TOTAL
Nat    3476      .      .   3476
Gra     784    554      .   1338
Con    1010    434     77   1521
Sed       .   1530    270   1800
Sug    4034      .      .   4034
Cer    5619      .      .   5619
Cut     175      .      .    175
Blb     257    149      .    406
Vgo     302    211      .    513

TOT   15657   2878    347  18882
------------------------------
Dist:32 AMSTLMER        Subd: 60
Lowland       LiteCla*/(HuLMCS)

CROP   UNSP     SW     GW  TOTAL
Nat    3108      .      .   3108
Gra    6376   3526      .   9902
Con     231    119      .    350
Sed       .   1398      .   1398
Sug    1498      .      .   1498
Cer    2356      .      .   2356
Blb    1163    759      .   1922
Vgo     469    374      .    843
Fru      83     44      .    127
Vgg       .      7      .      7
Flr       .     24      .     24

TOT   15284   6251      .  21535
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------------------------------
Dist:33 MEDMBLIK        Subd: 61
Lowland       LiteCla*/(HuLMCS)

CROP   UNSP     SW     GW  TOTAL
Nat    2854      .      .   2854
Gra    5850   5027      .  10877
Con     481    100      .    581
Sed     329    172      .    501
Sug     182      .      .    182
Cer     282      .      .    282
Blb     538   1237      .   1775
Vgo     608   2206      .   2814
Fru     228    355      .    583
Vgg       .     19      .     19
Flr       .     39      .     39

TOT   11352   9155      .  20507
------------------------------
Dist:34 HOORN           Subd: 62
Lowland       LiteCla*/(HuLMCS)

CROP   UNSP     SW     GW  TOTAL
Nat    1746      .      .   1746
Gra    2352   1858      .   4210
Blb     171    289      .    460
Vgo     138    332      .    470
Fru     248    302      .    550
Vgg       .     16      .     16
Flr       .     17      .     17

TOT    4655   2814      .   7469
------------------------------
Dist:35 SCHERMER        Subd: 63
Lowland       Peat/Peat

CROP   UNSP     SW     GW  TOTAL
Nat    4948      .      .   4948
Gra   11742   2267      .  14009

TOT   16690   2267      .  18957
------------------------------
Dist:35 SCHERMER        Subd: 64
Lowland       Peat/Peat

CROP   UNSP     SW     GW  TOTAL
Nat    4948      .      .   4948
Gra   11742   2267      .  14009

TOT   16690   2267      .  18957
------------------------------
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Table 6.4 (continued)

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------------------------------
Dist:35 SCHERMER       Subd: 65
Lowland       BasnCla*/BasinCla

CROP    UNSP     SW    GW  TOTAL
Nat     3299      .     .   3299
Gra     2558   1284     .   3842
Con      513    328     .    841
Sed      218    772     .    990
Sug     1353      .     .   1353
Cer     2119      .     .   2119
Fru      194      .     .    194

TOT    10254   2384     .  12638
------------------------------
Dist:35 SCHERMER       Subd: 66
Lowland       LiLoMCS*/(HuLMCS)

CROP    UNSP     SW    GW  TOTAL
Nat     3299      .     .   3299
Gra     1891   2244   178   4313
Cut      142      .     .    142
Blb     1253    995    82   2330
Vgo     1203   1204   100   2507
Vgg        .     45     .     45
Flr        .     48     .     48

TOT     7788   4536   360  12684
------------------------------
Dist:36 WATRLAND       Subd: 67
Lowland       Peat/Peat

CROP    UNSP     SW    GW  TOTAL
Nat     1405      .     .   1405
Gra     4295    443     .   4738
Cer      110      .     .    110
Flr        .      1     .      1

TOT     5810    444     .   6254
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------------------------------
Dist:37 NZKANGEB       Subd: 68
Lowland       SandCla*/(HuLMCS)

CROP    UNSP     SW    GW  TOTAL
Nat     5146      .     .   5146
Gra     1604    391     .   1995
Con      163    229     .    392
Sug      707      .     .    707
Cer     1222      .     .   1222
Blb      120      .     .    120
Vgo      132      .     .    132
Vgg        .      4     .      4
Flr        .     28     .     28

TOT     9094    652     .   9746
------------------------------
Dist:37 NZKANGEB       Subd: 69
Lowland       Peat/Peat

CROP    UNSP     SW    GW  TOTAL
Nat     2771      .     .   2771
Gra     2500      .     .   2500

TOT     5271      .     .   5271
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Summary for region
North Holland

CROP    UNSP     SW    GW  TOTAL
Nat    37000      .     .  37000
Gra    51694  19861   178  71733
Con     2398   1210    77   3685
Sed      547   3872   270   4689
Sug     7774      .     .   7774
Cer    11708      .     .  11708
Cut      317      .     .    317
Blb     3502   3429    82   7013
Vgo     2852   4327   100   7279
Fru      753    701     .   1454
Vgg        .     91     .     91
Flr        .    157     .    157

TOT   118545  33648   707 152900
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PAWN Region 5:
Midwest and Utrecht
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Dist:38 RIJNLAND       Subd: 70
Lowland       SandCla*/(HuLMCS)

CROP    UNSP     SW    GW  TOTAL
Nat    12217      .     .  12217
Gra     6784    962     .   7746
Con      952   1180     .   2132
Sed        .    293     .    293
Sug     4079      .     .   4079
Cer     6802      .     .   6802
Cut      203      .     .    203
Blb      521    112     .    633
Vgo     1222    305     .   1527
Fru      155     29     .    184
Vgg        .    226     .    226
Flr        .    862     .    862

TOT    32935   3969     .  36904
------------------------------
Dist:38 RIJNLAND       Subd: 71
Lowland       Peat/Peat

CROP    UNSP     SW    GW  TOTAL
Nat     9773      .     .   9773
Gra    15944   2100     .  18044
Tre      607    305     .    912

TOT    26324   2405     .  28729
------------------------------
Dist:38 RIJNLAND       Subd: 72
Lowland       LoMeCoS*/LoMeCoS*

CROP    UNSP     SW    GW  TOTAL
Nat     1222      .     .   1222
Blb     2758    350     .   3108

TOT     3980    350     .   4330
------------------------------
Dist:38 RIJNLAND       Subd: 73
Lowland       BasnCla*/Peat

CROP    UNSP     SW    GW  TOTAL
Nat     1222      .     .   1222
Gra      399   2101     .   2500

TOT     1621   2101     .   3722
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Dist:39 AMSTLAND       Subd: 74
Lowland       Peat/Peat

CROP    UNSP     SW    GW  TOTAL
Nat     3272      .     .   3272
Gra     8500    500     .   9000
Vgg        .     24     .     24
Flr        .    170     .    170

TOT    11772    694     .  12466
------------------------------
Dist:39 AMSTLAND       Subd: 75
Lowland       BasnCla*/Peat

CROP    UNSP     SW    GW  TOTAL
Nat     1762      .     .   1762
Gra     2523   1265     .   3788
Con      205      .     .    205
Sug      296      .     .    296
Cer      588      .     .    588
Vgo      102      .     .    102

TOT     5476   1265     .   6741
------------------------------
Dist:40 GOOI           Subd: 76
Lowland       Peat/Peat

CROP    UNSP     SW    GW  TOTAL
Nat     9080      .     .   9080
Gra     9919    923     .  10842
Cer      116      .     .    116
Cut      139      .     .    139
Tre      140      .     .    140
Vgg        .     13     .     13
Flr        .     10     .     10

TOT    19394    946     .  20340
------------------------------
Dist:41 KROMRIJN       Subd: 77
Hi High       LoMeCoS*/LoMeCoSa

CROP    UNSP     SW    GW  TOTAL
Nat     9164      .     .   9164
Gra     6097      .   757   6854
Cer        3    118   159    280
Cut      819      .     .    819
Fru      146      .   311    457

TOT    16229    118  1227  17574
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Table 6.4 (continued)

Dist:41 KROMRIJN Subd: 78
Lowland LiteCla*/(HuLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	6108	.	.	6108
Gra	3823	3177	.	7000
Fru	915	585	.	1500
Vgg	.	26	.	26
Flr	.	12	.	12
TOT	10846	3800	.	14646

Dist:42 LEIDRIJN Subd: 79
Lowland BasnCla*/(SanCla)

CROP	UNSP	SW	GW	TOTAL
Nat	3763	.	.	3763
Gra	4604	720	.	5324
Cut	128	.	.	128
Fru	429	.	.	429
Vgg	.	43	.	43
Flr	.	20	.	20
TOT	8924	783	.	9707

Dist:43 WOERDEN Subd: 80
Lowland Peat/Peat

CROP	UNSP	SW	GW	TOTAL
Nat	4520	.	.	4520
Gra	9276	1708	.	10984
Fru	262	.	.	262
Vgg	.	12	.	12
Flr	.	6	.	6
TOT	14058	1726	.	15784

Dist:44 LOPIKWAR Subd: 81
Lowland BasnCla*/(SanCla)

CROP	UNSP	SW	GW	TOTAL
Nat	1860	.	.	1860
Gra	3228	570	.	3798
TOT	5088	570	.	5658

Dist:44 LOPIKWAR Subd: 82
Lowland BasnCla*/Peat

CROP	UNSP	SW	GW	TOTAL
Nat	1395	.	.	1395
Gra	2425	425	.	2850
TOT	3820	425	.	4245

Dist:44 LOPIKWAR Subd: 83
Lowland LiteCla*/(HuLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	1395	.	.	1395
Gra	2063	363	.	2426
Fru	359	.	.	359
Vgg	.	8	.	8
Flr	.	3	.	3
TOT	3817	374	.	4191

Dist:45 KRIMPWAR Subd: 84
Lowland Peat/Peat

CROP	UNSP	SW	GW	TOTAL
Nat	2016	.	.	2016
Gra	6406	836	.	7242
Vgg	.	27	.	27
Flr	.	6	.	6
TOT	8422	869	.	9291

Dist:45 KRIMPWAR Subd: 85
Lowland Loam/(LiLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	504	.	.	504
Gra	859	112	.	971
Con	112	.	.	112
Sug	123	.	.	123
Cer	228	.	.	228
Vgo	142	161	.	303
TOT	1968	273	.	2241

Dist:46 SCIELAND Subd: 86
Lowland Peat/Peat

CROP	UNSP	SW	GW	TOTAL
Nat	1828	.	.	1828
Gra	3483	696	.	4179
Vgg	.	308	.	308
Flr	.	131	.	131
TOT	5311	1135	.	6446

Dist:46 SCIELAND Subd: 87
Lowland SandCla*/(BasCla)

CROP	UNSP	SW	GW	TOTAL
Nat	1828	.	.	1828
Con	244	199	.	443
Sed	33	294	.	327
Sug	1213	.	.	1213
Cer	1971	.	.	1971
Cut	174	.	.	174
Vgo	457	117	.	574
Fru	120	23	.	143
TOT	6040	633	.	6673

Dist:47 DELFLAND Subd: 88
Lowland BasnCla*/Peat

CROP	UNSP	SW	GW	TOTAL
Nat	2431	.	.	2431
Gra	9695	1735	.	11430
TOT	12126	1735	.	13861

Dist:47 DELFLAND Subd: 89
Lowland LiLoMCS*/(LiLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	936	.	.	936
Vgo	414	292	.	706
Vgg	.	2254	.	2254
Flr	.	1341	.	1341
TOT	1350	3887	.	5237

Dist:47 DELFLAND Subd: 90
Lowland SandCla*/(BasCla)

CROP	UNSP	SW	GW	TOTAL
Nat	374	.	.	374
Con	.	214	.	214
Sug	243	.	.	243
Cer	662	.	.	662
TOT	1279	214	.	1493

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Summary for region
Midwest and Utrecht

CROP	UNSP	SW	GW	TOTAL
Nat	76670	.	.	76670
Gra	96028	18193	757	114978
Con	1513	1593	.	3106
Sed	33	587	.	620
Sug	5954	.	.	5954
Cer	10370	118	159	10647
Cut	1463	.	.	1463
Bib	3279	462	.	3741
Vgo	2337	875	.	3212
Fru	2386	637	311	3334
Tre	747	305	.	1052
Vgg	.	2941	.	2941
Flr	.	2561	.	2561
TOT	200780	28272	1227	230279

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Table 6.4 (continued)

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PAWN Region 6:
Large Rivers & Northern Delta
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Dist:48 VOORNE Subd: 91
Lowland Loam/(LiLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	7093	.	.	7093
Gra	5342	889	.	6231
Con	1775	785	.	2560
Sed	39	63	.	102
Sug	2896	.	.	2896
Cer	5000	.	.	5000
Cut	420	.	.	420
Blb	64	46	.	110
Vgo	938	825	.	1763
Fru	223	127	.	350
Vgg	.	111	.	111
Flr	.	23	.	23
TOT	23790	2869	.	26659

Dist:49 GOEREE Subd: 92
Lowland Loam/(LiLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	3253	.	.	3253
Con	1357	.	.	1357
Sug	1259	.	.	1259
Cer	2012	.	.	2012
Blb	190	.	.	190
Vgo	1300	.	.	1300
Fru	100	.	.	100
Vgg	.	2	.	2
Flr	.	1	.	1
TOT	9471	3	.	9474

Dist:50 IJSLMOND Subd: 93
Lowland Loam/(LiLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	3208	.	.	3208
Gra	1950	714	.	2664
Con	855	895	.	1750
Sug	2004	.	.	2004
Cer	3537	.	.	3537
Cut	163	.	.	163
Vgo	853	549	.	1402
Fru	262	115	.	377
Vgg	.	72	.	72
Flr	.	16	.	16
TOT	12832	2361	.	15193

Dist:52 DORDRECT Subd: 95
Lowland Loam/(LiLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	2584	.	.	2584
Gra	768	398	.	1166
Con	506	510	.	1016
Sug	1146	.	.	1146
Cer	2022	.	.	2022
Vgo	515	315	.	830
Fru	216	91	.	307
Vgg	.	41	.	41
Flr	.	9	.	9
TOT	7757	1364	.	9121

Dist:53 ABLASWAR Subd: 96
Lowland BasnCla*/Peat

CROP	UNSP	SW	GW	TOTAL
Nat	2842	.	.	2842
Gra	9201	1435	.	10636
Fru	260	.	.	260
TOT	12303	1435	.	13738

Dist:53 ABLASWAR Subd: 97
Lowland BasnCla*/(SanCla)

CROP	UNSP	SW	GW	TOTAL
Nat	1292	.	.	1292
Gra	4463	530	.	4993
TOT	5755	530	.	6285

Dist:53 ABLASWAR Subd: 98
Lowland Peat/Peat

CROP	UNSP	SW	GW	TOTAL
Nat	1034	.	.	1034
Gra	3980	.	.	3980
Vgg	.	4	.	4
TOT	5014	4	.	5018

Dist:55 TIELWARD Subd:102
Lowland LiteCla*/(HuLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	5203	.	.	5203
Gra	7747	3000	771	11518
Con	.	242	.	242
Sug	757	.	.	757
Cer	1201	.	.	1201
Cut	536	.	.	536
Vgo	72	58	25	155
Fru	1462	730	309	2501
Tre	59	37	16	112
Vgg	.	17	.	17
Flr	.	25	.	25
TOT	17037	4109	1121	22267

Dist:55 TIELWARD Subd:103
Lowland BasnCla*/(SanCla)

CROP	UNSP	SW	GW	TOTAL
Nat	5203	.	.	5203
Gra	8873	6566	.	15439
Fru	730	637	.	1367
TOT	14806	7203	.	22009

Dist:57 BETUWE Subd:107
Lowland LiteCla*/(HuLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	9053	.	.	9053
Gra	9407	4575	1242	15224
Con	.	383	.	383
Sug	833	.	.	833
Cer	1414	.	.	1414
Cut	551	.	.	551
Vgo	136	104	91	331
Fru	1902	861	752	3515
Tre	84	50	43	177
Vgg	.	74	.	74
Flr	.	68	.	68
TOT	23380	6115	2128	31623

Dist:59 RECMAASN Subd:109
Lowland LiteCla*/(HuLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	696	.	.	696
Gra	825	.	.	825
Sug	268	.	.	268
Cer	519	.	.	519
Fru	149	.	.	149
Vgg	.	7	.	7
Flr	.	4	.	4
TOT	2457	11	.	2468

Dist:59 RECMAASN Subd:110
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	1624	.	.	1624
Gra	3234	.	458	3692
Cut	436	.	.	436
TOT	5294	.	458	5752

Table 6.4 (continued)

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Summary for region
Large Rivers & Northern Delta

CROP	UNSP	SW	GW	TOTAL
Nat	43085	.	.	43085
Gra	55790	18107	2471	76368
Con	4493	2815	.	7308
Sed	39	63	.	102
Sug	9163	.	.	9163
Cer	15705	.	.	15705
Cut	2106	.	.	2106
Blb	254	46	.	300
Vgo	3814	1851	116	5781
Fru	5304	2561	1061	8926
Tre	143	87	59	289
Vgg	.	328	.	328
Flr	.	146	.	146
TOT	139896	26004	3707	169607

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PAWN Region 7:
West Brabant & Southern Delta

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Dist:51 HOLNDIEP Subd: 94
Lowland Loam/(LiLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	8311	.	.	8311
Gra	6077	1258	671	8006
Con	1731	1110	183	3024
Sed	93	470	78	641
Sug	4279	.	.	4279
Cer	7593	.	.	7593
Cut	1312	.	.	1312
Blb	121	34	12	167
Vgo	2171	724	259	3154
Fru	522	123	44	689
Tre	85	24	9	118
Vgg	.	49	.	49
Flr	.	9	.	9
TOT	32295	3801	1256	37352

Dist:54 BIESBOSH Subd: 99
Lowland Loam/(LiLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	1446	.	.	1446
Gra	1561	431	.	1992
Con	567	624	.	1191
Sug	1761	.	.	1761
Cer	3130	.	.	3130
Vgo	747	246	.	993
TOT	9212	1301	.	10513

Dist:54 BIESBOSH Subd:100
Lowland LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	1084	.	.	1084
Gra	5566	425	.	5991
Cut	731	.	.	731
Vgg	.	37	.	37
Flr	.	20	.	20
TOT	7381	482	.	7863

Dist:54 BIESBOSH Subd:101
Lowland LiteCla*/(HuLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	1084	.	.	1084
Gra	1241	867	.	2108
Con	286	332	.	618
Sug	1198	.	.	1198
Cer	1861	.	.	1861
Vgo	542	100	.	642
Fru	407	.	.	407
TOT	6619	1299	.	7918

Dist:74 MARK Subd:137
Lo High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	2374	.	.	2374
Gra	2745	988	.	3733
Con	180	187	.	367
Vgo	177	423	.	600
TOT	5476	1598	.	7074

Dist:74 MARK Subd:138
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	13450	.	.	13450
Gra	14989	.	2645	17634
Sug	826	.	362	1188
Cer	994	.	113	1107
Cut	3739	.	.	3739
Vgo	1164	.	653	1817
Fru	138	.	53	191
Tre	567	.	266	833
Vgg	.	.	123	123
Flr	.	.	17	17
TOT	35867	.	4232	40099

Dist:75 ROSENDAL Subd:139
Lowland Loam/(LiLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	2019	.	.	2019
Gra	695	305	.	1000
Con	693	386	.	1079
Sed	128	319	.	447
Sug	1812	.	.	1812
Cer	3068	.	.	3068
Blb	83	21	.	104
Vgo	1076	325	.	1401
Fru	336	74	.	410
TOT	9910	1430	.	11340

Dist:75 ROSENDAL Subd:140
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	3749	.	.	3749
Gra	5703	.	933	6636
Con	432	.	168	600
Sug	720	.	146	866
Cer	1549	.	.	1549
Cut	1321	.	.	1321
Vgo	570	.	459	1029
Vgg	.	.	43	43
Flr	.	.	6	6
TOT	14044	.	1755	15799

Dist:76 ZOOM Subd:141
Lowland Loam/(LiLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	15315	.	.	15315
Gra	4951	.	.	4951
Con	5928	.	.	5928
Sed	638	.	.	638
Sug	8265	.	.	8265
Cer	14528	.	.	14528
Blb	583	.	.	583
Vgo	3680	.	.	3680
Fru	3444	.	.	3444
Vgg	.	26	.	26
Flr	.	6	.	6
TOT	57332	32	.	57364

Dist:76 ZOOM Subd:142
Lowland LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	1042	.	.	1042
Gra	858	.	.	858
Cer	834	.	.	834
Cut	873	.	.	873
Vgo	461	.	.	461
TOT	4068	.	.	4068

Dist:77 SCHOUWEN Subd:143
Lowland Loam/(LiLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	5158	.	.	5158
Gra	2062	.	.	2062
Con	3043	.	.	3043
Sug	3297	.	.	3297
Cer	7273	.	.	7273
Cut	316	.	.	316
Blb	260	.	.	260
Vgo	2053	.	.	2053
Fru	299	.	.	299
Vgg	.	4	.	4
Flr	.	3	.	3
TOT	23761	7	.	23768

Table 6.4 (continued)

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Summary for region
West Brabant & Southern Delta

CROP	UNSP	SW	GW	TOTAL
Nat	55032	.	.	55032
Gra	46448	4274	4249	54971
Con	12860	2639	351	15850
Sed	859	789	78	1726
Sug	22158	.	508	22666
Cer	40830	.	113	40943
Cut	8292	.	.	8292
Blb	1047	55	12	1114
Vgo	12641	1818	1371	15830
Fru	5146	197	97	5440
Tre	652	24	275	951
Vgg	.	116	166	282
Flr	.	38	23	61
TOT	205965	9950	7243	223158

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PAWN Region 8:
Southeast Highlands
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Dist:56 DENBOSCH Subd:104
Lowland LiteCla*/(HuLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	5043	.	.	5043
Gra	3814	5456	.	9270
Con	222	555	177	954
Sug	826	.	.	826
Cer	1214	.	.	1214
Vgo	96	394	.	490
Fru	282	472	.	754
Vgg	.	100	.	100
Flr	.	59	.	59
TOT	11497	7036	177	18710

Dist:56 DENBOSCH Subd:105
Lowland LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	1512	.	.	1512
Gra	3389	696	.	4085
TOT	4901	696	.	5597

Dist:56 DENBOSCH Subd:106
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	3529	.	.	3529
Gra	5887	.	1170	7057
Cut	2093	.	.	2093
Vgo	161	.	219	380
TOT	11670	.	1389	13059

Dist:58 MAASWAAL Subd:108
Lowland LiteCla*/(HuLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	4139	.	.	4139
Gra	7610	3457	1261	12328
Sug	386	.	.	386
Cer	854	.	.	854
Cut	457	.	.	457
Fru	252	569	304	1125
Vgg	.	12	.	12
Flr	.	9	.	9
TOT	13698	4047	1565	19310

Dist:60 RECMAASM Subd:111
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	4420	.	.	4420
Gra	2457	447	355	3259
Con	92	68	41	201
Sug	367	110	66	543
Cer	745	56	34	835
Cut	389	.	.	389
Vgo	191	125	128	444
Fru	66	26	26	118
Vgg	.	.	34	34
Flr	.	.	7	7
TOT	8727	832	691	10250

Dist:61 MASKANTE Subd:112
Lo High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	2527	.	.	2527
Gra	5291	.	.	5291
TOT	7818	.	.	7818

Dist:61 MASKANTE Subd:113
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	10108	.	.	10108
Gra	9435	.	3070	12505
Con	479	.	232	711
Sug	1602	.	389	1991
Cer	1489	.	.	1489
Cut	3959	.	.	3959
Vgo	290	.	190	480
Fru	105	.	46	151
Tre	217	.	118	335
Vgg	.	.	18	18
Flr	.	.	4	4
TOT	27684	.	4067	31751

Dist:62 MASKANTW Subd:114
Lowland LiteCla*/(HuLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	3694	.	.	3694
Gra	4269	1159	.	5428
Con	.	203	87	290
Sug	674	.	.	674
Cer	984	.	.	984
Fru	114	.	.	114
TOT	9735	1362	87	11184

Dist:62 MASKANTW Subd:115
Lo High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	1477	.	.	1477
Gra	2312	538	.	2850
Vgo	.	100	.	100
TOT	3789	638	.	4427

Dist:62 MASKANTW Subd:116
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	2216	.	.	2216
Gra	1965	.	665	2630
Cut	1676	.	.	1676
Vgg	.	.	9	9
Flr	.	.	1	1
TOT	5857	.	675	6532

Dist:63 AA Subd:117
Lo High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	8753	.	.	8753
Gra	9533	1207	.	10740
Con	132	269	.	401
Vgo	188	152	.	340
TOT	18606	1628	.	20234

Dist:63 AA Subd:118
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	26257	.	.	26257
Gra	17250	.	3895	21145
Con	191	.	181	372
Sug	1371	.	567	1938
Cer	1668	.	.	1668
Cut	7397	.	.	7397
Vgo	656	.	362	1018
Fru	255	.	97	352
Tre	130	.	60	190
Vgg	.	.	86	86
Flr	.	.	15	15
TOT	55175	.	5263	60438

Dist:64 DEPEEL Subd:119
Lo High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	2678	.	.	2678
Gra	939	1193	.	2132
Con	180	720	.	900
Vgo	582	418	.	1000
TOT	4379	2331	.	6710

Table 6.4 (continued)

Dist:64 DEPEEL Subd:120
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	15175	.	.	15175
Gra	8783	.	1717	10500
Con	181	.	148	329
Sug	2282	.	846	3128
Cer	3600	.	.	3600
Cut	2993	.	.	2993
Blb	137	.	42	179
Vgo	978	.	347	1325
Fru	366	.	93	459
Tre	205	.	62	267
Vgg	.	.	163	163
Flr	.	.	25	25
TOT	34700	.	3443	38143

Dist:65 RECMAASS Subd:121
Lo High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	2719	.	.	2719
Gra	2286	214	.	2500
Con	67	133	.	200
Vgo	155	145	.	300
TOT	5227	492	.	5719

Dist:65 RECMAASS Subd:122
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	8157	.	.	8157
Gra	1608	.	558	2166
Con	328	.	109	437
Sug	1359	.	239	1598
Cer	2127	.	.	2127
Cut	910	.	.	910
Vgo	914	.	159	1073
Fru	244	.	32	276
Tre	219	.	33	252
Vgg	.	.	128	128
Flr	.	.	19	19
TOT	15866	.	1277	17143

Dist:66 ROERMOND Subd:123
Lo High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	681	.	.	681
Gra	269	302	.	571
Con	60	210	.	270
Vgo	100	.	.	100
TOT	1110	512	.	1622

Dist:66 ROERMOND Subd:124
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	6128	.	.	6128
Gra	2174	.	561	2735
Sug	1620	.	390	2010
Cer	2721	.	.	2721
Cut	523	.	.	523
Vgo	183	.	73	256
Fru	121	.	35	156
Vgg	.	.	4	4
Flr	.	.	1	1
TOT	13470	.	1064	14534

Dist:67 SLIMBURG Subd:125
Hi High Loam /Loam

CROP	UNSP	SW	GW	TOTAL
Nat	21619	.	.	21619
Gra	16643	229	399	17271
Con	1464	.	200	1664
Sug	4969	.	.	4969
Cer	7278	.	.	7278
Cut	2774	.	.	2774
Vgo	230	.	.	230
Fru	2358	.	.	2358
Vgg	.	.	1	1
Flr	.	.	3	3
TOT	57335	229	603	58167

Dist:68 MLIMBURG Subd:126
Lo High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	3003	.	.	3003
Gra	1234	1401	.	2635
Con	88	857	.	945
Vgo	266	534	.	800
TOT	4591	2792	.	7383

Dist:68 MLIMBURG Subd:127
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	12015	.	.	12015
Gra	6383	.	1433	7816
Sug	1688	.	826	2514
Cer	2845	.	.	2845
Cut	2509	.	.	2509
Blb	115	.	35	150
Vgo	765	.	273	1038
Fru	288	.	74	362
Tre	214	.	65	279
Vgg	.	.	123	123
Flr	.	.	19	19
TOT	26822	.	2848	29670

Dist:69 EDOMMEL Subd:128
Lo High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	2844	.	.	2844
Gra	3505	.	600	4105
TOT	6349	.	600	6949

Dist:69 EDOMMEL Subd:129
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	8530	.	.	8530
Gra	5287	.	942	6229
Con	304	.	174	478
Sug	735	.	206	941
Cer	1055	.	.	1055
Cut	2904	.	.	2904
Vgo	359	.	136	495
Fru	81	.	22	103
Vgg	.	.	23	23
Flr	.	.	5	5
TOT	19255	.	1508	20763

Dist:70 MDOMMEL Subd:130
Lo High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	2074	.	.	2074
Gra	3013	.	524	3537
TOT	5087	.	524	5611

Dist:70 MDOMMEL Subd:131
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	8300	.	.	8300
Gra	7013	.	1157	8170
Con	320	.	161	481
Sug	625	.	157	782
Cer	937	.	.	937
Cut	3282	.	.	3282
Vgo	253	.	73	326
Fru	103	.	22	125
Tre	90	.	22	112
Vgg	.	.	11	11
Flr	.	.	4	4
TOT	20923	.	1607	22530

Table 6.4 (continued)

Dist:71 WDOMMEL Subd:132
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	14770	.	.	14770
Gra	10611	254	1844	12709
Con	283	.	187	470
Sug	688	.	216	904
Cer	1060	.	.	1060
Cut	3641	.	.	3641
Vgo	145	.	119	264
Vgg	.	.	9	9
Flr	.	.	4	4
TOT	31198	254	2379	33831

Dist:72 NDOMMEL Subd:133
Lo High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	2003	.	.	2003
Gra	2592	.	.	2592
TOT	4595	.	.	4595

Dist:72 NDOMMEL Subd:134
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	11352	.	.	11352
Gra	9361	.	1041	10402
Con	147	.	78	225
Sug	315	.	82	397
Cer	396	.	.	396
Cut	2597	.	.	2597
Vgo	285	.	112	397
Fru	146	.	41	187
Tre	136	.	46	182
Vgg	.	.	21	21
Flr	.	.	5	5
TOT	24735	.	1426	26161

Dist:73 DONGE Subd:135
Lo High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	2894	.	.	2894
Gra	3410	.	350	3760
TOT	6304	.	350	6654

Dist:73 DONGE Subd:136
Hi High LoMeCoS*/LoMeCoSa

CROP	UNSP	SW	GW	TOTAL
Nat	8682	.	.	8682
Gra	6514	.	710	7224
Con	180	.	88	268
Sug	383	.	95	478
Cer	500	.	.	500
Cut	2471	.	.	2471
Vgo	113	.	135	248
Vgg	.	.	14	14
Flr	.	.	4	4
TOT	18843	.	1046	19889

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Summary for region
Southeast Highlands

CROP	UNSP	SW	GW	TOTAL
Nat	207299	.	.	207299
Gra	164837	16553	22252	203642
Con	4718	3015	1863	9596
Sug	19890	110	4079	24079
Cer	29473	56	34	29563
Cut	40575	.	.	40575
Blb	252	.	77	329
Vgo	6910	1868	2326	11104
Fru	4781	1067	792	6640
Tre	1211	.	406	1617
Vgg	.	112	644	756
Flr	.	68	116	184
TOT	479946	22849	32589	535384

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PAWN Region 9:
Markerwaard (Proposed)

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Dist:78 MARKWARD Subd:144
Lowland SaClLoam/(HuLMCS)

CROP	UNSP	SW	GW	TOTAL
Nat	19000	.	.	19000
Gra	1900	950	.	2850
Con	3325	950	.	4275
Cer	19000	.	.	19000
Vgo	1425	.	.	1425
Fru	950	.	.	950
TOT	45600	1900	.	47500

NOTE: Asterisks denote substitution soils. See note to Table 6.5.

national distribution system in the same way. The internal details of surface water movements within a district are regarded as unimportant from a national water management standpoint. The selection of districts for the PAWN analysis was the result of a lengthy discussion between members of the PAWN team and employees of different departments of the Rijkswaterstaat. Proposals were made on the basis of an existing division of the country used by an earlier computer model of the distribution system [6.5], taking into account other relevant divisions such as waterboards, drainage, and water supply regions, etc. After a number of iterations a reasonable compromise was achieved between reality (level of detail) and practical considerations (data available, computational costs). Seventy seven districts were so identified (see Fig. 2.3).

Within the 77 districts we distinguished 143 subdistricts. Within a given district, more than one subdistrict was defined when different soil types existed, when there were different landforms, or when seepage rates were different. The possible soil types were selected from a list of 20 standard soils [6.6]. The allocation of soil types to (parts of) districts was based on soil maps [6.7] and a general knowledge of and experience with the Dutch situation. (See Sec. 6.2.1.) The distinction between lowlands and highlands is relatively easy because the theoretical line dividing the low Northwest from the higher Southeast is well-defined. The low and high highlands were defined on the basis of the average groundwater level. The low highlands is that part of the highlands with an average groundwater level less than one meter below the surface, and the high highlands is the remaining part.

Information about groundwater levels in the form of areas by groundwater table class was provided by the Landinrichtingsdienst (Land Development Department). These data were available by municipality. In total, eight groundwater table classes have been distinguished, each reflecting a certain range of groundwater levels. We assumed the area associated with the first three classes to be the low highlands. The estimates of the low and high parts of the highlands districts were then obtained by summing the low highlands areas for all municipalities in the district. This procedure leads to a very crude approximation of the actual situation.

6.1.4. Urban Area, Surface Water Area and Volume, and "Nature"

Primary Municipality Data. Many steps were taken to derive the data described above. The primary source of the data consists of statistics on land use published by the Centraal Bureau voor de Statistiek (Central Bureau of Statistics, or CBS). The most recently available data at the time we were assembling these files were for 1975, and consisted of a detailed breakdown of all kinds of land uses by municipality. Table B.1 shows these data, aggregated into six broad categories, by municipality.

Urban area represents the CBS category called "city area," consisting partly of gardens, parks, recreational areas, and the like, and not exclusively land that is impervious to the vertical flow of water, as we have defined the term "urban area." On the other hand, the "noncity" data in the CBS statistics do contain land that does qualify as "urban": roads, airports, scattered buildings, etc. We felt it was reasonable to assume that these "mistakes" compensate, so we used the CBS value for "city area" to represent what we call "urban area." The surface water value in the CBS data represents all bodies of water that are wider than 6m. Unfortunately, this area includes some parts of "outside" waters such as the North Sea, the Waddenzee, and some of the estuaries in Zeeland. Moreover, the CBS surface water areas include areas that must be treated by DM (e.g., the major rivers) separately from the districts. For these reasons, we corrected the surface water areas to reflect our needs. Woodland areas were recorded to be included in the "nature" category. The cultivated area provided by CBS in these statistics includes not only the actual cash crops but also ditches, pathways, verges, yards, and scattered buildings around the fields: the so-called "gross" cultivated area.

Derivation of District Data from Municipality Data and Other Sources. Using a map, we determined the fraction of each municipality lying in each district (Table B.2). We assumed first that the various land-use components are homogeneously distributed over the area of the municipality. Using this assumption, we converted the CBS data into data describing the districts, shown in Table B.3. We then made additional changes to the district data. First of all, we corrected the surface water areas to account for the problems involving the nondistrict waters and to include bodies of water narrower than 6m. We consulted maps [6.8] and estimated, for each district, what fraction of the total surface area consisted of bodies of water narrower than 6m--typically this area was estimated to be from 1 percent to 3 percent of the total area. We also used these maps to estimate what part of each district consisted of water in polders, and water in boezems. (This distinction is relevant only in the lowlands.)

The "net" cultivated area (actual cash cropland) by district was obtained from other sources, as described in Sec. 6.1.5. Using the total area of each district, the urban area, the area of the surface water (corrected as described above) and the net cultivated area, we computed a balance term that we called "nature." This term includes woods, heath, marshes, and also such areas as gardens, recreational areas, verges, etc. The area of "woods" and gross cultivated area compiled from the municipality data were not used, but did serve as a rough check on our allocation procedures.

To estimate the volume of the surface water system of each district, we assumed:

- Bodies of water broader than 6 m in polders have an average depth of 1.25 m.

- Other bodies of water broader than 6 m have an average depth of 2 m.
- Bodies of water narrower than 6 m have an average depth of 0.5 m.

The results of the computations of surface water areas and volumes and of "nature" area by district are given in Table B.4. The estimates for water areas and volumes are really very crude, as they are based on simple map observations and conversions, and a number of rough and arbitrary estimates. Therefore for some individual districts fairly large errors should be expected.

6.1.5. Agricultural Data

Detailed information about crop areas by region is collected every year by CBS (e.g., Refs. 6.9 through 6.11). More than 100 different crop types are distinguished in these statistics. Crop inventories are available by province, by municipality, and by two types of agricultural regions: for 14 aggregate regions distinguished by the Landbouw Ekonomisch Instituut (Agricultural Economics Institute) or for a more detailed breakdown of these 14 regions into 122 small agricultural regions. For the primary crop data we used the crop inventory for the 122 agricultural regions for the year 1976 (the most recently available data at the time.) The total areas by crop type were held constant for the entire analysis.

Selection of Crop Types. We aggregated the 100 different crop types treated in the CBS statistics to 13 aggregate "types," taking into account such characteristics as root depth, length and time of the growing season, crop value, susceptibility to drought and salt damage, etc. The 13 types considered are

1. Grass
2. Consumption potatoes
3. Milling potatoes
4. Seed potatoes
5. Sugar beets
6. Cereals
7. Cut corn
8. Bulbs
9. Vegetables grown in open air
10. Pit and stone fruits
11. Ornamental trees
12. Vegetables grown under glass
13. Flowers grown under glass

Grass alone makes up 60 percent of all cultivated area. Potatoes and sugar beets make up almost entirely the CBS category "tuber and root crops." Because of differences in value and growing season a distinction between consumption, milling, and seed potatoes is needed. Other tuber and root crops are not considered separately, and are allocated proportionally across the three kinds of potatoes and sugar beets. Cut corn represents the CBS category "green fodder," of which cut corn actually comprises 97 percent of the entire category. "Cereals" is the name we give to all the remaining CBS "arable" crops, 83 percent of which are actually cereals.

What we call "bulbs" includes all open-air flower production, although bulbs comprise 93 percent of this category. Pit and stone fruits comprise a "pure" CBS category; apples and pears are by far the most important individual crops. The crop type "ornamental trees" includes the CBS categories "tree cultures" and "perennial plants." "Vegetables grown in open air" includes all the remaining horticultural categories, including vegetables, seed onions, small fruits, and horticultural seeds. Vegetables make up almost 70 percent of this group, but there are many different types.

Vegetables and flowers under glass are almost pure CBS categories. The categories "trees and fruits under glass" are included in these two crop types, but they make up less than 2 percent of the area containing glasshouse crops.

Primary Crop and Irrigation Data. The primary crop data shown in Table B.5 were compiled from CBS statistics. The entry called "other" reflects the temporarily unoccupied cultivated land (i.e., fallow land.)

Table B.6 contains primary information about irrigated areas in 1976. The data in this table are obtained from an inquiry carried out by ICW [6.12]. The table contains crop areas broken down by three main crop groups (grass, arable crops, and horticultural crops), four types of irrigation (sprinkling from surface water, sprinkling from groundwater, surface irrigation from surface water, surface irrigation from groundwater), and the 122 agricultural areas. As we mentioned in Sec. 2.3.2, we did not make a distinction between sprinkling and surface irrigation.

Conversion of Crop and Irrigation Data to PAWN Districts. Using a map, we estimated what fraction of the crop area of each of the 122 agricultural regions fell in each district. We also estimated what fraction of the land irrigated from surface water and what fraction of the land irrigated from groundwater fell in each district. These three fractions are given in Table B.7. Because some parts of an agricultural region may or may not have access to good quality surface water or groundwater, we could not assume that irrigated areas are distributed homogeneously over the agricultural region. Based on very crude information [6.13] about surface water supply possibilities and groundwater availability, the conversion fractions for total crop areas were adjusted at several places to obtain a more realistic allocation of sprinkled areas.

Conversion of Crop and Irrigation Data to Subdistricts. The 143 subdistricts that were distinguished are described in Table B.8. The conversion of the district crop and irrigation data to subdistricts was very difficult, and some arbitrary choices were made. From the conversion of crop areas to PAWN districts we knew what crop areas in the districts came from what agricultural regions. In most cases a unique soil type from the range of standard soils that were used in defining the subdistricts could be associated with each of the 122 agricultural regions. In subdistricts that were distinguished because of differences in soil types, crops could be assigned to these subdistricts by considering the soil types of the agricultural regions that contributed to the district. In addition, a few simple rules were used: only grass grows in peat soils, potatoes grow in clay soils rather than sand, etc. Allocating crops to subdistricts that were distinguished only by landform was more difficult. We used more or less arbitrary rules of thumb. For example, we assumed grass, consumption and seed potatoes, and horticultural crops were more likely to be found in the low parts of the highlands than the high parts, while crops like milling potatoes, cereals, sugar beets, and cut corn would be found in the higher parts.

The irrigation data for subdistricts were obtained in more or less the same way. Knowing the contribution of each of the 122 agricultural regions to the total surface water and groundwater sprinkled area of a district, we found it relatively easy to allocate these irrigation data to subdistricts distinguished by soil type. For allocations to the low and high parts of the highlands, we assumed surface water sprinkling occurred in the low parts, groundwater sprinkling in the high parts.

In allocating crop and irrigation areas to the subdistricts, we tried to avoid creating many small areas in many places. Small crop and irrigation areas within a district were allocated to only one subdistrict and were sometimes moved to a nearby district containing a larger area of the same crop and sprinkling type.

The results of these conversion procedures are given in Table B.9. This table shows the vegetation areas for the 143 subdistricts broken down into four main categories: nature, grass, arable crops, and horticultural crops. The non-nature area is broken down further into the 13 crop types. Sprinkled areas from both surface water and groundwater are given only for the three major open-air crop groups, grass, arable crops, and horticultural crops, as the ICW inquiry did not contain information about individual crop types.

Selection of Plots. A plot is an area with a single crop type, soil type, drainage characteristic, and sprinkling condition. Except for crop and sprinkling type, all these properties are associated with the subdistrict. In Table B.9 the areas devoted to each crop and the total sprinkled area broken down into three major categories are given for each subdistrict. It is a relatively small step to define the plots from this table. What needs to be done is to allocate the sprinkled areas to individual crop types within the two categories containing more than one crop: the arable crops and the horticultural crops.

We assigned weights to the arable crops and the horticultural crops that reflected the likelihood that the crop would be sprinkled. These weights were based on a mixture of crude data and practical considerations derived from discussions with agricultural experts.

For arable crops on nonsandy soils, we know that milling potatoes, sugar beets, cereals, and cut corn are hardly ever sprinkled. Therefore, we assigned sprinkling weight zero to these crops. We assumed a given hectare of seed potatoes would be twice as likely to be sprinkled as a given hectare of consumption potatoes, since seed potatoes are roughly twice as valuable as consumption potatoes.

For arable crops on sandy soils, we know that milling potatoes, sugar beets, and cereals are sometimes sprinkled. Using relative crop values, we estimated that milling potatoes and sugar beets were about a third as likely to be sprinkled as seed potatoes, and cereals a tenth as likely. It is not regarded as very likely that cereals are ever sprinkled, but cereals represent a number of crops, so we assigned a small positive sprinkling weight to this crop type.

For horticultural crops the same set of weights was applied to all soils. The weights were based on information provided by Reinds and Van Hemert [6.14]. An overview of the irrigation weights by crop group is given in Table B.10.

The allocation of sprinkled areas to crop types was the final step in deriving the basic agricultural data. However, the initial number of plots was very large, and many of the plots were very small. Simple aggregation routines were applied to combine the smaller plots with more or less comparable larger ones. The final results of these manipulations are shown in Table 6.4.

6.2. SOIL AND CROP PARAMETERS

The plot water, plot salt, and plot damage models, explained in Chaps. 4 and 5, use a number of parameters that depend on the soil types and the crop type of the plot. We will describe the files and the sources of these parameters in this section. To organize our discussion, we will first discuss those parameters that depend only on the soil types, then those that depend only on the crop type, and finally those that depend on both the soil type and the crop type.

6.2.1. Soil Types and Soil Parameters

Selecting Soil Types. A map has been published containing as many as 156 different soil types in the Netherlands [6.7]. To make our computer implementation practical, we needed to select a rather limited number of soil types, based on the following criteria:

- Data about any soil type selected must be available.
- Different soil types should be distinguished if properties that affect water requirements and groundwater/surface water interactions are significantly different.

Papers by Rijtema [6.6] and Bloemen [6.15] contain a full description of 20 homogeneous standard subsoils. We matched each of the 156 soil types in the above-mentioned map to a root zone and subsoil type chosen from this list of 20. Initially, only nine different soil types and 16 different root zone/subsoil combinations were selected.

In some places, the root zone soil and the subsoil are technically of the same type. However, we found that in some of these places we were unable to accurately estimate capillary rise, because the subsoil was in fact inhomogeneous (e.g., clay lenses). In such places, we assumed a different subsoil type, although we used the parameters associated with this subsoil only for calculating capillary rise. For other calculations, we used the properties of the root zone soil.

We discovered that the soil moisture capacity of the root zone soil types described by Rijtema were considerably lower than those estimated by an interim report of SWLT [6.16]. Apparently, the properties reported by Rijtema hold only for subsoils, and root zone properties are generally different because of cultivation activities and the presence of roots and organic materials. The moisture-holding capacities of Rijtema's soils seemed to be lower than the capacities estimated by SWLT by a factor of 1.5 for sandy soils, and by a factor of from 2 to 3 for clay soils.

To adjust for this problem, we changed the parameters affecting the root zone soil moisture retention properties for three sand soils and three clay soils. Because the 20 soil types in Rijtema's paper were the only soils for which complete data were easily available, we used these data. For each of the 6 soils that we wanted to change, we selected a substitute from the 20 soil types in Rijtema's paper that improved the moisture retention properties by the necessary amount, but which still had a pF-curve of roughly the same shape.

The soil types and root zone/subsoil combinations that were finally used are presented in Table 6.5, together with the total surface area of each combination. Soil types marked with an asterisk are the ones that received substitute root zone properties. Subsoil types placed between parentheses are those for which only the properties governing capillary rise are used.

Soil Parameters. For each plot, the plot water model (PLOTWAT), described in Chap. 4, requires 15 parameters characterizing the root zone/subsoil combination of the plot. These parameters are contained in three input files, SOILFIL, COEFFIL, and SCAPFIL, which are described in Table 6.6. Each of the three files contains 26 records, one for each soil type. Although only 9 soil types were actually used, data from all 20 soil types in Rijtema's paper were placed in these files, and the 6 additional soil types described above were added later.

Table 6.5

SOIL TYPE IDENTIFIERS AND AREAS

ROOT ZONE SOIL TYPES		SUBSOIL TYPES		TOTAL AREA
SHORT FORM	LONG FORM	SHORT FORM	LONG FORM	
21 LoMeCoS*	Loamy medium coarse sand*	7 LoMeCoSa	Loamy medium coarse sand	1372605
24 LiteCla*	Light clay*	-5 (HuLMCS)	(Hum. loamy med. coarse sand)	409106
13 Loam	Loam	-6 (LiLMCS)	(Light loamy med. coarse sand)	229743
20 Peat	Peat	20 Peat	Peat	221621
14 SaClLoam	Sandy clay loam	-5 (HuLMCS)	(Hum. loamy med. coarse sand)	185581
22 HuLoMCS*	Hum. loamy med. coarse sand*	7 LoMeCoSa	Loamy medium coarse sand	95712
26 BasnCla*	Basin clay*	19 BasinCla	Basin clay	79311
26 BasnCla*	Basin clay*	20 Peat	Peat	73910
23 LiLoMCS*	Light loamy med. coarse sand*	-6 (LiLMCS)	(Light loamy med. coarse sand)	69687
13 Loam	Loam	13 Loam	Loam	58167
25 SiltCla*	Silty clay*	-5 (HuLMCS)	(Hum. loamy med. coarse sand)	46650
26 BasnCla*	Basin clay*	-18 (SanCla)	(Silty clay)	43659
25 SiltCla*	Silty clay*	18 SiltClay	Silty clay	27412
23 LiLoMCS*	Light loamy med. coarse sand*	-5 (HuLMCS)	(Hum. loamy med. coarse sand)	12684
25 SiltCla*	Silty clay*	-19 (BasCla)	(Basin clay)	8166
21 LoMeCoS*	Loamy medium coarse sand*	21 LoMeCoS*	Loamy medium coarse sand*	4330

Substitutions (marked with *) are:

Original	Substituted
LoMeCoS*	Hum. loamy med. coarse sand
LiLoMCS*	Hum. loamy med. coarse sand
HuLoMCS*	Laom
LiteCla*	Loess loam
SiltCla*	Loess loam
BasnCLa*	Loess loam

Table 6.6

SOIL CHARACTERISTICS DATA FILES

File	Field	Column	Format	Description	Source Code Identifier	Documentation
SOILFIL				SOIL MOISTURE PARAMETERS		
	1	1- 2	F(2)	Index of soil type	ISOIL	
	2	4-19	A(16)	Name of soil		
	3	20-27	F(8,5)	The parameter ALHPA (1/mm)	SOIL.DATA.ALPHA (ISOIL)	ALPHA
	4	28-35	F(8,1)	The parameter K-null (mm/day)	SOIL.DATA.KNULL (ISOIL)	KNULL
	5	36-43	F(8)	The parameter PSI-A (mm)	SOIL.DATA.PSIA (ISOIL)	PSIA
	6	44-51	F(8)	The parameter PSI-max (mm)	SOIL.DATA.PSIX (ISOIL)	PSIX
	7	52-69	F(8,3)	Saturation capacity, (ratio)	SOIL.DATA.SATCAP (ISOIL)	SATCAP
	8	70-77	F(8,3)	Wilting point (ratio)	SOIL.DATA.WILTPT (ISOIL)	WILTPT
COEFFIL				SOIL MOISTURE RELATIONSHIPS		
	1	1- 2	F(2)	Index of soil	ISOIL	
	2	4-19	A(16)	Name of soil		
	3	20-29	F(10,5)	Parameter A for pf-curve relation	SOIL.EMP_COEFS.PF_A (ISOIL)	PF_A
	4	30-39	F(10,5)	Parameter B for pf-curve relation	SOIL.EMP_COEFS.PF_B (ISOIL)	PF_B
	5	40-49	F(10,5)	Parameter A for deficit relation	SOIL.EMP_COEFS.DEF_A (ISOIL)	DEF_A
	6	50-59	F(10,5)	Parameter B for deficit relation	SOIL.EMP_COEFS.DEF_B (ISOIL)	DEF_B
	7	60-69	F(10,5)	Parameter C for deficit relation	SOIL.EMP_COEFS.DEF_C (ISOIL)	DEF_C
	8	70-79	F(10,5)	Parameter D for deficit relation	SOIL.EMP_COEFS.DEF_D (ISOIL)	DEF_D
SCAPFIL				CAPILLARY RISE PARAMETERS		
	1	1- 2	F(2)	Index of subsoil type	ISOIL	
	2	3-12	F(10,4)	Parameter A1	SOIL.SIMCAP.A1 (ISOIL)	A1
	3	13-22	F(10,4)	Parameter A2	SOIL.SIMCAP.A2 (ISOIL)	A2
	4	23-32	F(10,4)	Parameter A3	SOIL.SIMCAP.A3 (ISOIL)	A3

The 15 soil parameters (other than root depth) associated with each combination are listed in Table 6.7. The definitions of the parameters and the way they are used are explained in Chaps. 4 and 5. We point out that the parameters ALPHA, KNULL, PSIA, PSIX, A1, A2, and A3 depend on the subsoil type; the parameters SATCAP, WILTPT, PF_A, and PF_B depend on the root zone soil type; the parameters DEF_A, DEF_B, DEF_C, and DEF_D depend on the root zone soil type for some combinations (those for which the subsoil type is enclosed in parentheses) and on the subsoil type for others.

The parameters contained in the file SOILFIL are all taken from Rijtema [6.6]. The parameters in the file COEFFIL are used to evaluate the functions F_{PSI},F_{THETA}, and F_{GWL} described in Sec. 5.3, while the parameters in the file SCAPFIL are used to evaluate the function $F_{CAPRISE}$. We have already explained how these parameters were obtained (in Sec. 5.3.1).

6.2.2. Crop Parameters

In Sec. 6.1.5 we explained how 13 different crop "types" were selected for the agricultural analysis. Three data files contain data for these crop types, described in Table 6.8. VALUFIL contains crop values in thousands of guilders per hectare. CFACFIL contains crop factors, relating potential evapotranspiration to open water evaporation. The parameters of the crop damage model for both drought and salt damage are contained in DAMFIL.

Crop Values. An overview of the crop types, their total areas, and values for both an average and an extremely dry year are given in Table 6.9. Crop values for an average year were obtained from actual data for the year 1975. The values for the extremely dry year were based on observations for the actual year 1976. Other files have been created for years of still different dryness, based on an interpolation between the average and extremely dry year described here. Appendix A describes how crop values were obtained and how the interpolation was carried out.

Crop Factors. Crop factors by crop and decade are displayed in Table 6.10. For open-air crops, the potential evapotranspiration is obtained by multiplying the open water evaporation by the appropriate crop factor. For those crops that are only in the field during the growing season, a "crop factor" for bare soil is used outside the growing season. For glasshouse crops, the crop factor is the potential evapotranspiration (mm/day). Initial estimates for these crop factors were obtained from Hellings [6.17] and other sources and were revised after discussions with the agricultural experts of SWLT.

Damage Parameters. In Sec. 4.4 we explained how the damage parameters are used. Estimates for these parameters were generally not readily available. Using information from the literature on the subject

Table 6.7

SOIL PARAMETERS FOR SOIL COMBINATIONS ACTUALLY USED

ROOT ZONE	SUBSOIL	ALPHA	KNULL	PSA	PSX	SATCP	WILTP	PF_A	PF_B	DEF_A	DEF_B	DEF_C	DEF_D	A1	A2	A3
Loam	(LiLMCS)	0.00562	23.0	0	1000	0.503	0.098	-0.08648	1.94209	100.78629	2.33365	1.98963	0.38597	16.9946	-3.0581	2.2208
Loam	Loam	0.00231	50.0	0	3000	0.503	0.098	-0.08648	1.94209	100.78629	2.33365	1.98963	0.38597	0.0000	0.0000	0.0000
SaClLoam	(HuLMCS)	0.00269	10.0	0	1650	0.432	0.180	1.04189	3.07906	148.55872	3.80685	4.42919	0.48018	13.2363	-2.4253	2.7775
Peat	Peat	0.01045	53.0	0	500	0.863	0.265	1.91696	6.59880	143.76340	1.34404	9.79020	0.58426	13.0549	-2.5847	2.4742
LoMeCoS*	LoMeCoSa	0.00378	3.6	0	1350	0.470	0.105	1.55011	6.16259	132.50705	3.15460	12.39992	0.47965	11.7474	-2.2596	1.5369
LoMeCoS*	LoMeCoS*	0.00269	10.0	0	1650	0.470	0.105	1.55011	6.16259	158.31252	2.34407	7.26849	0.55901	13.2363	-2.4253	2.7775
HuLoMCS*	LoMeCoSa	0.00378	3.6	0	1350	0.503	0.098	-0.08648	1.94209	132.50705	3.15460	12.39992	0.47965	11.7474	-2.2596	1.5369
LiLoMCS*	(LiLMCS)	0.00562	23.0	0	1000	0.470	0.105	1.55011	6.16259	158.31252	2.34407	7.26849	0.55901	16.9946	-3.0581	2.2208
LiLoMCS*	(HuLMCS)	0.00269	10.0	0	1650	0.470	0.105	1.55011	6.16259	158.31252	2.34407	7.26849	0.55901	13.2363	-2.4253	2.7775
LiteCla*	(HuLMCS)	0.00269	10.0	0	1650	0.455	0.110	-0.12173	1.70523	111.29831	2.75169	3.31224	0.49605	13.2363	-2.4253	2.7775
SandCla*	(BasCla)	0.00380	2.2	0	800	0.455	0.110	-0.12173	1.70523	111.29831	2.75169	3.31224	0.49605	7.7295	-1.7664	2.1518
SandCla*	(HuLMCS)	0.00269	10.0	0	1650	0.455	0.110	-0.12173	1.70523	111.29831	2.75169	3.31224	0.49605	13.2363	-2.4253	2.7775
SandCla*	SandClay	0.00480	13.0	0	500	0.455	0.110	-0.12173	1.70523	269.84424	3.72048	15.76823	0.55924	8.2912	-1.7268	2.8249
BasnCla*	(SanCla)	0.00480	13.0	0	500	0.455	0.110	-0.12173	1.70523	111.29831	2.75169	3.31224	0.49605	8.2912	-1.7268	2.8249
BasnCla*	BasinCla	0.00380	2.2	0	800	0.455	0.110	-0.12173	1.70523	275.43921	4.81669	42.94133	0.54083	7.7295	-1.7664	2.1518
BasnCla*	Peat	0.01045	53.0	0	500	0.455	0.110	-0.12173	1.70523	143.76340	1.34404	9.79020	0.58426	13.0549	-2.5847	2.4742

Table 6.8

CROP CHARACTERISTICS DATA FILES

File	Field	Column	Format	Description	Source Code Identifier	Documentation
VALUFIL				VALUES OF CROPS		
	1	1- 2	F(2)	Index of crop	ICROP	
	2	4-11	A(8)	Crop name		
	3	12-18	F(7,2)	Value of crop (thousands of Dfl/ha)	VALDATA.CROP_VALUES (ICROP)	CROP_VALUE
CFACFIL				CROP FACTORS		
	1	1- 3	F(3)	Index of crop	ICROP	
	2	5-12	A(8)	Crop name		
	3	25-28	F(4)	Crop factor code	CROP.CFAC_CODE (ICROP)	
	4-40	29-172	36 F(4)	Crop factors, per decade (IDEC)	CROP.CROPFACTOR (ICROP,IDEC)	CROPFACTOR
DAMFIL				CROP DAMAGE MODEL PARAMETERS		
	Record 1					
	1	1- 5	F(5)	Index of crop	ICROP	
	2	6-10	F(5)	Reduction point	DAMAGE.WATER.REDUC_POINT (ICROP)	REDUCE_POINT
	3	11-15	F(5)	Death point	DAMAGE.WATER.DYING_POINT (ICROP)	DYING_POINT
	Record 2					
	1	1- 5	F(5)	Index of crop	ICROP	
	2-15	6-185	F(5)	Reduction damage, per decade (IDEC)	DAMAGE.WATER.COEF.REDUC_DAM (ICROP,IDEC)	REDUC_DAM
	Record 3					
	1	1- 5	F(5)	Index of crop	ICROP	
	2-15	6-185	14 F(5)	Remaining yield, per decade (IDEC)	DAMAGE.WATER.COEF.REMAIN_YIELD (ICROP,IDEC)	REMAIN_YIELD
	Record 4					
	1	1- 5	F(5)	Index of crop	ICROP	
	2-15	6-185	14 F(5)	Death damage, per decade (IDEC)	DAMAGE.WATER.COEF.DYING_DAM (ICROP,IDEC)	DYING_DAM
	Record 5					
	1	1- 5	F(5)	Index of crop	ICROP	
	2	6-10	F(5)	Minimum salt concentration	DAMAGE.SALT.MIN_CONC (ICROP)	MIN_CONC
	3	11-20	F(10)	Salt damage slope parameter	DAMAGE.SALT.DAM_SLOPE (ICROP)	DAM_SLOPE

Table 6.9

CROP TYPE IDENTIFIERS, AREAS, AND VALUES

	CROP TYPE SHORT NAME	DESCRIPTION	AREA	AVERAGE YEAR PRICES		DRY YEAR (1976) PRICES	
			ha	Dfl/ha	Dflm	Dfl/ha	Dflm
0	Nature	"Nature" (everything except cash crops)	928704		0		0
1	Grass	Grass	1252497	3000	3757	5000	6262
2	Conspot	Consumption potatoes	59204	10000	592	16250	962
3	Millpot	Milling potatoes	71625	3830	274	5830	418
4	Seedpot	Seed potatoes	27493	13500	371	20300	558
5	Sugarbt	Sugar beets	127507	5200	663	5200	663
6	Cereals	Cereals (and others)	269986	3150	850	3150	850
7	Cutcorn	Cut corn	89305	3600	321	6000	536
8	Bulbs	Bulbs	13228	27400	362	30140	399
9	Vegopen	Vegetables grown in open air	55657	15600	868	20280	1129
10	Fruit	Pit and stone fruits	30331	10400	315	10400	315
11	Trees	Ornamental trees	4945	42800	212	42800	212
12	Veglass	Vegetables grown under glass	4596	232000	1066	278400	1280
13	Flowers	Flowers grown under glass	3266	485000	1584	412250	1346

Table 6.10

CROP FACTORS

DECADE	NATURE	GRASS	CONSPOT	MILLPOT	SEEDPOT	SUGARBT	CEREALS	CUTCORN	BULBS	VEGOPEN	FRUIT	TREES	VEGLASS	FLOWERS
Jan 1	0.70	0.70	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.50	0.50
2	0.70	0.70	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.50	0.50
3	0.70	0.70	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.60	0.60
Feb 1	0.70	0.70	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.80	0.80
2	0.70	0.70	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.70	0.70	0.70	1.00	1.00
3	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	1.20	1.20
Mar 1	0.70	0.70	0.60	0.60	0.60	0.60	0.60	0.60	0.40	0.70	0.70	0.70	1.50	1.50
2	0.70	0.70	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.70	0.70	0.70	1.80	1.80
3	0.70	0.70	0.40	0.40	0.40	0.40	0.40	0.40	0.60	0.70	0.70	0.70	2.20	2.20
Apr 1	0.80	0.80	0.40	0.40	0.40	0.40	0.40	0.40	0.70	0.80	0.80	0.80	2.60	2.60
2	0.80	0.80	0.30	0.30	0.30	0.30	0.50	0.30	0.70	0.80	0.80	0.80	3.00	3.00
3	0.80	0.80	0.20	0.20	0.20	0.20	0.60	0.20	0.70	0.80	0.80	0.80	3.40	3.40
May 1	0.80	0.80	0.40	0.40	0.40	0.40	0.70	0.40	0.80	0.80	0.80	0.80	3.70	3.70
2	0.80	0.80	0.50	0.50	0.50	0.50	0.80	0.50	0.80	0.80	0.80	0.80	4.00	4.00
3	0.80	0.80	0.60	0.60	0.60	0.60	0.90	0.60	0.80	0.80	0.80	0.80	4.10	4.10
Jun 1	0.80	0.80	0.70	0.70	0.70	0.70	1.00	0.70	0.80	0.80	0.80	0.80	4.20	4.20
2	0.80	0.80	0.80	0.80	0.80	0.80	1.00	0.80	0.80	0.80	0.80	0.80	4.30	4.30
3	0.80	0.80	0.90	0.90	0.90	0.90	0.90	0.90	0.70	0.80	0.80	0.80	4.20	4.20
Jul 1	0.80	0.80	0.90	0.90	0.90	0.90	0.90	0.90	0.60	0.80	0.80	0.80	4.10	4.10
2	0.80	0.80	0.90	0.90	0.90	0.90	0.90	0.90	0.50	0.80	0.80	0.80	4.00	4.00
3	0.80	0.80	0.90	0.90	0.90	0.90	0.80	0.90	0.40	0.80	0.80	0.80	3.80	3.80
Aug 1	0.80	0.80	0.90	0.90	0.10	0.90	0.60	0.90	0.10	0.80	0.80	0.80	3.50	3.50
2	0.80	0.80	0.80	0.80	0.10	0.90	0.30	0.90	0.10	0.80	0.80	0.80	3.20	3.20
3	0.80	0.80	0.70	0.70	0.10	0.90	0.20	0.90	0.10	0.80	0.80	0.80	2.90	2.90
Sep 1	0.80	0.80	0.60	0.60	0.20	0.90	0.20	0.90	0.20	0.80	0.80	0.80	2.70	2.70
2	0.80	0.80	0.50	0.50	0.30	0.90	0.30	0.90	0.30	0.80	0.80	0.80	2.50	2.50
3	0.80	0.80	0.40	0.40	0.40	0.90	0.40	0.90	0.40	0.80	0.80	0.80	2.10	2.10
Oct 1	0.70	0.70	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.70	0.70	0.70	1.70	1.70
2	0.70	0.70	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.70	0.70	0.70	1.30	1.30
3	0.70	0.70	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.70	0.70	0.70	1.00	1.00
Nov 1	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
2	0.70	0.70	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.50	0.50
3	0.70	0.70	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.50	0.50
Dec 1	0.70	0.70	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.50	0.50
2	0.70	0.70	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.50	0.50
3	0.70	0.70	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.50	0.50

(discussed below), we made a complete set of initial estimates and sent them to the Ministry of Agriculture for comments. We then used the comments and suggestions that were returned to change the initial estimates. The final results are listed in Table 6.11.

Recall that for each of the thirteen crop types there are seven data elements, four that are independent of time and three that can vary by timestep. The parameters that are independent of time are:

- The reduction point (RP): the ratio of actual evapotranspiration to potential evapotranspiration (E_A/E_P) where the slope of the drought damage curve changes.
- The dying point (DP): the value of E_A/E_P where maximum drought damage begins to occur.
- The critical salt concentration (MIN): level of the salt concentration in the root zone where salt damage begins.
- The salt damage slope (SD): the amount of salt damage if MIN is exceeded by one unit (mg/l) during one timestep of the growing season.

The time-dependent parameters are:

- The reduction damage (RD): the damage fraction if E_A/E_P is equal to RP.
- The dying damage (DD): the damage fraction if E_A/E_P is equal to DP.
- The remaining potential yield (YELD): the yield that is still to be produced as a fraction of the potential annual yield.

We estimated values for all these parameters for both open-air crops and crops grown under glass. However, since crops grown under glass always receive all the water they need in our analysis, the drought parameters associated with these crops were never used.

Originally, the estimates discussed with the Ministry of Agriculture were made for a timestep of one month. The parameters DP and DD were then estimated for all open-air crops to be 0.2 and 1.0, respectively. These estimates reflected the belief that the entire crop would die if the actual evapotranspiration were less than 20 percent of the potential evapotranspiration for an entire month. When these values were used for timesteps as short as a decade, we found that the damage model predicted far too much damage. Therefore we developed parameters that caused the model, when run for decades, to make monthly estimates consistent with our original intention. Values of 0.0 and 0.7 for DP and DD, respectively, were finally chosen.

Table 6.11

PARAMETERS OF THE DAMAGE MODEL

	GRASS			CONSPOT			MILLPOT			SEEDPOT			SUGARBT			CEREALS			CUTCORN		
Reduction pnt. (RP)		.6			.6			.6			.6			.6			.6			.6	
Death pnt. (DP)		0			0			0			0			0			0			0	
Minimum salt (MIN)		1000			700			700			700			700			1000			1000	
Salt slope (SD)		.000012			.000025			.000025			.000033			.000008			.000017			.000009	
Decade	RD	YELD	DD	RD	YELD	DD	RD	YELD	DD	RD	YELD	DD	RD	YELD	DD	RD	YELD	DD	RD	YELD	DD
Jan 1	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7
2	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7
3	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7
Feb 1	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7
2	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7
3	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7
Mar 1	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7
2	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7
3	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7
Apr 1	.05	1.0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	.01	1	.7	0	0	.7
2	.05	.95	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	.01	1	.7	0	0	.7
3	.05	.89	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	.01	1	.7	0	0	.7
May 1	.05	.83	.7	.01	1	.7	.01	1	.7	.03	1	.7	.04	1	.7	.04	1	.7	.03	1	.7
2	.05	.78	.7	.01	1	.7	.01	1	.7	.03	1	.7	.04	1	.7	.04	1	.7	.03	1	.7
3	.05	.72	.7	.01	1	.7	.01	1	.7	.03	1	.7	.04	1	.7	.04	1	.7	.03	1	.7
Jun 1	.05	.67	.7	.03	1	.7	.03	1	.7	.07	1	.7	.04	1	.7	.08	1	.7	.03	1	.7
2	.05	.62	.7	.03	1	.7	.03	1	.7	.07	1	.7	.04	1	.7	.08	1	.7	.03	1	.7
3	.05	.56	.7	.03	1	.7	.03	1	.7	.07	1	.7	.04	1	.7	.08	1	.7	.03	1	.7
Jul 1	.05	.50	.7	.06	1	.7	.06	1	.7	.07	1	.7	.04	1	.7	.04	1	.7	.06	1	.7
2	.05	.45	.7	.06	1	.7	.06	1	.7	.07	1	.7	.04	1	.7	.04	.80	.7	.06	.90	.7
3	.05	.39	.7	.07	1	.7	.07	1	.7	.07	1	.7	.04	1	.7	.04	.60	.7	.06	.80	.7
Aug 1	.05	.33	.7	.07	.90	.7	.07	.90	.7	.03	.30	.7	.04	1	.7	.04	.40	.7	.06	.70	.7
2	.05	.28	.7	.06	.70	.7	.06	.70	.7	0	0	.7	.04	.80	.7	0	0	.7	.06	.60	.7
3	.05	.22	.7	.06	.50	.7	.06	.50	.7	0	0	.7	.04	.60	.7	0	0	.7	.06	.50	.7
Sep 1	.05	.17	.7	.02	.30	.7	.02	.30	.7	0	0	.7	.04	.50	.7	0	0	.7	.03	.40	.7
2	.05	.12	.7	0	0	.7	0	0	.7	0	0	.7	.04	.40	.7	0	0	.7	.03	.27	.7
3	.05	.06	.7	0	0	.7	0	0	.7	0	0	.7	.04	.30	.7	0	0	.7	.03	.14	.7
Oct 1	0	0	.7	0	0	.7	0	0	.7	0	0	.7	.04	.20	.7	0	0	.7	0	0	.7
2	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7
3	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7
Nov 1	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7
2	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7
3	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7
Dec 1	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7
2	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7
3	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7	0	0	.7

Table 6.11 (continued)

	BULBS			VEGOPEN			FRUIT			TREES			VEGLASS			FLOWERS		
Reduction pnt. (RP)		.6			.6			.6			.6			.75			.75	
Death pnt. (DP)		0			0			0			0			.7			.7	
Minimum salt (MIN)		200			500			1000			250			200			200	
Salt slope (SD)		.000025			.000017			.000006			.000017			.000017			.000017	
Decade	RD	YELD	DD	RD	YELD	DD	RD	YELD	DD	RD	YELD	DD	RD	YELD	DD	RD	YELD	DD
Jan 1	0	0	.7	0	0	.7	0	0	.7	0	0	.7	.008	1	1	.008	1	1
2	0	0	.7	0	0	.7	0	0	.7	0	0	.7	.008	1	1	.008	1	1
3	0	0	.7	0	0	.7	0	0	.7	0	0	.7	.008	1	1	.008	1	1
Feb 1	0	0	.7	0	0	.7	0	0	.7	0	0	.7	.008	1	1	.008	1	1
2	0	0	.7	0	0	.7	0	0	.7	0	0	.7	.008	1	1	.008	1	1
3	0	0	.7	0	0	.7	0	0	.7	0	0	.7	.008	1	1	.008	1	1
Mar 1	.02	1	.7	0	0	.7	0	0	.7	0	0	.7	.008	1	1	.008	1	1
2	.02	1	.7	0	0	.7	0	0	.7	0	0	.7	.008	1	1	.008	1	1
3	.02	1	.7	0	0	.7	0	0	.7	0	0	.7	.008	1	1	.008	1	1
Apr 1	.04	1	.7	.05	.60	.7	.03	1	.7	.02	1	.7	.008	1	1	.008	1	1
2	.04	1	.7	.05	.60	.7	.03	1	.7	.02	1	.7	.008	1	1	.008	1	1
3	.04	1	.7	.05	.60	.7	.03	1	.7	.02	1	.7	.008	1	1	.008	1	1
May 1	.08	1	.7	.05	.60	.7	.03	1	.7	.02	1	.7	.008	1	1	.008	1	1
2	.08	1	.7	.05	.60	.7	.03	1	.7	.02	1	.7	.008	1	1	.008	1	1
3	.08	1	.7	.05	.60	.7	.03	1	.7	.02	1	.7	.008	1	1	.008	1	1
Jun 1	.04	.85	.7	.05	.60	.7	.03	1	.7	.02	1	.7	.008	1	1	.008	1	1
2	.04	.70	.7	.05	.60	.7	.03	1	.7	.02	1	.7	.008	1	1	.008	1	1
3	.04	.55	.7	.05	.60	.7	.03	1	.7	.02	1	.7	.008	1	1	.008	1	1
Jul 1	.02	.40	.7	.05	.60	.7	.03	1	.7	.02	1	.7	.008	1	1	.008	1	1
2	.02	.20	.7	.05	.60	.7	.03	1	.7	.02	1	.7	.008	1	1	.008	1	1
3	0	0	.7	.05	.60	.7	.03	1	.7	.02	1	.7	.008	1	1	.008	1	1
Aug 1	0	0	.7	.05	.60	.7	.03	1	.7	.02	1	.7	.008	1	1	.008	1	1
2	0	0	.7	.05	.60	.7	.03	1	.7	.02	1	.7	.008	1	1	.008	1	1
3	0	0	.7	.05	.60	.7	.03	1	.7	.02	1	.7	.008	1	1	.008	1	1
Sep 1	0	0	.7	.05	.60	.7	.03	1	.7	.02	1	.7	.008	1	1	.008	1	1
2	0	0	.7	.05	.60	.7	.03	.80	.7	.02	1	.7	.008	1	1	.008	1	1
3	0	0	.7	.05	.60	.7	.03	.60	.7	.02	1	.7	.008	1	1	.008	1	1
Oct 1	0	0	.7	.05	.60	.7	0	0	.7	0	0	.7	.008	1	1	.008	1	1
2	0	0	.7	.05	.60	.7	0	0	.7	0	0	.7	.008	1	1	.008	1	1
3	0	0	.7	.05	.60	.7	0	0	.7	0	0	.7	.008	1	1	.008	1	1
Nov 1	0	0	.7	0	0	.7	0	0	.7	0	0	.7	.008	1	1	.008	1	1
2	0	0	.7	0	0	.7	0	0	.7	0	0	.7	.008	1	1	.008	1	1
3	0	0	.7	0	0	.7	0	0	.7	0	0	.7	.008	1	1	.008	1	1
Dec 1	0	0	.7	0	0	.7	0	0	.7	0	0	.7	.008	1	1	.008	1	1
2	0	0	.7	0	0	.7	0	0	.7	0	0	.7	.008	1	1	.008	1	1
3	0	0	.7	0	0	.7	0	0	.7	0	0	.7	.008	1	1	.008	1	1

To estimate RP and RD, we accepted the following principle: if the actual evapotranspiration for the entire growing season is equal to 60 percent of the potential evapotranspiration, then 40 percent of the crop will be damaged. We set RP equal to 0.6, and then computed the values for RD that met this principle. In determining values for RD, we distinguished crops with specific drought sensitive stages from crops without such stages. For crops without such stages, we assumed RD was constant for all timesteps during the growing season. For the other crops, weights were applied to certain timesteps, based on the relative severity of drought over time. For cereals and potatoes, these weights were estimated from information provided by Hellings [6.18]. Estimates for cut corn and bulbs were based on information provided by LEI and the Laboratory for Research on Bulbs, respectively.

The parameters YELD, MIN, and SD are very crop specific, and we made separate estimates for each crop type [6.19-6.34].

6.2.3. Parameters Depending on Soil Types and Crop

For each plot, there are four parameters that depend on the crop type and soil types of the plot. These are contained in two files, RDEPFIL and PSIFIL, which are described in Table 6.12. RDEPFIL contains root depths, and PSIFIL contains soil moisture tension parameters.

Root Depths. Root depths vary with crop type, but also may vary from one soil to the next. Table 6.13 lists the root depths used, and contains a root depth for every root zone soil/crop combination. These depths were estimated with the help of agricultural experts of SWLT.

Soil Moisture Tension Parameters. Two parameters in the file PSIFIL (PSI_ALPHA and PSI_BETA) control the simple sprinkling model described in Sec. 4.2.1. The remaining parameter (PSI_REDUCE) controls the reduction in actual evapotranspiration that occurs as the soil dries out. The value for PSI_REDUCE was selected after a discussion with experts of SWLT--as it turned out, the same value was selected for all crops and all soils. For the sprinkling model, PSI_ALPHA was set equal to PSI_REDUCE, and PSI_BETA was set equal to something close to PSI_ALPHA, thus keeping the soil moisture of the root zone of a sprinkled plot close to the critical level, and varying between narrow bounds.

The program can accept different values of PSI_ALPHA, PSI_BETA, and PSI_REDUCE for different root zone soil types; we used the same values for all soils. We set PSI_ALPHA and PSI_REDUCE equal to 3.7 and PSI_BETA equal to 3.6. (We use millimeters instead of centimeters, the usual unit of measurement for suction. Therefore, the values for PSI_ALPHA and PSI_REDUCE are one unit larger then some readers would expect.)

Table 6.12

PARAMETERS THAT DEPEND ON SOIL AND CROP

File	Field	Column	Format	Description	Source Code Identifier	Documentation
RDEPFIL				ROOT DEPTHS		
	1	1- 2	F(2)	Index of root zone soil type	ISOIL	
	2-16	3-62	14 F(4)	Root depths, per crop type (ICROP)	SOIL.ROOTDEPTH (ISOIL,ICROP)	ROOTDEPTH
PSIFIL				SOIL MOISTURE TENSION PARAMETERS		
	Record 1					
	1	1- 2	F(2)	Index of soil type	ISOIL	
	2-15	3-58	14 F(4,2)	Log of psi alpha per crop (ICROP)	PSIDAT.LOG_PSI_A (ISOIL,ICROP)	LOG_PSI_A
	Record 2					
	1	1- 2	X(2)	Blank		
	2-15	3-58	14 F(4,2)	Log of psi beta per crop (ICROP)	PSIDAT.LOG_PSI_B (ISOIL,ICROP)	LOG_PSI_B
	Record 3					
	1	1- 2	X(2)	Blank		
	2-15	3-58	14 F(4,2)	Log of psi reduce per crop (ICROP)	PSIDAT.LOG_PSI_REDUCE(ISOIL,ICROP)	LOG_PSI_RED

Table 6.13

ROOT DEPTHS (MM) BY SOIL TYPE

ROOT ZONE	NATURE	GRASS	CONSPOT	MILLPOT	SEEDPOT	SUGARBT	CEREALS	CUTCORN	BULBS	VEGOPEN	FRUIT	TREES	VEGLASS	FLOWERS
LoMeCoS*	300	300	400	400	400	400	400	400	300	300	400	300	300	300
LiteCla*	300	300	400	400	400	800	800	800	300	300	600	300	300	300
Loam	300	300	400	400	400	700	700	600	300	300	600	300	300	300
Peat	300	300	400	400	400	800	800	800	300	300	600	300	300	300
BasnCla*	300	300	400	400	400	800	800	800	300	300	600	300	300	300
SaClLoam	300	300	400	400	400	800	800	800	300	300	600	300	300	300
HuLoMCS*	300	300	400	400	400	800	800	800	300	300	600	300	300	300
LiLoMCS*	300	300	400	400	400	800	800	800	300	300	600	300	300	300
SandCla*	300	300	400	400	400	800	800	800	300	300	600	300	300	300

6.3. SPRINKLING PARAMETERS

Sprinkling parameters are contained in two files. COSTFIL contains parameters from which the cost of sprinkling can be computed. SPRFIL contains the parameters of the sprinkling procedure described in Chap. 5 of Vol. XIII. These files are described in Table 6.14.

The cost of sprinkling a plot depends on the crop type, whether the plot lies in the lowlands or the highlands, and, if the plot lies in the highlands, whether the water is taken from the surface or the ground. Costs also vary with region, because type and size of farms vary with region and hence, type and size of sprinkler installation used. We assigned each subdistrict to one of 14 LEI agricultural regions, as shown in Table B.11. Volume XIII explains how data describing these regions were used to obtain our sprinkling cost parameters. Both energy and labor cost parameters are displayed in Table 6.15.

The file SPRFIL contains two parameters for each root zone/crop combination. They are displayed in Table 6.16. Volume XIII explains how these parameters were derived.

6.4. BASIC DRAINAGE PARAMETERS

As we explained in Sec. 2.1.2, gravity causes water to flow from the saturated zone of the highlands into brooks and streams. The phenomenon is called basic drainage. We assume that in any subdistrict, the rate of basic drainage is a simple function of the groundwater level:

$$\text{DRAINAGE} = \text{CONSTANT} + \text{COEFFICIENT} \times \text{GROUNDWATER LEVEL}.$$

Therefore, we assigned to each highlands subdistrict two basic drainage parameters, the constant and coefficient in the above expression.

It was impracticable to estimate a different pair of parameters for each subdistrict. Instead, we partitioned the highlands into 17 drainage regions based on geohydrologic properties (see Fig. 6.1), and then we divided each drainage region into a "low" part and a "high" part. For each part (low or high) of each drainage region we estimated a single constant and a single coefficient. We describe how we made these estimations below. The parameters so obtained are contained in the file DRANFIL, described in Table 6.17, and displayed in Table 6.18. Each highlands subdistrict was assigned to one of the drainage regions--this assignment is also indicated in Table 6.18.

We estimated the basic drainage parameters in two steps:

Table 6.14

SPRINKLING DATA FILES

File	Field	Column	Format	Description	Source Code Identifier	Documentation
SPRFIL				SPRINKLING MODEL PARAMETERS		
	Record 1					
	1	1- 2	F(2)	Index of soil type	ISOIL	
	2-15	3-58	14 F(4,3)	Sprinkling start per crop (ICROP)	SPRDAT.SPR_START (ISOIL,ICROP)	SPR_START
	Record 2					
	1	1- 2	X(2)	Blank		
	2-15	3-58	14 F(4,3)	Sprinkling gift per crop (ICROP)	SPRDAT.SPR_GIFT (ISOIL,ICROP)	SPR_GIFT
COSTFIL				SPRINKLING COSTS		
	Record 1					
	1	1- 2	F(2)	Agricultural index	IACR	
	2	3- 4	F(2)	"Type" of sprinkling (ITYPE)		
	3-15	5-74	14 F(5)	Energy costs per crop (ICROP)	COST.ENERGY_COST (IACR,ITYPE,ICROP)	COST_ENERGY
	Record 2					
	1	1- 2	X(2)	Blank		
	2	3- 4	X(2)	Blank		
	3-15	5-74	14 F(5)	Labor costs per crop (ICROP)	COST.LABOR_COST (IACR,ITYPE,ICROP)	COST_LABOR

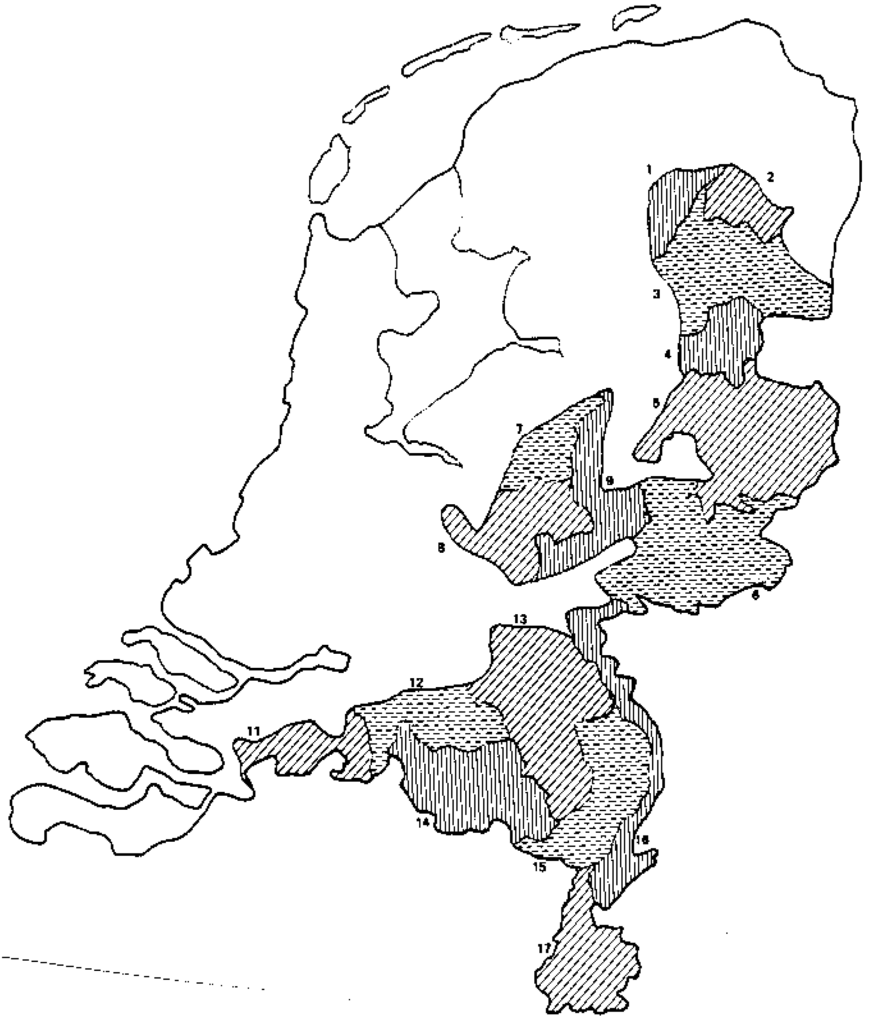

Fig. 6.1--Drainage regions

Table 6.15

SPRINKLING COSTS

AREA	TYPE	GRASS		CONSPOT		MILLPOT		SEEDPOT		SUGARBT		CEREALS		CUTCORN		BULBS		VEGOPEN		FRUIT		TREES	
		EN	LA	EN	LA	EN	LA	EN	LA	EN	LA	EN	LA	EN	LA	EN	LA	EN	LA	EN	LA	EN	LA
NorthSeaClay	Low	704	591	651	655	0	0	633	737	0	0	0	0	0	0	584	1075	564	1199	555	1062	0	0
	HiSW	665	1026	659	869	0	0	604	1072	0	0	0	0	0	0	352	1844	355	1809	614	919	0	0
	HiGW	661	1031	655	886	0	0	655	886	0	0	0	0	0	0	335	1888	346	1808	611	915	0	0
H-IJ Polder	Low	665	452	661	476	0	0	641	593	0	0	0	0	0	0	597	958	638	800	627	965	0	0
	HiSW	735	383	653	711	0	0	635	798	0	0	0	0	0	0	642	831	593	1118	562	783	0	0
	HiGW	735	384	710	455	0	0	657	694	0	0	0	0	0	0	632	900	587	1121	738	815	0	0
SW Sea Clay	Low	532	1213	574	1005	0	0	480	1521	0	0	0	0	0	0	594	988	561	1177	562	1102	361	2050
	HiSW	563	1203	612	915	0	0	510	1344	0	0	0	0	0	0	651	686	615	809	337	1676	347	2083
	HiGW	558	1233	610	918	0	0	596	978	0	0	0	0	0	0	642	724	604	874	327	1670	343	2038
River Clay	Low	620	784	618	830	0	0	0	0	653	658	0	658	0	0	0	0	344	2122	359	1729	345	2384
	HiSW	600	1091	572	1148	0	0	0	0	657	831	0	831	0	0	0	0	349	2068	332	1749	363	2187
	HiGW	597	1098	581	1100	0	0	0	0	654	834	0	834	0	0	0	0	325	2226	319	1759	331	2399
Loess	Low	460	1723	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	HiSW	345	2102	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	HiGW	328	2133	336	2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NorthPasture	Low	659	458	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	HiSW	661	630	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	HiGW	659	633	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West Pasture	Low	723	547	713	625	0	0	666	769	0	0	0	0	0	0	585	1096	583	1101	0	0	377	2374
	HiSW	691	993	767	786	0	0	656	1095	0	0	0	0	0	0	353	1836	360	1733	0	0	359	2499
	HiGW	688	998	764	792	0	0	651	1104	0	0	0	0	0	0	342	1835	340	1811	0	0	365	2410
North Sand	Low	614	812	727	623	0	0	727	623	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	HiSW	584	1130	869	493	0	0	869	493	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	HiGW	580	1136	868	494	868	494	868	494	0	0	0	0	0	0	0	0	309	2153	0	0	0	0
East Sand	Low	532	1208	620	966	0	0	0	0	620	966	0	966	0	0	0	0	0	0	0	0	0	0
	HiSW	562	1200	612	1237	0	0	0	0	612	1237	0	1237	0	0	0	0	0	0	0	0	0	0
	HiGW	569	1175	765	797	765	797	602	1289	765	797	765	797	0	0	0	0	316	2081	0	0	347	2542
Central Sand	Low	541	1193	0	0	0	0	0	0	0	0	584	0	0	0	0	0	0	0	506	1409	0	0
	HiSW	347	1944	0	0	0	0	0	0	0	0	566	0	0	0	0	0	0	0	550	975	0	0
	HiGW	339	1954	0	0	685	808	0	0	685	808	685	808	0	0	0	0	0	0	588	846	0	0
South Sand	Low	532	1202	480	1570	0	0	0	0	567	1071	567	1071	0	0	0	0	354	2125	352	1840	0	0
	HiSW	560	1208	337	2181	0	0	0	0	339	2060	339	2060	0	0	0	0	333	2004	334	1730	0	0
	HiGW	557	1222	332	2057	0	0	0	0	332	2057	332	2057	0	0	320	1798	308	2128	324	1724	333	2373
Peat	Low	620	779	0	0	784	489	784	489	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	HiSW	607	1082	0	0	907	475	907	475	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	HiGW	604	1088	0	0	906	477	906	477	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rest of NH	Low	741	568	657	664	0	0	657	664	0	0	0	0	0	0	352	2059	581	1084	358	1734	0	0
	HiSW	813	644	717	428	0	0	717	428	0	0	0	0	0	0	353	1871	636	746	332	1741	0	0
	HiGW	811	648	716	425	0	0	716	425	0	0	0	0	0	0	333	1970	634	738	323	1730	0	0
Rest of SH	Low	0	0	0	0	0	0	0	0	0	0	0	0	0	0	340	2211	582	1123	0	0	0	0
	HiSW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	350	2126	356	1788	0	0	0	0
	HiGW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	324	2303	346	1787	0	0	0	0

NOTES: EN: Energy costs (Dflm/mm)/ha. LA: Labor costs (Dflm/mm/ha.

Table 6.16

START-GIFT SPRINKLING MODEL PARAMETERS

SOIL/PARAMETER	CROPS										
	GRASS	CONSPOT	MILLPOT	SEEDPOT	SUGARBT	CEREALS	CUTCORN	BULBS	VEGOPEN	FRUIT	TREES
Loamy medium coarse sand*											
"START"	0.293	0.225	0.265	0.265	0.275	0.270	0.270	0.270	0.245	0.245	0.245
"GIFT"	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.030	0.030	0.030
Light clay*											
"START"	0.232	0.190	0.205	0.205	0.220	0.205	0.205	0.205	0.205	0.190	0.210
"GIFT"	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.030
Loam											
"START"	0.205	0.230	0.230	0.245	0.225	0.225	0.225	0.215	0.215	0.210	0.215
"GIFT"	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.030	0.025
Peat											
"START"	0.575	0.590	0.590	0.590	0.590	0.590	0.590	0.590	0.590	0.590	0.590
"GIFT"	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.030	0.025
Basin clay*											
"START"	0.232	0.190	0.205	0.205	0.220	0.205	0.205	0.205	0.205	0.190	0.210
"GIFT"	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.030
Sandy clay loam											
"START"	0.245	0.265	0.265	0.275	0.240	0.240	0.240	0.260	0.245	0.265	0.260
"GIFT"	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.030	0.025
Hum. loamy med. coarse sand*											
"START"	0.248	0.205	0.230	0.230	0.245	0.225	0.225	0.225	0.215	0.215	0.210
"GIFT"	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.030
Light loamy med. coarse sand*											
"START"	0.293	0.225	0.265	0.265	0.275	0.270	0.270	0.270	0.245	0.245	0.245
"GIFT"	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.030	0.030	0.030
Silty clay*											
"START"	0.232	0.190	0.205	0.205	0.220	0.205	0.205	0.205	0.205	0.190	0.210
"GIFT"	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.030

NOTE: Asterisks denote substitution soils. See note to Table 6.5.

Table 6.17

BASIC DRAINAGE FILE

File	Field	Column	Format	Description	Source Code Identifier	Documentation
DRANFIL				BASIC DRAINAGE PARAMETERS		
	1	1- 2	F(2)	Index of drainage region	IDRAN	
	2	3-11	F(9,4)	Constant term in low highlands	DRAN.DATA.BD_CON (IDRAN,1)	BD_CON_LOW
	3	12-21	F(10,4)	Coefficient term in low highlands	DRAN.DATA.BD_COEF (IDRAN,1)	BD_COEF_LOW
	4	22-30	F(9,4)	Constant term in high highlands	DRAN.DATA.BD_CON (IDRAN,2)	BD_CON_HI
	5	31-40	F(10,5)	Coefficient term in high highlands	DRAN.DATA.BD_COEF (IDRAN,2)	BD_COEF_HI

Table 6.18

BASIC DRAINAGE REGIONS AND PARAMETERS

DRAINAGE REGION 1

	LOW HIGHLANDS		HIGH HIGHLANDS	
CONSTANT	2.5707		2.694	
COEFFICIENT	-0.0024565		-0.0008353	
DISTRICT	SUBD	AREA	SUBD	AREA
1 FRIELAND			6	13335
9 WESKWART			18	11824
13 VOLENHOV			26	7602
TOTAL		0		32761
				32761

DRAINAGE REGION 2

	LOW HIGHLANDS		HIGH HIGHLANDS	
CONSTANT	5.6378		3.5222	
COEFFICIENT	-0.0051499		-0.0013156	
DISTRICT	SUBD	AREA	SUBD	AREA
8 NWDRENTE			16	23768
TOTAL		0		23768
				23768

DRAINAGE REGION 3

	LOW HIGHLANDS		HIGH HIGHLANDS	
CONSTANT	2.3517		4.2825	
COEFFICIENT	-0.0016139		-0.0015113	
DISTRICT	SUBD	AREA	SUBD	AREA
11 SEDRENTE	20	16773	21	25032
12 SWDRENTE			23	51228
TOTAL		16773		76260
				93033

DRAINAGE REGION 4

	LOW HIGHLANDS		HIGH HIGHLANDS	
CONSTANT	1.7559		3.4464	
COEFFICIENT	-0.0010133		-0.0009749	
DISTRICT	SUBD	AREA	SUBD	AREA
16 OVIJVECT	31	9980	32	29920
TOTAL		9980		29920
				39900

DRAINAGE REGION 5

	LOW HIGHLANDS		HIGH HIGHLANDS	
CONSTANT	2.801		2.9499	
COEFFICIENT	-0.0022557		-0.0008026	
DISTRICT	SUBD	AREA	SUBD	AREA
17 DINKEL	33	5732	34	17002
18 TWENTHE	35	26160	36	49035
19 SALLAND			38	15102
20 TWENTKAN	40	5553	41	11098
TOTAL		37445		92237
				129682

DRAINAGE REGION 6

	LOW HIGHLANDS		HIGH HIGHLANDS	
CONSTANT	2.394		2.855	
COEFFICIENT	-0.0013541		-0.0009509	
DISTRICT	SUBD	AREA	SUBD	AREA
24 BERKEL	47	17308	48	52454
25 OUDEIJSL			50	41687
TOTAL		17308		94141
				111449

Table 6.18 (continued)

BASIC DRAINAGE REGIONS AND PARAMETERS

DRAINAGE REGION 7

	LOW HIGHLANDS		HIGH HIGHLANDS	
CONSTANT	2.1435		4.6126	
COEFFICIENT	-0.0025006		-0.0024429	
DISTRICT	SUBD	AREA	SUBD	AREA
29 NWVELUWE	56	37131	57	15802
TOTAL		37131		15802 52933

DRAINAGE REGION 8

	LOW HIGHLANDS		HIGH HIGHLANDS	
CONSTANT	2.9729		2.0262	
COEFFICIENT	-0.0027422		-0.0002356	
DISTRICT	SUBD	AREA	SUBD	AREA
28 SWVELUWE	54	50018	55	33432
41 KROMRIJN			77	17574
TOTAL		50018		51006 101024

DRAINAGE REGION 9

	LOW HIGHLANDS		HIGH HIGHLANDS	
CONSTANT	2.9839		6.0378	
COEFFICIENT	-0.0028935		-0.0007109	
DISTRICT	SUBD	AREA	SUBD	AREA
23 NEVELUWE	45	11394	46	22940
27 SEVELUWE	52	4874	53	11246
TOTAL		16268		34186 50454

DRAINAGE REGION 10

	LOW HIGHLANDS		HIGH HIGHLANDS	
CONSTANT	2.3828		2.8199	
COEFFICIENT	-0.0023534		-0.0011528	
DISTRICT	SUBD	AREA	SUBD	AREA
TOTAL		0		0 0

DRAINAGE REGION 11

	LOW HIGHLANDS		HIGH HIGHLANDS	
CONSTANT	1.6546		2.5745	
COEFFICIENT	-0.000983		-0.0006746	
DISTRICT	SUBD	AREA	SUBD	AREA
74 MARK	137	7074	138	40099
75 ROSENDAL			140	15799
TOTAL		7074		55898 62972

DRAINAGE REGION 12

	LOW HIGHLANDS		HIGH HIGHLANDS	
CONSTANT	2.1399		2.4782	
COEFFICIENT	-0.0019739		-0.0008619	
DISTRICT	SUBD	AREA	SUBD	AREA
56 DENBOSCH			106	13059
72 NDOMMEL	133	4595	134	26161
73 DONGE	135	6654	136	19889
TOTAL		11249		59109 70358

Table 6.18 (continued)

BASIC DRAINAGE REGIONS AND PARAMETERS

DRAINAGE REGION 13

		LOW HIGHLANDS		HIGH HIGHLANDS	
CONSTANT		1.7866		2.7892	
COEFFICIENT		-0.0014588		-0.0009587	
DISTRICT		SUBD	AREA	SUBD	AREA
61	MASKANTE	112	7818	113	31751
62	MASKANTW	115	4427	116	6532
63	AA	117	20234	118	60438
TOTAL			32479		98721
					131200

DRAINAGE REGION 14

		LOW HIGHLANDS		HIGH HIGHLANDS	
CONSTANT		2.2237		2.431	
COEFFICIENT		-0.0016728		-0.0009689	
DISTRICT		SUBD	AREA	SUBD	AREA
69	EDOMMEL	128	6949	129	20763
70	MDOMMEL	130	5611	131	22530
71	WDOMMEL			132	33831
TOTAL			12560		77124
					89684

DRAINAGE REGION 15

		LOW HIGHLANDS		HIGH HIGHLANDS	
CONSTANT		3.4167		2.037	
COEFFICIENT		-0.00241		-0.0003959	
DISTRICT		SUBD	AREA	SUBD	AREA
64	DEPEEL	119	6710	120	38143
68	MLIMBURG	126	7383	127	29670
TOTAL			14093		67813
					81906

DRAINAGE REGION 16

		LOW HIGHLANDS		HIGH HIGHLANDS	
CONSTANT		1.4571		1.8978	
COEFFICIENT		-0.0005723		-0.0002773	
DISTRICT		SUBD	AREA	SUBD	AREA
59	RECMAASN			110	5752
60	RECMAASM			111	10250
65	RECMAASS	121	5719	122	17143
66	ROERMOND	123	1622	124	14534
TOTAL			7341		47679
					55020

DRAINAGE REGION 17

		LOW HIGHLANDS		HIGH HIGHLANDS	
CONSTANT		0		3.0465	
COEFFICIENT		0		-0.0002304	
DISTRICT		SUBD	AREA	SUBD	AREA
67	SLIMBURG			125	58167
TOTAL			0		58167
					58167

1. We determined representative groundwater levels for both high and low parts of the 17 drainage regions.
2. We estimated the drainage parameters by "calibrating" the plot water model so that it accurately replicated these groundwater levels.

In step 1, we obtained bimonthly groundwater level data from 224 wells from the period 1953-1977 [6.35]. We assigned each of these 224 wells to one of the 17 drainage regions. Wells with an average groundwater level less than 100 cm below the soil surface were assigned to the "low" part of the drainage regions, and the remaining wells were assigned to the "high" part. Thus, we obtained 34 sets of measured groundwater levels, with several individual wells in each set. Within each set, the individual observations were averaged to obtain a "representative" time series of groundwater levels for the part (low or high) of the drainage region to which the set of measurements belonged.

In step 2, we developed a special version of the plot water model that read the groundwater measurements developed in step 1 as data, and calculated the basic drainage as a balance term after all other water flows were calculated. We ran this model for the years 1967 through 1976, and we obtained a time series of groundwater levels (measured) and amounts of drainage (computed) for each part of each drainage region. From this time series, we calibrated the model by estimating the drainage parameters using ordinary least squares regression.

The correlation coefficient between measured groundwater levels and calculated drainage was not very high. Analysis showed that the groundwater levels computed by the plot water model were not very sensitive to changes in the slope of the basic drainage function, as long as the parameters were chosen so that the model correctly predicted long-term average groundwater levels. We used this fact to make some adjustments in the derived basic drainage parameters in order to obtain better water flow calculations in some districts. We will discuss these adjustments in Chap. 7.

It is important to note that by calculating the basic drainage as a balance term, after all other flows are calculated, the drainage includes all terms not otherwise accounted for. In particular, basic drainage includes extractions of groundwater by industries and drinking water companies. If we assume these extractions are not affected by changes in the groundwater level, then we can suppose they are embedded in the constant term (α) of our basic drainage function.

If we had used information about groundwater extractions by industries and drinking water companies to estimate the basic drainage parameters, the constant term would have been different, and we would have had to account for these extractions explicitly in the model. However, if these extractions are constant over the year, and if the extracted groundwater is ultimately discharged into the surface water of the district from which it is drawn (both reasonable assumptions), then dealing explicitly with these extractions would have led to exactly the same computations as we now obtain.

Industrial and drinking water company extractions can be specified as inputs to DISTAG. When we want to deal with situations in which these extractions are different from what they were when the parameters of the basic drainage equations were estimated, we can adjust the parameters by specifying the differences (positive or negative) from the present case.

Agricultural extractions from groundwater (for sprinkling) that are not constant over time are dealt with by an explicit term in the calculation of water balances, the term I_NET in the description of the "core" model of Sec. 5.3.

6.5. EXTERNAL SUPPLY

We use the term external supply to denote certain time-varying quantities that are governed by climate rather than by Dutch water management. These factors include precipitation, open water evaporation, river discharges, and salt loads at the Dutch border. DISTAG uses only rain and open water evaporation.

Each district is assigned to one of fourteen weather stations; we explain these assignments in Sec. 6.5.1. External supply data are read from a file called ESFILE, described in Sec. 6.5.2. In Sec. 6.5.3 we describe the source of the data, and the manner in which missing data were imputed.

As mentioned in Sec. 2.4, the basic timestep is called a decade. Each month of the year contains three decades; the first two decades are exactly ten days long, and the third contains as many days as are needed to complete the month.

6.5.1. Assignments to Weather Stations

For the purpose of recording, reporting, and analyzing weather data, the Netherlands is partitioned into fifteen regions, shown in Fig. 6.2. Rain and open water evaporation measurements are published for each region [6.36]. The rain data consist of areal averages over many stations in each region. The evaporation data consist of computations based on the Penman formula [6.37] for a single point in each region. We assigned each PAWN district to one weather station using a map supplied by KNMI. One of the KNMI regions consists almost entirely of North Sea islands that were not analyzed by PAWN, so this region was not used.

Table B.12 lists the fourteen weather regions used, and indicates which districts are assigned to each region. The table also gives surface areas.

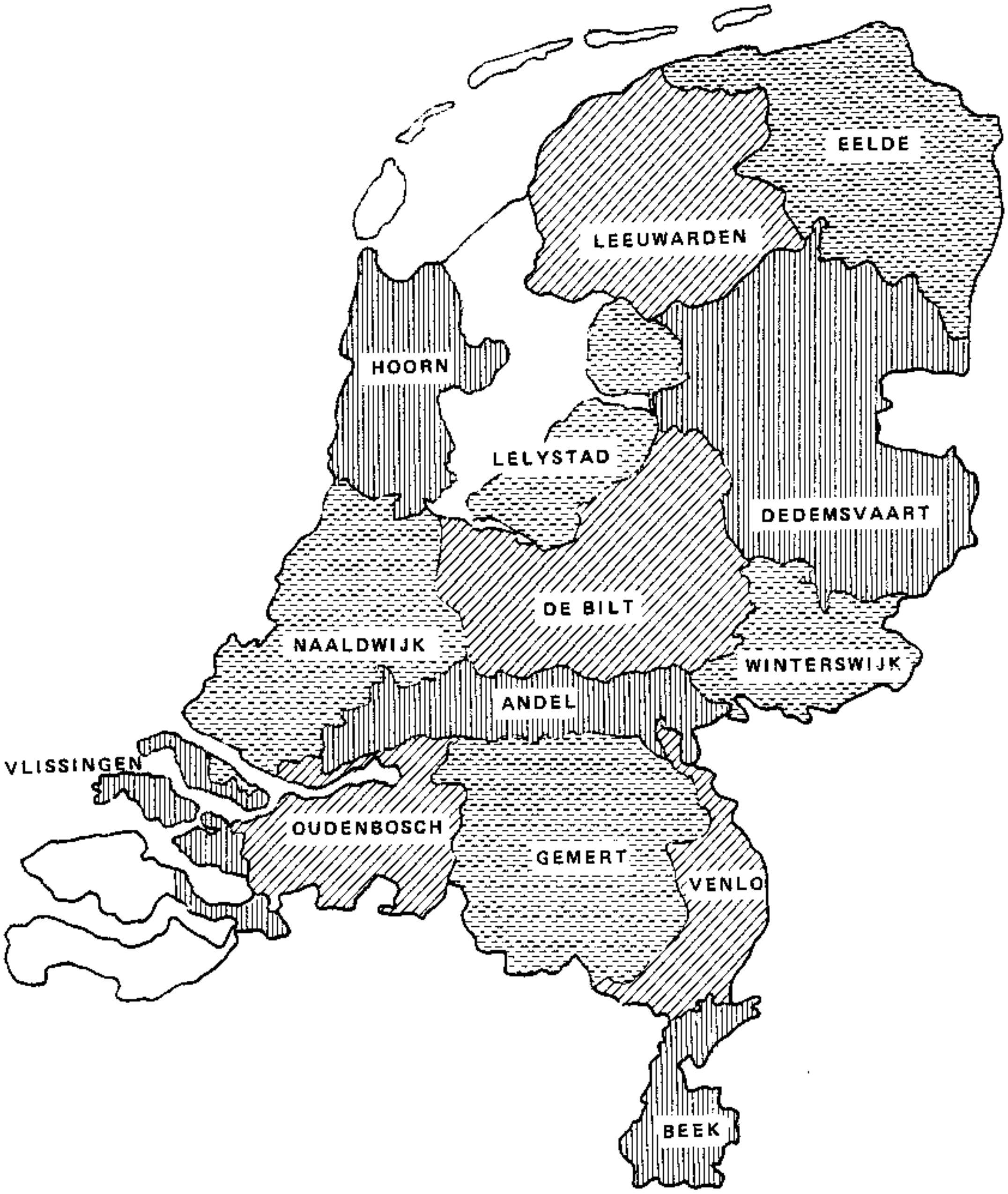

Fig. 6.2--Weather stations

In addition to the areal averages at the fifteen regions, point measurements were available for five weather stations, located near the municipalities of den Helder, Vlissingen, Maastricht, Groningen, and De Bilt. These point measurements were used to impute missing areal measurements, as described below in Sec. 6.5.3. Finally, a synthetic series for the IJsselmeer was available, though never used in the PAWN analysis.

6.5.2. External Supply File

External supply data used by DISTAG--rain and evaporation--are contained in a file called ESFILE, described in Table 6.19. External supply data used exclusively by DM--river discharges, salt concentrations--are described in Vol. XI. ESFILE contains two records for each decade; the first record contains rain data; the second contains evaporation data. In addition to external supply data, each record indicates the year and the number of days in the decade. It also contains two fields, one called period, the other called timestep. For PAWN, both period and timestep were identical to the index of the decade. Two fields allow greater flexibility. For example, they allow us to use files containing mixtures of monthly and decade data.

Each record contains 21 measurements. The first 5 correspond to the 5 stations where point measurements were available. The sixth corresponds to the synthetic IJsselmeer data. The last 15 correspond to the 15 KNMI weather regions.

As mentioned in Vol. I and elaborated in Vol. II, five years were chosen for extensive analysis. The external supply data corresponding to these five years are displayed in Tables 6.20 through 6.24.

6.5.3. Data Sources

Areal rain data for the 15 weather stations were available [6.36] from 1961 through 1978; areal evaporation data were available from 1971 through 1978. Point measurements of rain and evaporation for five stations were available from 1930 through 1975, in the form of a computer tape prepared by RWS [6.5]. We used the station data to impute the regional data for all the years from 1930 through 1978.

To impute the missing regional data, we expressed the rain for each region as a linear combination of the rain at three stations:

$$\mathrm{REGION} = \mathrm{A}\times\mathrm{POINT}_a + \mathrm{B}\times\mathrm{POINT}_b + \mathrm{C}\times\mathrm{POINT}_c$$

where REGION denotes the decade rainfall at a given region, and POINT_x denotes the decade rainfall at station x. The stations were chosen and the coefficients were estimated from the years for

Table 6.19

EXTERNAL SUPPLY FILE

File	Field	Column	Format	Description	Source Code Identifier	Documentation
ESFILE				RAIN AND EVAPORATION DATA		
	Record 1					
	1	1- 1	A(1)	Literal "R" (for "Rain")		
	2	2- 4	F(3)	Year	WEATHER.YEAR	
	3	5- 7	F(3)	Decade	WEATHER.PERIOD	
	4	8-10	F(3)	Decade	WEATHER.TIMESTEP	DECADE
	5	11-13	F(3)	Number of days in decade	WEATHER.NDAYS	NDAYS
	6-25	14-76	21 F(3)	Rain (mm), per station (ISTA)	WEATHER.RAIN (ISTA)	RAIN
	Record 2					
	1	1- 1	A(1)	Literal "E" (for "Evaporation")		
	2	2- 4	F(3)	Year		
	3	5- 7	F(3)	Decade		
	4	8-10	F(3)	Decade		
	5	11-13	F(3)	Number of days in decade		
	6-25	14-76	21 F(3)	Evaporation (mm), per station (ISTA)	WEATHER.EVAP (ISTA)	EVAP

Table 6.20

RAIN AND EVAPOTRANSPIRATION (mm) BY DECADE AND WEATHER STATION FOR EXTERNAL SUPPLY SCENARIO DEX

YEAR: 1976

		Leeuward		Eelde		Hoorn NH		Lelystad		Dedemsv		Naaldwyk		De Bilt		Winters		Andel		Vliss		Oudenbos		Gemert		Venlo		Beek ZL	
		RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV
Jan	1	76	3	78	3	61	8	61	5	72	4	54	8	64	5	58	3	54	6	29	7	38	6	46	5	41	4	32	5
	2	18	3	22	4	13	8	13	6	23	4	14	8	24	4	28	3	19	5	6	6	10	5	17	4	15	3	20	3
	3	23	1	24	1	23	7	17	5	25	2	25	7	22	2	27	1	20	4	24	7	25	5	23	3	29	3	32	3
Feb	1	5	4	2	4	6	7	3	6	2	5	5	8	3	6	2	5	4	8	3	7	2	7	2	7	2	5	1	6
	2	21	5	24	6	16	6	14	6	19	6	12	7	17	6	19	7	12	7	16	5	13	6	14	7	18	8	30	8
	3	2	5	2	5	1	5	1	5	1	5	1	8	1	5	1	5	1	5	1	5	1	5	1	5	1	5	1	5
Mar	1	6	11	7	12	7	14	9	13	9	11	6	14	7	12	5	12	5	14	5	15	4	14	3	13	2	12	2	12
	2	2	12	2	13	7	14	4	14	3	14	14	13	7	13	5	14	11	14	23	12	17	13	10	13	8	14	7	13
	3	14	18	17	20	13	23	16	19	18	21	12	24	20	19	17	20	16	22	11	23	17	24	16	23	13	22	17	23
Apr	1	2	20	4	22	3	23	4	22	7	21	3	23	6	20	7	20	5	22	2	23	3	23	5	20	8	22	8	22
	2	1	24	0	27	1	29	0	28	1	29	2	28	0	30	0	31	2	30	5	28	3	30	1	31	1	33	2	30
	3	2	28	2	31	1	34	2	34	0	30	1	34	1	31	0	31	0	33	1	34	1	34	0	33	0	32	6	30
May	1	7	35	7	37	4	40	7	36	8	38	4	41	5	40	7	42	4	42	3	41	7	44	7	42	8	45	6	43
	2	12	38	14	40	5	43	9	40	14	38	6	43	13	39	14	40	11	40	6	43	9	42	13	42	13	43	18	41
	3	23	33	26	34	7	41	14	44	35	35	10	42	18	38	27	38	16	39	12	43	17	42	20	40	24	38	22	38
Jun	1	7	43	16	42	5	48	4	49	7	43	9	49	9	45	9	44	8	46	4	48	4	48	7	44	8	44	15	42
	2	18	43	20	44	19	46	21	45	20	42	23	44	18	43	12	43	14	46	15	46	13	46	10	45	5	47	1	50
	3	1	61	1	58	2	63	4	61	11	60	6	65	14	65	10	64	12	68	6	64	8	65	6	66	3	68	3	68
Jul	1	0	60	0	63	0	66	0	66	0	64	0	66	0	66	1	66	0	67	0	65	0	66	0	70	0	70	0	66
	2	10	40	15	38	12	42	10	41	17	37	4	44	17	40	22	38	12	41	6	44	9	42	18	40	22	43	20	43
	3	26	40	24	38	27	42	24	48	28	36	26	45	27	35	20	36	18	37	17	47	27	39	15	36	29	37	43	35
Aug	1	15	33	18	31	13	37	12	37	11	31	9	42	12	35	10	34	6	38	7	43	7	40	10	39	12	39	10	35
	2	0	40	0	41	0	40	4	41	10	38	0	43	7	41	4	40	4	43	0	47	0	45	1	44	1	43	1	41
	3	14	38	12	38	12	41	9	45	11	38	7	46	9	43	7	40	7	46	9	50	8	46	12	40	11	43	9	41
Sep	1	37	20	28	21	47	23	35	26	23	20	50	28	28	21	20	20	34	22	44	30	36	24	28	22	23	21	33	23
	2	13	15	13	18	31	18	15	17	9	17	31	18	12	18	9	18	21	18	40	19	37	18	16	18	10	19	13	20
	3	8	14	16	14	14	15	17	15	22	14	15	16	16	17	21	16	14	16	11	16	10	17	21	15	22	17	29	17
Oct	1	21	10	24	9	23	13	17	12	20	12	29	14	17	12	20	11	21	12	31	16	24	13	19	14	18	15	18	15
	2	3	8	12	7	8	12	6	9	12	9	14	11	10	9	11	9	13	11	14	13	16	10	18	10	17	11	12	11
	3	8	5	4	5	13	7	7	6	4	5	10	7	5	6	3	6	7	7	8	7	9	6	4	6	3	7	4	7
Nov	1	23	3	18	4	14	6	13	5	19	4	10	6	19	5	20	4	19	5	14	7	11	5	33	4	40	6	37	6
	2	6	1	5	1	10	2	8	2	7	1	16	2	9	2	11	1	12	2	22	2	19	2	14	1	16	1	14	2
	3	26	3	26	3	25	5	22	4	21	3	26	9	21	3	19	2	21	4	25	7	22	4	21	3	24	4	29	4
Dec	1	52	0	46	0	73	3	54	1	35	1	51	6	41	0	34	1	39	1	37	5	44	0	38	0	32	1	31	1
	2	32	1	42	0	21	2	24	2	32	0	24	2	23	0	22	0	15	1	16	1	14	1	13	1	11	1	13	0
	3	19	0	17	0	18	1	15	1	11	0	22	2	13	0	7	0	14	1	20	2	16	1	10	0	7	1	6	1
TOTALS	(CM)																												
YEAR		55	72	59	73	55	83	49	82	57	74	55	87	53	78	51	76	49	82	49	88	50	84	49	81	50	83	54	81
GS		22	67	24	68	23	74	22	74	26	68	24	77	25	71	23	71	22	74	23	78	24	76	22	74	22	75	26	73

Table 6.21

RAIN AND EVAPOTRANSPIRATION (mm) BY DECADE AND WEATHER STATION FOR EXTERNAL SUPPLY SCENARIO D05

YEAR: 1959

		Leeuward		Eelde		Hoorn NH		Lelystad		Dedemsv		Naaldwyk		De Bilt		Winters		Andel		Vliss		Oudenbos		Gemert		Venlo		Beek ZL	
		RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV
Jan	1	61	3	58	0	61	4	58	4	55	0	59	5	57	0	52	1	52	1	54	6	53	2	50	2	47	2	51	3
	2	26	3	21	1	31	4	27	4	23	1	32	4	27	2	23	3	27	3	29	5	28	3	24	3	19	3	20	4
	3	20	2	20	1	19	3	17	3	17	1	17	3	15	2	16	3	14	2	17	3	16	2	15	3	15	3	17	4
Feb	1	0	1	0	1	0	2	0	2	0	1	0	2	0	1	0	2	0	1	0	2	0	1	0	2	0	2	0	3
	2	1	2	2	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	3	0	3	0	3
	3	5	5	5	5	4	6	5	6	5	5	5	6	6	6	5	6	5	6	5	6	5	6	5	7	4	8	4	8
Mar	1	11	12	11	11	11	15	13	15	14	12	15	13	16	14	15	14	16	14	14	12	16	13	16	16	15	16	17	17
	2	14	11	12	10	14	13	13	13	12	11	15	12	13	12	12	12	13	12	16	12	14	12	13	12	12	12	13	12
	3	26	12	20	12	31	15	28	15	26	13	33	16	31	15	28	16	32	15	27	16	30	15	30	17	27	18	30	19
Apr	1	18	16	19	16	16	18	18	18	19	16	16	19	21	17	18	18	18	18	13	19	16	18	17	20	16	21	17	22
	2	12	29	13	27	12	32	16	31	17	27	18	25	22	28	19	27	22	27	16	24	20	27	20	27	17	27	18	26
	3	20	24	16	21	23	27	20	27	16	22	28	25	18	24	15	25	21	24	34	25	27	24	19	27	12	28	12	29
May	1	12	34	12	31	10	39	10	39	10	33	8	38	9	37	8	35	7	38	8	38	7	37	6	36	6	36	7	34
	2	1	39	1	38	2	44	3	43	6	39	4	41	6	42	9	40	8	42	3	39	8	41	12	42	15	41	20	40
	3	2	42	1	40	2	48	2	48	2	41	2	45	3	46	3	44	3	46	1	43	3	45	3	45	4	45	5	43
Jun	1	6	46	6	44	6	51	6	50	7	44	6	47	7	46	8	44	7	47	7	46	9	46	10	46	11	46	15	44
	2	3	49	6	45	1	57	2	56	3	47	0	55	2	52	2	51	0	53	0	54	0	53	1	54	2	55	2	55
	3	32	46	34	49	27	47	27	46	26	46	22	44	23	46	23	42	18	46	22	42	20	45	18	43	19	41	20	38
Jul	1	16	47	18	45	15	52	18	52	18	45	17	51	21	49	16	48	18	50	12	50	14	49	14	50	11	51	9	50
	2	6	48	7	43	4	55	4	55	5	45	3	54	3	50	3	51	2	51	3	54	2	52	2	54	2	56	2	57
	3	21	44	17	39	25	51	23	50	20	40	29	49	25	44	21	44	26	46	28	49	26	46	22	47	17	48	17	49
Aug	1	13	34	15	31	11	36	16	35	22	30	21	31	23	30	25	29	26	31	24	31	29	30	30	31	32	31	40	31
	2	14	38	7	36	21	41	16	41	15	35	21	41	19	37	20	36	22	38	16	41	21	39	25	37	26	37	33	36
	3	8	38	8	33	7	43	6	42	6	33	5	37	5	36	5	35	4	37	5	37	4	36	3	37	3	37	3	36
Sep	1	0	34	0	31	0	40	0	40	0	33	0	40	0	38	0	38	0	39	0	39	0	38	0	40	0	41	0	41
	2	1	21	1	18	1	26	1	26	0	20	0	28	0	24	0	26	0	25	0	29	0	26	0	28	0	30	0	32
	3	3	20	4	17	2	24	3	24	4	18	4	21	4	21	4	21	4	21	5	21	5	21	5	22	5	23	7	23
Oct	1	0	17	0	16	0	21	0	21	0	18	0	21	0	21	0	21	0	21	0	20	0	21	0	23	0	23	0	24
	2	9	12	9	10	10	15	9	15	8	11	11	16	8	14	8	14	9	15	14	16	11	15	9	15	7	16	8	16
	3	62	15	53	9	68	18	57	17	49	9	60	14	51	10	46	10	47	11	53	15	49	12	44	11	39	11	41	11
Nov	1	25	3	22	2	26	4	23	4	20	2	28	4	21	2	18	3	21	2	31	4	25	3	19	3	14	3	14	4
	2	17	2	17	2	17	4	15	4	14	3	15	5	13	4	13	5	12	4	14	5	13	4	12	6	11	6	12	7
	3	7	1	3	0	11	2	7	2	4	0	9	2	6	1	4	2	6	1	6	2	5	1	5	2	3	2	3	3
Dec	1	7	2	4	2	10	3	8	3	7	2	14	3	9	2	9	2	12	2	18	3	15	2	13	3	10	3	13	3
	2	17	2	15	1	18	3	16	3	14	2	16	3	15	3	13	3	13	3	12	3	13	3	12	3	11	3	12	3
	3	32	3	26	2	36	4	34	4	32	2	43	5	37	3	33	4	40	3	43	5	42	4	38	5	32	6	36	7
TOTALS (CM)																													
YEAR		53	76	48	69	55	87	52	86	50	71	58	83	54	78	49	78	53	80	55	82	55	79	51	82	46	83	52	84
GS		24	68	23	64	24	77	24	77	25	65	27	73	27	71	25	70	27	72	25	72	27	71	27	73	25	74	29	73

Table 6.22

RAIN AND EVAPOTRANSPIRATION (mm) BY DECADE AND WEATHER STATION FOR EXTERNAL SUPPLY SCENARIO D10

YEAR: 1943

		Leeuward		Eelde		Hoorn NH		Lelystad		Dedemsv		Naaldwyk		De Bilt		Winters		Andel		Vliss		Oudenbos		Gemert		Venlo		Beek ZL	
		RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV
Jan	1	29	2	29	0	27	3	28	3	30	0	35	2	31	0	30	0	33	1	40	3	38	1	33	1	30	1	35	1
	2	21	2	20	1	21	3	21	3	19	1	23	2	22	2	19	2	21	2	22	2	21	2	18	3	15	3	16	3
	3	22	5	19	5	24	5	21	5	18	4	24	5	20	4	17	4	20	4	23	5	20	4	17	5	13	5	13	6
Feb	1	33	7	34	6	30	8	31	8	30	6	30	8	30	6	28	6	27	7	30	8	28	7	25	6	23	6	25	6
	2	16	9	16	8	15	9	16	8	17	7	16	8	19	6	18	6	17	7	13	8	16	7	17	7	17	7	19	7
	3	0	4	0	4	0	4	0	4	1	3	1	4	1	3	1	3	1	3	1	4	1	3	1	4	1	4	1	5
Mar	1	1	12	1	11	0	14	1	14	1	11	0	11	1	12	1	11	1	12	0	11	1	12	1	12	2	12	2	11
	2	3	14	4	15	2	14	2	14	3	14	1	14	2	14	2	13	1	14	0	14	0	14	0	14	1	14	0	13
	3	18	20	20	21	15	21	17	21	18	20	14	20	18	21	17	20	14	21	10	19	13	20	14	20	14	20	15	19
Apr	1	23	23	25	21	20	25	23	25	26	21	20	24	27	23	26	22	23	23	15	24	22	23	25	23	27	23	32	22
	2	3	23	4	23	3	25	3	25	5	24	4	28	5	26	6	26	5	27	4	28	5	27	6	27	7	28	9	28
	3	14	33	14	32	13	36	13	36	14	32	14	36	13	34	14	32	13	35	15	36	15	35	14	33	14	33	17	31
May	1	11	39	9	40	12	41	13	41	15	38	19	44	18	39	17	36	21	41	20	44	22	41	21	36	20	35	24	32
	2	4	49	3	48	5	54	4	54	4	48	5	53	4	52	4	50	5	53	5	52	5	52	4	51	3	51	3	49
	3	16	40	16	41	16	40	17	40	19	39	20	44	20	39	20	38	21	41	21	44	22	41	22	39	21	39	25	38
Jun	1	28	33	29	32	27	36	33	36	35	31	40	36	42	33	37	31	43	34	40	36	43	34	40	32	34	31	37	29
	2	43	43	46	41	37	45	40	45	38	39	34	47	38	39	34	38	31	42	29	49	29	43	27	41	26	41	26	41
	3	5	48	5	54	5	40	6	39	8	44	7	40	9	35	9	34	10	37	6	40	9	37	11	35	12	35	15	34
Jul	1	13	38	11	37	14	41	13	40	12	36	15	42	14	37	13	36	14	39	14	42	14	39	13	38	12	38	14	37
	2	13	39	15	38	10	43	12	43	13	38	9	45	12	40	11	40	9	42	8	45	9	42	9	43	10	44	11	45
	3	0	56	0	57	0	57	0	57	3	55	5	50	3	55	5	52	6	54	11	47	10	52	10	53	11	52	15	49
Aug	1	45	32	40	30	48	33	45	33	39	29	50	34	45	29	36	30	42	31	45	35	41	31	34	32	26	33	23	34
	2	14	36	14	34	15	39	16	39	17	34	17	41	20	36	18	36	19	38	13	42	17	38	18	39	17	39	19	40
	3	43	34	50	31	34	36	41	36	43	30	31	34	42	31	39	31	32	32	23	34	29	32	31	33	33	34	34	34
Sep	1	7	26	8	23	5	29	6	29	7	23	6	29	6	25	7	24	5	26	7	30	7	27	7	25	7	25	9	25
	2	8	21	7	19	8	22	10	21	10	18	11	22	12	18	11	19	13	19	10	23	12	20	12	21	11	22	12	23
	3	24	16	19	14	28	17	23	17	23	14	31	17	24	14	25	14	28	15	33	17	32	15	30	14	30	14	37	14
Oct	1	3	15	3	13	3	16	3	16	3	13	4	16	3	13	3	13	3	14	4	16	4	14	3	14	3	14	4	14
	2	8	9	6	9	9	8	8	8	7	8	9	9	8	7	7	7	8	8	8	10	8	8	7	8	6	9	6	9
	3	16	6	12	6	20	6	15	6	13	6	17	7	14	6	13	6	14	6	14	7	14	6	14	7	13	7	15	7
Nov	1	16	4	13	3	19	5	16	5	16	3	23	6	17	4	17	4	20	5	27	7	24	5	21	5	18	5	21	6
	2	33	2	28	1	37	3	30	3	26	1	42	4	27	2	24	2	30	2	51	4	39	3	28	3	21	3	22	3
	3	39	4	34	1	43	6	40	6	38	1	44	6	43	2	39	2	42	3	37	7	40	4	41	3	38	3	43	3
Dec	1	9	0	8	0	10	0	10	0	10	0	14	0	12	0	11	0	13	0	15	0	15	0	13	1	11	1	12	1
	2	18	0	17	0	20	1	18	1	17	0	21	2	18	0	16	0	18	0	21	2	19	1	17	1	15	1	17	1
	3	10	1	10	0	10	2	10	2	9	0	10	1	9	0	8	0	8	0	9	1	8	0	7	1	6	1	5	1
TOTALS	(CM)																												
YEAR		61	74	59	72	60	79	60	78	61	69	67	79	65	71	60	69	63	74	64	80	65	74	61	73	57	73	63	72
GS		34	67	34	66	32	71	34	70	35	64	35	71	37	65	35	63	36	68	33	71	36	67	35	66	34	66	38	65

Table 6.23

RAIN AND EVAPOTRANSPIRATION (mm) BY DECADE AND WEATHER STATION FOR EXTERNAL SUPPLY SCENARIO D50

YEAR: 1967

		Leeuward		Eelde		Hoorn NH		Lelystad		Dedemsv		Naaldwyk		De Bilt		Winters		Andel		Vliss		Oudenbos		Gemert		Venlo		Beek ZL	
		RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV
Jan	1	26	2	27	0	28	2	22	2	22	0	29	2	29	0	25	0	31	1	22	3	29	1	29	0	23	0	30	0
	2	4	2	5	2	4	2	4	2	6	2	4	2	5	1	6	1	3	1	3	2	3	1	4	1	3	1	6	1
	3	29	3	29	3	32	3	23	3	22	3	20	4	20	3	18	3	14	3	18	4	17	3	16	4	18	4	16	5
Feb	1	10	5	11	5	9	4	12	4	12	4	12	4	13	3	11	3	13	3	10	4	12	3	13	3	12	3	14	3
	2	14	7	11	7	16	7	13	7	11	6	15	8	13	6	14	6	10	7	10	9	9	7	10	7	8	8	19	8
	3	38	11	36	11	41	10	41	10	39	10	41	11	38	9	40	9	36	10	41	12	38	10	43	10	33	11	31	11
Mar	1	6	14	6	14	5	13	5	13	7	12	4	12	6	11	10	11	7	11	5	12	6	11	8	12	13	12	16	12
	2	13	17	17	15	8	18	12	17	19	14	12	17	15	13	22	12	17	14	18	18	21	15	22	13	25	13	32	12
	3	39	18	45	16	28	20	35	20	37	16	35	21	39	16	30	16	30	18	21	22	31	18	27	18	23	18	7	19
Apr	1	20	17	19	16	22	17	22	17	22	15	31	17	28	14	25	14	26	15	26	18	25	15	27	14	28	14	30	14
	2	18	23	23	23	17	23	14	22	11	21	10	21	10	21	5	21	6	21	7	20	9	21	5	22	9	23	9	23
	3	10	30	11	28	8	31	9	31	9	27	5	31	7	27	9	26	5	28	6	31	7	29	7	27	8	27	9	26
May	1	9	32	10	32	14	33	11	32	11	30	10	30	9	29	11	29	10	30	12	30	9	29	13	31	14	32	13	32
	2	39	31	40	29	28	35	31	34	30	30	24	34	28	33	22	33	24	33	19	33	27	33	21	35	21	36	26	36
	3	32	33	25	31	35	37	35	37	34	31	43	34	34	33	36	33	34	34	48	34	48	33	38	35	38	35	32	35
Jun	1	9	33	13	32	8	34	9	33	10	30	4	34	10	30	7	28	4	31	2	34	2	32	4	28	8	28	12	26
	2	1	38	0	39	2	39	2	39	4	37	2	36	4	38	7	36	3	38	0	35	2	37	5	37	9	36	15	34
	3	27	36	25	34	14	38	16	38	33	32	23	36	23	32	31	33	33	33	34	36	46	34	26	36	24	37	34	39
Jul	1	5	42	8	39	3	45	7	44	11	38	7	44	6	39	11	37	7	41	8	44	8	41	10	39	11	38	21	37
	2	26	41	29	40	7	46	23	45	20	41	14	46	17	44	16	44	15	45	22	46	36	45	21	47	26	48	19	49
	3	20	38	19	36	12	42	20	41	17	36	7	39	11	38	11	39	9	38	13	38	16	38	13	42	17	43	6	44
Aug	1	29	34	25	32	21	36	34	36	20	31	26	37	22	32	9	33	13	34	23	38	14	34	16	36	30	37	27	38
	2	41	29	36	26	38	31	48	31	62	24	62	29	66	24	66	24	76	26	61	30	87	26	66	25	42	26	30	26
	3	0	28	0	26	0	32	0	32	0	27	0	33	0	30	0	29	0	31	0	33	0	31	0	31	0	31	0	31
Sep	1	39	24	35	21	47	25	41	25	36	20	42	24	39	19	28	20	24	21	23	25	24	21	16	21	15	22	9	23
	2	35	16	33	14	32	16	30	16	30	13	50	17	28	13	18	13	31	14	28	18	34	15	23	14	21	15	36	15
	3	29	16	17	14	28	17	31	17	30	14	11	17	18	14	37	15	17	15	9	18	9	15	13	17	18	18	27	19
Oct	1	29	17	32	13	30	18	29	18	27	12	23	16	27	12	23	12	19	13	14	17	16	14	19	13	18	14	18	14
	2	48	15	39	12	53	17	46	16	35	11	45	17	37	11	37	12	38	13	37	18	35	14	33	14	28	15	23	16
	3	47	11	36	8	57	12	45	11	25	7	39	12	29	7	16	8	18	8	32	13	23	9	14	9	10	10	20	11
Nov	1	46	7	26	5	77	7	45	7	22	4	71	8	37	4	22	5	39	5	39	9	43	6	37	6	36	7	32	8
	2	12	4	11	2	12	4	11	4	11	2	9	3	13	1	14	1	10	1	7	3	9	2	13	2	18	2	25	2
	3	31	1	33	1	34	1	38	1	46	1	37	2	44	0	40	0	38	0	21	2	30	1	34	0	29	0	35	0
Dec	1	25	4	35	2	34	4	24	4	19	1	41	3	33	0	19	0	28	1	25	4	30	1	34	1	28	1	26	1
	2	22	2	24	0	20	3	16	3	17	0	16	2	18	0	16	0	15	0	13	2	17	1	17	1	16	1	28	1
	3	52	2	44	0	49	3	53	3	52	0	54	5	64	1	56	2	56	2	42	6	50	3	48	2	41	2	58	3
TOTALS	(CM)																												
YEAR		88	68	83	63	87	72	86	71	82	60	88	71	84	61	77	61	76	64	72	72	82	65	74	65	72	67	79	67
GS		45	59	44	56	38	63	43	62	45	54	42	61	42	55	41	55	39	57	38	61	46	57	38	58	40	59	41	59

Table 6.24

RAIN AND EVAPOTRANSPIRATION (mm) BY DECADE AND WEATHER STATION FOR EXTERNAL SUPPLY SCENARIO WEX

YEAR: 1965

		Leeuward		Eelde		Hoorn NH		Lelystad		Dedemsv		Naaldwyk		De Bilt		Winters		Andel		Vliss		Oudenbos		Gemert		Venlo		Beek ZL	
		RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV	RA	EV
Jan	1	33	1	34	0	27	1	31	1	44	0	42	2	50	0	52	0	49	0	56	2	56	1	57	1	50	1	75	1
	2	38	5	43	4	40	6	40	6	45	4	32	3	41	5	38	5	33	4	27	2	30	4	32	6	31	6	36	6
	3	14	1	12	1	10	2	10	2	11	1	13	2	10	2	11	2	11	2	12	2	13	2	11	2	9	2	15	2
Feb	1	5	4	7	3	5	4	5	4	7	3	5	4	7	3	6	3	6	3	3	4	4	3	5	3	6	3	7	3
	2	9	7	14	6	9	7	9	7	13	5	8	7	11	5	11	5	12	6	12	8	11	6	14	5	12	5	18	5
	3	6	4	5	4	6	5	6	5	5	4	3	5	3	4	4	4	3	4	3	5	2	4	2	4	2	4	2	4
Mar	1	2	9	3	7	2	10	2	9	3	7	1	9	2	7	2	7	1	8	1	9	1	8	1	7	1	7	3	7
	2	21	12	20	12	17	14	17	14	12	12	18	13	17	13	10	13	16	13	16	13	13	13	11	15	11	15	14	16
	3	27	14	20	14	28	16	31	16	31	14	39	17	37	15	33	15	35	16	42	17	42	16	31	16	26	17	37	17
Apr	1	18	13	15	13	17	14	17	14	15	13	6	15	10	15	9	16	5	15	2	15	2	15	4	17	4	18	5	19
	2	55	20	62	19	41	21	46	21	53	18	46	23	53	18	54	17	50	20	41	24	43	20	51	17	48	17	61	16
	3	17	22	16	22	21	22	19	21	30	20	21	18	34	18	40	16	23	18	23	18	18	18	31	16	38	16	55	14
May	1	59	25	69	24	50	26	62	26	65	23	69	28	69	24	62	24	71	25	48	28	63	25	51	25	40	25	48	25
	2	9	28	9	26	6	34	7	33	7	28	3	37	5	33	8	32	4	34	2	37	1	35	4	33	6	33	8	32
	3	11	33	16	30	7	36	13	36	24	30	13	36	24	32	17	32	22	33	23	37	17	34	15	34	13	34	26	34
Jun	1	20	31	23	31	16	32	29	31	30	29	18	30	17	29	20	28	19	29	16	29	16	29	25	28	14	28	21	27
	2	51	29	75	29	33	32	63	32	64	29	43	35	72	31	64	31	69	32	36	36	58	33	59	33	50	33	38	33
	3	13	43	18	42	10	45	8	45	11	40	9	46	11	41	12	42	9	43	9	46	6	43	8	46	6	47	7	49
Jul	1	34	35	45	32	27	38	43	37	44	30	34	36	45	30	39	28	40	32	38	37	34	33	25	29	32	28	26	27
	2	11	32	12	31	11	34	19	34	35	31	35	32	43	32	50	30	45	32	44	31	53	32	59	31	92	30	74	28
	3	102	32	91	29	70	36	87	36	93	29	62	37	66	31	72	31	69	33	47	38	53	34	60	33	74	33	72	33
Aug	1	4	35	8	32	8	39	15	38	18	31	20	36	26	32	28	30	29	33	16	37	21	34	28	32	42	31	37	30
	2	0	36	1	35	3	37	1	37	3	33	2	33	4	33	1	31	4	33	7	32	3	33	5	32	9	32	12	30
	3	60	26	44	23	74	29	69	29	51	23	69	31	62	24	41	24	48	26	63	32	63	27	45	25	38	25	46	25
Sep	1	31	22	28	18	54	24	41	24	33	18	77	25	56	19	45	18	51	21	59	26	48	22	52	19	50	19	58	18
	2	8	18	6	16	16	19	6	19	4	16	13	20	5	16	3	16	9	17	17	21	7	18	7	18	7	18	8	19
	3	10	16	4	14	13	17	6	17	4	14	12	20	5	14	0	15	2	16	4	21	2	17	2	17	5	18	14	19
Oct	1	7	12	3	10	10	14	7	14	2	11	9	15	6	12	4	12	8	13	12	16	10	13	5	13	4	14	3	14
	2	9	8	9	6	8	9	9	9	10	6	10	10	8	6	10	7	9	7	10	11	9	8	9	8	8	8	13	9
	3	6	9	6	7	4	10	5	10	5	7	3	11	4	7	4	8	3	8	3	12	1	9	7	9	11	9	11	10
Nov	1	18	5	18	3	20	6	19	6	21	3	23	7	19	3	14	3	16	4	20	8	19	5	11	4	8	4	6	5
	2	7	3	5	1	14	4	12	4	10	1	16	4	15	2	14	2	17	2	11	4	14	3	15	2	14	2	18	2
	3	51	4	45	2	58	5	54	5	57	2	60	7	73	2	79	3	65	4	41	9	51	5	65	3	55	3	52	4
Dec	1	88	4	83	2	86	4	77	4	67	2	97	6	89	2	79	3	93	3	79	7	86	4	89	3	74	3	68	4
	2	40	1	47	1	49	1	58	1	78	1	51	3	83	1	77	1	60	2	46	4	58	2	53	1	45	1	55	1
	3	28	1	25	0	28	2	26	2	27	0	32	3	38	0	36	1	38	1	40	4	39	1	39	1	36	1	53	2
TOTALS	(CM)																												
YEAR		92	60	94	55	90	65	97	65	103	54	101	67	112	56	105	55	104	59	93	68	97	61	99	59	97	59	110	59
GS		56	53	58	50	52	57	60	57	63	49	61	58	66	51	61	50	62	53	55	58	56	54	57	52	61	52	67	52

which both regional and station data were available, using a stepwise multivariate regression procedure. Similarly, we expressed the evaporation at each region as a linear combination of evaporation at two stations, using the same procedure. The estimates are displayed in Table 6.25.

6.6. MISCELLANEOUS PARAMETERS

Table 3.1 listed a number of parameters that are not contained in any of the input files. These parameters are given default values in the program, although the values can be changed without recompiling the program. In this section, we will discuss these parameters and discuss how the values were obtained.

DRAIN_MAXOUT: The maximum amount of basic drainage from the high highlands that drains directly into the distribution system. The reason it was necessary to include this term is explained in Sec. 7.3.1. We set it equal to 60 mm/year, basing this estimate on a comparison of computed and observed flows from the high highlands.

DRAIN_UG: This parameter controls the amount of flushing of the root zone of glasshouse crops. We set it equal to 200 mm/year.

LOAD_RZ: The root zone salt load due to diffuse sources of salt such as fertilizers, pesticides, etc. We set it equal to 6 $mg/m^2/day$ [6.4].

LOAD_SS: The subsoil salt load due to those diffuse salt loads that do not affect the root zone (e.g., salt spread on roads to melt ice). We set it equal to 12 $mg/m^2/day$ [6.4].

RAIN_CONC: The salt concentration of rain. We set it equal to 8 mg/l.

RAIN_SURP: The average rain surplus over the year (the difference between rainfall and evapotranspiration). We set it equal to 250 mm. (Rain and open water evaporation data are reported in Ref. 6.38. We assumed an average crop factor of 0.8.)

SPR_EFF: The sprinkling efficiency factor, the amount of sprinkling that actually enters the root zone divided by the amount extracted for that purpose. We set it equal to 0.85 [6.39].

SPR_EVAP: The fraction of the "lost" sprinkling water that evaporates (the remaining "lost" water soaks into the subsoil). We set it equal to 0.4 [6.39].

SPRINK_CAPACITY: The maximum amount of sprinkling that can be applied to any sprinkled field per unit of time. Based on Dutch sprinkling system characteristics, we set it equal to 4 mm/day.

Table 6.25

COEFFICIENTS FOR IMPUTING RAIN AND EVAPORATION DATA FOR REGIONS FROM POINT MEASUREMENTS

	Point Measurement Stations				
	Den Helder	Vlissingen	Maastricht	Groningen	De Bilt
Precipitation					
KNMI Region					
De Kooy	0.6627	0.0838		0.2253	
Leeuwarden	0.2901			0.4992	0.1997
Eelde	0.0378			0.8031	0.1178
Hoorn NH	0.5286			0.1418	0.3056
Lelystad	0.1924			0.3495	0.4261
Dedemsvaart			0.1697	0.4384	0.3582
Naaldwijk	0.2279	0.3026			0.4960
De Bilt			0.1086	0.2519	0.6541
Winterswijk			0.2893	0.2631	0.4038
Andel		0.1752	0.1804		0.6179
Vlissingen	0.0779	0.7071			0.1951
Oudenbosch		0.4165	0.2111		0.3787
Gemert		0.1588	0.4087		0.3930
Venlo			0.6072	0.0987	0.2085
Beek ZL			0.8853	0.0313	0.1129
Evaporation					
KNMI Region					
De Kooy	1.0000				
Leeuwarden	0.3968			0.6004	
Eelde				1.0000	
Hoorn NH	0.5512				0.4944
Lelystad	0.5188				0.5258
Dedemsvaar				0.5520	0.4189
Naaldwijk		0.7697			0.2500
De Bilt					1.0000
Winterswij			0.2915		0.6781
Andel		0.2234			0.7879
Vlissingen		1.0000			
Oudenbosch		0.3640			0.6378
Gemert		0.5075			0.5100
Venlo		0.6931			0.3262
Beek ZL		1.0000			

URB_CONC: The salt concentration of water that is discharged from urban areas. We set it equal to 50 mg/l.

VOLRZ_UG: The "active" volume of the root zone used to make salt balance computations for glasshouse crops. Because of the almost complete control of the root zone soil moisture, we assumed this to be a constant volume, estimated equal to 150 mm.

VOLSS_UG: The "active" volume of the subsoil used to make salt balance computations for glasshouse crops. This volume was also assumed to be constant and was estimated to be 500 mm. The effect of this parameter on the computed surface water salt concentration is very limited.

SSDEPTH: The "active" subsoil depth for the purpose of making salt balance calculations for open-air crops. We set it equal to 1000 mm, based on inspection of the behavior of the model.

In addition to the variables described here, there are a number of others. Some of these are related to the sprinkling model that is described in Vol. XIII. The remaining ones have to do with the control of the computer program (number of iterations, tolerances, etc.) and since they have nothing to do with the physical modeling, we will not discuss them.

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Chapter 7

EVALUATION OF DISTAG

Any model approximates reality. It may be very accurate in some respects, and very inaccurate in others. In this chapter we report on the accuracy of DISTAG. The chapter should be read by people interested in judging the accuracy of the PAWN results, as well as by readers interested in technical aspects of DISTAG.

7.1. INTRODUCTION

Throughout PAWN, we continually reexamined and attempted to improve DISTAG. Data and parts of models were changed many times, although not all problems were solved in a completely satisfactory way. While much time was devoted to testing the model, we lacked sufficient time and data to do a complete validation and sensitivity analysis. This chapter contains only a limited discussion of these matters.

In many instances, we were helped by Dutch agricultural experts, contacts with whom were coordinated by the Ministry of Agriculture and Fisheries. Contacts with the agricultural experts of SWLT[1] were especially important.

DISTAG computes many quantities. Since it was developed for the PAWN analysis, it should be more accurate for quantities that are critical to the PAWN analysis. In areas where PAWN is less concerned, the accuracy of DISTAG is less important. We discuss the quantities for which high accuracy is desired in Sec. 7.1.1.

There are three standards by which we evaluate DISTAG:

- Theoretical basis of the model.
- Comparisons between computations and actual measurements.
- Sensitivity of results.

These three standards are defined more completely in Sec. 7.1.2 through Sec. 7.1.4.

7.1.1. Where Should DISTAG Be Accurate?

As Vol. I describes in much more detail, PAWN is a study of the national water management system of the Netherlands. It emphasizes the nation as a whole, not local regions, and considers time intervals of about a year. Therefore DISTAG needs to make accurate estimates when the estimates are aggregated over rather large regions and long intervals of time.

The specific estimates made by DISTAG and used by PAWN are:

- Discharges into and extractions from the nodes of the distribution system.
- Salinity in each district.
- Crop damage over large regions.
- Groundwater levels, averaged for the year and for large geographical regions.
- Sprinkling quantities and costs.

In this chapter, we will discuss the accuracy of the first four of these five estimates. The fifth estimate , sprinkling quantities and costs, is discussed in Vol. XIII.

7.1.2. Theoretical Basis of the Model

A model is theoretically sound if it is based on well-accepted and appropriate physical laws. (Alternatives to such a model include strictly empirical ones, or models based on statistical analyses.)

When practical, a theoretically sound model is preferable to an empirical or statistical one. First, such a model provides better insights. Second, it gives more reliable results when it is applied to situations for which no measurements of the real world exist, either because the measurements have never been taken or because the new situation has never before existed.

On the other hand, a model based purely on theory can have two disadvantages. First of all, such a model may need more data than can be gathered. Second, it may be so complicated that the costs of development and application become too high.

DISTAG is for the most part based on physical laws, but it contains some parts that are largely statistical (e.g., the basic drainage functions) or empirical, and it contains some computational shortcuts. Furthermore, it deals with rather large aggregates, for which the underlying scientific principles can only be regarded as approximations.

In following sections, we will point out those parts of DISTAG that are soundly based on scientific principles, and then we will discuss the uncertainties. We deal with uncertainties in three ways. First, we can sometimes validate the model by comparing its computations with actual measurements. Second, we can calibrate the model (estimate an uncertain parameter) by making similar comparisons. Third, we can examine the sensitivity of its computations to various assumptions. These three aspects, validation, calibration, and sensitivity analysis, are discussed briefly in the next three subsections.

7.1.3. Validation

When a model of some "real world" situation is found to replicate actual measurements of that situation, we say the model is valid. While a valid model is necessary if one is to accept conclusions based on it, it is not sufficient. For example, a strictly statistical model may replicate the real world measurements upon which it is based rather well, but it may be impossible to adapt the model to a new situation. However, a theoretically based, valid model may be expected to produce estimates that are reasonably close to real world measurements for many different situations.

When we compare model results with measured data, we encounter two major difficulties:

- Existing measurements do not always coincide with what is being modeled.
- Measurements are not always available or accurate.

Many of our computational results are highly artificial. They apply to modeling units such as districts, subdistricts, and plots that were specifically defined for the PAWN analysis and cannot always be associated with actual geographical entities. The plot, for example, corresponds to a scattered collection of fields containing the same crop type, and the crop types themselves are mostly aggregates of individual crop types. The surface water system of a district is regarded as a single body of water, but the actual volume of water to which this body corresponds may consist of a collection of ditches and boezems that are not always connected together. Crop damages are expressed as a fraction of an estimated potential annual yield, whereas the actual potential yield varies from year to year. Time-dependent variables are computed as a constant over a timestep of about ten days, while in reality they may vary widely over much shorter intervals.

Actual data are limited, and their accuracy may sometimes be questioned. Flows in the big rivers and major canals are measured frequently and quite accurately, but not so in the smaller waterways and at the less important discharge/extraction points. Estimates of flow volumes may be based on pumping hours or fuel costs, and certain flows are only measured up to the point where unmeasured emergency drainage facilities begin to operate. Small-scale phenemona--infiltration losses from ditches, capillary rise, salt concentration in root zones--are rarely measured, and are sometimes nearly impossible to measure. Crop damage cannot be measured in a way that is fully comparable to our model results, because actual crop production levels depend on things not related to water management circumstances (e.g., damage due to disease, wind, hail, frost, etc.). Much of the available crop price information is based on quantities or values supplied by auctions, and so it is confounded with market effects (e.g., imports, exports, price supports, etc.).

7.1.4. Calibration

DISTAG contains some parameters that do not correspond to well-defined measurements (e.g., the parameters of the damage model). One way to estimate these parameters is to use the model and, by trial and error, find values such that the model results more or less agree with comparable measurements. Such a process is called calibration. All the problems with measured data that were discussed above apply to the use of measurements for calibration. In addition, one is faced with the problem of trusting the calibrated model when it is later used in a different situation.

7.1.5. Sensitivity Analysis of Results

When a model contains uncertain assumptions, we can run the model with alternatives to these assumptions and compare its results. If the results do not change very much under different assumptions, we can use the model believing that the exact assumptions may not matter very much anyway. If the model results are sensitive to assumptions, then we need to treat conclusions derived from the model with caution. Using sensitivity analysis, we may learn how and under what conditions our conclusions will change.

7.2. THEORETICAL BASIS OF THE MODEL

In this section, we will discuss the scientific and technical aspects of the four main classes of DISTAG estimates: discharges and extractions, salinity, crop damage, and groundwater levels.

7.2.1. Discharges and Extractions

Discharges and extractions from a district are computed using the plot water model (PLOTWAT) and DISTAG itelf. We discuss each in turn.

The Plot Water Model. The model treats two layers (root zone and subsoil) in one dimension, and all possible flows between the layers, between the root zone and the atmosphere, and between the subsoil and the surface water system. At its core is the steady state relationship between soil moisture tension at the interface of the root zone and the subsoil, the groundwater level, and capillary rise. This part of the model is based on the model of Rijtema [7.1], which is generally accepted and has been used in several other studies. Actual evapotranspiration is calculated as a function of available root zone soil moisture and potential evapotranspiration. Drainage from the subsoil is based on Darcy's law.

In the course of the PAWN study, one of our colleagues, J. De Haven, suggested that drainage calculations based strictly on Darcy's law using gravitational head differences may seriously underestimate lowlands drainage. This suggestion is discussed in App. C.

We point out several uncertainties embedded in the plot water model.

- Basic drainage in the highlands is treated with a model derived from a statistical analysis of historical data.
- A simple iteration scheme was introduced to compute capillary rise in order to reduce computing costs.
- An empirical function was developed to simplify calculation of capillary rise.

We will discuss these uncertainties below.

Water Flow Calculations in DISTAG. With respect to water flow calculations, DISTAG is largely an administrative model. It uses PLOTWAT to compute plot water flows, adds these flows up, adds in flows to and from the surface water system and the urban area of the district, and computes a net discharge or extraction. Mass balances always hold.

Three assumptions built into DISTAG may be questioned. First, we have assumed that level control is absolute. That means flows into and out of the district are determined in such a way that the volume of water in the district remains constant. In practice, such a situation does not occur everywhere, especially in drought years.

Second, we have assumed that urban runoff is available within the district in which the urban area occurs. In some places, however, this flow goes directly into the national system, or the sea. However, the flow is small, and practically nonexistent in dry periods, when the accuracy of the computations is most critical.

Third, we have assumed that only part of the basic drainage generated in a district is available within that district. The remaining part is assumed to flow out of the district as a groundwater flow, where it eventually ends up in the rivers and bigger streams of the national distribution system. The amount that flows out has been estimated on the basis of measurements of net discharges and extractions from rather large areas and is subject to uncertainty, if not controversy.

7.2.2. Salinity in District Waters

The salinity of the water discharged into the surface water of a district is computed by PLOTSLT using the basic salt model. DISTAG then uses the basic salt model to compute the salinity of the district surface water itself, and then estimates how much salt flows out in the discharged water. The distribution model uses these flows to estimate salinities at nodes.

The Plot Salt Model. The model is quite simple. It assumes salt mixes perfectly in the root zone and in the "active" layer of the subsoil, and uses the basic salt model, described in Sec. 4.3.1. Mass balance is always maintained, so if the inputs to the model are correct, we can only question the time phasing of the outputs.

The size of the "active" volume of the subsoil is uncertain, and its value somewhat affects the rate at which salt passes through the plot. The sensitivity of salt concentrations and damages to this active volume is described in Sec. 7.4.6.

Salt Computations in DISTAG. As with the water flow computations, DISTAG mostly performs a bookkeeping function with salt flows.

The assumption that salt mixes completely in the district waters is probably too simple, because, at least in the lowlands, these waters consist of polder ditches and boezem waters that are not directly connected together, and flow rates are quite different in different places.

7.2.3. Crop Damage

Crop damages are computed only in plots. DISTAG merely adds them up. Therefore, we need to consider only the plot damage model.

The drought damage model is based on two very simple assumptions:

- Drought damage depends primarily on the ratio of actual evapotranspiration over potential evapotranspiration.
- The smaller this ratio, the greater the damage.

Similarly, the salt damage model is based on two assumptions:

- Salt damage depends primarily on the salt concentration of the soil moisture in the root zone.
- Below a certain point, no damage occurs. Above that point, the greater the concentration the greater the damage.

Our damage models are simple implementations of these assumptions. The dynamic simulation over time and the fact that we consider different crops, each with specific features (e.g., growing season, drought sensitive stages), make the model somewhat complex. Much more complex and detailed crop yield models do exist, but they seemed neither feasible nor appropriate for PAWN.

7.2.4. Groundwater Levels

Groundwater levels are computed by PLOTWAT, and averaged over subdistricts by DISTAG. How accurate these levels are depends on how accurate PLOTWAT is in computing them.

The computation of groundwater levels is based on the same theoretical model used to calculate capillary rise. In the lowlands the levels are strongly related to the water levels in the surrounding ditches. In the highlands, they depend on the basic drainage functions, which were estimated by a statistical procedure that used the match between measured and calculated groundwater levels as an estimation criterion.

In order to improve estimates of basic drainage, the basic drainage parameters were changed. In Sec. 7.3.4 we show that the plot water model still gives reasonable estimates of groundwater levels.

There is some question as to whether in the high highlands the dependence of groundwater levels on capillary rise should be maintained. We discuss this problem in Sec. 7.4.3.

7.3. COMPARISONS BETWEEN COMPUTATIONS AND ACTUAL MEASUREMENTS

7.3.1. Water Flow Computations

It is difficult to compare computational results at the level of a plot with measured data because hardly any data exist at this level. Therefore we used DISTAG to evaluate the models on the basis of larger flows.

Water Flows in the Highlands. Section 6.4 describes how we initially estimated the parameters of the basic drainage model. These parameters were later changed, and the ones actually used for the PAWN analysis were developed as follows. In addition, several other changes to the original formulation of DISTAG were made.

When we compared calculated flows with measured flows for a number of small rivers in Drenthe, Overijssel, Gelderland, and Noord-Brabant, using the original basic drainage parameters, we found two serious discrepancies:

- The calculated annual flows were larger than the measured ones.
- The variation of the calculated discharges over the year was not as great as the measured ones--typically computed winter discharges were too small and summer discharges were too big.

After some investigation, we identified several features of the model which, when changed, resulted in lower discharges.

1. We originally assumed that the amount of rain entering the root zone was equal to the amount specified in the external supply data file. In fact, a small fraction of the rain that falls evaporates immediately--the process is called interception. We installed the capability of reducing the rain by a fraction, called the interception fraction.
2. When plants die, they do not transpire, and we had originally reduced the potential evapotranspiration from the land by multiplying it by the survival fraction. However, a small amount of evaporation continues from the surface of the bare soil. We added this evaporation term to our water balance calculations.
3. Not all drainage from a highlands district necessarily flows into the surface water system of the district itself. Instead, it may flow deep underground and enter the surface water system of some other district. We installed a feature in DISTAG that removed a certain constant amount of drainage each timestep, if enough drainage were available. This drainage (called "outside drainage") is passed as an output to the distribution model, so that it can be added to the distribution system where it seems appropriate.
4. The basic drainage functions were recalibrated to cause a stronger variation of discharges over the year. In this recalibration we used the fact that the average computed groundwater levels are not very sensitive to the slope of the basic drainage functions, which enabled us to change the behavior with respect to generated discharges without affecting the computed groundwater levels very much.

Table 7.1 and Figs. 7.1 and 7.2 show the computed and measured discharges for the catchment areas of the Vecht in Overijssel and the Dieze in Noord-Brabant, respectively, for the years 1973 through 1976. The location of these areas is shown in Fig. 7.3. The model still seems to produce too much drainage in the Vecht during dry periods. In the Dieze area, the model seems to underpredict drainage somewhat in dry periods. During wet periods, the model computes discharges that are far larger than the ones observed. However, we can attribute this last observation to the fact that in times of high discharges, emergency drainage facilities were used, and the flows in these facilities were not added to the measurements.

Given the uncertainties that still surround the drainage computations and the fact that in most areas the computed water balances tend to underestimate shortages, special care should be taken in:

- Predicting peak demands in the highlands.

Table 7.1

MEASURED AND COMPUTED DISCHARGES FOR THE VECHT AND DIEZE
(m^3/s)

		-------Vecht-------		-------Dieze-------	
Year	Month	Measured	Computed	Measured	Computed
1973	Jan	7.7	11.0	10.1	10.5
	Feb	30.0	26.2	21.8	28.7
	Mar	22.1	22.5	12.7	24.5
	Apr	23.3	19.8	17.9	23.6
	May	12.5	12.3	13.7	15.3
	Jun	0.5	6.3	7.5	9.4
	Jul	-0.8	7.9	4.5	11.6
	Aug	-0.6	4.6	4.4	3.7
	Sep	1.4	6.5	3.6	5.1
	Oct	9.1	7.6	8.2	6.5
	Nov	14.5	13.9	9.4	9.4
	Dec	39.9	36.8	18.8	24.8
1974	Jan	32.5	33.3	17.7	33.8
	Feb	28.2	27.7	22.4	47.6
	Mar	18.1	19.0	20.2	32.4
	Apr	1.0	10.7	8.5	19.4
	May	-1.8	9.8	8.2	15.6
	Jun	-2.0	6.1	5.3	9.5
	Jul	0.3	5.4	7.0	7.0
	Aug	-1.0	1.5	7.0	3.9
	Sep	0.6	4.1	11.2	9.5
	Oct	7.9	13.8	20.0	20.7
	Nov	74.7	31.5	33.6	48.5
	Dec	58.0	56.2	30.7	78.1

Table 7.1 (continued)

		-------Vecht-------		-------Dieze-------	
Year	Month	Measured	Computed	Measured	Computed
1975	Jan	49.8	49.9	29.1	59.7
	Feb	32.1	35.7	24.5	40.1
	Mar	27.2	29.1	26.5	36.4
	Apr	29.1	31.2	23.3	32.9
	May	12.9	18.1	10.6	18.6
	Jun	0.2	12.2	9.8	18.0
	Jul	-0.2	11.3	6.6	9.6
	Aug	-2.5	5.1	3.9	3.7
	Sep	-1.5	4.6	4.5	4.1
	Oct	-1.1	0.5	5.5	0.5
	Nov	-0.7	4.4	8.6	9.1
	Dec	2.4	5.4	9.9	6.5
1976	Jan	25.2	35.8	22.4	26.8
	Feb	22.4	20.9	16.5	19.9
	Mar	8.9	11.6	10.8	11.1
	Apr	0.2	4.1	8.2	5.0
	May	-3.2	3.7	5.5	4.9
	Jun	-1.5	1.2	2.5	1.2
	Jul	-0.4	1.3	1.6	0.4
	Aug	-1.3	0.5	0.2	-1.8
	Sep	-0.7	2.3	2.8	2.9
	Oct	-2.4	1.2	3.4	2.2
	Nov	-1.3	2.4	5.2	7.7
	Dec	0.4	16.9	8.8	19.7

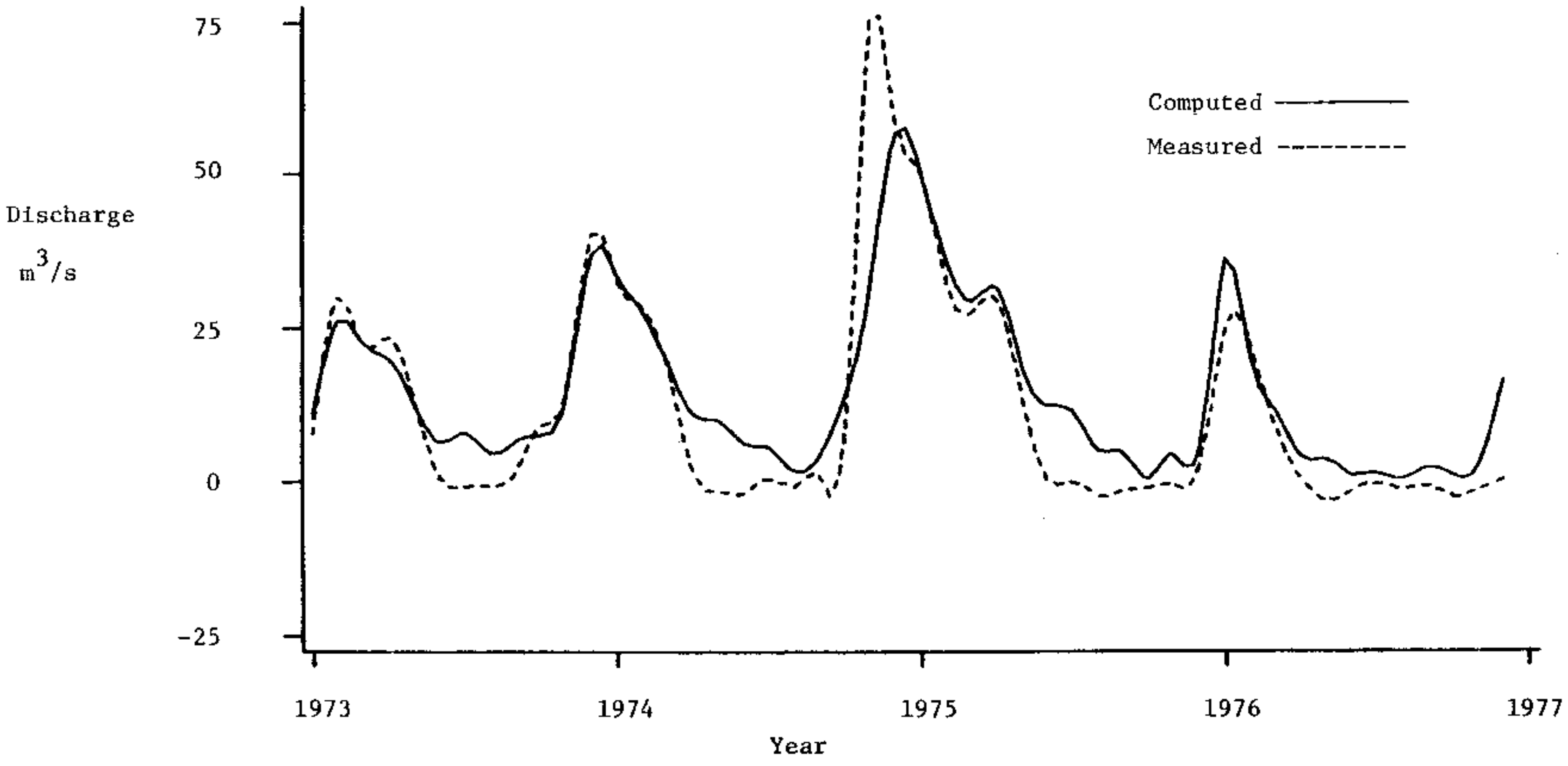

Fig. 7.1--Comparison of measured and computed discharges of the Vecht, 1973-1976

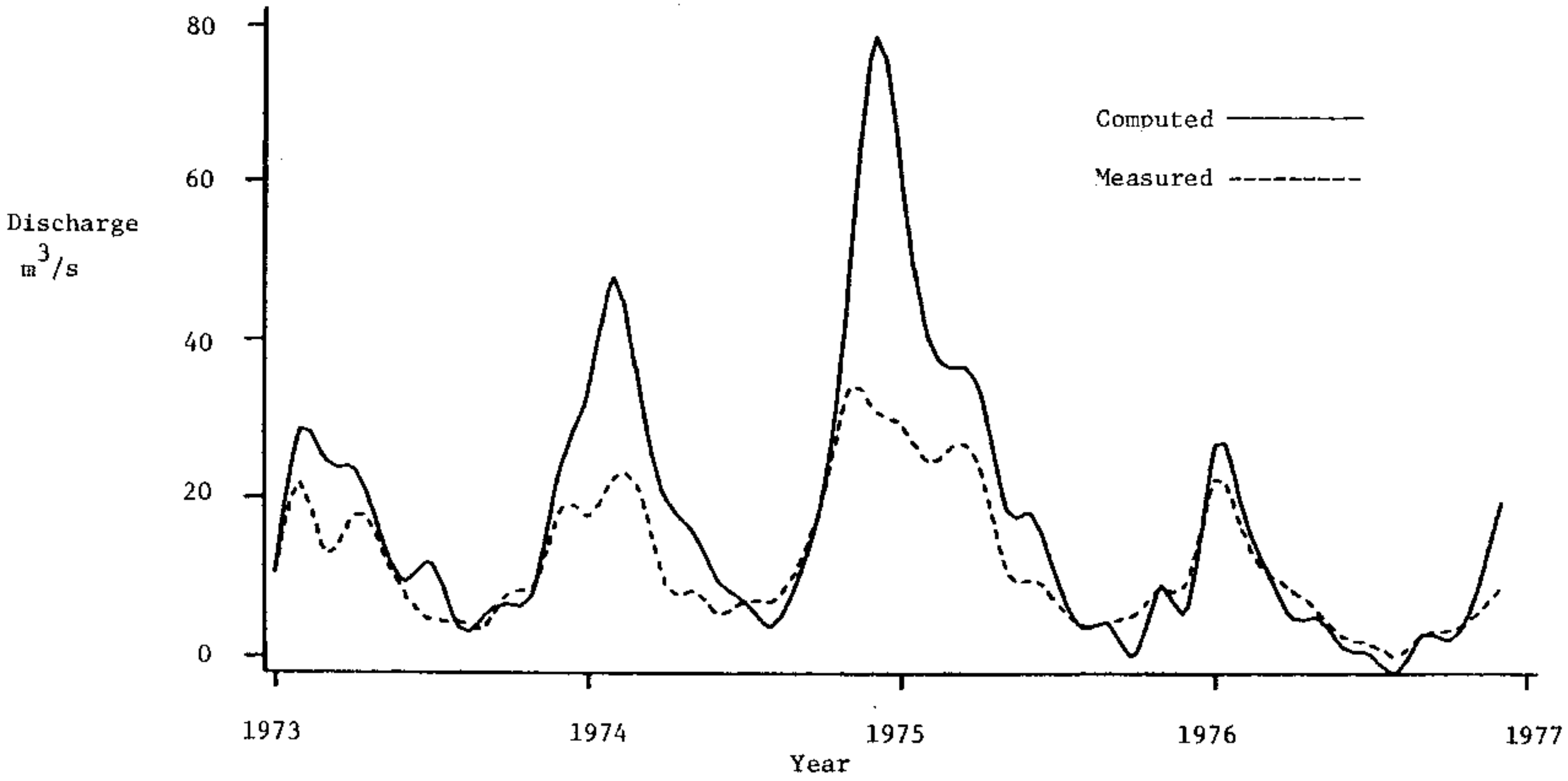

Fig. 7.2--Comparison of measured and computed discharges of the Dieze, 1973-1976

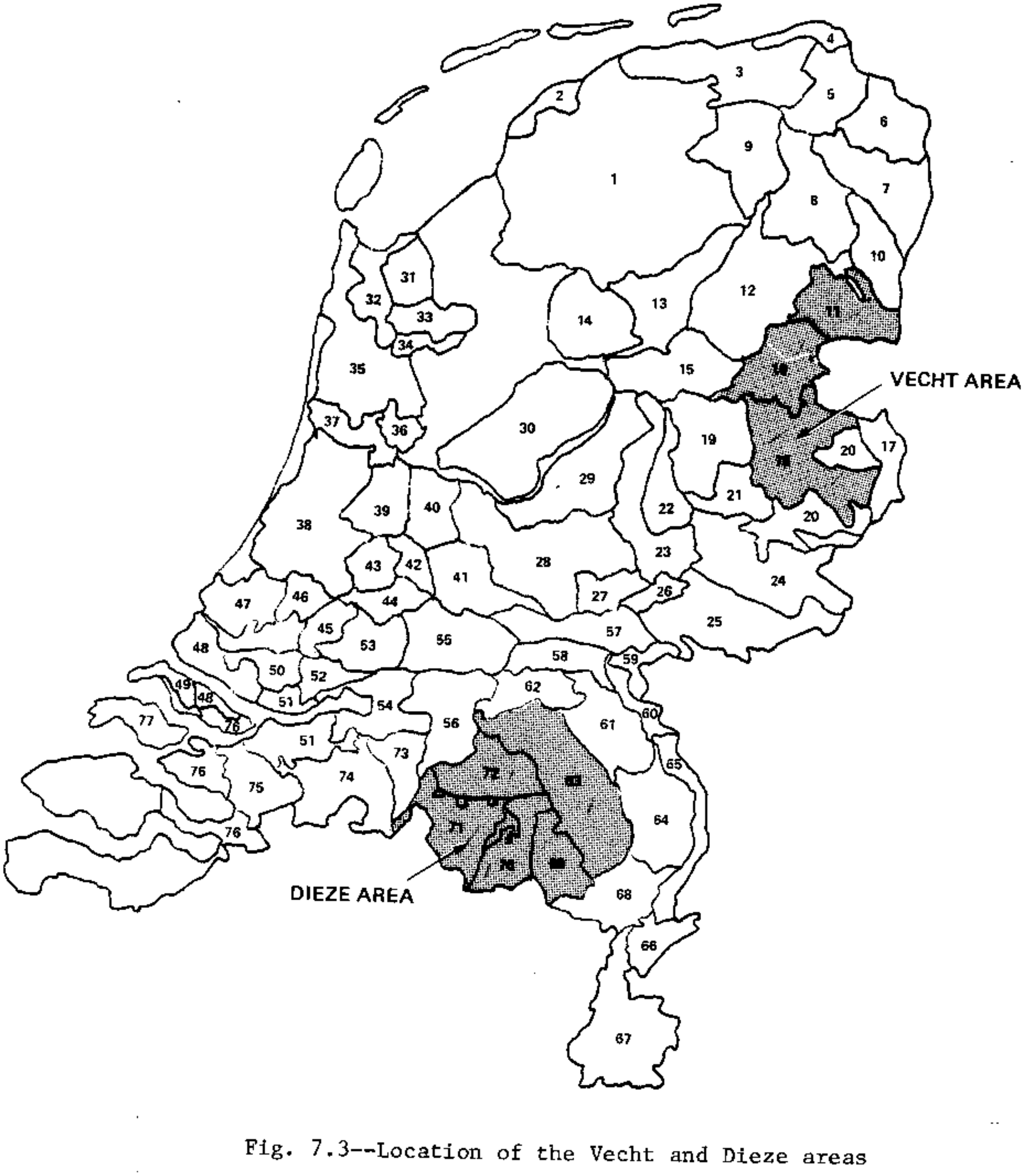

Fig. 7.3--Location of the Vecht and Dieze areas

- Evaluating highlands policies when demands are low.
- Determining impacts of highlands policies on groundwater levels and river discharges.

Some sensitivity analysis has been carried out for the basic drainage functions, which we discuss in Sec. 7.4.

We should emphasize that the measured and computed water flows in both the lowlands and the highlands are subject to some degree of uncertainty. Moreover, in the highlands it is difficult to match the actual watersheds with PAWN districts. Therefore, discrepancies between computed and measured flows might be observed even if the models did a perfect job.

Water Flows in the Lowlands. Measurements were available for four lowlands regions:

- Rijnland
- Friesland/Groningen
- Flevoland
- Schermerboezem

The districts comprising these regions are shown in Fig. 7.4.

In Rijnland, we had seven years of observations (1970-1976). The computed and measured flows matched reasonably well for the years 1972 through 1976. The overall annual discrepancies were always smaller than 1.5 m^3/s with an average annual (absolute) flow on the order of 15 m^3/s. Moreover, both the average annual discrepancies and the discrepancies by decade had varying signs, so there does not seem to be any systematic error. The match between computed and measured flows was not as good for 1970 and 1971, but it was later discovered that some measured flows were subject to big errors in those years. Table 7.2 and Fig. 7.5 show the measured and computed discharges for Rijnland for the years 1973-1976. The match is generally reasonable. Water shortages in 1973, 1974, and the slightly dry year 1975 are predicted well, although sometimes overestimated just a little. The peak shortages in the extremely dry year of 1976 are underestimated to a large degree. The main reason for this underestimate is that the levels of the ditches were raised in the summer, which caused an extra temporary demand. Because DISTAG always treats the water volume as fixed, it does not reflect this situation. (A rise of 20 cm over a period of a month in Rijnland roughly corresponds to a water flow of 5 m^3/s.)

In Friesland and Groningen only two years of data were available, 1975 and 1976. The comparisons between measured and computed data are given in Table 7.3 and Fig. 7.6. As with Rijnland, the match is reasonable. Again, we find that shortages are predicted well in 1975, but underestimated in 1976 because of the raised water levels in summer. Because of the large water areas in Friesland and Groningen, the raised levels account for considerable extra demand.

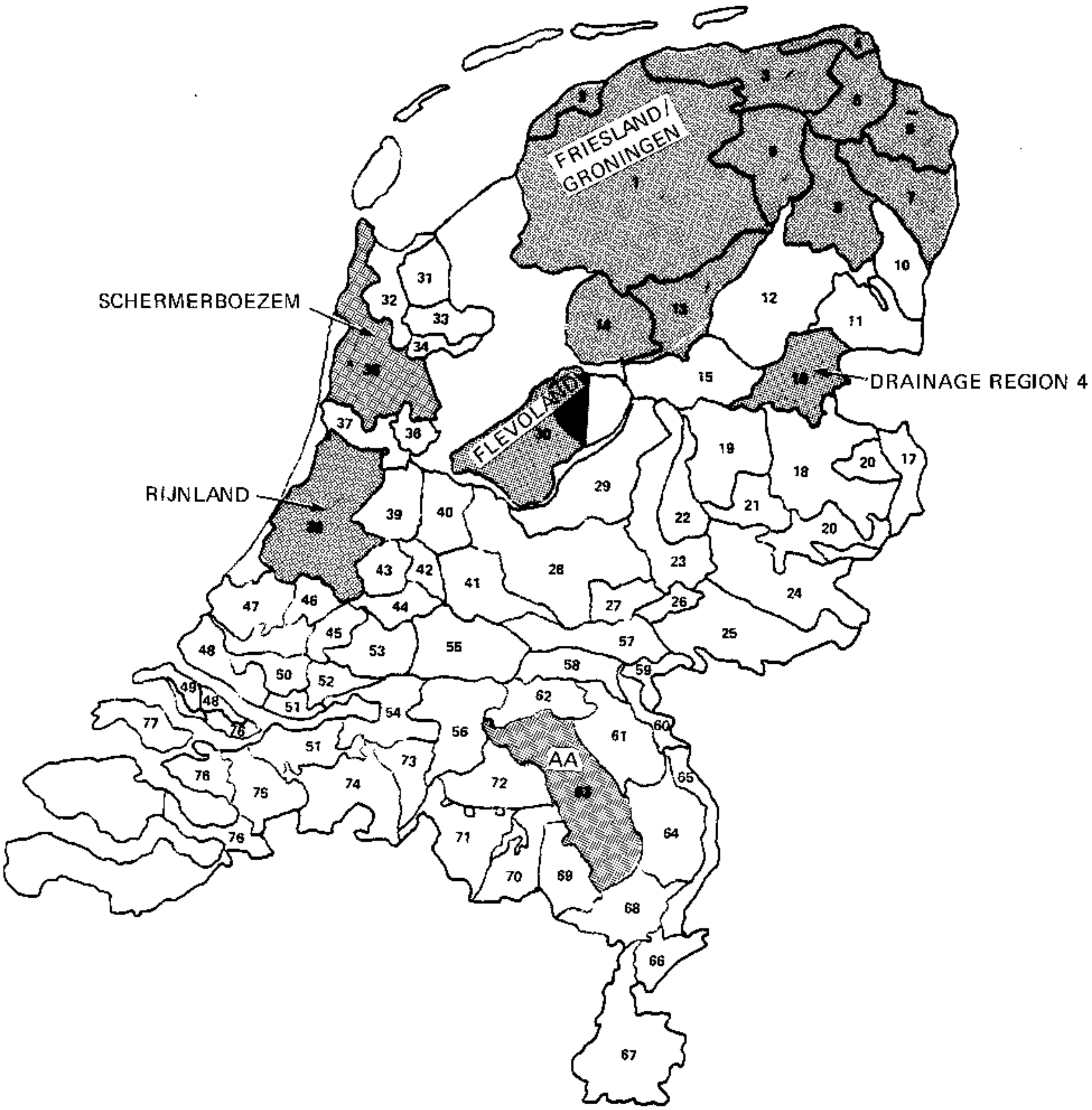

Fig. 7.4--Location of Rijnland, Friesland/Groningen, Schermerboezem, Flevoland, and drainage region 4

Table 7.2

MEASURED AND COMPUTED DISCHARGES FOR RIJNLAND
(m^3/s)

Year	Month	Measured	Computed
1973	Jan	8.1	5.0
	Feb	22.8	18.6
	Mar	6.1	3.8
	Apr	6.1	5.0
	May	4.5	2.7
	Jun	-5.4	-3.8
	Jul	-0.1	0.1
	Aug	-6.4	-3.5
	Sep	8.2	5.0
	Oct	28.5	20.9
	Nov	23.8	28.0
	Dec	28.5	24.6
1974	Jan	17.6	17.6
	Feb	15.5	12.4
	Mar	13.1	13.6
	Apr	-3.7	-2.5
	May	-1.5	-4.3
	Jun	-1.2	-2.9
	Jul	3.3	0.0
	Aug	-0.6	-0.5
	Sep	14.2	16.5
	Oct	51.9	48.8
	Nov	35.5	36.6
	Dec	32.4	28.7

Table 7.2 (continued)

Year	Month	Measured	Computed
1975	Jan	30.3	28.9
	Feb	10.1	8.2
	Mar	17.5	20.3
	Apr	16.9	13.3
	May	-2.4	-2.7
	Jun	-0.9	-2.0
	Jul	-4.5	-5.0
	Aug	-6.3	-4.6
	Sep	4.1	2.4
	Oct	1.9	-0.4
	Nov	16.1	19.9
	Dec	13.4	12.0
1976	Jan	24.2	29.7
	Feb	11.4	5.2
	Mar	3.9	3.5
	Apr	-3.4	-2.6
	May	-6.9	-6.9
	Jun	-7.0	-7.3
	Jul	-15.3	-9.7
	Aug	-13.8	-8.3
	Sep	6.2	3.9
	Oct	5.9	2.2
	Nov	7.6	5.5
	Dec	20.7	25.6

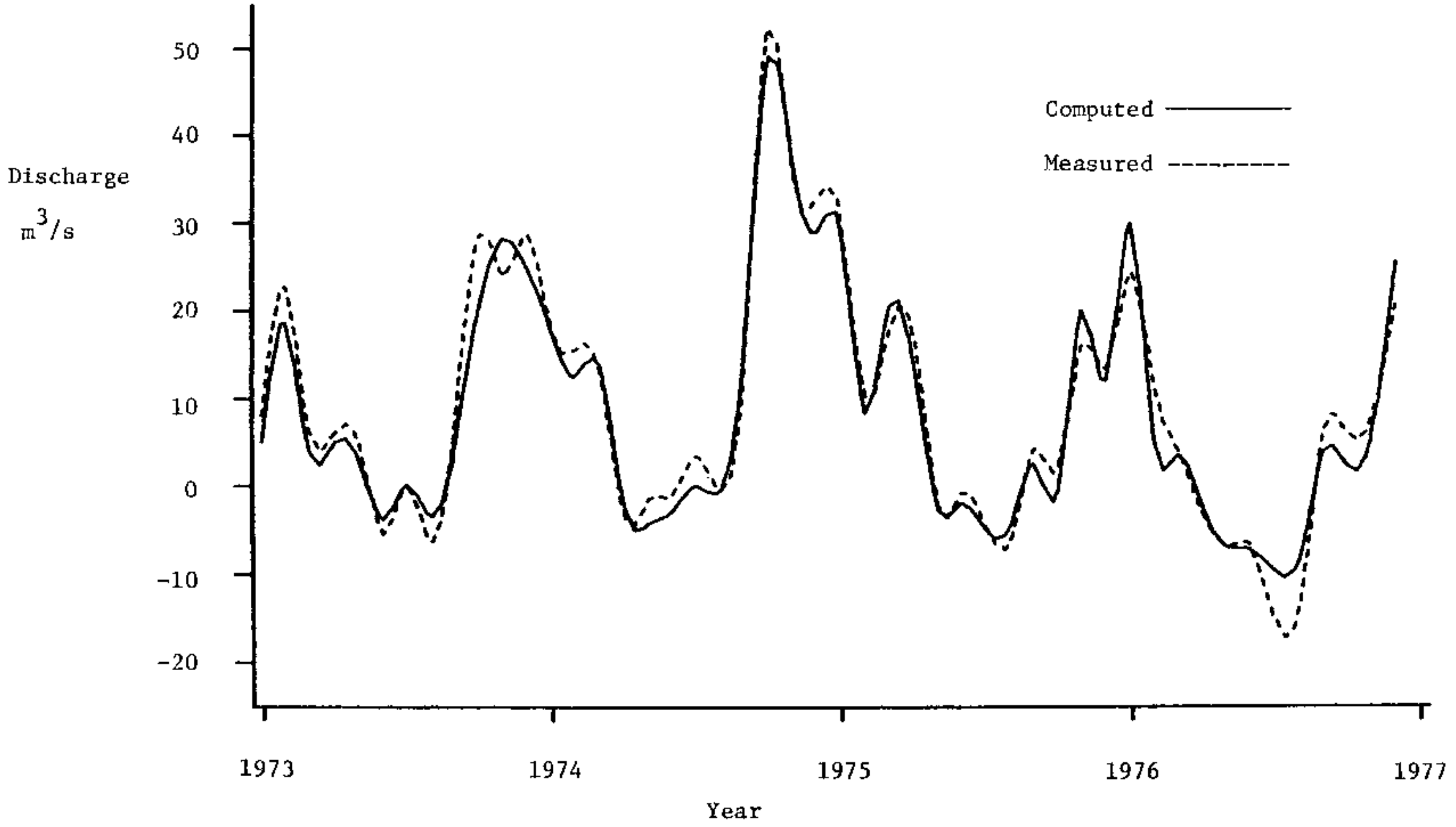

Fig. 7.5--Comparison of measured and computed discharges from Rijnland, 1973-1976

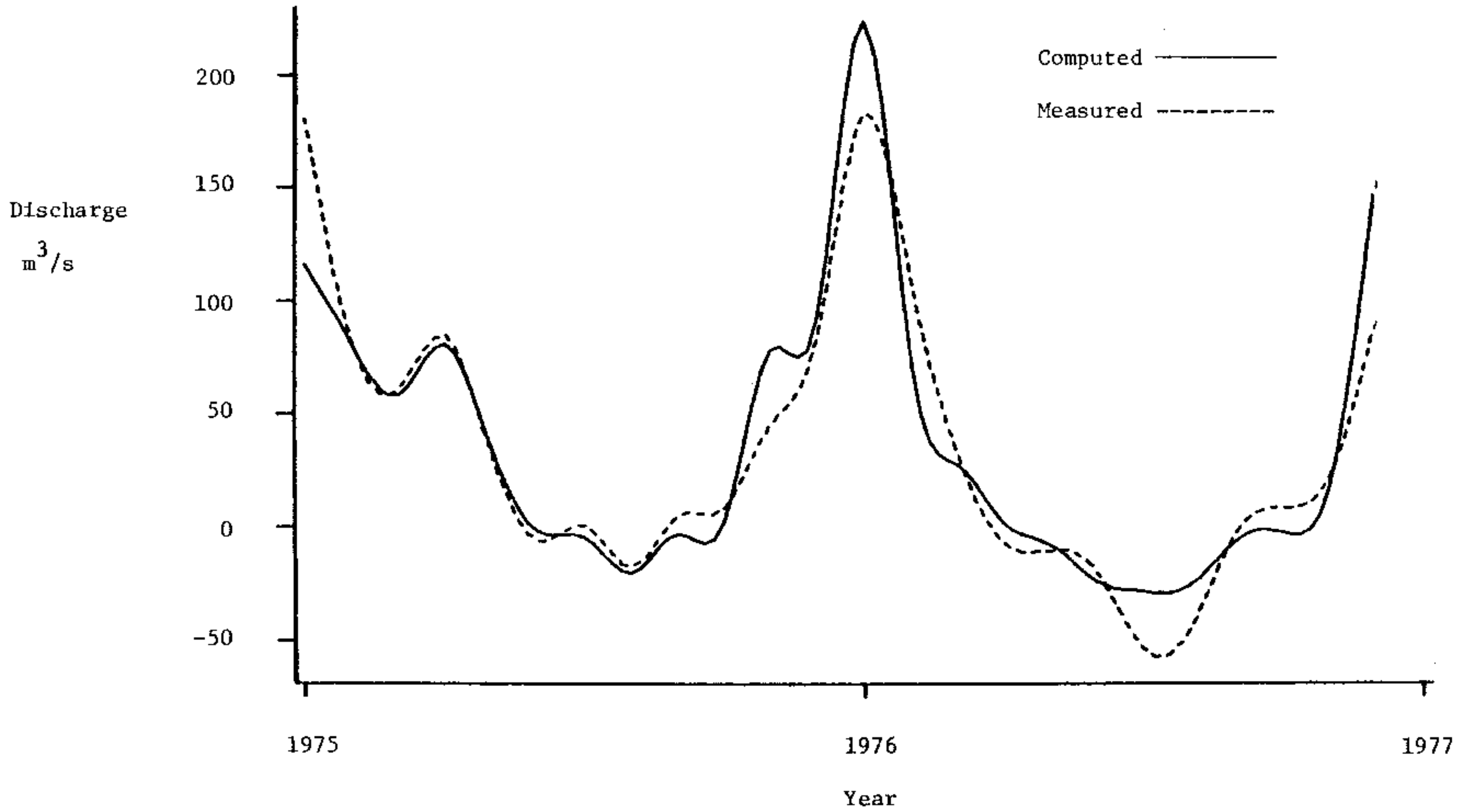

Fig. 7.6--Comparison of measured and computed discharges from Friesland/Groningen, 1975-1976

Table 7.3

MEASURED AND COMPUTED DISCHARGES FOR FRIESLAND/GRONINGEN (m^3/s)

Year	Month	Measured	Computed
1975	Jan	180.8	116.3
	Feb	83.4	81.6
	Mar	60.3	57.8
	Apr	84.4	80.6
	May	32.9	36.0
	Jun	-6.2	-1.9
	Jul	0.5	-4.4
	Aug	-17.7	-20.2
	Sep	4.4	-3.3
	Oct	8.1	1.8
	Nov	44.4	77.4
	Dec	82.6	91.2
1976	Jan	181.1	223.1
	Feb	108.7	73.2
	Mar	32.0	27.4
	Apr	-7.6	1.8
	May	-10.6	-7.8
	Jun	-20.1	-23.8
	Jul	-54.1	-28.4
	Aug	-44.7	-25.7
	Sep	-2.4	-6.1
	Oct	8.6	-2.3
	Nov	21.3	17.0
	Dec	90.5	153.0

In Flevoland the computational results are greatly affected by the assumed rates of seepage. The observed discrepancies between computed and measured flows could have been eliminated if we had slightly changed the seepage rates and the fraction of seepage directly flowing into the surface water. Because the amount of seepage and the phenomena related to seepage flows are subject to a great deal of uncertainty, there is no reason to question the model's basic behavior because of these discrepancies, although perhaps the input data could have been improved.

In Schermerboezem the measured discharges were always substantially greater than the ones computed by DISTAG. On the basis of rough annual water balance computations, it appears that the measured data are not consistent. However, discussions with the local experts failed to turn up any explanations for these inconsistencies.

After examining these lowlands discharges, we believe that DISTAG computes lowlands water flows with sufficient accuracy for PAWN. However, as the example of Schermerboezem shows, there is always the possibility of substantial discrepancies at some locations, caused by the omission of specific conditions or erroneous inputs.

7.3.2. Salinity Calculations

The salt concentrations observed in national and regional waters result from complicated interactions among the many parts of the system. The only meaningful way to compare calculated salt concentrations with measured ones is to look at the results of the Distribution Model, which deals with interactions between districts and the distribution system. We compared the situation observed in 1976 with that predicted by our models. The match seemed reasonable with respect to

- The overall picture of salty and less salty regions.
- Salt concentrations at nodes and districts.

However, these findings are based on rough indications rather than solid comparisons. There are a number of reasons why a more thorough validation could not be carried out:

- The model's level of aggregation is not appropriate for localized aspects of salinity.
- Measurements are often done at specific locations that are not representative of larger parts of the system.
- Parts of some boezems are associated with nodes of DM, whereas other parts and polder waters are associated with district water. Therefore computed salt concentrations are not always comparable with measurements.

- Measured data are very sparse in time, while salt concentrations may vary considerably over time.

In Figs. 7.7 and 7.8 we compare measured and computed chloride concentrations for the districts Delfland and Rijnland for the year 1976. In Delfland, measured data were available for a few months of the summer [7.2], for both the entire boezem of Delfland and for the Westland area separately. Westland is the most important glasshouse area in the Netherlands. We compare the measured values with computed ones for both the district and the DM node that represents Delfland. As can be seen in Fig. 7.7, the order of magnitude is roughly the same.

For Rijnland we also compared the measured boezem chloride concentration [7.3] with the computed concentrations for both the district and the DM node. As Fig. 7.8 shows, computed chloride concentrations are lower in the first part of the summer half-year and quite a bit higher in the second part. The overall averages are roughly the same. Within the limitations mentioned above, we believe the model results agree reasonably with actual measurements.

7.3.3. Crop Damage

For reasons outlined in Sec. 7.1, it is not possible to make any direct comparisons between computed and observed crop damage. We compared our model to the "real world" by considering more global information.

It was never our aim to have models that accurately predict <u>absolute yields</u>. Instead, we wanted a flexible instrument to estimate agricultural <u>damages</u> caused by <u>changes</u> in the quantity and/or quality of available water. Such damages are computed by <u>comparing</u> yields in different situations. Hence it can be expected that systematic errors cancel when numbers that reflect two different situations are subtracted. We will discuss drought damage and salt damage separately.

<u>Drought Damage</u>. We paid the most attention to (very) dry years, in which substantial crop damage occurred, especially 1976 because it is the most extreme and recent year. From some general literature and information [7.4-7.7], we learned:

- In 1959 the average yield reduction of arable crops was around 12 percent.
- In 1959, in the driest part of the country, yield reductions were around 35 percent .
- In 1976, in the peat areas of Groningen and Drenthe yield reductions for arable crops (mostly milling potatoes) were around 30 percent.

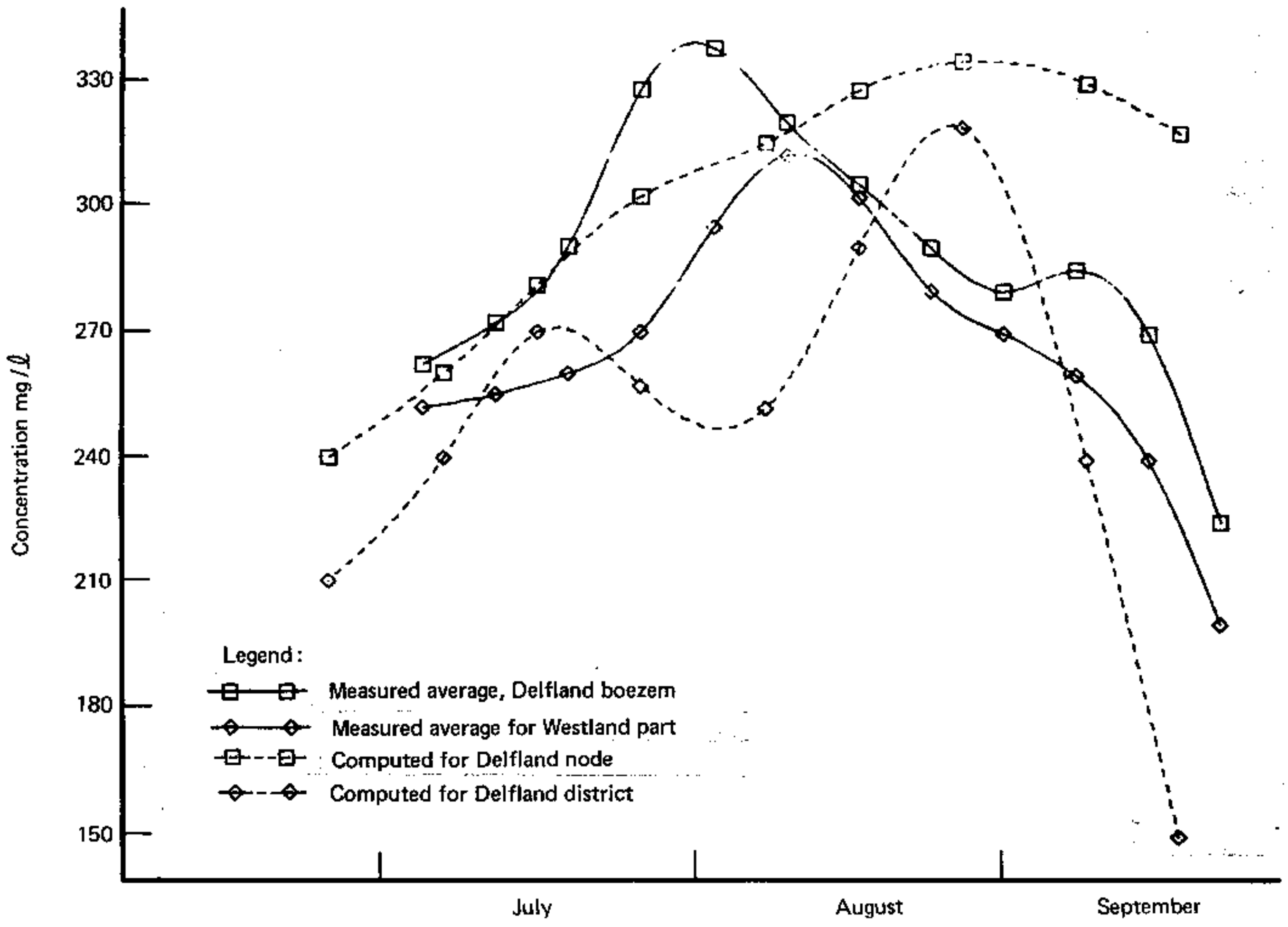

Fig. 7.7 — Comparison of measured and computed chloride concentrations of Delfland in 1976

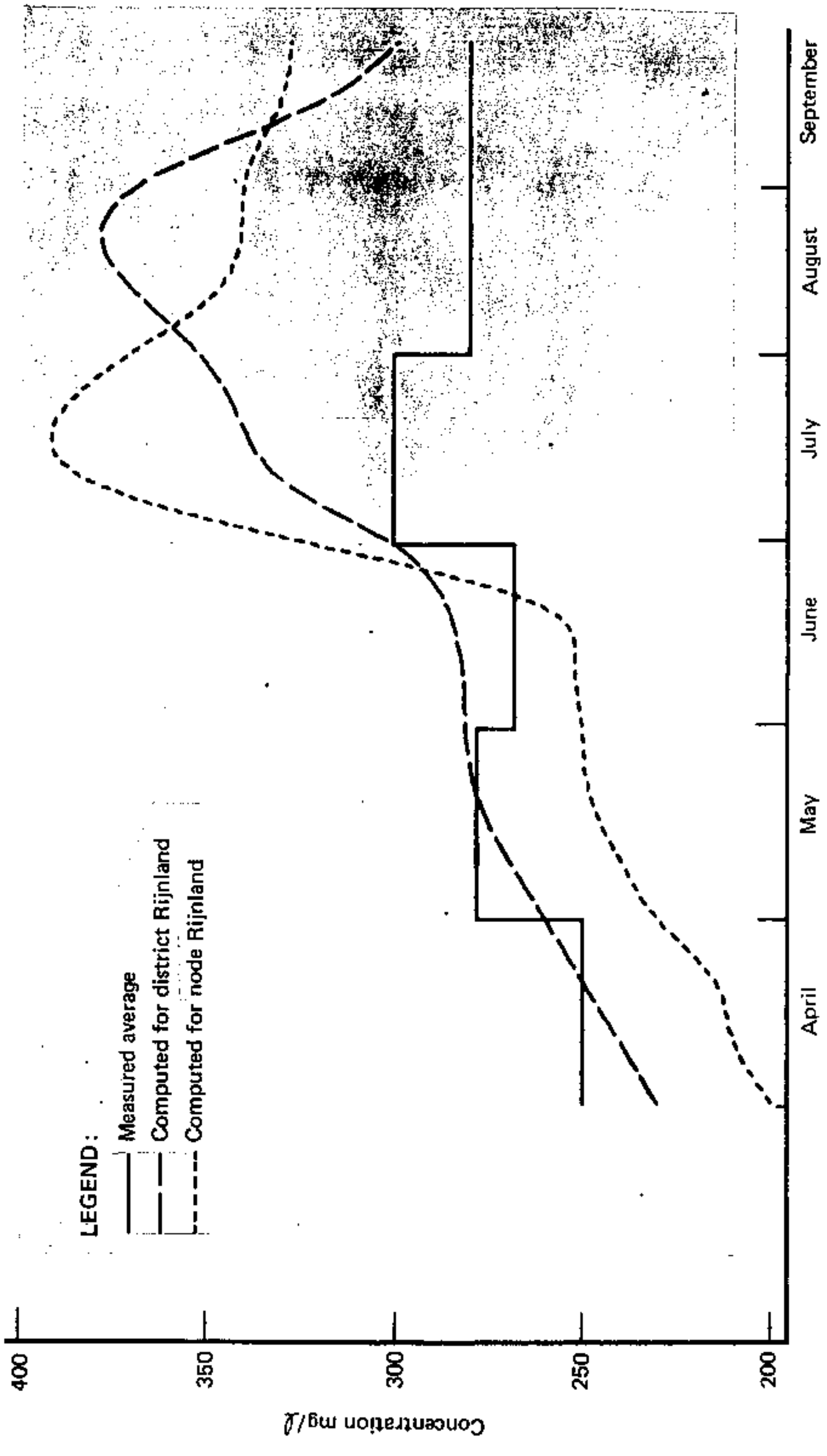

Fig. 7.8 — Comparison of measured and computed chloride concentrations in Rijnland in 1976

- In 1976 there was "quite some" damage to fodder crops (grass, cut corn) and considerable damage to milling potatoes. Consumption potatoes suffered less damage, and seed potatoes still less. Cereals and sugar beets suffered damages on sandy soils, but sometimes there was an above normal production on clay soils. This latter observation is consistent with the experience in other dry years.
- In 1976, at some critical locations, crops were destroyed completely.

There are two problems involved in comparing estimates of our model with actual observations:

- Observed damages are expressed as comparisons with the "normal" situation, yet even in the "normal" situation some damage will occur.
- In dry years, there is generally more sun, and therefore the potential production of certain crops may be higher, even if the drought damage is higher too.

Here is an example involving these two problems:

> Suppose "normally" 10 percent of the potential yield is damaged, and in some dry year, 40 percent of the potential yield is damaged. Suppose further that in the dry year the potential production is 125 percent of the potential production in the normal year. Then the observed damage (i.e., the difference between the observed production of the two years, normal and dry), expressed as a percentage of "normal" yield, is
>
> $$(100 - 0.1\times100) - (125 - 0.4\times125) = 15 \text{ percent.}$$

We ran DM for the years 1967, 1959, and 1976. We adjusted the computed damages using the procedure illustrated in this example, assuming:

- 1967 was a "normal" year.
- Potential production in 1959 was 20 percent above normal.
- Potential production in 1976 was 25 percent above normal.

Using these rather crude assumptions, we computed the following yield depressions for arable crops:

- For 1959:

Consumption potatoes	1 percent	
Milling potatoes	24 percent	
Seed potatoes	-10 percent	(increase in production)
Sugar beets	7 percent	
Cut corn	33 percent	
Cereals	2 percent	

- For 1976:

Consumption potatoes	16 percent	
Milling potatoes	40 percent	
Seed potatoes	-4 percent	(increase in production)
Sugar beets	9 percent	
Cut corn	46 percent	
Cereals	11 percent	

These observations are not inconsistent with our general impression of the actual situation. For milling potatoes and cut corn the calculated damages seem high. (High calculated damages were also observed for some other crops.) The model indicates that in 1976 in a number of highlands districts some crops were almost totally destroyed. In fact, crops were occasionally destroyed totally in 1976, but never on really large areas. Hence, we feel the model probably overestimates damage, at least for some crops at some locations.

Salt Damage. Open-air crops do not generally suffer salt damage, because

- Most open-air crops are not very sensitive to salt.
- Salt brought into the root zone by sprinkling (the main source of salt) is diluted and flushed out by rain.

Glasshouse crops *do* suffer salt damage, because they *are* very sensitive to salt, and salt is *not* diluted and flushed out by rain. As a rough indication of this fact, the Experimental Station for Crops under Glass at Naaldwijk has estimated that in an average situation about 10 percent of the potential annual yield of glasshouse crops is damaged by salt in the midwestern part of the Netherlands.

Except for a few specific locations, where the salt concentration of the seepage water is very high, our model predicts very little salt damage to open-air crops. The model predicts that about 10 percent of the glasshouse crops are damaged by salt in normal and moderately dry years, and around 15 to 20 percent are damaged in an extremely dry year (like 1976). These results indicate that our model seems to be sufficiently accurate for PAWN.

7.3.4. Groundwater levels

Table 7.4 and Fig. 7.9 give a comparison between observed and computed groundwater levels for the "high" part of drainage region 4, for the years 1973-1976. The location of this region is shown in Fig. 6.1. The computations were based on the basic drainage functions described in Sec. 7.3.1. The match between computed and measured groundwater levels is reasonable, despite the changes to these functions. The discrepancies are on the order of 5 to 15 cm, while the match over time looks fairly close. Overall, the computed groundwater depths tend to be a little higher (i.e., further below the soil surface) than the observed ones.

7.4. SENSITIVITY OF RESULTS

Uncertainties in the model that could not be resolved by comparing its estimates with actual measurements have been examined by testing the sensitivity of its predictions to assumptions. The specific areas reported in this section are:

- The capillary rise iteration scheme
- The empirical capillary rise function
- The groundwater function
- Basic drainage functions
- Damage model parameters

7.4.1. The Capillary Rise Iteration Scheme

In Sec. 5.3.4 we described the iteration scheme used to compute water flows in a plot when capillary rise is positive. In our scheme, we always stopped after three iterations. An alternate would have been to continue the iterations until the flows stabilized (e.g., until capillary rise in successive iterations differed by less than, say, 0.1 mm/day).

An earlier implementation of the model used this alternative iteration scheme. The number of iterations depended mainly on the starting value given to capillary rise. During changing weather conditions (spring or fall), it was difficult to find good estimates, and it often took many iterations until stable values were reached. We found, however, that if we stopped after three iterations regardless of how much the estimate of capillary rise was changing, the resulting "error" did not affect the aggregated results of the model. An overestimate of capillary rise in one timestep leads to a bigger subsoil deficit, a deeper groundwater level, and a decrease in root zone suction. The deeper groundwater level and decrease in root zone suction leads to a lower capillary rise in the next timestep. Thus, an "error" in one timestep is compensated for in the next. Moreover, these "errors" happen mainly in the spring, and during that period there is normally enough water stored in the root zone so that plants

Table 7.4

MEASURED AND COMPUTED GROUNDWATER LEVELS IN DRAINAGE REGION 4
(mm)

Year	Month	Measured	Computed
1973	Jan	2720	2499
	Feb	2405	2259
	Mar	2363	2343
	Apr	2370	2347
	May	2517	2508
	Jun	2660	2564
	Jul	2740	2570
	Aug	2548	2578
	Sep	2765	2601
	Oct	2485	2677
	Nov	2242	2412
	Dec	2065	2076
1974	Jan	2145	2090
	Feb	2247	2212
	Mar	2320	2382
	Apr	2570	2479
	May	2632	2511
	Jun	2660	2557
	Jul	2620	2681
	Aug	2655	2741
	Sep	2630	2753
	Oct	2430	2550
	Nov	2156	2187
	Dec	1915	1698

Table 7.4 (continued)

Year	Month	Measured	Computed
1975	Jan	1772	1780
	Feb	1935	2052
	Mar	2158	2185
	Apr	2183	2196
	May	2073	2391
	Jun	2323	2451
	Jul	2392	2463
	Aug	2420	2514
	Sep	2540	2663
	Oct	2560	2755
	Nov	2588	2761
	Dec	2510	2745
1976	Jan	2188	2159
	Feb	2118	2323
	Mar	2423	2539
	Apr	2453	2637
	May	2538	2653
	Jun	2560	2664
	Jul	2595	2669
	Aug	2595	2667
	Sep	2678	2679
	Oct	2833	2729
	Nov	2825	2754
	Dec	2698	2457

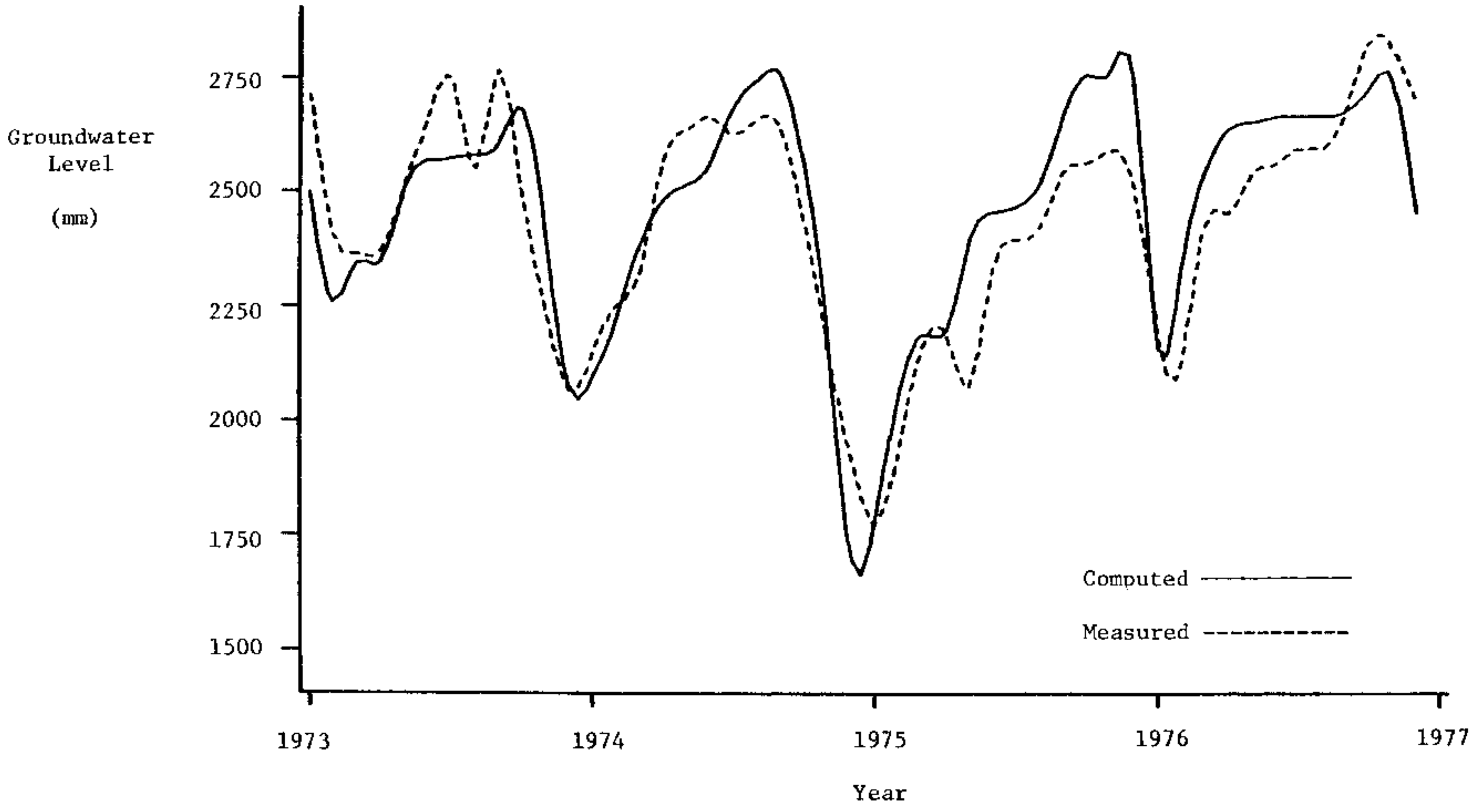

Fig. 7.9--Comparison of measured and computed groundwater levels for high highlands part of drainage region 4

do not suffer drought damage anyway. Thus the damage calculations of the model are not affected by this simplification of our model.

Two examples illustrating the differences between the full iteration scheme and the limited one actually used in the analysis are given in Table 7.5.

7.4.2. The Capillary Rise Function

To reduce computational costs, we derived a formula that gives the capillary rise as a function of the root zone suction and groundwater level. The formula is described in Sec. 5.3.2. The alternative to using the formula is also described in Sec. 5.3.2--this alternative involves solving a complicated nonlinear equation.

The simple formula gives values that are within 0.05-0.1 mm/day of the complicated alternative. This difference is small enough for most purposes, but in some cases it makes a difference, especially:

- During extremely dry periods in the lowlands.
- When the groundwater level is deep (more than 150 cm from the soil surface).

During dry years the capillary rise is of vital importance for the lowlands. Even a slight change in the estimated capillary rise causes a big change in the estimated damage. In Rijnland, for example, the simple formula overestimated the capillary rise by about 10 mm for a plot containing potatoes in 1959. This overestimate caused a decrease in damage from 20.1 percent to 17.6 percent.

Such an effect, however, is very local. Differences as large as these are not seen when looking at results derived from larger areas, containing a mix of crops, soil types, landforms, etc.

The ability to use either the simple formula or the alternate computation scheme allows the user of DISTAG to choose the more accurate scheme when considering local matters.

The problem associated with deep groundwater levels is discussed next.

7.4.3. The Groundwater Function

In comparing the simple capillary rise function with the more complicated alternative for highlands districts, we found big differences. These differences involved groundwater levels and drainage, not capillary rise itself or crop damage. In PLOTWAT calculations, the groundwater level depends among other things on capillary rise (see Sec. 5.3), and for some soil types the computed groundwater level is *very* sensitive to small changes in capillary rise when the ground-

Table 7.5

DIFFERENCES BETWEEN FULL ITERATION AND LIMITED ITERATION SCHEMES FOR CAPILLARY RISE COMPUTATIONS FOR THE YEAR 1976, IN RIJNLAND AND AA

District	Variable	Full Iteration	Limited Iteration	Difference
RIJNLAND	E_A/E_P	75.4%	75.6%	--
	Shortage	168.0 mm	166.9 mm	--
	Survival fract.	0.44	0.44	--
	% damage	28.2%	28.3%	--
	Damage	33.75 Dflm	33.80 Dflm	0.16%
	Discharge/decade	--	--	<.2 m^3/s
AA	E_A/E_P	64.8%	64.7%	--
	Shortage	114.3 mm	113.9 mm	--
	Survival fract.	0.26	0.26	--
	% damage	39.3%	40.2%	--
	Damage	93.71 Dflm	93.79 Dflm	0.08%
	Discharge/decade	--	--	<.1 m^3/s

NOTE: The first four variables in each district summarize what happened to a grass plot lying in the district. The last two variables summarize what happened to the entire district.

Table 7.6

THE SENSITIVITY OF GROUNDWATER LEVEL TO CAPILLARY RISE FOR LOAMY MEDIUM COARSE SAND

Capillary Rise	Groundwater Level	
	Subsoil Deficit 100 mm	Subsoil Deficit 200 mm
0.06 mm/day	1319 mm	1862 mm
0.03	1410	2043
Difference	91 mm	181 mm

water level is deep. An example is given in Table 7.6 where groundwater levels are computed for different values of capillary rise and subsoil deficit. As it turns out, a change in capillary rise of only 0.03 mm/day results in a drop in the groundwater level of nearly 20 cm.

In the highlands, a small change in the groundwater level may lead to a big change in drainage. For example, in the district Aa (see Fig. 7.4), located in drainage region 13, if the groundwater level below the soil surface is increased by 10 cm, then the drainage from that district will decrease by almost 2 m^3/s.

A small difference in capillary rise of 0.03 mm/day as given in the example should not have such a large effect on groundwater level. That it does in our model is caused by our assumption that steady state conditions hold. When the groundwater level is deep, it takes much longer than the ten-day timestep used in our analysis for steady state conditions to occur. Future implementations of PLOTWAT should take this problem into consideration. A solution might be to make groundwater level computations in the high highlands (where deep groundwater levels are found) independent of capillary rise.

7.4.4. Basic Drainage Functions

In our discussion of the water flow computations for the highlands (in Sec. 7.3.1), we noted that in some places we computed more drainage than is actually observed. We experimented with a different set of basic drainage parameters to learn about the extent to which drainage is affected by changes in these parameters.

In our experiment, we defined a set of drainage parameters with these properties:

- When the average annual groundwater level is used, the average annual rain surplus (average rain minus average actual evapotranspiration) drains out.
- The slope is twice as steep as the ones originally used.

Using these experimental parameters, we should observe the same annual drainage, but the variation over the year will be increased. We will observe more drainage when groundwater levels are high (spring and fall), but less in summer. Problems associated with drought will increase.

In Table 7.7 and Fig. 7.10 we compare actual measurements, with estimates using the original drainage parameters and the experimental ones for the Vecht area in Overijssel, for the years 1973 through 1976. We see that the experimental parameters do a better job in predicting low discharges, and the high discharges are more pronounced.

Table 7.7

MEASURED AND COMPUTED VECHT DISCHARGES FOR TWO VERSIONS OF BASIC DRAINAGE FUNCTIONS (m^3/s)

Year	Month	Measured	----------Computed----------	
			Old Parameters	New Parameters
1973	Jan	7.7	11.0	7.1
	Feb	30.0	26.2	30.9
	Mar	22.1	22.5	24.7
	Apr	23.3	19.8	19.4
	May	12.5	12.3	9.0
	Jun	0.5	6.3	1.8
	Jul	-0.8	7.9	3.5
	Aug	-0.6	4.6	0.4
	Sep	1.4	6.5	3.3
	Oct	9.1	7.6	12.4
	Nov	14.5	13.9	26.7
	Dec	39.9	36.8	47.3
1974	Jan	32.5	33.3	35.6
	Feb	28.2	27.7	25.8
	Mar	18.1	19.0	16.5
	Apr	1.0	10.7	6.3
	May	-1.8	9.8	4.8
	Jun	-2.0	6.1	2.9
	Jul	0.3	5.4	3.9
	Aug	-1.0	1.5	0.6
	Sep	0.6	4.1	3.7
	Oct	7.9	13.8	18.9
	Nov	74.7	31.5	38.9
	Dec	58.0	56.2	66.4

Table 7.7 (continued)

			Computed	
Year	Month	Measured	Old Parameters	New Parameters
1975	Jan	49.8	49.9	52.3
	Feb	32.1	35.7	35.8
	Mar	27.2	29.1	24.3
	Apr	29.1	31.2	33.5
	May	12.9	18.1	12.8
	Jun	0.2	12.2	5.2
	Jul	-0.2	11.3	5.9
	Aug	-2.5	5.1	2.4
	Sep	-1.5	4.6	3.6
	Oct	-1.1	0.5	0.0
	Nov	-0.7	4.4	4.4
	Dec	2.4	5.4	9.8
1976	Jan	25.2	35.8	45.2
	Feb	22.4	20.9	23.3
	Mar	8.9	11.6	7.5
	Apr	0.2	4.1	0.5
	May	-3.2	3.7	1.0
	Jun	-1.5	1.2	-1.9
	Jul	-0.4	1.3	-1.9
	Aug	-1.3	0.5	-2.3
	Sep	-0.7	2.3	0.7
	Oct	-2.4	1.2	1.1
	Nov	-1.3	2.4	3.0
	Dec	0.4	16.9	30.4

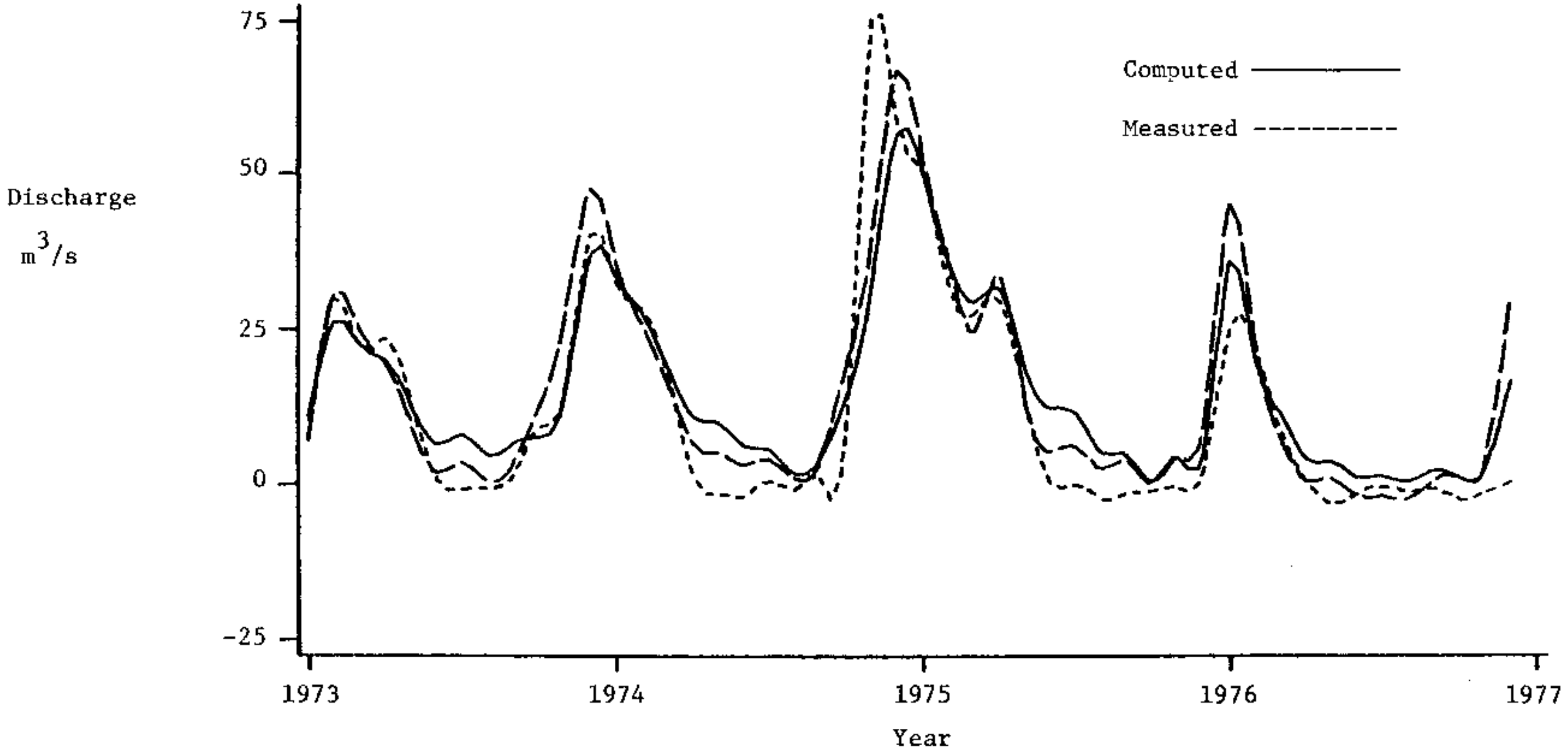

Fig. 7.10--Comparison of measured Vecht discharges with discharges computed using original, and new versions of the basic drainage parameters

The interesting question is what the effects are on computed groundwater levels and damages. In Table 7.8 and Fig. 7.11 we compare the observed and computed groundwater levels for drainage region 4 (see Fig. 6.1). We consider both versions of the basic drainage functions for the years 1973 through 1976. We observe that the performance of the new basic drainage function does not seem to be much worse than the original one. In general, the new basic drainage function shows a little less variation in low and high groundwater levels.

The effect of the experimental basic drainage parameters on computed damages is very small. The largest difference for any year in the entire Vecht area is less than 2 percent of the computed damages.

Looking at separate districts, we find that estimated water demands are still less than those actually observed, even in timesteps where the basic drainage is reduced to zero and hence is not contributing to supply. This means that the behavior of the basic drainage functions can only in part account for the local underestimates of demands. There must be other reasons to fully explain the observed discrepancies.

We conclude:

- Changing the slope of the basic drainage functions could improve estimates of generated discharges.
- The effect of this change on estimated groundwater levels would not be very great.
- Damage estimates are quite insensitive to changes in the basic drainage functions.
- The discrepancies in discharges from the highlands would only be partially resolved by adjusting the basic drainage functions.

7.4.5. Damage Parameters

In Sec. 4.4 we described the theoretical background of the damage model, and in Sec. 6.2.2 we explained how the estimates for the various damage parameters were obtained. The values of these parameters have a very direct influence on the computed potential agricultural benefits and hence on the results of the entire analysis. However, as was pointed out in Sec. 6.2.2, we are quite uncertain about the "correct" values of these damage parameters. Existing estimates in the form required for PAWN were hardly available. Many had to be assumed, and a validation based on real world observations was only possible to a limited extent. Therefore we need some insights into the effect of different assumptions on damage estimates, especially for the drought damage parameters. (The salt damage model is so simple that the effects of changing the parameters are obvious.)

Table 7.8

MEASURED AND COMPUTED GROUNDWATER LEVELS FOR DRAINAGE REGION 4 FOR TWO VERSIONS OF BASIC DRAINAGE FUNCTIONS (mm)

			Computed	
Year	Month	Measured	Old Parameters	New Parameters
1973	Jan	2720	2499	2548
	Feb	2405	2259	2322
	Mar	2363	2343	2476
	Apr	2370	2347	2445
	May	2517	2508	2574
	Jun	2660	2564	2612
	Jul	2740	2570	2614
	Aug	2548	2578	2615
	Sep	2765	2601	2621
	Oct	2485	2677	2497
	Nov	2242	2412	2327
	Dec	2065	2076	2215
1974	Jan	2145	2090	2310
	Feb	2247	2212	2423
	Mar	2320	2382	2510
	Apr	2570	2479	2576
	May	2632	2511	2587
	Jun	2660	2557	2589
	Jul	2620	2681	2607
	Aug	2655	2741	2644
	Sep	2630	2753	2636
	Oct	2430	2550	2438
	Nov	2156	2187	2246
	Dec	1915	1698	1995

Table 7.8 (continued)

			Computed	
Year	Month	Measured	Old Parameters	New Parameters
1975	Jan	1772	1780	2178
	Feb	1935	2052	2374
	Mar	2158	2185	2389
	Apr	2183	2196	2392
	May	2073	2391	2530
	Jun	2323	2451	2575
	Jul	2392	2463	2577
	Aug	2420	2514	2581
	Sep	2540	2663	2584
	Oct	2560	2755	2633
	Nov	2588	2761	2651
	Dec	2510	2745	2607
1976	Jan	2188	2159	2147
	Feb	2118	2323	2465
	Mar	2423	2539	2606
	Apr	2453	2637	2637
	May	2538	2653	2643
	Jun	2560	2664	2647
	Jul	2595	2669	2649
	Aug	2595	2667	2647
	Sep	2678	2679	2643
	Oct	2833	2729	2647
	Nov	2825	2754	2582
	Dec	2698	2457	2294

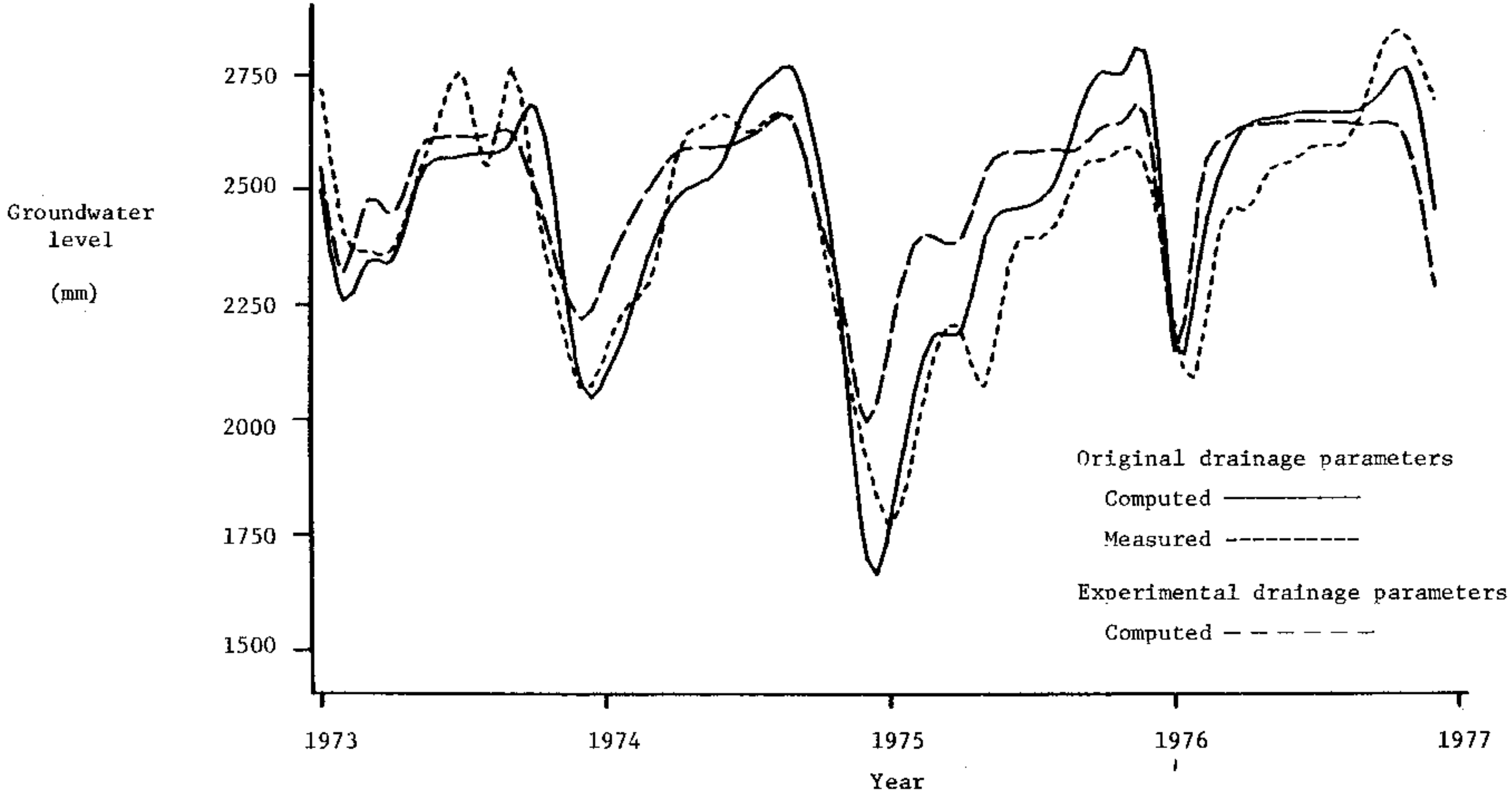

Fig. 7.11--Comparison of measured groundwater levels in drainage region 4 with levels computed using original, and new basic drainage parameters

To this end, we made computations for years of different dryness, varying two essential parameters: reduction point (RP) and dying damage (DD). RP is the ratio of actual over potential evapotranspiration at which the slope of the drought damage curve is assumed to change (see Fig. 4.10). DD is the drought damage fraction at dying point (DP), which is the value of this ratio where the maximum drought damage in the timestep occurs (for decades, DP was set to zero). The original values for RP and DD were 0.6 and 0.7, respectively (see Sec. 6.2.2).

We experimented with RP values of 0.5 and 0.7, and DD values of 0.5 and 1.0, for three different years: an average year (1967), a moderately dry year (1943), and an extremely dry year (1976). Changing the DD value affects only the steeper part of the drought damage curve (beyond RP). Changing the value of RP (assuming the damage fraction at the shifted RP remains the same) affects both the steeper and less steep part of the curve (see Fig. 4.10). The results of these experiments are summarized in Table 7.9. They apply to a district in the province of Drenthe, containing a low highlands and a high highlands subdistrict, which was arbitrarily selected.

Table 7.9 shows--for each of the 15 cases (3 years and 5 variations on RP and DD)--the total drought damage as a percentage of total crop value and the percent change of the damage relative to the base case (with RP = 0.6 and DD = 0.7).

For the average year 1967, changing DD makes no difference at all. Apparently, the steeper part of the drought damage curve is never used. Changing RP, however, has quite an effect. There is a substantial reduction in damage if RP is set to 0.5. The increase in damage if RP is set to 0.7 is much greater, however. This is because the steeper part of the curve is now brought forward, so that it is actually used in the average year, causing a more than proportional increase in damage.

The same effects can be observed in the moderately dry year (1943). Changing DD, while RP remains 0.6, now starts to have a small effect, indicating that the steeper part of the curve is used to some extent. Changing RP now has a large effect, especially if RP is increased, because of the reason given above.

In the extremely dry year, the effect of changing DD is substantial. This is because the steeper part of the damage curve is much more used. Relatively, the effect of changing RP is less than in the moderately dry year. Because the absolute damage in the dry year is much greater, the damage computed for timesteps later in the growing season is very much influenced by damage in previous timesteps (the survival fraction). This has a stabilizing effect on the damage computations, because the potential contribution of subsequent timesteps to the total damage gradually decreases. The effect of changing the damage parameters under these extreme conditions is therefore limited.

Table 7.9

SENSITIVITY ANALYSIS OF DROUGHT DAMAGE PARAMETERS

Damage Parameters RP DD	1967 (D50) Pct Damage	1967 (D50) Change from Base	1943 (D10) Pct Damage	1943 (D10) Change from Base	1976 (DEX) Pct Damage	1976 (DEX) Change from Base
0.6 0.7 (base)	6.1		17.0		45.2	
0.5 0.7	4.9	-19	12.7	-25	36.9	-18
0.7 0.7	8.0	+31	25.1	+47	52.5	+16
0.6 0.5	6.1	0	16.2	-4	39.8	-12
0.6 1.0	6.1	0	18.1	+6	52.0	+15

Table 7.10

SENSITIVITY OF DISTRICT WATER SALT CONCENTRATION AND SALT DAMAGE TO SUBSOIL DEPTH

		Subsoil Depth 1000 mm	Subsoil Depth 3000 mm	Subsoil Depth 10000 mm
Salt Concentration				
1973	Minimum	163 mg/l	162 mg/l	162 mg/l
	Average	217	212	209
	Maximum	277	258	209
1974	Minimum	194	186	181
	Average	257	250	245
	Maximum	288	286	282
1975	Minimum	185	179	175
	Average	221	236	240
	Maximum	245	272	280
1976	Minimum	208	190	179
	Average	266	253	246
	Maximum	310	298	292
Salt Damage				
1973		48030 Dflm	47258 Dflm	46983 Dflm
1974		88033	84200	82256
1975		79483	86078	87398
1976		95745	93727	92306

We conclude:

- Changing DD causes very little change in damage estimates except in extreme droughts, when the effect is only moderate.
- Changing RP causes fairly large changes in damage estimates, especially in moderately dry years.

There is some uncertainty about DD, as it reflects the behavior of crops under serious drought conditions over relatively small timesteps, while DISTAG is probably too aggregated for this purpose. We see, however, that this parameter does not seem to be the most critical element.

The values for RP and the associated reduction damage fraction (RD) are not so uncertain. Changing RP to 0.5 means that drought damage would be 40 percent if E_A/E_P were 0.5 for the entire growing season. Similarly, changing RP to 0.7 means that drought damage would be 40 percent if E_A/E_P were 0.7 for the entire growing season. We believe that the actual drought damage is clearly within those bounds. The largest error would be made if RP is indeed greater than 0.6, which would increase damage substantially. However, the results of the damage model indicate that computed damages are high rather than low. Hence the error is more likely to be in the other, less sensitive, direction.

7.4.6. Active Volume of Subsoil

The active volume of the subsoil that is used in the salinity computations is expressed by a subsoil depth that indicates the layer of soil holding the active volume. For lowland areas this subsoil depth is more or less arbitrarily set equal to 1000 mm. Such a relatively shallow mixing zone causes the subsoil salt concentration to respond fairly quickly to changes in salt inflows and outflows. The sensitivity of computed salt concentrations and damages to this assumption was tested by comparing DISTAG calculations for Rijnland with subsoil depths of 1000, 3000, and 10,000 mm for the years 1973 through 1976. As Table 7.10 shows, the differences in average salt concentrations and salt damages are moderate. The differences are always below 10 percent and usually considerably below. We should remark that the absolute numbers in this example are not realistic. The computations were based on a constant salt concentration of the inlet water equal to 200 mg/l and not on the actual salt concentrations of these waters for these particular years.

NOTE

1. Studiecommissie Waterbehoefte Land- en Tuinbouw (Study Committee for Water Demands by Agriculture and Horticulture).

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Appendix A

DETERMINATION OF CROP PRICES

by N. A. Katz

In Sec. 6.2.2 we briefly mentioned that crop values for an average year, and for an extremely dry year were obtained from actual data, and that values for years of other dryness were obtained by interpolation. This appendix describes our data and explains the interpolation technique.

A.1. INTRODUCTION

In DISTAG, agricultural damages are determined in a relative way, i.e., they are expressed as a fraction that indicates the reduction of potential yield on a per hectare basis. In order to convert these fractions into financial terms, we need to establish a money value per hectare of crop. (We call this value a price in most of this volume.) The values of most crops vary from one year to the next due to changes in production levels in countries participating in the same market and related market responses. The relations involved here are complex, and there are so many dimensions to this problem that results are in fact unpredictable. Yet there seems to be a significant relation between the value of certain crops and the dryness of the year, where the value tends to increase as the year gets drier. We attempted to take this phenomenon into account by associating different crop values with years of different dryness, i.e., years with a different external supply scenario. The method that was used will be described in this appendix. It is based on the following principle. We estimated crop values for an average and an extremely dry year, based on market observations of recent years (1975 and 1976). Crop values for years of different dryness were then obtained by interpolation, using a weighted average drought damage fraction as an index to characterize the dryness of the year. In Sec. A.2 we will explain how the values for the average and extremely dry year were obtained. Section A.3 describes how the interpolation was done. Section A.4 summarizes the final results for the years that were actually used in the analysis.

Two remarks should be made at the outset. First it must be made clear that this procedure is only a very crude approximation of what might happen in reality. Its main merit is that a number of crop value scenarios are obtained that are somehow consistent and that are probably more realistic than a single set of average values.

Second, there may be a difficulty in interpreting these results. Because of the way they are used, the numbers that are determined should be regarded as potential crop values per hectare. There are in fact two reasons why these potential values may vary for different years:

- Changes in crop prices.
- Changes in potential physical yield.

These two effects are closely connected. To the extent that high potential yields result in actually higher yields, they may adversely affect prices because of an increase in supply. On the other hand, in years where severe drought damage occurs, prices may rise, while in the same time potential yields are high. Potential crop values in that case are favorably affected by both phenomena. The values for the average and extremely dry year were based mainly on market observations of prices. Given the uncertainties about potential yield changes and the way they interact with prices, we made no explicit assumptions about these matters. As a result, there may be some inconsistencies in our estimates. We recommend that these topics be subject to further study.

A.2. CROP VALUES FOR AN AVERAGE AND AN EXTREMELY DRY YEAR

Crop values for an average year were based on the year 1975, as it was the most recent and a more or less normal (although a little dry) year. We chose a fairly recent, rather than an earlier year, so that there would be less change in the structure of prices over the different crops between then and now. To determine the measure per hectare, we divided the total production values for each of the 13 crop types considered by the total area occupied by each crop type. Total values were meant to reflect production values to the farmers and were based on various statistics [A.1, A.2, A.3, A.4]. Unfortunately, the information was not always readily available or it was ambiguous. The main difficulties were:

- Production values are sometimes given by calendar year, sometimes by book year (e.g., May to May).
- Sometimes they represented producer's prices (e.g., bulbs, trees, arable crops) and sometimes market prices.
- Production values are mostly based on auction supplies only (e.g., vegetables, flowers, fruits), ignoring those sold elsewhere and, thus underestimating total production.
- Little information was available for crop types that are not normally sold in markets (e.g., grass).

To supplement published information, we consulted several crop-raising and pricing handbooks [A.5, A.6], and we met with a number of farm experts from the Ministry of Agriculture and the Agricultural Economics Institute (LEI).

Finally, to reflect the fact that actual yields were necessarily less than potential yields, we increased our price (value) estimates by 10 percent. This increase of 10 percent is not completely arbitrary, since the yield from horticulture under glass in the midwest of the

Netherlands is about 10 percent less than potential yield due to salt damage. The values obtained in this way represent our best guess concerning the potential crop values for an average year. An overview of these values is given in Table 6.9.

For the extremely dry year, we based our estimates on observations of market conditions in 1976, which is the driest year in our 50-year data base. The main sources were Refs. A.3 and A.4 and personal correspondence with LEI. We based our estimates on 1976 data, but did not attempt to replicate 1976 prices. We tried to construct a set of realistic scenario assumptions about market conditions in an extremely dry year. We considered each crop type separately, but in several instances common assumptions were adopted.

Grass and Cut Corn. We based the value of these crops on the cost of substitute fodder, a cost that increases substantially in dry years. We obtained estimates of 0.60 Dfl per starch unit in the average year and 1.00 Dfl in the extremely dry year. So we multiplied our average-year value estimate by a factor of 1.67 to represent the dry year.

Consumption Potatoes and Seed Potatoes. These are major export crops for the Netherlands. Historically, prices have been cyclic. Analysis of data for the last 20 to 25 years indicates a three-year cycle, with two years of low prices followed by one year of high prices. But that pattern has been occasionally interrupted by the intervention of a very dry year. In 1976, which historically should have been a low-priced year, prices were higher than ever before, substantially higher than in 1975, the most recent high-priced year. If the 1976 dryness had occurred during a year when the price of potatoes was expected to be high, there is no estimate of how high the price would have risen.

Our average-year prices for potatoes reflected the three-year cycle. We set that price one-third of the way between the historical trend for low-priced and high-priced years, as they would be expressed in 1975 Dfl. Then we desired to use the same procedure for the dry-year price, so we computed the relation between the actual 1976 (marketwide average) price and the trend of the low-priced-year prices expressed in 1976 Dfl. This yielded a factor of 1.63 for consumption potatoes and 1.5 for seed potatoes. We then applied those factors to our average-year prices to synthesize what we believe to be reasonable dry-year prices.

Milling Potatoes. The EEC supports the price of these potatoes by supporting the price of starch, the most important product. Historically, the Dutch price has nearly always remained at the support level. During the Europe-wide drought of 1976, however, the market price was well above the support level because the supply of consumption and seed potatoes was not large enough to meet the demand for current consumption. The normally undesirable milling potatoes were being used as food. As those circumstances may occur again in the next extremely dry year, we decided to set the dry-year price about 50 percent above the average-year price, approximating the relationship that held in 1976.

Sugar Beets and Cereal Grains. Since the EEC supports the prices of these crops at levels above those reached in 1976, we assume their value will be the same in the extremely dry year as in the average year.

Bulbs. This is another major export crop for the Netherlands. Most bulbs (e.g., tulips, hyacinths, narcissuses, and crocuses) are early season crops, but about 30 percent of the Netherland's bulb crop area is devoted to summer varieties (primarily lilies and gladioluses). 1976 was the driest year on record, but the drought was concentrated in the summer months. The near-normal winter precipitation yielded about average crops and prices. That may simply have been a fortuitous accident, but it represents the most reliable drought experience we have to examine. We incorporated it into our pricing scenarios, but with a slight hedge against the drought occurring earlier in the year, by assuming that bulb prices in the extremely dry year would be about 10 percent higher than in the year of average dryness.

Vegetables in the Open Air. Vegetable prices increased in 1976. The average effect was on the order of 30 percent. Therefore, we assumed the dry-year values would be about 1.3 times the average-year values.

Pit and Stone Fruits. In 1976 the pear crop was larger than usual, perhaps from the extra sunshine. This large crop depressed the prices of both apples and pears, although the combined yield was apparently near normal. Not knowing how to deal with that phenomenon, or how to forecast sunlight in future years, we retained the average-year value estimate for use in dry years.

Ornamental Trees. There was no apparent drought effect on this crop in 1976, so we again assume a single estimate will suffice for both types of year.

Vegetables under Glass. The price of most of the crops grouped under this heading increased 1976, but by widely varying amounts. We estimate the average changes can be captured by using a 1.2 factor.

Flowers under Glass. The price of flowers dropped in 1976. We are not sure why, but the decline probably represented a slackness in demand that more than balanced any decrease in supply. We estimate a value for this crop in the extremely dry year that is only 85 percent of the average-year value.

A.3. CROP VALUES FOR OTHER YEARS

In the previous sections we described how crop values were determined for an "average" year and an "extremely dry" year. Ideally, similar methods could be used in assigning values to crops in other years. In reality, however, this is not possible. It is more than likely that for a given year we are interested in, historical data is unavailable or, if it does exist, is impossible to adjust into monetary units comparable to the crop values one already has. Such was the case in

PAWN, and so it was necessary to devise an analytical procedure that could be used in determining crop values for any external supply scenario. A description of the methodology of such a procedure follows, after which, the results of an application of the procedure are presented.

A.3.1. Methodology

Any procedure to calculate crop values for a year with a given external supply scenario must make use of information which can be computed by the PAWN agricultural models, as well as known crop value data. Up to this point we know the values of crops in two years, an average one and an extremely dry one. What we need to do then is find a variable (or variables) which will allow us to make a linkage between an external supply scenario and these known crop value scenarios. Such a variable would need to give an indication of the severity of the external supply scenario based on its effect on agriculture. We would then be able to associate the average-year crop values with years in which this variable takes on a particular value, e.g., its average over many external supply scenarios. Similarly, the crop values for the extremely dry year would be associated with external supply scenarios where the variable took on an extreme value. For external supply scenarios where our variable fell somewhere in the middle, we might estimate crop values by performing some sort of interpolation on the known crop values. We would then be left only with the problem of what to do about external supply scenarios where the value of the chosen variable was in the direction of the other extreme (i.e., a wetter than average year).

The above is a rough outline of the procedure used in this analysis. The variable selected as the indicator of the severity of an external supply scenario was "physical crop damage" in the Netherlands, i.e., the percentage that physical crop yield was below its "optimum" level.

To perform the analysis in the most straightforward manner, we would have liked to compute this physical crop damage for many years using the plot file containing all plots in the Netherlands in 1976. However, such a procedure was deemed to be prohibitively expensive. Instead, a sample of plots from the 1976 plot file was selected and was used to represent agriculture in the Netherlands. (The sample was originally drawn for use in the calculation of sprinkler scenarios. A detailed discussion of the selection of the sample is in Vol. XIV.)

The sample was selected by first creating four categories of crops: grass, potatoes, arable crops other than potatoes, and horticultural crops. Glasshouse crops were not included in the sample because they are always sprinkled and suffer no shortage damage. The country was then broken up into areas representing the cross product of drainage regions and weather stations. Within each of these areas, the largest plot in each of the four crop groups was selected for inclusion in the sample (subject to certain minimum size requirements). A total of 77 plots were thus selected. They encompass 30 percent of the cultivated area of the Netherlands (not counting nature plots). Table A.1 gives an overview of the sample by crop group.

Table A.1

OVERVIEW OF SAMPLE OF PLOTS

Crop Group	Area in the Netherlands (thousand ha)	Area in the Sample of Plots (thousand ha)	Area in Sample of Plots as a Percent of Netherlands' Area
Grass	1252	416	33
Potatoes	158	41	26
Other arable	487	108	22
Horticultural	104	40	38
All groups(a)	2002	605	30

(a) Columns may not sum due to rounding.

In selecting the 77 plots, no attention was paid to whether or not they were sprinkled. A separate procedure was used to create an unsprinkled portion and a surface water sprinkled portion. This was done based on the split in the 1976 plot file within the drainage region/weather station area from which the sample plot came. Groundwater sprinkling was combined with surface water sprinkling. This procedure yielded a total of 136 plots. Table A.2 gives a comparison between the proportion of sprinkled and unsprinkled areas in the 1976 plot file and the sample plot file by crop group. As can be seen, there is very close agreement. This sample plot file was used in the remainder of the analysis.

Table A.2

COMPARISON OF SPRINKLING IN THE NETHERLANDS
WITH SPRINKLING IN THE SAMPLE OF PLOTS

Crop Group	Percent of Area Sprinkled in Netherlands	Percent of Area Sprinkled in Sample of Plots
Grass	15	14
Potatoes	23	22
Other arable	1	1
Horticultural	29	24
All groups	12.9	12.6

To determine an "average physical crop damage" and a "maximum physical crop damage," we ran the DEMGEN model for 19 years, 1960-1978, on the sample plot file. These were the values we would associate with crop prices for an average year and those for an extremely dry year. The period 1960-1978 was chosen because these were the only years for which complete weather data for 21 weather stations were available.

Once DEMGEN was run, its output was processed to determine the yearly total physical crop damage in the Netherlands. This was done by first determining in each year the physical crop damage to each sample plot. Then, again for each year, we calculated the physical crop damage to each crop group. The damage associated with a sample plot in a group was weighted based on the area the plot represented in the 1976 plot file. Finally, for each year, the total physical crop damage in the Netherlands was computed. Here, each crop group was weighted according to its area in the 1976 plot file. We thus were left with 19 numbers, each representing the total physical crop damage in the Netherlands in a year. The average of these values became the average physical crop damage; the maximum value became the maximum physical crop damage.

At this point, by making two further assumptions, we will be in a position to compute crop values for any external supply scenario. The first assumption has to do with years in which physical crop damage is less than average. When this occurs, we will assign the average-year crop values to the external supply scenario. In fact this is not a very important assumption. As we are interested only in problems related to water shortage, external supply scenarios that are wetter than average were never actually used. The second assumption relates to how to interpolate between crop values for the average year and those for the extremely dry year. Because we have no information to suggest one method over another, we used linear interpolation.

We now have all the elements necessary to compute crop values for any external supply scenario. The formula we use is:

$$\text{VALUE} = \text{AVG\_VAL} + \text{maximum of 0 or } \frac{(\text{DRY\_VAL} - \text{AVG\_VAL}) * (\text{DMG\_PCT} - \text{AVG\_DMG\_PCT})}{(\text{MAX\_DMG\_PCT} - \text{AVG\_DMG\_PCT})}$$

where:

VALUE	is the crop's value in years with the given external supply scenario.
AVG_VAL	is the crop's value in an average year.
DRY_VAL	is the crop's value in an extremely dry year.
DMG_PCT	is the total physical crop damage in the Netherlands in years with the given external supply scenario. This is computed by running DEMGEN on the sample plot file for the desired

year and then using the procedure outlined above to calculate damage in the country as a whole.

AVG_DMG_PCT is the total physical crop damage in the Netherlands in an average year.

MAX_DMG_PCT is the total physical crop damage in the Netherlands in an extremely dry year.

A.3.2. Results

The results of the estimation of physical crop damage in the Netherlands for several years are displayed in Table A.3. The estimates were made by DEMGEN, described in Sec. 5.6.3. It is clear from looking at the table that only rarely is physical crop damage for an individual year significantly higher than the average yearly physical crop damage. The average damage for the period 1960-1978, 6.1 percent, was assigned to variable AVG_DMG_PCT in the formula described above. The physical crop damage in 1976, 36.1 percent, was assigned to variable MAX_DMG_PCT.

Table A.3

PHYSICAL CROP DAMAGE IN THE NETHERLANDS BY YEAR

Year	Percent Physical Crop Damage	Year	Percent Physical Crop Damage
1943	11.0	1969	3.3
1959	26.7	1970	10.7
1960	4.4	1971	6.7
1961	1.0	1972	0.0
1962	3.5	1973	11.4
1963	0.9	1974	7.2
1964	4.4	1975	10.4
1965	0.1	1976	36.1
1966	0.7	1977	5.0
1967	4.6	1978	4.6
1968	0.7	19-year average	6.1

The actual PAWN analysis was based on only four years of the external supply scenario's ranking in dryness from average to extremely dry. Table A.4 summarizes the crop values for the years that were actually used, which are 1967 (D50), 1943 (D10), 1959 (D05), and the extremely dry year 1976 (DEX). As it turns out, crop values in the 10-percent dry year (D10) are not very much higher than average. Looking at the 5-percent dry year (1959), there is a considerable difference.

Table A.4

CROP VALUES FOR DIFFERENT YEARS
(In Dfl)

Crop	D50, (1967)	DEX (1976)	D10 (1943)	D05 (1959)
Grass	3000	5000	3330	4380
Consumption Pot.	10000	16250	11030	14300
Milling Potatoes	3830	5830	4160	5210
Seed Potatoes	13500	20300	14620	18180
Sugar Beets	5200	5200	5200	5200
Cereals	3150	3150	3150	3150
Cut Corn	3600	6000	3990	5250
Bulbs	27400	30140	27850	29290
Vegetables (OA)	15600	20280	16370	18820
Fruits	10400	10400	10400	10400
Trees	42800	42800	42800	42800
Vegetables (UG)	232000	278000	239590	263650
Flowers (UG)	485000	412250	472990	434950

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Appendix B

SUPPLEMENTARY DATA TABLES

Table B.1

PRIMARY MUNICIPALITY DATA
(ha)

MUNICIPALITY	TOTAL	URBAN	WATER	WOODS	CULT	ND
Adorp	1875	44	18	0	1788	0
Aduard	3076	59	54	5	2908	0
Appingedam	2517	242	75	14	2109	0
Baflo	3508	76	194	5	3059	170
Bedum	4505	201	37	34	4153	0
Beerta	8248	136	3258	20	4449	3181
Bellingwedde	11013	461	162	114	10043	0
Bierum	4966	143	245	2	4395	203
Boer, Ten	4661	173	48	49	4319	0
Delfzijl	5254	640	722	11	3298	540
Eenrum	3777	65	576	19	2982	557
Ezinge	2349	44	55	1	2221	0
Finsterwolde	4596	121	942	9	3286	915
Groningen	8249	2816	263	38	4674	0
Grootegast	6662	281	76	15	6105	0
Grijpskerk	3242	105	39	2	3033	0
Haren	5070	526	393	277	3651	0
Hoogezand-Sappemeer	7306	934	577	122	5437	0
Kantens	3314	59	29	2	3175	0
Kloosterburen	3444	48	468	6	2794	451
Leek	6689	441	82	116	5911	0
Leens	3726	100	84	10	3484	0
Loppersum	2591	116	22	65	2347	0
Marum	6278	295	37	99	5723	0
Meeden	1702	72	7	1	1604	0
Middelstum	2547	75	28	3	2399	0
Midwolda	4127	173	22	73	3808	0
Muntendam	2110	135	38	0	1883	0
Nieuwe Pekela	3125	178	81	9	2798	0
Nieuweschans	799	62	50	13	634	0
Nieuwolda	3503	65	138	7	3176	103
Oldehove	4152	49	134	1	3913	0
Oldekerk	2149	74	20	2	2011	0
Oosterbroek	4416	211	51	19	4045	0
Oude Pekela	1911	245	22	8	1587	0
Scheemda	4661	287	58	7	4203	0
Slochteren	15873	549	514	46	14511	0
Stadskanaal	11976	986	140	114	10341	0
Stedum	2454	55	13	2	2345	0
Termunten	5503	152	1504	6	3739	1446
Uithuizen	3648	116	558	8	2863	530
Uithuizermeeden	6717	166	734	6	4963	574
Ulrum	8863	68	2211	245	6291	839
Usquert	3638	56	905	6	2502	887
Veendam	7881	1098	216	54	6309	0
Vlagtwedde	16601	627	200	629	14826	0
Warffum	2925	72	680	16	1802	656
Winschoten	2225	512	40	10	1505	0
Winsum	2797	129	55	6	2551	0
Zandt, 't	3898	85	35	2	3686	5
Zuidhorn	2373	149	45	3	2123	0
Total Groningen	249490	14572	16955	2331	207762	11057
Achtkarspelen	10349	773	122	140	8995	0
Ameland	6377	167	651	139	2598	608
Baarderadeel	7333	140	111	3	6925	0
Barradeel	6698	148	1233	6	5223	1142
Bildt, het	11140	249	3321	3	7438	3231
Bolsward	938	156	27	10	672	0
Dantumadeel	9466	542	183	69	8335	0
Dokkum	983	279	29	7	622	0
Doniawerstal	12505	198	2616	250	9064	0
Ferwerderadeel	12640	175	3336	5	8322	3261
Franeker	1730	212	47	4	1404	0
Franekeradeel	5626	95	66	4	5397	0
Gaasterland	8940	250	1230	947	6280	436
Harlingen	1173	271	108	13	716	55
Haskerland	11182	388	1315	189	8934	0
Heerenveen	13955	941	465	721	11238	0
Hemelumer Oldeferd	8646	167	2041	29	6168	100
Hennaarderadeel	5934	111	70	1	5654	0
Hindeloopen	706	12	138	0	510	111
Idaarderadeel	6892	166	646	38	5789	0
Kollumerland c.a.	11591	308	639	75	10385	0
Leeuwarden	6976	1363	123	22	4218	0
Leeuwarderadeel	4298	146	49	3	3934	0
Lemsterland	8578	228	1664	21	6345	675
Menaldumadeel	7758	288	119	7	6951	0
Oostdongeradeel	10986	187	2302	6	8346	1514
Ooststellingwerf	22618	614	181	2466	17351	0
Opsterland	23051	892	324	2075	18772	0
Rauwerderhem	3476	66	124	7	3216	0
Schiermonnikoog	16888	70	13015	53	918	12986
Sloten	225	14	12	2	193	0
Smallingerland	12724	894	774	198	10137	0
Sneek	1679	451	85	15	1023	0
Staveren	495	20	151	4	289	75
Terschelling	10780	208	1828	631	2360	1642
Tietjerksteradeel	17312	823	1364	230	14140	0
Utingeradeel	6718	151	666	25	5737	0
Vlieland	5103	50	1694	282	100	1615
Westdongeradeel	11140	143	4251	4	6439	4196
Weststellingwerf	22839	810	591	818	19571	0
Wonseradeel	18567	258	2110	18	15546	1800
Workum	3331	81	281	4	2897	150
Wymbritseradeel	16020	284	2402	29	13005	0
IJist	661	48	44	2	541	0
Total Friesland	387027	13837	52548	9575	282698	33597

Table B.1 (continued)

MUNICIPALITY	TOTAL	URBAN	WATER	WOODS	CULT	ND	MUNICIPALITY	TOTAL	URBAN	WATER	WOODS	CULT	ND
Anloo	9243	281	78	813	7651	0	Goor	809	402	9	9	372	0
Assen	5530	818	140	343	3355	0	Gramsbergen	5879	129	157	153	5294	0
Beilen	16725	630	219	1550	12695	0	Haaksbergen	10540	416	42	1522	6795	0
Borger	13043	396	70	1252	10658	0	Ham, den	4409	307	35	191	3756	0
Coevorden	4057	427	57	0	3245	0	Hardenberg	18414	802	279	1472	14911	0
Dalen	6810	149	86	59	5987	0	Hasselt	4243	62	76	0	3823	0
Diever	7512	112	50	2672	4109	0	Heino	3423	192	27	345	2804	0
Dwingelo	6882	140	73	1325	4489	0	Hellendoorn	13850	636	74	2926	8448	0
Eelde	2558	241	91	139	1903	0	Hengelo	6436	1084	57	772	3801	0
Emmen	28540	2848	587	1002	20621	0	Holten	6587	150	9	1569	4153	0
Gasselte	4059	163	24	654	3064	0	Kampen	8138	278	1650	1	5876	1514
Gieten	4142	201	27	372	3413	0	Losser	10175	375	59	1963	6918	0
Havelte	7614	253	91	1039	5241	0	Markelo	9229	159	47	1210	6894	0
Hoogeveen	6455	795	101	543	4804	0	Nieuwleusen	3956	222	31	0	3616	0
Meppel	1463	321	45	0	951	0	Noordoostpolder	50120	712	3667	2080	41920	2700
Norg	11307	277	147	2034	7524	0	Oldenzaal	1510	542	0	131	725	0
Nijeveen	2556	90	17	8	2370	0	Olst	6283	414	234	628	4761	110
Odoorn	14754	505	378	1579	11931	0	Ommen	18842	280	219	3865	11932	0
Oosterhesselen	6879	173	84	580	5661	0	Ootmarsum	345	87	1	6	222	0
Peize	2865	154	23	34	2593	0	Raalte	13859	452	170	1030	11775	0
Roden	6469	383	224	482	5063	0	Rijssen	2609	406	7	411	1672	0
Rolde	10489	188	70	2320	6840	0	Stad-Delden	592	106	12	53	335	0
Ruinen	11413	221	108	1543	8089	0	Staphorst	13650	282	130	992	11666	0
Ruinerwold	4026	94	24	95	3731	0	Steenwijk	8372	493	77	897	6595	0
Schoonebeek	6081	246	57	37	3641	0	Tubbergen	14733	345	44	1410	12173	0
Sleen	7543	273	65	872	6069	0	Urk	612	125	81	144	207	22
Smilde	6411	216	101	410	5331	0	Vriezenveen	7394	376	84	41	5194	0
Vledder	4800	147	37	1247	2947	0	Weerselo	9332	205	33	1638	6912	0
Vries	10942	347	137	511	9325	0	Wierden	9698	437	50	600	7772	0
Westerbork	13677	289	126	1610	10656	0	Wijhe	5562	123	127	282	4899	80
Wijk, de	4251	115	35	260	3706	0	IJsselham	10323	172	389	557	6844	0
Zuidlaren	3531	267	177	234	2738	0	IJsselmuiden	8282	179	319	19	7583	130
Zuidwolde	9748	197	94	611	8279	0	Zwartsluis	1270	68	172	1	802	0
Zweeloo	6077	142	21	989	4657	0	Zwolle	10109	1625	391	234	7384	130
Total Drenthe	268452	12099	3664	27219	203337	0	Total Overijssel	392763	18464	12355	37160	296664	4827
Almelo	3882	822	81	295	2259	0	Aalten	8341	265	27	491	7348	0
Ambt Delden	8506	72	69	1491	6312	0	Ammerzoden	1056	102	50	7	865	30
Avereest	7417	296	154	257	6369	0	Angerlo	3042	105	125	42	2648	80
Bathmen	2788	80	18	302	2246	0	Apeldoorn	34112	3209	87	15659	10212	0
Borne	4208	245	26	415	3380	0	Appeltern	3611	137	296	55	3002	125
Brederwiede	14047	250	2760	288	9728	0	Arnhem	9699	1872	253	2752	2931	160
Dalfsen	13228	310	107	1472	10711	0	Barneveld	17640	691	25	4296	10378	0
Denekamp	8842	204	79	1315	6572	0	Batenburg	758	15	37	17	663	25
Deventer	3619	1283	115	154	1893	70	Beesd	3499	79	72	254	2988	0
Diepenheim	2651	31	0	460	2044	0	Bemmel	4271	344	260	20	3485	155
Diepenveen	6858	216	62	1194	5153	25	Bergh	7656	465	25	1577	5266	0
Enschede	14158	1938	78	2349	8469	0	Bergharen	2138	129	20	172	1758	0
Genemuiden	2974	74	47	16	2694	46	Beuningen	2073	180	150	31	1585	80

Table B.1 (continued)

MUNICIPALITY	TOTAL	URBAN	WATER	WOODS	CULT	ND
Beusichem	1439	56	37	9	1311	30
Borculo	5588	212	62	327	4782	0
Brakel	3802	164	476	40	3010	200
Brummen	8505	430	117	1472	6108	70
Buren	1992	70	11	16	1840	0
Buurmalsen	2108	66	23	100	1833	0
Culemborg	3018	279	136	202	2296	80
Deil	3005	159	38	72	2621	0
Didam	3517	347	30	45	2879	0
Dinxperlo	1354	128	2	19	1184	0
Dodewaard	1934	105	164	10	1588	100
Doesburg	1288	172	131	1	924	50
Doetinchem	5110	637	41	540	3594	0
Dreumel	1909	111	158	44	1536	85
Druten	2900	329	324	45	2030	170
Duiven	3518	287	49	5	2880	35
Echteld	3390	185	315	18	2658	175
Ede	31981	1742	28	9819	11551	0
Eibergen	11752	267	57	928	9786	0
Elburg	6582	398	281	935	3122	188
Elst	4309	384	187	0	3553	80
Epe	15737	820	89	5923	7211	0
Ermelo	8620	833	54	4189	2177	35
Est, Opijnen	720	50	62	11	582	40
Ewijk	2657	173	146	30	2176	85
Geldermalsen	1877	210	26	18	1507	0
Gendringen	6522	490	38	148	5726	0
Gendt	1490	212	174	2	1015	100
Gorssel	8949	394	153	1584	6490	80
Groenlo	941	184	12	14	680	0
Groesbeek	4417	527	4	1353	2320	0
Haaften	2145	84	232	40	1682	120
Harderwijk	4123	706	350	1293	1343	232
Hattem	2402	289	91	489	1381	65
Hedel	1288	77	75	8	1055	35
Heerde	8040	518	144	2216	4082	60
Heerewaarden	708	34	150	2	481	95
Hengelo	4936	139	8	612	4010	0
Herwen, Aerdt	3339	224	514	25	2431	0
Herwijnen	2399	67	153	43	2061	85
Heteren	3450	215	161	5	2937	140
Heumen	2135	141	54	651	999	25
Hoevelaken	919	171	6	58	629	0
Horssen	1214	39	6	61	1069	0
Huissen	1417	187	99	7	1014	60
Hummelo, Keppel	4325	115	72	628	3410	0
Kerkwijk	4060	167	266	82	3448	180
Kesteren	1746	191	61	9	1406	50
Lichtenvoorde	7383	352	5	332	6305	0
Lienden	3983	193	94	31	3512	70
Lochem	12905	311	95	2027	10074	0
Maasdriel	2962	155	225	10	2461	85
Maurik	4209	194	213	33	3610	140
Millingen a/d Rijn	1037	118	124	7	758	50
Neede	4601	214	17	499	3645	0
Nunspeet	12963	313	100	6630	3092	28
Nijkerk	6503	513	145	428	5144	114
Nijmegen	4439	1949	183	383	1456	90
Oldebroek	9888	451	68	1590	5441	0
Ophemert	1746	58	81	15	1551	50
Overasselt	2621	121	131	212	2100	80
Pannerden	1114	64	108	20	863	65
Putten	8579	568	84	2636	4874	0
Renkum	4720	645	122	1583	1786	90
Rheden	8433	974	192	3123	2837	110
Rossum	1456	84	150	5	1159	75
Rozendaal	2801	34	3	1606	153	0
Ruurlo	6530	142	42	680	5475	0
Scherpenzeel	1385	156	2	178	1020	0
Steenderen	5026	126	118	78	4580	70
Tiel	1796	336	138	6	1159	80
Ubbergen	3892	270	422	297	2643	200
Valburg	5256	294	229	57	4537	140
Varik	1147	55	151	17	903	85
Voorst	12660	584	300	810	10462	130
Vorden	5726	107	22	1265	3877	0
Vuren	2907	69	241	141	2322	125
Waardenburg	1853	59	80	45	1603	45
Wageningen	3231	568	117	487	1817	85
Wamel	3068	263	163	120	2416	110
Warnsveld	3641	145	77	640	2616	35
Wehl	2348	110	0	172	2009	0
Westervoort	782	127	56	0	549	40
Winterswijk	13880	504	44	2211	10701	0
Wisch	7279	422	18	449	6228	0
Wijchen	3544	538	92	149	2388	25
Zaltebommel	1144	136	137	18	752	80
Zelhem	8173	222	5	523	7205	0
Zevenaar	2763	484	34	38	1969	0
Zoelen	3632	124	44	37	3303	0
Zutphen	1650	570	115	0	783	70
Total Gelderland	513129	35100	12081	89109	329675	5772
Abcoude	2879	138	258	36	2254	0
Amerongen	3078	131	75	971	1717	60
Amersfoort	5662	1458	72	611	3251	0
Baarn	3331	504	46	1630	984	0
Benschop	2302	127	18	22	2123	0
Bilt, de	2699	709	17	1016	859	0

Table B.1 (continued)

MUNICIPALITY	TOTAL	URBAN	WATER	WOODS	CULT	ND
Breukelen	3391	179	710	131	2229	0
Bunnik	3756	195	37	178	3225	0
Bunschoten	3215	241	87	2	2749	55
Cothen	1190	34	15	25	1078	0
Doorn	2226	238	8	1172	696	0
Drieb. Rijsenburg	2643	380	15	1021	1030	0
Eemnes	3156	138	50	42	2841	20
Harmelen	2341	147	49	25	2057	0
Houten	5892	130	228	56	5337	140
Kamerik	2943	102	235	25	2535	0
Kockengen	1949	75	88	10	1754	0
Langbroek	1794	43	8	418	1283	0
Leersum	3022	184	23	1421	1104	0
Leusden	6205	391	35	1512	3393	0
Linschoten	2739	125	35	71	2463	0
Loenen	2379	153	175	89	1895	0
Loosdrecht	2649	183	1337	160	670	0
Lopik	4432	197	265	90	3739	0
Maarn	2536	148	4	1293	897	0
Maarssen	3176	298	367	124	1914	0
Maartensdijk	4054	279	34	494	3028	0
Montfoort	147	88	3	0	46	0
Mijdrecht	3065	220	148	16	2592	0
Nieuwegein	3261	265	197	74	2457	90
Nigtevecht	594	21	64	9	490	0
Oudewater	1108	109	23	6	949	0
Polsbroek	1162	55	30	3	1073	0
Renswoude	1849	80	11	139	1568	0
Rhenen	4310	344	108	1324	2341	90
Snelrewaard	1093	42	14	3	1030	0
Soest	4614	853	18	1404	1489	0
Utrecht	5656	2538	189	140	1992	0
Veenendaal	1791	509	17	61	950	0
Vinkeveen c.a.	3671	176	1106	19	2294	0
Vlauten - De Meern	3498	297	48	142	2881	0
Willeskop	1433	64	10	3	1345	0
Wilnis	2408	116	181	6	2065	0
Woudenberg	3671	216	26	909	2420	0
Wijk bij Duurstede	1940	98	140	14	1521	90
IJsselstein	2232	255	33	10	1884	0
Zegveld	1533	50	55	7	1400	0
Zeist	4868	1234	17	2285	981	0
Total Utrecht	139543	14557	6729	19219	90873	545
Aalsmeer	3328	446	1140	137	1362	0
Abbekerk	795	57	10	5	692	0
Akersloot	2550	99	519	8	1847	0
Alkmaar	3091	904	112	23	1859	0
Amstelveen	4246	835	216	264	2704	0
Amsterdam	20765	7416	3701	243	4027	1650
Andijk	1623	165	185	3	1242	33
Anna Paulowna	5257	284	274	14	4545	48
Avenhorn	906	67	76	0	732	17
Barsingerhorn	3925	132	70	4	3677	0
Beemster	7207	243	153	2	6657	0
Bennebroek	178	109	4	18	32	0
Bergen	3355	394	65	581	1555	18
Berkhout	2615	124	91	3	2366	0
Beverwijk	1915	554	60	71	687	9
Blaricum	1055	316	31	90	449	25
Bloemandaal	3894	514	96	1047	627	31
Blokker	1271	98	1	0	1146	0
Bovenkarspel	875	136	55	4	667	0
Broek in Waterland	2128	39	246	1	1771	33
Bussum	810	604	4	67	61	0
Callantsoog	2767	86	157	70	1695	73
Castricum	3227	347	72	741	1116	0
Diemen	1217	227	88	1	603	15
Edam-Volendam	2346	329	131	3	1803	68
Egmond aan Zee	196	80	11	12	0	11
Egmond-Binnen	3041	119	55	196	1712	33
Enkhuizen	1655	222	430	15	907	365
Graft- de Rijp	1518	94	156	1	1192	0
Graveland, 's-	2936	155	761	559	1167	0
Grootebroek	1237	103	115	1	955	0
Haarlem	3212	1790	205	64	832	0
Haarlemmerliede	2748	98	140	107	1829	0
Haarlemmermeer	18535	1320	435	109	14600	0
Harenkarspel	2393	139	43	4	2136	0
Heemskerk	2760	400	31	498	1141	17
Heemstede	964	433	49	147	312	0
Heerhugowaard	3820	530	47	16	2844	0
Heiloo	2143	393	26	136	1483	0
Helder, Den	5089	883	593	81	2421	369
Hensbroek	1032	43	15	3	944	0
Hilversum	4630	1310	49	1401	1012	0
Hoogkarspel	1349	117	41	1	1165	0
Hoogwoud	2380	128	26	3	2184	0
Hoorn	945	516	123	6	176	77
Huizen	1626	457	69	334	214	59
Ilpendam	2914	85	276	6	2234	0
Jisp	1021	22	189	6	777	0
Katwoude	738	10	62	0	645	26
Landsmeer	1356	144	170	6	914	0
Langedijk	2707	210	320	15	2068	0
Laren	1237	393	22	214	125	0
Limmen	1271	115	35	9	1083	0
Marken	365	27	130	0	204	116
Medemblik	922	128	84	2	696	25

Table B.1 (continued)

MUNICIPALITY	TOTAL	URBAN	WATER	WOODS	CULT	ND
Midwoud	1208	56	30	0	1113	0
Monnickendam	2479	67	1021	2	1294	925
Muiden	3104	109	1683	37	1111	1500
Naarden	2371	327	341	428	1017	80
Nederhorst den Berg	1462	111	268	12	901	0
Nibbixwoud	1048	78	12	0	953	0
Niedorp	4611	208	101	7	4218	0
Obdam	1271	66	25	0	1116	0
Oostzaan	1667	106	327	7	1101	0
Opmeer	2046	111	19	0	1879	0
Opperdoes	393	45	13	2	326	0
Oudendijk	623	17	38	0	561	0
Ouder-Amstel	2611	268	90	10	1943	0
Purmerend	1503	433	57	2	831	0
Schagen	2011	251	51	12	1551	0
Schermer	4741	91	252	9	4248	0
Schoorl	3283	210	71	961	1189	33
Sint Maarten	1408	58	13	2	1298	0
Sint Pancras	769	96	76	1	553	0
Sijbekarspel	1586	76	6	1	1481	0
Texel	18360	471	2756	627	10684	2374
Twisk	734	37	15	2	677	0
Uitgeest	2281	159	332	10	1655	0
Uithoorn	2016	333	135	6	1471	0
Ursem	1559	78	37	0	1402	0
Velsen	5013	1130	632	532	1629	67
Venhuizen	3613	224	205	6	3119	111
Warmenhuizen	1309	70	40	1	1154	0
Weesp	2185	219	121	6	1745	0
Wervershoof	1520	99	151	16	1237	30
Westwoud	1339	72	1	2	1235	0
Wieringen	3398	197	845	15	2197	643
Wieringermeer	21019	263	1569	768	18162	550
Wognum	1666	103	6	1	1525	0
Wormer	1689	160	356	1	1144	0
Wijdewormer	1668	43	35	4	1525	0
Zaanstad	8189	1650	846	44	4987	0
Zandvoort	3427	288	243	379	79	56
Zeevang	3933	132	335	3	3346	89
Zwaag	698	82	1	1	608	0
Zijpe	7287	262	202	140	6252	51
Total N. Holland	291184	33845	25622	11409	186411	9627
Aar, Ter	1990	169	189	10	1580	0
Abbenbroek	958	23	6	0	915	0
Alblasserdam	978	252	105	9	557	50
Alkemade	2877	240	411	18	2129	0
Alphen a/d Rijn	5780	767	197	27	4243	0
Ameide	530	51	34	15	413	25
Ammerstol	75	22	17	0	35	0
Arkel	831	62	29	6	692	0
Asperen	333	59	21	10	227	0
Baarendrecht	2172	324	118	13	1575	65
Benthuizen	1249	33	20	1	1183	0
Bergambacht	2590	168	233	15	2135	100
Bergschenhoek	1552	138	19	1	1359	0
Berkel, Rodenrijs	1966	239	21	2	1674	0
Berkenwoude	1155	50	88	6	1002	0
Bleiswijk	2197	142	82	44	1857	0
Bleskensgraaf c.a.	1271	65	45	1	1154	0
Bodegraven	3817	380	73	20	3267	0
Boskoop	1667	251	174	15	1198	0
Brandwijk	1135	33	35	2	1059	0
Brielle	559	170	68	13	269	0
Capelle a/d IJssel	1488	471	87	7	886	0
Delft	2628	1098	56	0	1194	0
Dirksland	7949	134	3178	4	4348	2356
Dordrecht	8947	1482	1792	511	4589	1650
Driebruggen	3026	146	124	16	2700	0
Everdingen	1102	29	24	64	965	15
Geervliet	2252	36	69	1	2087	0
Giessenburg	2481	128	45	14	2258	0
Goedereede	12066	292	5000	88	4660	4635
Gorinchem	1281	351	253	42	582	100
Gouda	1619	1051	115	14	397	0
Gouderak	1046	75	71	11	881	0
Goudriaan	811	33	25	3	746	0
Goudswaard	3282	31	1300	2	1863	650
Gravendeel, 's-	2172	120	133	1	1887	100
Gravenhage, 's-	6676	4649	165	215	912	0
Gravenzande, 's-	1754	311	55	81	1168	0
Groot-Ammers	1550	69	107	7	1304	45
Haastrecht	1875	110	80	5	1666	0
Hagestein	1076	39	89	12	890	40
Hardinx.Giessendam	1957	236	287	71	1318	150
Hazerswoude	3489	191	113	7	3136	0
Heenvliet	1094	69	101	0	870	0
Heerjansdam	638	32	66	22	404	40
Hei-, Boeicop	944	39	10	28	860	0
Heinenoord	1794	69	217	61	1377	135
Hellevoetsluis	4623	260	1432	27	2689	1329
Hendrik-Ido-Ambacht	1195	219	129	8	807	70
Heukelum	563	72	85	54	283	0
Hillegom	1347	274	68	21	948	0
Hoogblokland	782	33	8	1	720	0
Hoornaar	554	37	18	1	494	0
Katwijk	1393	404	30	33	279	13
Kedichem	1016	37	22	9	918	0
Klaaswaal	1470	71	3	1	1371	0

Table B.1 (continued)

MUNICIPALITY	TOTAL	URBAN	WATER	WOODS	CULT	ND
Koudekerk a/d Rijn	1029	91	12	2	898	0
Krimpen a/d Lek	772	102	133	15	467	50
Krimpen a/d IJssel	829	468	113	9	133	0
Langerak	1154	42	92	3	990	40
Leerbroek	1150	41	12	5	1081	0
Leerdam	1780	230	26	25	1465	0
Leiden	2313	1135	62	37	678	0
Leiderdorp	1209	283	51	7	783	0
Leidschendam	3624	365	107	81	2773	0
Leimuiden	1453	92	64	13	1259	0
Lekkerkerk	2410	151	224	23	1967	90
Lexmond	2265	74	115	114	1863	55
Lier, de	893	185	8	1	669	0
Lisse	1608	337	58	177	967	0
Maasdam	810	61	57	9	672	0
Maasland	2442	131	61	0	2153	0
Maassluis	910	335	163	3	310	65
Meerkerk	1542	77	31	37	1347	0
Middelharnis	8711	289	2631	8	5550	2550
Moerkapelle	731	35	4	0	686	0
Molenaarsgraaf	763	28	16	2	714	0
Monster	1496	403	52	8	812	0
Moordrecht	1470	88	59	9	1232	0
Mijnsheerenland	1785	85	77	2	1578	0
Naaldwijk	2531	633	19	6	1821	0
Nieuw Beijerland	1338	58	95	0	1169	0
Nieuwerkerk IJssel	1918	191	112	10	1533	0
Nieuwkoop	3529	179	771	50	2018	0
Nieuwland	996	28	15	1	933	0
Nieuw Lekkerland	1280	129	253	9	819	120
Nieuwpoort	61	17	19	2	24	0
Nieuwveen	875	51	18	0	795	0
Noordeloos	1543	50	27	0	1453	0
Noordwijk	3709	354	126	333	1318	0
Noordwijkerhout	2341	250	103	122	1689	0
Nootdorp	1085	119	25	3	822	0
Numansdorp	5612	145	1691	80	3575	1582
Oegstgeest	773	258	52	31	389	0
Oostflakkee	10551	155	3789	16	6328	3669
Oostvoorne	3271	250	857	147	1523	227
Ottoland	862	30	29	2	794	0
Oud-Alblas	1318	62	22	6	1216	0
Oud-Beijerland	1819	253	272	39	1162	0
Oudenhoorn	1488	32	537	0	899	511
Ouderkerk IJssel	1822	330	155	2	1326	0
Papendrecht	1092	391	151	7	463	85
Piershil	1149	32	28	1	1075	0
Poortugaal	1054	201	104	53	649	55
Puttershoek	585	93	71	8	385	50
Pijnacker	3346	318	59	17	2885	0
Reeuwijk	3574	187	943	24	2344	0
Rhoon	1647	137	123	7	1249	70
Ridderkerk	2532	572	152	43	1551	80
Rockanje	3084	171	130	316	1883	90
Rotterdam	24748	6919	5981	182	5660	3022
Rozenburg	3165	169	1182	74	929	200
Rijnsaterwoude	929	29	334	3	551	0
Rijnsburg	606	149	16	1	422	0
Rijswijk	1818	609	19	28	914	0
Sassenheim	661	201	29	10	381	0
Schelluinen	377	22	3	4	342	0
Schiedam	1995	847	170	26	640	60
Schipluiden	3003	166	43	14	2707	0
Schoonhoven	683	158	57	1	449	25
Schoonrewoerd	939	46	17	31	839	0
Sliedrecht	1389	336	115	7	857	75
Spijkenisse	2043	322	140	30	1403	120
Stolwijk	2783	119	200	9	2427	0
Streefkerk	1801	78	184	7	1526	80
Strijen	5835	195	734	164	4587	660
Tienhoven	431	23	37	3	358	0
Valkenburg	576	30	29	162	259	0
Vianen	1675	208	94	0	1142	50
Vierpolders	1074	53	31	3	967	0
Vlaardingen	2664	836	262	21	977	80
Vlist	999	37	37	3	918	0
Voorburg	634	550	5	0	35	0
Voorhout	1262	93	39	11	1081	0
Voorschoten	1156	273	47	107	631	0
Waddinxveen	2926	323	134	16	2363	0
Warmond	1466	83	428	50	830	0
Wassenaar	5305	733	208	836	1518	33
Wateringen	1217	252	11	1	899	0
Westmaas	752	40	48	1	642	0
Woerden	2146	400	37	5	1597	0
Woubrugge	2229	98	138	14	1931	0
Wijngaarden	639	19	8	4	599	0
Zevenhoven	1657	47	62	6	1519	0
Zevenhuizen	2947	146	195	40	2482	0
Zoetermeer	3511	455	63	27	2186	0
Zoeterwoude	2258	138	107	10	1902	0
Zuid-Beijerland	4508	57	1457	1	2930	1365
Zuidland	2223	68	252	2	1513	200
Zwartewaal	337	24	18	1	285	0
Zwijndrecht	1633	612	169	18	654	100
Total Z. Holland	332556	43103	45458	5528	210969	27027
Aardenburg	4971	177	45	23	4636	0
Arnemuiden	1689	36	205	61	1286	146

Table B.1 (continued)

MUNICIPALITY	TOTAL	URBAN	WATER	WOODS	CULT	ND
Axel	7230	353	103	112	6422	0
Borssele	19470	497	5160	25	13250	5058
Brouwershaven	8970	165	2585	55	6012	2469
Bruinisse	3774	65	2823	2	763	2782
Domburg	2634	197	378	218	1472	358
Duiveland	5412	98	952	57	4118	850
Goes	10182	618	859	71	8216	679
Hontenisse	11189	266	3631	33	6997	3529
Hulst	13871	482	1403	271	9431	1123
Kapelle	4973	239	1231	20	3342	1186
Kortgene	6830	115	2868	29	3654	2855
Mariekerke	3500	86	16	7	3303	0
Middelburg	3268	584	75	39	2382	0
Middenschouwen	4930	79	465	8	4234	372
Oostburg	22500	534	2760	57	18652	2605
Reimerswaal	24329	360	14106	65	8158	13734
Sas van Gent	6374	248	302	93	5457	0
Sint Philipsland	2902	41	812	14	1790	778
Sluis	3407	115	76	6	3087	27
Terneuzen	18173	713	6347	105	10043	5978
Tholen	21462	321	9370	13	11079	9246
Valkenisse	2939	191	164	77	2294	148
Veere	8647	156	4951	103	3093	4864
Vlissingen	22172	642	18669	75	1919	18569
Westerschouwen	10288	363	4449	515	3485	4381
Westkapelle	990	60	160	23	670	124
Wissenkerke	5269	104	708	207	4014	656
Zierikzee	12150	174	9862	9	1954	9795
Total Zeeland	274495	8079	95535	2393	155213	92312
Aalburg	5248	270	275	95	4492	110
Aarle-Rixtel	1672	126	24	182	1305	0
Alphen c.a.	5665	302	7	1081	4125	0
Asten	7031	295	33	711	4747	0
Baarle-Nassau	7641	186	4	877	6404	0
Bakel c.a.	6631	210	27	2038	3720	0
Beek c.a.	1681	215	23	50	1341	0
Beers	2948	74	105	152	2528	45
Bergen op Zoom	4719	608	1083	1091	1340	923
Bergeijk	5255	314	29	1391	3405	0
Berghem	1335	76	3	178	971	0
Berke-Enschot	1989	216	28	200	1395	0
Berlikum	2513	288	32	174	1941	0
Best	3577	429	20	766	1975	0
Bladel c.a.	3331	271	12	752	2104	0
Boekel	3456	181	1	121	3061	0
Boxmeer	3133	254	94	223	2423	50
Boxtel	5126	514	75	775	3179	0
Breda	6055	2089	75	936	2560	0

MUNICIPALITY	TOTAL	URBAN	WATER	WOODS	CULT	ND
Budel	4051	443	87	691	1961	0
Chaam	2991	107	2	516	2331	0
Cuyk c.a.	2116	284	75	75	1432	60
Deurne	11800	592	87	1535	7614	0
Diessen	2943	137	16	314	2416	0
Dinteloord, Prins	5722	109	1081	1	4314	995
Dongen	2462	447	13	107	1825	0
Drunen	3350	273	33	832	1711	0
Dungen, den	854	78	14	5	735	0
Dussen	3968	126	408	155	3156	150
Eersel	3609	313	8	846	2339	0
Eindhoven	7909	3206	90	765	2905	0
Erp	3599	94	23	431	2995	0
Esch	448	53	7	3	364	0
Etten-Leur	5900	647	38	183	4827	0
Fijnaart Heijningen	4533	149	362	8	3852	301
Geertruidenberg	551	103	77	11	247	25
Geffen	1403	81	0	41	1220	0
Geldrop	1987	449	32	380	736	0
Gemert	5724	300	3	765	4393	0
Gilze, Rijen	7121	509	8	1230	4530	0
Goirle	2571	197	6	645	1328	0
Grave	2137	99	67	131	1772	40
Gravenmoer, 's-	524	51	9	3	455	0
Haaren	1809	91	5	64	1407	0
Halsteren	2859	294	257	128	2083	233
Haps	1525	73	5	46	1339	0
Heesch	2610	161	0	157	2146	0
Heeswijk-Dinther	3403	132	19	297	2696	0
Heeze	3895	291	116	981	1505	0
Helmond	4588	1162	50	866	2299	0
Helvoirt	2648	84	11	722	1731	0
Hertogenbosch, 's-	5531	1420	407	21	3019	150
Heusden	2130	246	153	59	1592	75
Hilvarenbeek	6819	220	78	2321	3875	0
Hoeven	3015	173	14	233	2459	0
Hoogeloon c.a.	4023	251	8	1014	2449	0
Hooge, Lage Mierde	4735	135	53	1454	2803	0
Hooge, Lage Zwaluwe	4408	125	1185	121	2885	792
Huijbergen	1070	46	0	395	541	0
Klundert	4457	131	1100	20	2554	1048
Leende	4152	161	32	1752	1722	0
Liempde	1927	97	17	435	1320	0
Lieshout	2574	190	16	471	1812	0
Lith	5419	147	232	25	4763	145
Loon op Zand	5219	425	15	1591	2924	0
Luyksgestel	2264	116	0	821	1269	0
Maarheeze	5522	277	30	1591	3109	0
Made, Drimmelen	6034	310	3108	645	1874	2650
Megen c.a.	1634	65	39	10	1476	25

Table B.1 (continued)

MUNICIPALITY	TOTAL	URBAN	WATER	WOODS	CULT	ND
Mierlo	2775	234	30	672	1400	0
Mill c.a.	5113	341	68	728	3661	0
Moergestel	2797	186	34	373	2115	0
Nieuw Ginneken	4209	244	30	707	3124	0
Nieuw Vossemeer	1678	45	199	3	1314	185
Nistelrode	3269	131	3	500	2484	0
Nuenen c.a.	3449	427	29	518	2185	0
Nuland	1628	107	6	88	1348	0
Oeffelt	954	55	34	10	817	25
Oirschot	6044	382	30	897	3990	0
Oisterwijk	2795	219	65	720	1272	0
O.,W. Middelbeers	4169	186	67	1212	2516	0
Oosterhout	7147	762	122	1222	4552	0
Oploo c.a.	5830	149	15	944	4477	0
Oss	2966	1034	46	99	1554	0
Ossendrecht	2956	116	49	986	1570	0
Oudenbosch	1174	186	11	16	877	0
OudenNieuw Gastel	3313	182	25	12	3003	0
Prinsenbeek	3374	184	56	87	2971	0
Putte	1850	89	2	1245	324	0
Raamsdonk	2272	197	188	26	1510	60
Ravenstein	4257	136	123	413	3463	80
Reusel c.a.	3152	154	2	538	2153	0
Riethoven	1717	113	4	469	1103	0
Roosendaal, Nispen	5760	1100	58	186	4164	0
Rosmalen	3334	695	24	289	2104	0
Rucphen	6091	447	2	1094	4208	0
Rijsbergen	3711	141	12	368	3123	0
Schaijk	4115	176	9	1068	2773	0
Schijndel	4748	367	22	459	3605	0
Sint-Michielsgestel	2156	171	36	124	1758	0
Sint-Oedenrode	6675	242	34	655	5516	0
Someren	8356	242	131	1247	6035	0
Son c.a.	2667	353	34	476	1658	0
Sprang-Capelle	2561	197	97	42	2145	40
Standdaarbuiten	1356	77	17	1	1176	0
Steenbergen	9709	336	902	147	7721	740
Terheijden	2632	178	43	59	2304	0
Teteringen	1403	118	1	212	1037	0
Tilburg	8018	2666	71	1148	3525	0
Uden	6286	454	3	607	4558	0
Udenhout	2690	175	2	464	1971	0
Valkenswaard	5312	649	104	1436	2742	0
Veghel	4294	436	44	78	3497	0
Veldhoven	4282	667	27	536	2525	0
Vessem c.a.	4829	237	26	1465	2904	0
Vierlingsbeek	6393	295	78	1213	4547	60
Vlijmen	2475	370	21	5	2016	0
Vught	3806	479	127	440	2509	0
Waalre	2188	343	30	698	939	0

MUNICIPALITY	TOTAL	URBAN	WATER	WOODS	CULT	ND
Waalwijk	2358	484	122	43	1557	50
Wanroij	5140	142	33	413	4430	0
Waspik	1869	97	95	2	1614	40
Werkendam	8571	309	2121	455	5476	1820
Westerhoven	1089	58	27	237	726	0
Willemstad	3116	94	1327	17	1639	1235
Woensdrecht	4503	225	855	590	2330	851
Woudrichem	5149	231	217	122	4415	100
Wouw	5147	205	2	445	4383	0
Zeeland	3447	119	0	479	2536	0
Zevenbergen	4942	220	36	9	3784	0
Zundert	8943	326	38	873	7332	0
Total N. Brabant	510558	42568	19512	68393	345191	13103
Amstenrade	289	56	0	5	207	0
Arsen, Velden	4203	186	106	1371	2401	85
Baexem	901	59	3	35	781	0
Beegden	919	39	92	267	406	40
Beek	1861	390	1	20	1322	0
Beesel	2912	227	55	342	2179	50
Belfeld	1398	137	35	213	924	30
Bemelen	281	11	0	21	243	0
Berg, Terblijt	747	85	4	80	543	0
Bergen	10947	328	275	2656	6243	170
Bingelrade	359	27	0	6	317	0
Bocholtz	848	74	0	5	653	0
Born	1539	169	70	89	1014	30
Broekhuizen	1163	53	44	225	804	35
Brunssum	1257	494	10	260	58	0
Bunde	534	85	13	55	360	10
Cadier, Keer	857	77	0	68	690	0
Echt	7159	423	44	997	5402	0
Elsloo	819	98	40	42	608	25
Eijgelshoven	332	134	4	27	117	0
Eijsden	1853	157	48	38	1436	40
Geleen	1219	768	2	0	392	0
Gennep	4955	322	120	397	3666	80
Geulle	696	61	37	83	467	25
Grathem	2107	56	27	138	1842	0
Grevenbicht	359	52	28	0	274	15
Gronsveld	1089	89	0	141	836	0
Grubbenvorst	4365	208	73	856	3039	65
Gulpen	2126	100	5	176	1812	0
Haelen	2059	167	92	476	1157	45
Heel c.a.	1076	71	140	190	630	0
Heerlen	3447	1246	8	197	1516	0
Helden	6920	320	10	1060	5183	0
Herten	687	84	167	5	383	60
Heythuysen	2938	122	11	521	2097	0

Table B.1 (continued)

MUNICIPALITY	TOTAL	URBAN	WATER	WOODS	CULT	ND
Hoensbroek	892	289	11	21	442	0
Horn	1159	122	115	269	585	40
Horst	8033	435	69	693	6100	0
Hulsberg	899	86	0	28	763	0
Hunsel	3263	90	14	120	2972	0
Jabeek	398	13	0	29	338	0
Kerkrade	1860	786	25	146	740	0
Kessel	2220	89	83	295	1699	65
Klimmen	793	84	1	2	659	0
Limbricht	913	96	1	23	777	0
Linne	1512	100	112	105	1147	40
Maasbracht	1630	174	219	143	813	80
Maasbree	5118	217	21	800	3858	25
Maastricht	5894	1946	185	100	3199	150
Margraten	984	90	0	15	842	0
Meerlo-Wanssum	3947	259	74	628	2847	65
Meerssen	867	154	11	112	511	0
Melick, Herkenbosch	3229	171	24	781	1572	0
Merkelbeek	456	49	0	5	383	0
Meijel	1994	110	19	174	1578	0
Mheer	898	36	0	23	804	0
Montfort	994	66	0	218	680	0
Mook c.a.	1883	127	129	493	905	60
Munstergeleen	447	73	1	15	352	0
Nederweert	9460	353	118	572	7552	0
Neer	2181	97	63	235	1613	30
Nieuwenhagen	704	129	0	169	271	0
Nieuwstadt	873	57	60	155	483	0
Noorbeek	793	33	0	19	676	0
Nuth	936	123	4	33	696	0
Obbicht c.a.	497	50	13	9	414	10
Ohe, Laak	449	31	179	0	229	65
Oirsbeek	720	80	0	15	609	0
Posterholt	1207	100	1	122	950	0
Roermond	2886	739	168	45	1818	70
Roggel	2287	153	11	597	1433	0
Roosteren	767	42	45	1	662	30
Schaesberg	683	320	5	54	174	0
Schimmert	911	70	0	8	812	0
Schinnen	1464	124	6	120	1173	0
Schinveld	1190	74	2	362	720	0
Sevenum	4929	178	34	580	3609	0
Simpelveld	819	131	0	21	508	0
Sint Geertruid	916	33	0	38	832	0
Sint Odilienberg	1308	62	15	272	936	0
Sittard	2104	891	2	135	832	0
Slenaken	725	17	0	96	598	0
Spaubeek	561	88	1	26	422	0
Stein	1009	195	57	52	622	30
Stevensweert	614	38	190	0	373	65
Stramproij	1207	74	2	119	916	0
Susteren	1746	153	20	177	1317	0
Swalmen	2199	210	39	465	1360	25
Tegelen	1042	373	20	150	382	15
Thorn	685	70	85	17	478	30
Ubach over Worms	1008	148	3	86	702	0
Ulestraten	807	101	1	27	551	0
Urmond	539	81	28	13	395	25
Vaals	2395	167	4	550	1599	0
Valkenburg-Houthem	2555	191	11	307	1960	0
Venlo	4677	1268	82	617	1719	75
Venraij	14616	820	28	2312	10463	0
Vlodrop	1894	56	18	734	912	0
Voerendaal	2272	143	1	61	1965	0
Weert	9954	893	88	1650	5986	0
Wessem	582	58	155	9	315	70
Wittem	3565	187	8	447	2866	0
Wijlre	1910	77	7	102	1672	0
Wijnandsrade	779	28	0	29	702	0
Total Limburg	220929	21943	4252	27908	149845	1870
Dronten	28957	1180	4805	3796	16256	4380
Oostelijk Flevoland	35044	1072	5362	3261	24007	4890
Zuidelijk Flevoland	51232	3	8939	796	17096	8150
Total IJpolders	115233	2255	19106	7853	57359	17420
Total Nation	3695359	260422	313817	308097	2515997	217157

Table B.2

PERCENTAGE OF MUNICIPALITIES IN PAWN DISTRICTS

Pro	Municipality	Districts 1	2	3	4	5	6	7
Gr	Adorp	.	.	100	.	.	.	.
	Aduard	.	.	30	.	.	.	.
	Appingedam	.	.	.	.	100	.	.
	Baflo	.	.	70	30	.	.	.
	Bedum	.	.	100	.	.	.	.
	Beerta	.	.	.	.	.	100	.
	Bellingwedde	.	.	.	.	.	60	40
	Bierum	.	.	.	40	60	.	.
	Boer, Ten	.	.	70	.	30	.	.
	Delfzijl	.	.	.	.	80	20	.
	Eenrum	.	.	90	10	.	.	.
	Ezinge	.	.	100	.	.	.	.
	Finsterwolde	.	.	.	.	.	100	.
	Groningen	.	.	20	.	20	.	.
	Grootegast	100	.	.	.	.	.	.
	Grijpskerk	80	.	20	.	.	.	.
	Hoogezand-Sappemeer	.	.	.	.	20	.	60
	Kantens	.	.	100	.	.	.	.
	Kloosterburen	.	.	100	.	.	.	.
	Leens	.	.	100	.	.	.	.
	Loppersum	.	.	.	.	100	.	.
	Meeden	.	.	.	.	.	100	.
	Middelstum	.	.	100	.	.	.	.
	Midwolda	.	.	.	.	.	100	.
	Muntendam	.	.	.	.	.	40	60
	Nieuwe Pekela	.	.	.	.	.	.	100
	Nieuweschans	.	.	.	.	.	100	.
	Nieuwolda	.	.	.	.	.	100	.
	Oldehove	.	.	100	.	.	.	.
	Oosterbroek	.	.	.	.	.	70	30
	Oude Pekela	.	.	.	.	.	.	100
	Scheemda	.	.	.	.	.	100	.
	Slochteren	.	.	.	.	100	.	.
	Stadskanaal	.	.	.	.	.	.	100
	Stedum	.	.	80	.	20	.	.
	Termunten	.	.	.	.	20	80	.
	Uithuizen	.	.	40	60	.	.	.
	Uithuizermeeden	.	.	30	70	.	.	.
	Ulrum	.	.	100	.	.	.	.
	Usquert	.	.	30	70	.	.	.
	Veendam	.	.	.	.	.	.	100
	Vlagtwedde	.	.	.	.	.	.	100
	Warffum	.	.	60	40	.	.	.
	Winschoten	.	.	.	.	.	90	10
	Winsum	.	.	100	.	.	.	.
	Zandt, 't	.	.	.	10	90	.	.
	Zuidhorn	.	.	50	.	.	.	.

Pro	Municipality	Districts 1	2	3	4	5	6	7
Fr	Achtkarspelen	100	.	.	.	.	.	.
	Baarderadeel	20	80	.	.	.	.	.
	Barradeel	100	.	.	.	.	.	.
	Bildt, het	.	100	.	.	.	.	.
	Bolsward	100	.	.	.	.	.	.
	Dantumadeel	100	.	.	.	.	.	.
	Dokkum	50	.	50	.	.	.	.
	Doniawerstal	100	.	.	.	.	.	.
	Ferwerderadeel	80	20	.	.	.	.	.
	Franeker	80	20	.	.	.	.	.
	Franekeradeel	100	.	.	.	.	.	.
	Gaasterland	100	.	.	.	.	.	.
	Harlingen	100	.	.	.	.	.	.
	Haskerland	100	.	.	.	.	.	.
	Heerenveen	100	.	.	.	.	.	.
	Hemelumer Oldeferd	100	.	.	.	.	.	.
	Hennaarderadeel	100	.	.	.	.	.	.
	Hindeloopen	100	.	.	.	.	.	.
	Idaarderadeel	100	.	.	.	.	.	.
	Kollumerland c.a.	70	.	30	.	.	.	.
	Leeuwarden	100	.	.	.	.	.	.
	Leeuwarderadeel	100	.	.	.	.	.	.
	Lemsterland	100	.	.	.	.	.	.
	Menaldumadeel	100	.	.	.	.	.	.
	Oostdongeradeel	.	.	100	.	.	.	.
	Ooststellingwerf	80	.	.	.	.	.	.
	Opsterland	100	.	.	.	.	.	.
	Rauwerderhem	100	.	.	.	.	.	.
	Sloten	100	.	.	.	.	.	.
	Smallingerland	100	.	.	.	.	.	.
	Sneek	100	.	.	.	.	.	.
	Staveren	100	.	.	.	.	.	.
	Tietjerksteradeel	100	.	.	.	.	.	.
	Utingeradeel	100	.	.	.	.	.	.
	Westdongeradeel	20	.	80	.	.	.	.
	Weststellingwerf	100	.	.	.	.	.	.
	Wonseradeel	100	.	.	.	.	.	.
	Workum	100	.	.	.	.	.	.
	Wymbritseradeel	100	.	.	.	.	.	.
	IJlst	100	.	.	.	.	.	.
Dr	Vledder	20	.	.	.	.	.	.
Ov	Steenwijk	10	.	.	.	.	.	.
	IJsselham	10	.	.	.	.	.	.

Table B.2 (continued)

PERCENTAGE OF MUNICIPALITIES IN PAWN DISTRICTS

Pro	Municipality	Districts 8	9	13	14	15
Gr	Aduard	.	70	.	.	.
	Groningen	10	50	.	.	.
	Haren	90	10	.	.	.
	Hoogezand-Sappemeer	20	.	.	.	.
	Leek	.	100	.	.	.
	Marum	.	100	.	.	.
	Oldekerk	.	100	.	.	.
	Zuidhorn	.	50	.	.	.
Fr	Ooststellingwerf	.	.	20	.	.
Dr	Anloo	100	.	.	.	.
	Assen	100	.	.	.	.
	Beilen	10	.	.	.	.
	Borger	70	.	.	.	.
	Diever	.	.	100	.	.
	Eelde	20	80	.	.	.
	Gasselte	80	.	.	.	.
	Gieten	100	.	.	.	.
	Havelte	.	.	40	.	.
	Meppel	.	.	.	.	10
	Norg	.	100	.	.	.
	Nijeveen	.	.	100	.	.
	Peize	.	100	.	.	.
	Roden	.	100	.	.	.
	Rolde	90	.	.	.	.
	Smilde	.	10	.	.	.
	Vledder	.	.	80	.	.
	Vries	40	60	.	.	.
	Zuidlaren	100	.	.	.	.
Ov	Avereest	.	.	.	.	20
	Brederwiede	.	.	100	.	.
	Dalfsen	.	.	.	.	40
	Genemuiden	.	.	.	.	100
	Hasselt	.	.	.	.	100
	Kampen	.	.	.	.	100
	Nieuwleusen	.	.	.	.	100
	Noordoostpolder	.	.	.	100	.
	Ommen	.	.	.	.	10
	Staphorst	.	.	.	.	80
	Steenwijk	.	.	90	.	.
	Urk	.	.	.	100	.
	IJsselham	.	.	90	.	.
	Zwartsluis	.	.	40	.	60
	Zwolle	.	.	.	.	50

Pro	Municipality	Districts 10	11	12	16
Dr	Beilen	.	.	90	.
	Borger	30	.	.	.
	Coevorden	.	50	.	50
	Dalen	.	80	.	20
	Dwingelo	.	.	100	.
	Emmen	50	50	.	.
	Gasselte	20	.	.	.
	Havelte	.	.	60	.
	Hoogeveen	.	.	80	20
	Meppel	.	.	90	.
	Odoorn	70	.	30	.
	Oosterhesselen	.	90	10	.
	Rolde	.	.	10	.
	Ruinen	.	.	100	.
	Ruinerwold	.	.	100	.
	Schoonebeek	.	100	.	.
	Sleen	.	80	20	.
	Smilde	.	.	90	.
	Westerbork	.	.	100	.
	Wijk, de	.	.	100	.
	Zuidwolde	.	.	80	20
	Zweeloo	.	90	10	.
Ov	Avereest	.	.	.	50
	Dalfsen	.	.	.	20
	Gramsbergen	.	.	.	100
	Hardenberg	.	.	.	80
	Ommen	.	.	.	50
	Staphorst	.	.	20	.

Pro	Municipality	Districts 17	18	19	20	21	24	25
Ov	Almelo	.	70	.	30	.	.	.
	Ambt Delden	.	40	.	60	.	.	.
	Avereest	.	30	.	.	.	.	.
	Bathmen	.	.	.	.	100	.	.
	Borne	.	90	.	10	.	.	.
	Dalfsen	.	.	40	.	.	.	.
	Denekamp	90	.	.	10	.	.	.
	Deventer	.	.	10	.	90	.	.
	Diepenheim	.	.	.	100	.	.	.
	Diepenveen	.	.	80	.	20	.	.
	Enschede	30	30	.	40	.	.	.
	Goor	.	100	.	.	.	.	.
	Haaksbergen	.	.	.	70	30	.	.
	Ham, den	.	100	.	.	.	.	.

Table B.2 (continued)

Pro	Municipality	Districts						
		17	18	19	20	21	24	25
Ov	Hardenberg	.	20	.	.	.	.	.
	Heino	.	.	100	.	.	.	.
	Hellendoorn	.	80	20	.	.	.	.
	Hengelo	.	70	.	30	.	.	.
	Holten	.	20	.	.	80	.	.
	Losser	100	.	.				
	Markelo	.	40	.	20	40	.	.
	Oldenzaal	.	90	.	10	.	.	.
	Olst	.	.	100	.	.	.	.
	Ommen	.	30	10	.	.	.	.
	Ootmarsum	100	.	.	.	.	.	.
	Raalte	.	.	80	.	20	.	.
	Rijssen	.	100	.	.	.	.	.
	Stad-Delden	.	80	.	20	.	.	.
	Tubbergen	.	50	.	50	.	.	.
	Vriezenveen	.	100	.	.	.	.	.
	Weerselo	20	20	.	60	.	.	.
	Wierden	.	100	.	.	.	.	.
	Wijhe	.	.	100	.	.	.	.
	Zwolle	.	.	50	.	.	.	.
Ge	Aalten	.	.	.	.	.	20	80
	Angerlo	.	.	.	.	.	.	90
	Bergh	.	.	.	.	.	.	100
	Borculo	.	.	.	40	.	60	.
	Didam	.	.	.	.	.	.	100
	Dinxperlo	.	.	.	.	.	.	100
	Doesburg	.	.	.	.	.	.	70
	Doetinchem	.	.	.	.	.	.	100
	Duiven	.	.	.	.	.	.	100
	Eibergen	.	.	.	10	.	90	.
	Gendringen	.	.	.	.	.	.	100
	Gorssel	.	.	.	.	20	80	.
	Groenlo	.	.	.	.	.	100	.
	Hengelo	.	.	.	.	.	100	.
	Herwen, Aerdt	.	.	.	.	.	.	60
	Hummelo, Keppel	.	.	.	.	.	.	100
	Lichtenvoorde	.	.	.	.	.	90	10
	Lochem	.	.	.	30	20	50	.
	Neede	.	.	.	70	30	.	.
	Oldebroek	.	.	.	80	.	.	.
	Pannerden	.	.	.	.	.	.	90
	Ruurlo	.	.	.	10	.	90	.
	Steenderen	.	.	.	.	.	60	40
	Vorden	.	.	.	.	.	100	.
	Warnsveld	.	.	.	.	.	100	.
	Wehl	.	.	.	.	.	.	100
	Westervoort	.	.	.	.	.	.	100
Ge	Winterswijk	.	.	.	.	.	50	50
	Wisch	.	.	.	.	.	10	90
	Zelhem	.	.	.	.	.	60	40
	Zevenaar	.	.	.	.	.	.	100
	Zutphen	.	.	.	.	.	80	.

Pro	Municipality	Districts						
		22	23	26	27	28	29	30
Ov	IJsselmuiden	.	50	.	.	.	50	.
Ge	Angerlo	.	.	10	.	.	.	.
	Apeldoorn	20	40	.	.	20	20	.
	Arnhem	.	.	20	60	.	.	.
	Barneveld	.	.	.	.	100	.	.
	Brummen	.	100	.	.	.	.	.
	Doesburg	.	.	30	.	.	.	.
	Ede	.	.	.	20	80	.	.
	Elburg	.	.	.	.	.	100	.
	Epe	20	80	.	.	.	.	.
	Ermelo	.	.	.	.	.	100	.
	Harderwijk	.	.	.	.	.	100	.
	Hattem	20	80	.	.	.	.	.
	Heerde	50	50	.	.	.	.	.
	Hoevelaken	.	.	.	.	60	40	.
	Nunspeet	.	.	.	.	.	100	.
	Nijkerk	.	.	.	.	10	90	.
	Oldebroek	.	20	.	.	.	.	.
	Putten	.	.	.	.	.	100	.
	Renkum	.	.	.	100	.	.	.
	Rheden	.	40	60	.	.	.	.
	Rozendaal	.	40	10	50	.	.	.
	Scherpenzeel	.	.	.	.	100	.	.
	Voorst	90	10	.	.	.	.	.
	Wageningen	.	.	.	20	80	.	.
	Zutphen	.	20	.	.	.	.	.
Ut	Amerongen	.	.	.	.	40	.	.
	Amersfoort	.	.	.	.	100	.	.
	Baarn	.	.	.	.	100	.	.
	Bilt, de	.	.	.	.	10	.	.
	Bunschoten	.	.	.	.	70	30	.
	Eemnes	.	.	.	.	100	.	.
	Leersum	.	.	.	.	50	.	.
	Leusden	.	.	.	.	100	.	.
	Maarn	.	.	.	.	100	.	.
	Renswoude	.	.	.	.	100	.	.
	Rhenen	.	.	.	.	60	.	.

Table B.2 (continued)

Pro	Municipality	Districts						
		22	23	26	27	28	29	30
Ut	Veenendaal	.	.	.	.	100	.	.
	Woudenberg	.	.	.	.	90	.	.
	Zeist	.	.	.	.	10	.	.
NH	Blaricum	.	.	.	.	50	.	.
	Hilversum	.	.	.	.	10	.	.
	Huizen	.	.	.	.	40	.	.
	Laren	.	.	.	.	40	.	.
IJ	Dronten	.	.	.	.	.	.	100
	Oostelijk Flevoland	.	.	.	.	.	.	100
	Zuidelijk Flevoland	.	.	.	.	.	.	100

Pro	Municipality	Districts						
		31	32	33	34	35	36	37
NH	Abbekerk	.	.	100	.	.	.	.
	Akersloot	.	.	.	.	100	.	.
	Alkmaar	.	.	.	.	100	.	.
	Amsterdam	.	.	.	.	.	.	60
	Andijk	.	.	100	.	.	.	.
	Anna Paulowna	.	100	.	.	.	.	.
	Avenhorn	.	.	100	.	.	.	.
	Barsingerhorn	.	100	.	.	.	.	.
	Beemster	.	.	.	.	100	.	.
	Bergen	.	.	.	.	60	.	.
	Berkhout	.	.	.	100	.	.	.
	Beverwijk	.	.	.	.	.	.	100
	Blokker	.	.	50	50	.	.	.
	Bovenkarspel	.	.	100	.	.	.	.
	Broek in Waterland	.	.	.	.	.	100	.
	Callantsoog	.	.	.	.	100	.	.
	Castricum	.	.	.	.	70	.	.
	Edam-Volendam	.	.	.	.	100	.	.
	Egmond-Binnen	.	.	.	.	80	.	.
	Enkhuizen	.	.	100	.	.	.	.
	Graft- de Rijp	.	.	.	.	100	.	.
	Grootebroek	.	.	100	.	.	.	.
	Haarlemmerliede	.	.	.	.	.	.	70
	Harenkarspel	.	70	.	.	30	.	.
	Heemskerk	.	.	.	.	80	.	10
	Heerhugowaard	.	10	.	.	90	.	.
	Heiloo	.	.	.	.	100	.	.
	Helder, Den	.	.	.	.	100	.	.
	Hensbroek	.	100	.	.	.	.	.
	Hoogkarspel	.	.	100	.	.	.	.
	Hoogwoud	.	10	90	.	.	.	.
	Hoorn	.	.	.	100	.	.	.

Pro	Municipality	Districts						
		31	32	33	34	35	36	37
NH	Ilpendam	.	.	.	.	20	80	.
	Jisp	.	.	.	.	100	.	.
	Katwoude	.	.	.	.	100	.	.
	Landsmeer	.	.	.	.	.	100	.
	Langedijk	.	.	.	.	100	.	.
	Limmen	.	.	.	.	100	.	.
	Medemblik	.	.	100	.	.	.	.
	Midwoud	.	.	100	.	.	.	.
	Monnickendam	.	.	.	.	60	40	.
	Nibbixwoud	.	.	100	.	.	.	.
	Niedorp	.	100	.	.	.	.	.
	Obdam	.	100	.	.	.	.	.
	Oostzaan	.	.	.	.	.	20	80
	Opmeer	.	40	40	20	.	.	.
	Opperdoes	.	.	100	.	.	.	.
	Oudendijk	.	.	100	.	.	.	.
	Purmerend	.	.	.	.	100	.	.
	Schagen	.	100	.	.	.	.	.
	Schermer	.	.	.	.	100	.	.
	Schoorl	.	.	.	.	40	.	.
	Sint Maarten	.	40	.	.	60	.	.
	Sint Pancras	.	.	.	.	100	.	.
	Sijbekarspel	.	.	100	.	.	.	.
	Twisk	.	.	100	.	.	.	.
	Uitgeest	.	.	.	.	100	.	.
	Ursem	.	.	100	.	.	.	.
	Velsen	.	.	.	.	.	.	90
	Venhuizen	.	.	.	100	.	.	.
	Warmenhuizen	.	.	.	.	100	.	.
	Wervershoof	.	.	100	.	.	.	.
	Westwoud	.	.	100	.	.	.	.
	Wieringen	.	100	.	.	.	.	.
	Wieringermeer	100	.	.	.	.	.	.
	Wognum	.	.	70	30	.	.	.
	Wormer	.	.	.	.	100	.	.
	Wijdewormer	.	.	.	.	50	50	.
	Zaanstad	.	.	.	.	50	.	50
	Zeevang	.	.	.	.	100	.	.
	Zwaag	.	.	.	100	.	.	.
	Zijpe	.	.	.	.	100	.	.

Pro	Municipality	Districts				
		38	39	40	46	47
Ut	Abcoude	.	100	.	.	.
	Breukelen	.	20	50	.	.

Table B.2 (continued)

Pro	Municipality	Districts 38	39	40	46	47
Ut	Kockengen	.	20	.	.	.
	Loenen	.	10	90	.	.
	Loosdrecht	.	.	100	.	.
	Maarssen	.	.	80	.	.
	Maartensdijk	.	.	50	.	.
	Mijdrecht	.	100	.	.	.
	Nigtevecht	.	10	90	.	.
	Vinkeveen c.a.	.	100	.	.	.
	Wilnis	.	100	.	.	.
NH	Aalsmeer	100	.	.	.	.
	Amstelveen	20	80	.	.	.
	Amsterdam	30	10	.	.	.
	Bennebroek	100	.	.	.	.
	Blaricum	.	.	50	.	.
	Bloemandaal	50	.	.	.	.
	Bussum	.	.	100	.	.
	Diemen	.	100	.	.	.
	Graveland, 's-	.	.	100	.	.
	Haarlem	100	.	.	.	.
	Haarlemmerliede	30	.	.	.	.
	Haarlemmermeer	100	.	.	.	.
	Heemskerk	10	.	.	.	.
	Heemstede	100	.	.	.	.
	Hilversum	.	.	90	.	.
	Huizen	.	.	60	.	.
	Laren	.	.	60	.	.
	Muiden	.	.	100	.	.
	Naarden	.	.	100	.	.
	Nederhorst den Berg	.	.	100	.	.
	Ouder-Amstel	.	100	.	.	.
	Uithoorn	.	100	.	.	.
	Weesp	.	.	100	.	.
ZH	Aar, Ter	100	.	.	.	.
	Alkemade	100	.	.	.	.
	Alphen a/d Rijn	100	.	.	.	.
	Benthuizen	70	.	.	30	.
	Bergschenhoek	.	.	.	100	.
	Berkel, Rodenrijs	.	.	.	.	100
	Bleiswijk	.	.	.	100	.
	Bodegraven	40	.	.	.	.
	Boskoop	100	.	.	.	.
	Capelle a/d IJssel	.	.	.	30	.
	Delft	.	.	.	.	100
	Driebruggen	10	.	.	.	.
	Gouda	60	.	.	40	.
	Gravenhage, 's-	.	.	.	.	10
	Gravenzande, 's-	.	.	.	.	100
ZH	Hazerswoude	100	.	.	.	.
	Hillegom	100	.	.	.	.
	Katwijk	60	.	.	.	.
	Koudekerk a/d Rijn	100	.	.	.	.
	Leiden	100	.	.	.	.
	Leiderdorp	100	.	.	.	.
	Leidschendam	70	.	.	.	30
	Leimuiden	100	.	.	.	.
	Lier, de	.	.	.	.	100
	Lisse	100	.	.	.	.
	Maasland	.	.	.	.	100
	Moerkapelle	.	.	.	100	.
	Monster	.	.	.	.	100
	Moordrecht	.	.	.	100	.
	Naaldwijk	.	.	.	.	100
	Nieuwerkerk IJssel	.	.	.	70	.
	Nieuwkoop	90	.	.	.	.
	Nieuwveen	60	40	.	.	.
	Noordwijk	60	.	.	.	.
	Noordwijkerhout	100	.	.	.	.
	Nootdorp	.	.	.	.	100
	Oegstgeest	100	.	.	.	.
	Pijnacker	.	.	.	.	100
	Reeuwijk	100	.	.	.	.
	Rotterdam	.	.	.	10	10
	Rijnsaterwoude	100	.	.	.	.
	Rijnsburg	100	.	.	.	.
	Rijswijk	.	.	.	.	60
	Sassenheim	100	.	.	.	.
	Schiedam	.	.	.	.	50
	Schipluiden	.	.	.	.	100
	Valkenburg	100	.	.	.	.
	Voorhout	100	.	.	.	.
	Voorschoten	100	.	.	.	.
	Waddinxveen	30	.	.	70	.
	Warmond	100	.	.	.	.
	Wassenaar	60	.	.	.	.
	Wateringen	.	.	.	.	100
	Woubrugge	100	.	.	.	.
	Zevenhoven	50	50	.	.	.
	Zevenhuizen	.	.	.	100	.
	Zoetermeer	80	.	.	20	.
	Zoeterwoude	100	.	.	.	.

Table B.2 (continued)

Pro	Municipality	Districts 41	42	43	44	45
Ut	Amerongen	60	.	.	.	.
	Benschop	.	.	.	100	.
	Bilt, de	90	.	.	.	.
	Breukelen	.	30	.	.	.
	Bunnik	100	.	.	.	.
	Cothen	100	.	.	.	.
	Doorn	100	.	.	.	.
	Drieb. Rijsenburg	100	.	.	.	.
	Harmelen	.	60	40	.	.
	Houten	100	.	.	.	.
	Kamerik	.	.	100	.	.
	Kockengen	.	80	.	.	.
	Langbroek	100	.	.	.	.
	Leersum	50	.	.	.	.
	Linschoten	.	.	50	50	.
	Lopik	.	.	.	100	.
	Maarssen	.	20	.	.	.
	Maartensdijk	50	.	.	.	.
	Montfoort	.	.	.	100	.
	Nieuwegein	.	80	.	20	.
	Oudewater	.	.	10	90	.
	Polsbroek	.	.	.	100	.
	Rhenen	40	.	.	.	.
	Snelrewaard	.	.	100	.	.
	Soest	30	.	70	.	.
	Utrecht	80	20	.	.	.
	Vlauten - De Meern	.	100	.	.	.
	Willeskop	.	.	.	100	.
	Woudenberg	10	.	.	.	.
	Wijk bij Duurstede	100	.	.	.	.
	IJsselstein	.	.	.	100	.
	Zegveld	.	.	100	.	.
	Zeist	90	.	.	.	.
ZH	Bergambacht	.	.	.	.	20
	Berkenwoude	.	.	.	.	100
	Bodegraven	.	.	60	.	.
	Capelle a/d IJssel	.	.	.	.	40
	Driebruggen	.	.	90	.	.
	Gouderak	.	.	.	.	100
	Haastrecht	.	.	.	80	20
	Hendrik-Ido-Ambacht	.	.	.	.	10
	Krimpen a/d Lek	.	.	.	.	100
	Krimpen a/d IJssel	.	.	.	.	100
	Lekkerkerk	.	.	.	.	100
	Nieuwerkerk IJssel	.	.	.	.	30
	Nieuwkoop	.	.	10	.	.
	Ouderkerk IJssel	.	.	.	.	100

Pro	Municipality	Districts 41	42	43	44	45
ZH	Ridderkerk	.	.	.	.	80
	Stolwijk	.	.	.	.	100
	Vlist	.	.	.	.	40
	Woerden	.	.	100	.	.

Pro	Municipality	Districts 48	49	50	52	53	55	57	59
Ge	Arnhem	.	.	.	.	.	.	20	.
	Beesd	.	.	.	.	.	100	.	.
	Bemmel	.	.	.	.	.	.	100	.
	Beusichem	.	.	.	.	.	100	.	.
	Buren	.	.	.	.	.	100	.	.
	Buurmalsen	.	.	.	.	.	100	.	.
	Culemborg	.	.	.	.	.	100	.	.
	Deil	.	.	.	.	.	100	.	.
	Dodewaard	.	.	.	.	.	.	100	.
	Echteld	.	.	.	.	.	.	100	.
	Elst	.	.	.	.	.	.	100	.
	Est, Opijnen	.	.	.	.	.	100	.	.
	Geldermalsen	.	.	.	.	.	100	.	.
	Gendt	.	.	.	.	.	.	100	.
	Groesbeek	.	.	.	.	.	.	.	70
	Haaften	.	.	.	.	.	100	.	.
	Herwen, Aerdt	.	.	.	.	.	.	.	40
	Herwijnen	.	.	.	.	.	100	.	.
	Heteren	.	.	.	.	.	.	100	.
	Huissen	.	.	.	.	.	.	100	.
	Kesteren	.	.	.	.	.	.	100	.
	Lienden	.	.	.	.	.	.	100	.
	Maurik	.	.	.	.	.	20	80	.
	Millingen a/d Rijn	.	.	.	.	.	.	.	100
	Nijmegen	.	.	.	.	.	.	.	30
	Ophemert	.	.	.	.	.	100	.	.
	Pannerden	.	.	.	.	.	.	.	10
	Tiel	.	.	.	.	.	100	.	.
	Ubbergen	.	.	.	.	.	.	.	100
	Valburg	.	.	.	.	.	.	100	.
	Varik	.	.	.	.	.	100	.	.
	Vuren	.	.	.	.	.	100	.	.
	Waardenburg	.	.	.	.	.	100	.	.
	Zoelen	.	.	.	.	.	90	10	.
ZH	Abbenbroek	100	.	.	.	.	.	.	.
	Alblasserdam	.	.	.	.	100	.	.	.
	Ameide	.	.	.	.	100	.	.	.
	Ammerstol	.	.	.	.	100	.	.	.

Table B.2 (continued)

Pro	Municipality	Districts 48	49	50	52	53	55	57	59
ZH	Arkel	.	.	.	.	100	.	.	.
	Asperen	.	.	.	.	.	100	.	.
	Baarendrecht	.	.	100	.	.	.	.	.
	Bergambacht	.	.	.	.	80	.	.	.
	Bleskensgraaf c.a.	.	.	.	.	100	.	.	.
	Brandwijk	.	.	.	.	100	.	.	.
	Brielle	100	.	.	.	.	.	.	.
	Dirksland	.	80	.	.	.	.	.	.
	Dordrecht	.	.	.	80	.	.	.	.
	Everdingen	.	.	.	.	.	100	.	.
	Geervliet	30	.	70	.	.	.	.	.
	Giessenburg	.	.	.	.	100	.	.	.
	Goedereede	.	100	.	.	.	.	.	.
	Gorinchem	.	.	.	.	100	.	.	.
	Goudriaan	.	.	.	.	100	.	.	.
	Goudswaard	100	.	.	.	.	.	.	.
	Gravendeel, 's-	.	.	.	80	.	.	.	.
	Groot-Ammers	.	.	.	.	100	.	.	.
	Hagestein	.	.	.	.	.	100	.	.
	Hardinx.Giessendam	.	.	.	.	100	.	.	.
	Heenvliet	100	.	.	.	.	.	.	.
	Heerjansdam	.	.	50	50	.	.	.	.
	Hei-, Boeicop	.	.	.	.	.	100	.	.
	Heinenoord	.	.	100	.	.	.	.	.
	Hellevoetsluis	100	.	.	.	.	.	.	.
	Hendrik-Ido-Ambacht	.	.	.	90	.	.	.	.
	Heukelum	.	.	.	.	.	100	.	.
	Hoogblokland	.	.	.	.	100	.	.	.
	Hoornaar	.	.	.	.	100	.	.	.
	Kedichem	.	.	.	.	.	100	.	.
	Klaaswaal	.	.	30	.	.	.	.	.
	Langerak	.	.	.	.	100	.	.	.
	Leerbroek	.	.	.	.	.	100	.	.
	Leerdam	.	.	.	.	.	100	.	.
	Lexmond	.	.	.	.	.	100	.	.
	Maasdam	.	.	70	.	.	.	.	.
	Meerkerk	.	.	.	.	100	.	.	.
	Middelharnis	90	.	.	.	.	.	.	.
	Molenaarsgraaf	.	.	.	.	100	.	.	.
	Mijnsheerenland	.	.	100	.	.	.	.	.
	Nieuw Beijerland	100	.	.	.	.	.	.	.
	Nieuwland	.	.	.	.	.	100	.	.
	Nieuw Lekkerland	.	.	.	.	100	.	.	.
	Nieuwpoort	.	.	.	.	100	.	.	.
	Noordeloos	.	.	.	.	100	.	.	.
	Oostflakkee	30	.	.	.	.	.	.	.
	Oostvoorne	100	.	.	.	.	.	.	.
ZH	Ottoland	.	.	.	.	100	.	.	.
	Oud-Alblas	.	.	.	.	100	.	.	.
	Oud-Beijerland	10	.	90	.	.	.	.	.
	Oudenhoorn	100	.	.	.	.	.	.	.
	Papendrecht	.	.	.	100	.	.	.	.
	Piershil	100	.	.	.	.	.	.	.
	Poortugaal	.	.	100	.	.	.	.	.
	Puttershoek	.	.	50	50	.	.	.	.
	Rhoon	.	.	100	.	.	.	.	.
	Ridderkerk	.	.	10	10	.	.	.	.
	Rockanje	100	.	.	.	.	.	.	.
	Rozenburg	20	.	.	.	.	.	.	.
	Schelluinen	.	.	.	.	100	.	.	.
	Schoonhoven	.	.	.	.	100	.	.	.
	Schoonrewoerd	.	.	.	.	.	100	.	.
	Sliedrecht	.	.	.	.	100	.	.	.
	Spijkenisse	.	.	50	.	.	.	.	.
	Streefkerk	.	.	.	.	100	.	.	.
	Strijen	.	.	.	10	.	.	.	.
	Tienhoven	.	.	.	.	100	.	.	.
	Vianen	.	.	.	.	.	100	.	.
	Vierpolders	100	.	.	.	.	.	.	.
	Vlist	.	.	.	.	60	.	.	.
	Westmaas	.	.	100	.	.	.	.	.
	Wijngaarden	.	.	.	.	100	.	.	.
	Zuid-Beijerland	.	.	100	.	.	.	.	.
	Zuidland	100	.	.	.	.	.	.	.
	Zwartewaal	100	.	.	.	.	.	.	.
	Zwijndrecht	.	.	.	100	.	.	.	.
NB	Oudenbosch	.	.	.	.	.	50	.	.

Pro	Municipality	Districts 51	54	74	75	76	77
ZH	Dirksland	.	.	.	.	.	20
	Dordrecht	.	20	.	.	.	.
	Gravendeel, 's-	20	.	.	.	.	.
	Klaaswaal	70	.	.	.	.	.
	Maasdam	30	.	.	.	.	.
	Middelharnis	.	.	.	.	10	.
	Numansdorp	100	.	.	.	.	.
	Oostflakkee	.	.	.	.	70	.
	Spijkenisse	50	.	.	.	.	.
	Strijen	90	.	.	.	.	.
Ze	Brouwershaven	.	.	.	.	.	100
	Bruinisse	.	.	.	.	.	100

Table B.2 (continued)

Pro	Municipality	Districts 51	54	74	75	76	77
Ze	Duiveland	.	.	.	.	.	100
	Middenschouwen	.	.	.	.	.	100
	Reimerswaal	.	.	.	.	100	.
	Sint Philipsland	.	.	.	.	100	.
	Tholen	.	.	.	.	100	.
	Westerschouwen	.	.	.	.	.	100
	Zierikzee	.	.	.	.	.	100
NB	Alphen c.a.	.	.	20	.	.	.
	Baarle-Nassau	.	.	80	.	.	.
	Bergen op Zoom	.	.	.	90	10	.
	Breda	.	.	100	.	.	.
	Chaam	.	.	100	.	.	.
	Dinteloord, Prins	60	.	.	40	.	.
	Dussen	.	80	.	.	.	.
	Etten-Leur	30	.	70	.	.	.
	Fijnaart Heijningen	100	.	.	.	.	.
	Geertruidenberg	.	100	.	.	.	.
	Gilze, Rijen	.	.	50	.	.	.
	Gravenmoer, 's-	.	50	.	.	.	.
	Halsteren	.	.	.	50	50	.
	Hoeven	30	.	60	10	.	.
	Hooge, Lage Zwaluwe	50	50	.	.	.	.
	Huijbergen	.	.	.	100	.	.
	Klundert	100	.	.	.	.	.
	Made, Drimmelen	20	30	.	.	.	.
	Nieuw Ginneken	.	.	100	.	.	.
	Nieuw Vossemeer	.	.	.	.	100	.
	Oosterhout	10	30	30	.	.	.
	Ossendrecht	.	.	.	.	100	.
	Oudenbosch	.	.	50	.	.	.
	OudenNieuw Gastel	50	.	50	.	.	.
	Prinsenbeek	50	.	50	.	.	.
	Putte	.	.	.	.	100	.
	Raamsdonk	.	100	.	.	.	.
	Roosendaal, Nispen	.	.	.	100	.	.
	Rucphen	.	.	50	50	.	.
	Rijsbergen	.	.	100	.	.	.
	Sprang-Capelle	.	100	.	.	.	.
	Standdaarbuiten	100	.	.	.	.	.
	Steenbergen	.	.	.	100	.	.
	Terheijden	70	30	.	.	.	.
	Teteringen	30	.	70	.	.	.
	Waalwijk	.	100	.	.	.	.
	Waspik	.	100	.	.	.	.
	Werkendam	.	90	.	.	.	.
	Willemstad	100	.	.	.	.	.
	Woensdrecht	.	.	.	.	100	.

Pro	Municipality	Districts 51	54	74	75	76	77
NB	Woudrichem	.	90	.	.	.	.
	Wouw	.	.	.	100	.	.
	Zevenbergen	90	10	.	.	.	.
	Zundert	.	.	100	.	.	.

Pro	Municipality	Districts 56	58	61	62	70	71	72	73
Ge	Ammerzoden	100	.	.	.	.	.	.	.
	Appeltern	.	100	.	.	.	.	.	.
	Batenburg	.	100	.	.	.	.	.	.
	Bergharen	.	100	.	.	.	.	.	.
	Beuningen	.	100	.	.	.	.	.	.
	Brakel	100	.	.	.	.	.	.	.
	Dreumel	.	100	.	.	.	.	.	.
	Druten	.	100	.	.	.	.	.	.
	Ewijk	.	100	.	.	.	.	.	.
	Hedel	100	.	.	.	.	.	.	.
	Heerewaarden	.	.	.	100	.	.	.	.
	Heumen	.	30	.	.	.	.	.	.
	Horssen	.	100	.	.	.	.	.	.
	Kerkwijk	100	.	.	.	.	.	.	.
	Maasdriel	100	.	.	.	.	.	.	.
	Nijmegen	.	40	.	.	.	.	.	.
	Overasselt	.	10	90	.	.	.	.	.
	Rossum	100	.	.	.	.	.	.	.
	Wamel	.	100	.	.	.	.	.	.
	Wijchen	.	20	80	.	.	.	.	.
	Zaltebommel	100	.	.	.	.	.	.	.
NB	Aalburg	100	.	.	.	.	.	.	.
	Alphen c.a.	.	.	.	.	.	.	.	80
	Baarle-Nassau	.	.	.	.	.	10	.	10
	Beers	.	.	100	.	.	.	.	.
	Bergeijk	.	.	.	.	100	.	.	.
	Berghem	.	.	.	100	.	.	.	.
	Berke-Enschot	20	.	.	.	.	.	80	.
	Best	.	.	.	.	20	.	60	20
	Bladel c.a.	.	.	.	.	.	100	.	.
	Boxmeer	.	.	100	.	.	.	.	.
	Boxtel	.	.	.	.	.	.	100	.
	Cuyk c.a.	.	.	100	.	.	.	.	.
	Diessen	.	.	.	.	.	80	10	10
	Dongen	.	.	.	.	.	.	.	100
	Drunen	100	.	.	.	.	.	.	.
	Dungen, den	.	.	.	.	.	.	40	.
	Dussen	10	.	.	.	.	.	.	.

Table B.2 (continued)

Pro	Municipality	Districts							
		56	58	61	62	70	71	72	73
NB	Eersel	.	.	.	.	80	20	.	.
	Eindhoven	.	.	.	.	70	.	.	20
	Esch	.	.	.	.	.	.	100	.
	Geffen	.	.	.	70	.	.	.	.
	Gilze, Rijen	.	.	.	.	.	.	.	50
	Goirle	.	.	.	.	.	80	.	20
	Grave	.	.	50	50	.	.	.	.
	Gravenmoer, 's-	.	.	.	.	.	.	.	50
	Haaren	70	.	.	.	.	.	30	.
	Haps	.	.	100	.	.	.	.	.
	Heesch	.	.	.	10	.	.	.	.
	Heeze	.	.	.	.	10	.	.	.
	Helvoirt	100	.	.	.	.	.	.	.
	Hertogenbosch, 's-	30	.	.	30	.	.	.	.
	Heusden	100	.	.	.	.	.	.	.
	Hilvarenbeek	.	.	.	.	.	90	.	10
	Hoogeloon c.a.	.	.	.	.	.	.	.	100
	Hooge, Lage Mierde	.	.	.	.	.	100	.	.
	Leende	.	.	.	.	20	.	.	.
	Liempde	.	.	.	.	.	.	100	.
	Lith	.	.	.	100	.	.	.	.
	Loon op Zand	20	.	.	.	.	.	.	80
	Luyksgestel	.	.	.	.	100	.	.	.
	Megen c.a.	.	.	.	100	.	.	.	.
	Mill c.a.	.	.	100	.	.	.	.	.
	Moergestel	.	.	.	.	.	.	100	.
	Nuenen c.a.	.	.	.	.	60	.	.	.
	Nuland	.	.	.	60	.	.	.	.
	Oeffelt	.	.	100	.	.	.	.	.
	Oirschot	.	.	.	.	.	40	50	10
	Oisterwijk	10	.	.	.	.	.	90	.
	O.,W. Middelbeers	.	.	.	.	.	100	.	.
	Oosterhout	.	.	.	.	.	.	.	30
	Oploo c.a.	.	.	100	.	.	.	.	.
	Oss	.	.	.	90	.	.	.	.
	Ravenstein	.	.	10	90	.	.	.	.
	Reusel c.a.	.	.	.	.	.	100	.	.
	Riethoven	.	.	.	.	100	.	.	.
	Rosmalen	.	.	.	70	.	.	.	.
	Schaijk	.	.	10	70	.	.	.	.
	Schijndel	.	.	.	.	.	.	30	.
	Sint-Michielsgestel	.	.	.	.	.	.	80	.
	Sint-Oedenrode	.	.	.	.	.	.	100	.
	Son c.a.	.	.	.	.	50	.	50	.
	Tilburg	30	.	.	.	.	30	10	30
	Uden	.	.	10	.	.	.	.	.
	Udenhout	100	.	.	.	.	.	.	.
NB	Valkenswaard	.	.	.	.	100	.	.	.
	Veldhoven	.	.	.	.	50	.	.	50
	Vessem c.a.	.	.	.	.	.	100	.	.
	Vierlingsbeek	.	.	90	.	.	.	.	.
	Vlijmen	100	.	.	.	.	.	.	.
	Vught	60	.	.	.	.	.	40	.
	Waalre	.	.	.	.	100	.	.	.
	Wanroij	.	.	100	.	.	.	.	.
	Westerhoven	.	.	.	.	100	.	.	.
	Woudrichem	10	.	.	.	.	.	.	.
	Zeeland	.	.	80	.	.	.	.	.

Pro	Municipality	Districts							
		60	63	64	65	66	67	68	69
Ge	Groesbeek	30	.	.	.	.	.	.	.
	Heumen	70	.	.	.	.	.	.	.
	Nijmegen	30	.	.	.	.	.	.	.
NB	Aarle-Rixtel	.	100	.	.	.	.	.	.
	Asten	.	100	.	.	.	.	.	.
	Bakel c.a.	.	100	.	.	.	.	.	.
	Beek c.a.	.	100	.	.	.	.	.	.
	Berlikum	.	100	.	.	.	.	.	.
	Boekel	.	100	.	.	.	.	.	.
	Budel	.	.	.	.	.	.	20	80
	Deurne	.	100	.	.	.	.	.	.
	Dungen, den	.	60	.	.	.	.	.	.
	Eindhoven	.	.	.	.	.	.	.	10
	Erp	.	100	.	.	.	.	.	.
	Geffen	.	30	.	.	.	.	.	.
	Geldrop	.	.	.	.	.	.	.	100
	Gemert	.	100	.	.	.	.	.	.
	Heesch	.	90	.	.	.	.	.	.
	Heeswijk-Dinther	.	100	.	.	.	.	.	.
	Heeze	.	.	.	.	.	.	.	90
	Helmond	.	100	.	.	.	.	.	.
	Hertogenbosch, 's-	.	40	.	.	.	.	.	.
	Leende	.	.	.	.	.	.	.	80
	Lieshout	.	100	.	.	.	.	.	.
	Maarheeze	.	.	.	.	.	.	.	100
	Mierlo	.	50	.	.	.	.	.	50
	Nistelrode	.	100	.	.	.	.	.	.
	Nuenen c.a.	.	.	.	.	.	.	.	40
	Nuland	.	40	.	.	.	.	.	.
	Oss	.	10	.	.	.	.	.	.
	Rosmalen	.	30	.	.	.	.	.	.

Table B.2 (continued)

Pro	Municipality	Districts 60	63	64	65	66	67	68	69
NB	Schaijk	.	20	.	.	.	.	.	.
	Schijndel	.	70	.	.	.	.	.	.
	Sint-Michielsgestel	.	20	.	.	.	.	.	.
	Someren	.	50	.	.	.	.	.	50
	Uden	.	90	.	.	.	.	.	.
	Veghel	.	100	.	.	.	.	.	.
	Vierlingsbeek	.	.	10	.	.	.	.	.
	Zeeland	.	20	.	.	.	.	.	.
Li	Amstenrade	.	.	.	.	.	100	.	.
	Arsen, Velden	.	.	.	100	.	.	.	.
	Baexem	.	.	.	.	.	.	100	.
	Beegden	.	.	.	.	.	.	100	.
	Beek	.	.	.	.	.	100	.	.
	Beesel	.	.	.	100	.	.	.	.
	Belfeld	.	.	.	100	.	.	.	.
	Bemelen	.	.	.	.	.	100	.	.
	Berg, Terblijt	.	.	.	.	.	100	.	.
	Bergen	10	.	.	90	.	.	.	.
	Bingelrade	.	.	.	.	.	100	.	.
	Bocholtz	.	.	.	.	.	100	.	.
	Born	.	.	.	.	.	100	.	.
	Broekhuizen	.	.	100	.	.	.	.	.
	Brunssum	.	.	.	.	.	100	.	.
	Bunde	.	.	.	.	.	100	.	.
	Cadier, Keer	.	.	.	.	.	100	.	.
	Echt	.	.	.	.	80	20	.	.
	Elsloo	.	.	.	.	.	100	.	.
	Eijgelshoven	.	.	.	.	.	100	.	.
	Eijsden	.	.	.	.	.	100	.	.
	Geleen	.	.	.	.	.	100	.	.
	Gennep	100	.	.	.	.	.	.	.
	Geulle	.	.	.	.	.	100	.	.
	Grathem	.	.	.	.	.	.	100	.
	Grevenbicht	.	.	.	.	.	100	.	.
	Gronsveld	.	.	.	.	.	100	.	.
	Grubbenvorst	.	.	100	.	.	.	.	.
	Gulpen	.	.	.	.	.	100	.	.
	Haelen	.	.	.	.	.	.	100	.
	Heel c.a.	.	.	.	.	.	.	100	.
	Heerlen	.	.	.	.	.	100	.	.
	Helden	.	.	50	.	.	.	50	.
	Herten	.	.	.	.	100	.	.	.
	Heythuysen	.	.	.	.	.	.	100	.
	Hoensbroek	.	.	.	.	.	100	.	.
	Horn	.	.	.	.	.	.	100	.
	Horst	.	.	100	.	.	.	.	.
	Hulsberg	.	.	.	.	.	100	.	.

Pro	Municipality	Districts 60	63	64	65	66	67	68	69
Li	Hunsel	.	.	.	.	.	.	100	.
	Jabeek	.	.	.	.	.	100	.	.
	Kerkrade	.	.	.	.	.	100	.	.
	Kessel	.	.	.	.	.	.	100	.
	Klimmen	.	.	.	.	.	100	.	.
	Limbricht	.	.	.	.	.	100	.	.
	Linne	.	.	.	.	100	.	.	.
	Maasbracht	.	.	.	.	80	20	.	.
	Maasbree	.	.	100	.	.	.	.	.
	Maastricht	.	.	.	.	.	100	.	.
	Margraten	.	.	.	.	.	100	.	.
	Meerlo-Wanssum	.	.	100	.	.	.	.	.
	Meerssen	.	.	.	.	.	100	.	.
	Melick, Herkenbosch	.	.	.	.	100	.	.	.
	Merkelbeek	.	.	.	.	.	100	.	.
	Meijel	.	40	.	.	.	.	60	.
	Mheer	.	.	.	.	.	100	.	.
	Montfort	.	.	.	.	100	.	.	.
	Mook c.a.	100	.	.	.	.	.	.	.
	Munstergeleen	.	.	.	.	.	100	.	.
	Nederweert	.	20	.	.	.	.	60	20
	Neer	.	.	.	.	.	.	100	.
	Nieuwenhagen	.	.	.	.	.	100	.	.
	Nieuwstadt	.	.	.	.	.	100	.	.
	Noorbeek	.	.	.	.	.	100	.	.
	Nuth	.	.	.	.	.	100	.	.
	Obbicht c.a.	.	.	.	.	.	100	.	.
	Ohe, Laak	.	.	.	.	.	100	.	.
	Oirsbeek	.	.	.	.	.	100	.	.
	Posterholt	.	.	.	.	100	.	.	.
	Roermond	.	.	.	90	10	.	.	.
	Roggel	.	.	.	.	.	.	100	.
	Roosteren	.	.	.	.	.	100	.	.
	Schaesberg	.	.	.	.	.	100	.	.
	Schimmert	.	.	.	.	.	100	.	.
	Schinnen	.	.	.	.	.	100	.	.
	Schinveld	.	.	.	.	.	100	.	.
	Sevenum	.	.	100	.	.	.	.	.
	Simpelveld	.	.	.	.	.	100	.	.
	Sint Geertruid	.	.	.	.	.	100	.	.
	Sint Odilienberg	.	.	.	.	100	.	.	.
	Sittard	.	.	.	.	.	100	.	.
	Slenaken	.	.	.	.	.	100	.	.
	Spaubeek	.	.	.	.	.	100	.	.
	Stein	.	.	.	.	.	100	.	.
	Stevensweert	.	.	.	.	.	100	.	.
	Stramproij	.	.	.	.	.	.	100	.

Table B.2 (continued)

Pro	Municipality	Districts							
		60	63	64	65	66	67	68	69
Li	Susteren	.	.	.	.	.	100	.	.
	Swalmen	.	.	.	100	.	.	.	.
	Tegelen	.	.	.	100	.	.	.	.
	Thorn	.	.	.	.	.	.	100	.
	Ubach over Worms	.	.	.	.	.	100	.	.
	Ulestraten	.	.	.	.	.	100	.	.
	Urmond	.	.	.	.	.	100	.	.
	Vaals	.	.	.	.	.	100	.	.
	Valkenburg-Houthem	.	.	.	.	.	100	.	.
	Venlo	.	.	50	50	.	.	.	.
	Venraij	.	.	100	.	.	.	.	.
	Vlodrop	.	.	.	.	100	.	.	.
	Voerendaal	.	.	.	.	.	100	.	.
	Weert	.	.	.	.	.	.	60	40
	Wessem	.	.	.	.	.	.	100	.
	Wittem	.	.	.	.	.	100	.	.
	Wijlre	.	.	.	.	.	100	.	.
	Wijnandsrade	.	.	.	.	.	100	.	.

Table B.3

FINAL URBAN, WATER, AND OTHER AREAS
(ha)

DISTRICT	TOTAL	URBAN	WATER	WOODS	CULT	ND
1 FRIELAND	311693	12708	25490	8346	251870	7992
2 HETBILDT	19880	438	4086	7	14923	3883
3 LAUWMEER	83248	2460	10948	427	67358	7825
4 UITHUIZN	14414	349	1971	24	11007	1791
5 EEMSKANN	37773	2425	1853	185	32094	847
6 OLDAMBT	45635	2105	6007	228	35776	5464
7 WESTWOLD	53096	4074	1112	939	45634	0
8 NWDRENTE	57673	3336	1143	5914	43446	0
9 WESKWART	52981	3623	929	3277	42275	0
13 VOLENHOV	52858	1419	3417	6183	36547	0
14 NEPOLDER	50732	837	3748	2224	42127	2722
15 MASTBROK	44853	1958	2307	1955	36361	1625
North	824836	35732	63011	29709	659418	32149
10 NEDRENTE	29322	1929	584	2113	22472	0
11 SEDRENTE	45522	2505	594	2695	34505	0
12 SWDRENTE	90928	3167	1075	9379	70203	0
16 OVIJVECT	43016	1562	673	3929	33952	0
17 DINKEL	24592	1268	161	4185	16978	0
18 TWENTHE	82294	5815	642	9536	58324	0
19 SALLAND	47203	2483	860	4727	37055	282
20 TWENTKAN	59343	2890	337	8327	41906	0
21 SHIPBEEK	28063	1882	261	3953	19860	84
24 BERKEL	73882	2870	615	8363	58831	197
25 OUDEIJSL	70722	4615	1066	5419	56910	268
Northeast Highlands	594887	30986	6868	62626	450996	831
22 IJSELGEB	25864	1648	395	6251	15218	160
23 NEVELUWE	52889	3615	672	16273	26386	288
26 ARNHEM	7970	1024	218	2589	2846	121
27 SEVELUWE	18982	2247	304	6098	6295	203
28 SWVELUWE	93524	8256	664	24663	46302	252
29 NWVELUWE	59015	4152	1205	19233	26148	667
30 FLEVLAND	115233	2255	19106	7853	57359	17420
Flevoland & Veluwe	373477	23197	22564	82960	180554	19111
31 WIERGMER	21019	263	1569	768	18162	550
32 AMSTLMER	25182	1412	1431	60	21517	691
33 MEDMBLIK	24134	1834	1335	57	20399	470
34 HOORN	9415	1048	426	16	7675	188
35 SCHERMER	78185	7227	5461	2371	57657	1295
36 WATRLAND	7974	320	1128	16	6176	403
37 NZKANGEB	26513	7039	3635	848	9338	1061
North Holland	192422	19143	14985	4136	140924	4658
38 RIJNLAND	99608	15082	7988	2956	64109	540
39 AMSTLAND	25884	3000	2771	370	17900	180
40 GOOI	30868	4179	5510	3404	14317	1628
41 KROMRIJN	39636	5622	757	8549	22141	302
42 LEIDRIJN	11854	1278	630	316	8934	72
43 WOERDEN	18728	1701	625	1100	14345	0
44 LOPIKWAR	16227	1088	501	188	14120	18
45 KRIMPWAR	15425	2091	1264	121	11466	231
46 SCIELAND	16933	2263	1220	144	13269	302
47 DELFLAND	28679	5910	1153	227	24132	332
Midwest and Utrecht	303842	42214	22419	17375	204733	3605
48 VOORNE	36976	1617	8644	543	23741	6443
49 GOEREE	18425	399	7542	91	8138	6520
50 IJSLMOND	19820	1511	2632	215	16639	1803
52 DORDRECT	14144	2621	2133	477	8032	1767
53 ABLASWAR	30750	2600	2110	273	25079	790
55 TIELWARD	50188	2842	2099	1390	41858	928
57 BETUWE	36916	2852	1969	739	29509	1214
59 RECMAASN	10800	1438	820	1378	6520	283
Large Rivers & North	218019	15880	27949	5106	159516	19748
51 HOLNDIEP	47341	2078	7267	892	34528	6363
54 BIESBOSH	34627	2446	4950	1510	25885	3584
74 MARK	52756	4738	285	6320	39158	0
75 ROSENDAL	32998	2666	2500	2790	23132	2085
76 ZOOM	69838	1542	28545	3101	32725	27826
77 SCHOUWEN	47114	971	21772	647	21436	21120
West-Brabant & South	284674	14441	65319	15260	176864	60978
56 DENBOSCH	44556	4066	2175	3464	32465	940
58 MAASWAAL	23715	2318	1421	974	17805	736
60 RECMAASM	12084	1323	370	2132	7027	201
61 MASKANTE	42999	2398	738	4650	32994	354
62 MASKANTW	25759	2597	758	1795	19289	402
63 AA	88857	6602	709	10861	63075	60
64 DEPEEL	48609	2993	397	7054	34626	233
65 RECMAASS	26542	2727	695	5280	15360	458
66 ROERMOND	18151	1190	564	3153	11734	171
67 SLIMBURG	71882	11796	1205	5172	48753	536
68 MLIMBURG	40699	2329	1050	5394	28977	320
69 EDOMMEL	31186	2628	421	6826	16933	0
70 MDOMMEL	33728	5001	333	7683	18381	0
71 WDOMMEL	37073	2482	283	9237	22724	0
72 NDOMMEL	34233	2864	394	4775	23565	0
73 DONGE	30861	3780	154	5730	19001	0
Southeast Highlands	610934	57094	11667	84180	412709	4411
Total Nation	3403091	238687	234782	301352	2385714	145491

Table B.4

SURFACE WATER AREAS AND VOLUMES, NATURE AREAS
(Areas ha, volume 1000m^3)

DISTRICT	----------AREA----		SURFACE WATER	--VOLUME---------			
	BOEZEM	POLDER	TOTAL	BOEZEM	POLDER	TOTAL	"NATURE"
1 FRIELAND	13900	12700	26609	278000	90530	368530	38150
2 HETBILDT	153	530	683	3060	3025	6085	3885
3 LAUWMEER	2623	2763	5386	52460	17565	70025	18367
4 UITHUIZN	.	.	432	.	.	4860	3555
5 EEMSKANN	856	1258	2114	17120	7415	24535	3209
6 OLDAMBT	443	903	1346	8860	5265	14125	4721
7 WESTWOLD	400	1574	1974	8000	11710	19710	3118
8 NWDRENTE	1288	632	1920	21440	5732	27172	10905
9 WESKWART	1130	859	1989	14650	6762	21412	8258
13 VOLENHOV	3217	1257	4474	64340	7785	72125	10249
14 NEPOLDER	.	.	1986	.	.	25320	3611
15 MASTBROK	532	1230	1762	10640	7275	17915	4830
North	24542	23706	50675	478570	163064	671814	112858
10 NEDRENTE	.	.	1170	.	.	14610	2868
11 SEDRENTE	.	.	1277	.	.	15295	6667
12 SWDRENTE	.	.	2439	.	.	28320	11053
16 OVIJVECT	.	.	1533	.	.	17760	7366
17 DINKEL	.	.	407	.	.	4450	4729
18 TWENTHE	.	.	1465	.	.	16955	18802
19 SALLAND	.	.	1282	.	.	15080	5325
20 TWENTKAN	.	.	930	.	.	9705	18543
21 SHIPBEEK	.	.	457	.	.	4940	7361
24 BERKEL	.	.	1155	.	.	12045	7966
25 OUDEIJSL	.	.	1503	.	.	19485	11082
Northeast Highlands	0	0	13618	0	0	158645	101762
22 IJSELGEB	.	.	492	.	.	5985	6159
23 NEVELUWE	.	.	910	.	.	10310	12243
26 ARNHEM	.	.	175	.	.	2330	1551
27 SEVELUWE	.	.	289	.	.	2960	4475
28 SWVELUWE	.	.	1811	.	.	15235	24360
29 NWVELUWE	338	783	1121	6760	5415	12175	14328
30 FLEVLAND	.	.	2664	.	.	38610	29895
Flevoland & Veluwe	338	783	7462	6760	5415	87605	93011
31 WIERGMER	.	.	793	.	.	9725	2681
32 AMSTLMER	1065	1045	2110	21300	7550	28850	2902
33 MEDMBLIK	600	975	1575	12000	6862	18862	2643
34 HOORN	175	340	515	3500	2172	5672	1682
35 SCHERMER	2000	4472	6472	40000	38605	78605	13850
36 WATRLAND	500	452	952	10000	3948	13948	1383
37 NZKANGEB	1400	1187	2587	28000	9115	37115	7049
North Holland	5740	8471	15004	114800	68252	192777	32190

Table B.4 (continued)

DISTRICT	----------AREA----		SURFACE	WATER --VOLUME	---------		"NATURE"
	BOEZEM	POLDER	TOTAL	BOEZEM	POLDER	TOTAL	
38 RIJNLAND	3900	6520	10420	90000	60000	150000	20955
39 AMSTLAND	950	2012	2962	19000	19368	38368	4615
40 GOOI	420	3838	4258	8400	41405	49805	5660
41 KROMRIJN	150	841	991	3000	4618	7618	6692
42 LEIDRIJN	150	411	561	3000	2490	5490	3419
43 WOERDEN	170	1017	1187	3400	8497	11897	3411
44 LOPIKWAR	70	749	819	1400	5717	7117	4455
45 KRIMPWAR	333	1056	1389	6660	9780	16440	2394
46 SCIELAND	400	618	1018	8000	3975	11975	3470
47 DELFLAND	670	1001	1671	13400	6138	19538	3095
Midwest and Utrecht	7213	18063	25276	156260	161988	318248	58166
48 VOORNE	1000	1464	2464	20000	12577	32577	6479
49 GOEREE	172	448	620	3440	3365	6805	3149
50 IJSLMOND	300	629	929	6000	4487	10487	2961
52 DORDRECT	250	363	613	5000	2685	7685	2088
53 ABLASWAR	420	1200	1620	8400	8250	16650	4891
55 TIELWARD	910	1191	2101	12050	8737	20787	8642
57 BETUWE	.	.	1169	.	.	12670	8242
59 RECMAASN	.	.	445	.	.	6530	933
Large Rivers & Northern	3052	5295	9961	54890	40101	114191	37385
51 HOLNDIEP	600	1124	1724	12000	7900	19900	7363
54 BIESBOSH	466	1230	1696	9320	8400	17720	2079
74 MARK	.	.	863	.	.	8590	9384
75 ROSENDAL	.	.	1033	.	.	11390	2940
76 ZOOM	.	.	1349	.	.	17530	7009
77 SCHOUWEN	500	672	1172	10000	4500	14500	4480
West-Brabant & Southern	1566	3026	7837	31320	20800	89630	33255
56 DENBOSCH	635	1591	2226	12700	12455	25155	6391
58 MAASWAAL	.	.	1145	.	.	16000	3070
60 RECMAASM	.	.	288	.	.	3975	2252
61 MASKANTE	.	.	810	.	.	9810	7940
62 MASKANTW	.	.	610	.	.	8390	5574
63 AA	.	.	1537	.	.	1740	24070
64 DEPEEL	.	.	648	.	.	5700	10668
65 RECMAASS	.	.	498	.	.	6045	5480
66 ROERMOND	.	.	573	.	.	8760	3630
67 SLIMBURG	.	.	1382	.	.	16945	16439
68 MLIMBURG	.	.	1134	.	.	16620	8095
69 EDOMMEL	.	.	733	.	.	9980	4521
70 MDOMMEL	.	.	670	.	.	8245	2664
71 WDOMMEL	.	.	654	.	.	7515	5512
72 NDOMMEL	.	.	736	.	.	9590	8551
73 DONGE	.	.	463	.	.	4625	5827
Southeast Highlands	635	1591	14107	12700	12455	159095	120684

Table B.5

PRIMARY CROP DATA
(ha)

AGRICULTURAL REGION	TOTAL	GRASS	EAT	MILL	SEED	SUGAR	CEREA	CUT	BULBS	VEGOA	FRUIT	TREES	VEGUG	FLOWR	OTHER
Humsterland	8180	4588	235	0	377	623	2278	39	2	13	14	0	1	0	10
Hogeland	41315	10880	1715	19	3950	6049	17722	204	11	514	100	6	21	10	114
Centrale Bouwstreek	7684	5498	3	21	1	289	1735	11	1	95	2	0	1	2	25
Oost-Fivelgo	7436	2435	59	69	29	495	4108	137	0	87	0	0	0	0	17
Niew-Oldambt	13602	1745	43	523	104	1120	8914	611	0	424	45	11	0	0	62
Oud-Oldambt	18211	2534	58	3883	264	2049	8742	244	2	249	1	150	2	6	27
Centrale Wiedestreek	11979	10699	39	97	37	137	925	20	0	12	0	1	0	0	12
Zuid. Westerkwartier	16602	16416	11	34	18	26	47	30	1	1	9	1	1	1	6
Goorecht	2511	2308	15	46	0	17	53	29	2	3	8	23	0	1	6
Westerwolde	21999	2974	11	9760	53	3436	5621	132	0	6	0	4	0	0	2
Woldstreek	12311	3386	19	3160	60	647	4985	14	0	16	0	1	0	1	22
Veenkolonien	17032	1945	45	7391	109	1674	5565	70	2	33	6	149	13	13	17
TOTAL Groningen	178862	65408	2253	25003	5002	16562	60695	1541	21	1453	185	346	39	34	320
Het Bildt	10984	4318	344	0	1573	1725	2387	0	25	458	100	0	13	5	36
Weide-en Bouwstreek	42678	32823	538	0	2193	2580	4003	0	72	359	64	6	9	4	27
Kleiweidestreek	46746	45383	140	4	242	360	481	10	4	48	28	1	8	5	32
Veenweidestreek	47956	47703	32	0	13	43	76	67	0	13	1	3	2	1	2
Eilanden	3469	3436	1	0	1	0	10	0	0	17	0	0	0	0	4
De Wouden	81609	79046	67	533	615	289	585	263	18	14	1	37	2	4	135
TOTAL Friesland	233442	212709	1122	537	4637	4997	7542	340	119	909	194	47	34	19	236
Weidegebied Noorverve	7239	6827	29	0	6	117	164	22	7	16	0	7	2	7	35
Centraal Zandgebied	67886	38583	461	13373	1753	4748	7194	1587	1	125	0	23	1	1	36
Dieverderdingspel	26422	23275	113	1172	193	276	854	526	0	3	0	8	0	1	1
Hoogeveen	2952	2396	18	243	16	80	98	53	3	28	0	10	1	1	5
Zuidwest Weidegebied	9848	9693	7	19	4	6	26	82	0	1	0	0	0	0	10
Hondsrug	21912	7319	94	6960	272	2955	4127	137	0	20	0	21	0	0	7
Veenkolonien	31752	2929	17	14405	191	5665	7842	200	1	411	1	2	58	20	10
Smilde	5095	946	1	2156	50	643	1214	74	0	8	0	3	0	0	0
TOTAL Drenthe	173106	91968	740	38328	2485	14490	21519	2681	12	612	1	74	62	30	104

Table B.5 (continued)

AGRICULTURAL REGION	TOTAL	GRASS	EAT	MILL	SEED	SUGAR	CEREA	CUT	BULBS	VEGOA	FRUIT	TREES	VEGUG	FLOWR	OTHER
Oist en Wijhe	8558	7650	51	54	2	109	126	411	0	2	133	16	0	0	4
Westelijk Weidegebied	30462	29957	36	0	4	34	51	191	4	117	32	16	16	3	1
Oostelijk Weidegebied	24989	23972	69	71	14	38	182	617	0	12	0	8	3	1	2
Giethoorn Steenwijkerwol	8452	6850	16	805	16	57	450	217	1	0	3	8	1	1	27
Zand-en Veengebied	23043	14389	60	3984	58	1191	2265	1020	0	55	6	11	1	2	1
Salland en Twente	116690	98535	721	1949	133	682	3205	11230	10	42	7	77	2	11	86
TOTAL Overijssel	212194	181353	953	6863	227	2111	6279	13686	15	228	181	136	23	18	121
Westelijke IJsselstreek	13220	11139	137	13	13	243	500	894	3	108	122	9	5	6	28
Oostelijke IJsselstreek	9530	7721	56	19	24	344	289	956	1	93	19	3	0	0	5
Lijmers	13088	9826	92	0	0	532	970	1051	3	197	373	6	19	6	13
Oostelijke Betuwe	4335	2818	48	0	0	178	309	115	10	176	539	10	61	42	29
Midden-Betuwe	30109	20676	288	20	5	1092	1841	727	11	112	4960	241	21	43	72
Westelijke Betuwe	11870	9556	80	0	9	187	323	192	4	65	1094	7	8	8	337
Bommerelerwaard	10098	7733	513	1	78	124	225	270	13	275	542	3	71	46	204
Land van Maas Waal-Noord	8047	6446	28	1	0	139	233	207	4	59	823	10	10	7	80
Land van Maas Waal-Zuid	5278	4313	16	0	0	139	393	129	0	12	265	0	1	0	10
Noordelijke Veluwe	8593	8320	31	0	0	3	75	136	1	23	0	2	2	0	0
Westelijke Veluwe	31599	27867	223	209	9	21	816	2325	7	7	6	48	1	5	55
Oostlijke Veluwe	15148	13006	176	90	0	70	803	841	8	5	73	35	5	10	26
Veluwezoom	6276	4095	143	224	6	126	942	574	3	27	100	25	2	3	6
Noordelijke Achterhoek	53150	43883	407	258	55	421	2460	5525	4	48	10	65	3	5	6
Zuidelijke Achterhoek	28095	21482	272	59	122	274	2167	3564	3	97	7	37	1	1	9
Oude IJssel-Gebied	9202	6878	77	16	11	151	853	1190	0	12	0	12	1	0	1
Rijk van Nijmegen	7157	5231	127	0	28	359	759	403	4	57	122	39	4	7	17
TOTAL Gelderland	264795	210990	2714	910	360	4403	13958	19099	79	1373	9055	552	215	189	898
Kromme Rijn-Streek	10866	8507	53	0	0	93	91	405	1	19	1668	2	8	1	18
De Ronde Venen	5390	5178	10	0	0	20	59	17	11	19	12	5	14	31	14
Veenweidegebied	14296	13857	6	0	0	6	44	128	4	91	95	29	20	6	10
Gebied van IJssel Oude R	7381	6564	7	0	0	0	7	71	9	39	534	5	68	32	45
Lopikerwaard	11000	10504	2	0	0	8	21	26	0	0	432	2	0	0	5
Eemland	3059	3010	9	0	0	6	0	12	0	2	7	10	0	0	3
Zandgbied	12238	11309	35	0	0	1	74	712	5	7	43	37	3	5	7
Heuvelrug	6456	5294	54	26	0	17	268	566	3	4	175	42	1	4	2
TOTAL Utrecht	70686	64223	176	26	0	151	564	1937	33	181	2966	132	114	79	104

Table B.5 (continued)

AGRICULTURAL REGION	TOTAL	GRASS	EAT	MILL	SEED	SUGAR	CEREA	CUT	BULBS	VEGOA	FRUIT	TREES	VEGUG	FLOWR	OTHER
Amsteldieppolders	8993	2823	244	0	1009	1243	1822	31	1542	152	21	0	0	6	100
Wieringermeerpolder	15329	1338	1521	0	1800	4034	5619	77	406	498	0	9	0	0	27
Haarlemmermeer IJ-Polder	14742	2523	1860	0	82	3364	5699	50	272	546	133	15	19	131	48
Aalsmeer	1010	280	54	0	0	95	137	0	121	1	3	16	0	271	32
Amstelland	2985	1742	205	0	0	280	550	6	20	12	0	7	2	139	22
Land van Zijpe	10179	7535	144	0	223	255	350	48	1248	242	4	2	3	3	122
Noord. West-Friesland	13726	11324	154	0	262	173	210	18	537	705	251	2	8	22	60
Waterland	19601	18953	75	0	21	113	227	3	114	58	2	5	1	5	24
Droogmakerijen	12942	9964	401	0	183	817	1061	33	21	263	166	1	10	4	18
't Gein	5749	5669	1	0	0	0	8	2	8	12	5	17	5	12	10
Texel en Wieringen	10876	7543	75	18	438	749	1578	87	248	57	10	0	0	0	73
Gooiland	1738	1541	25	0	0	3	76	34	2	2	11	34	0	2	8
Noord-Kennemerland	5446	4127	54	0	0	110	230	24	495	279	2	4	20	15	86
Zuid-Kennemerland	1554	1001	25	0	0	57	185	0	212	19	1	17	2	7	28
Geestmerambacht	1991	872	126	0	105	23	35	4	92	709	8	0	3	2	12
Randgebied Geestmeramba	6610	3470	98	0	642	121	447	43	383	1325	11	2	12	30	26
Zuidelijk West-Friesland	3349	2739	19	0	60	2	16	5	323	146	19	1	1	1	17
Bangert	3879	2758	24	0	22	2	3	2	109	154	728	1	21	20	35
Oostelijk West-Friesland	9062	3617	358	0	280	75	135	21	1578	2605	238	5	9	22	119
TOTAL N. Holland	149761	89819	5463	18	5127	11516	18388	488	7731	7785	1613	138	116	692	867
Droogmakerijen	9871	3041	605	0	398	1689	2723	117	7	757	76	45	266	113	34
Rozenburg-Oost.Voorne	9586	4287	1033	0	28	1268	2238	186	3	409	92	0	25	4	13
Voornse Duinstreek	2809	1117	213	0	0	290	513	66	10	403	61	2	77	16	41
Ijsselmonde	5330	1143	561	0	0	614	1107	36	9	1488	222	15	94	21	20
Hoeksche, Dordsche Waard	24895	4117	4211	0	32	4810	8452	361	12	1920	827	6	66	15	66
Goeree en Overflakkee	17364	1435	3392	0	123	3147	5031	222	476	3245	249	5	5	2	32
De Vennen	8451	6107	240	0	50	508	757	90	168	171	9	13	15	208	115
Rijnland	11906	10674	116	0	41	202	305	24	59	137	0	230	29	33	56
Boskoop	1028	443	0	0	0	0	0	0	15	0	0	537	0	18	15
Land van Gouda Woerden	8001	7888	0	0	0	0	1	4	4	16	32	39	7	5	5
Delf-en Schieland	16173	13668	133	0	12	210	433	91	14	294	29	13	811	350	115
Krimpenerwaard	10711	10646	0	0	0	0	0	0	1	7	41	2	10	2	2
Alblasserwaard	17250	16998	14	0	0	19	37	6	1	15	148	7	3	0	2
Vijfheerenlanden	11191	10145	43	0	0	31	41	25	1	9	877	10	1	0	8
Bollenstreek	6692	2795	3	0	0	4	2	0	2936	519	0	60	3	143	227
Westland	5314	1179	114	0	37	85	337	10	36	438	11	10	1646	1078	333
TOTAL Z. Holland	166572	95683	10678	0	721	12877	21977	1238	3752	9828	2674	994	3058	2008	1084

Table B.5 (continued)

AGRICULTURAL REGION	TOTAL	GRASS	EAT	MILL	SEED	SUGAR	CEREA	CUT	BULBS	VEGOA	FRUIT	TREES	VEGUG	FLOWR	OTHER
Schowen en Duiveland	15251	1775	2365	0	56	2668	6267	272	165	1394	249	9	3	3	25
Sint Philipsland	1605	88	212	0	5	296	809	34	37	50	73	1	0	0	0
Tholen	9805	1391	1800	0	53	1520	3255	177	181	1111	278	11	12	2	14
Noord-Beveland	6614	203	1035	0	7	1413	3118	180	14	476	164	0	0	0	4
Walcheren	13767	4128	878	0	9	2462	4814	411	16	851	152	9	11	7	19
Zuid-Beveland	27539	3185	3014	0	252	4858	9459	959	240	1833	2980	44	8	8	699
West Zeeuwsch-Vlaanderen	22820	2655	1630	0	38	4228	12931	255	5	816	240	2	1	0	19
Oost Zeeuwsch-Vlaanderen	31012	4006	3214	0	730	5307	15304	737	32	946	644	17	4	3	68
TOTAL Zeeland	128413	17431	14148	0	1150	22752	55957	3025	690	7477	4780	93	39	23	848
Noordwesthoek	27042	4423	3202	0	942	4529	8671	670	235	3502	766	23	19	2	58
Westelijke Langstraat	7166	4048	344	7	1	750	1062	407	5	444	66	5	16	10	1
Biesbosch	8016	1876	923	0	1	1468	2658	73	0	802	200	1	1	2	11
Oostelijke Langstraat	5723	4743	56	0	5	159	188	340	5	142	30	17	27	8	3
Land van Altena	7240	4472	318	0	0	638	1094	198	4	358	126	5	5	10	12
Maaskant	7903	6015	56	0	0	369	743	612	1	22	72	5	3	0	5
Land van Bergen op Zoom	4446	1226	320	0	32	552	1191	334	6	658	90	4	14	1	18
Noordweste. Zandgronden	23334	13748	755	0	151	1749	1979	2382	19	2081	193	162	77	13	25
Land van Breda	17021	11766	72	0	19	410	259	1781	9	1689	106	697	94	11	108
Westelijke Kempen	24766	18255	227	0	0	845	847	4146	7	266	89	43	19	6	16
Meijerij	59514	44746	784	0	2	1313	1311	8849	37	1422	410	437	74	19	110
Oostelijke Kempen	33596	20665	1140	0	10	1860	2303	6848	22	526	82	79	10	5	46
Noordelijk Peelgebied	33074	22080	775	0	23	2263	1620	5326	42	591	171	100	23	4	56
Zuidelijk Peelgebied	18828	13065	208	0	1	672	573	3389	13	617	168	33	54	8	27
Land van Cuyk	7003	4548	246	0	15	633	517	763	15	59	48	142	4	2	11
TOTAL N. Brabant	284672	175676	9426	7	1202	18210	25016	36118	420	13179	2617	1753	440	101	507
Zuid-Limburg	36557	17271	1652	0	12	4969	7278	2774	7	230	2306	46	1	3	8
Westelijk Noord-Limburg	39864	20295	1612	0	19	4288	4455	5134	177	2879	561	175	148	24	97
Noordelijke Maasvallei	30248	11664	1500	0	30	3996	5317	2276	56	3432	690	629	321	47	290
Land van Montfort	9434	3306	270	0	23	2010	2721	523	14	356	156	24	4	1	26
TOTAL Limburg	116103	52536	5034	0	84	15263	19771	10707	254	6897	3713	874	474	75	421
Noordoostpolder	39352	7051	3485	0	5334	9333	7538	441	587	4081	1412	34	5	24	27
Oostelijk	37608	5219	5196	0	2455	8335	12041	225	41	2882	948	135	1	0	130
Zuidelijk Flevoland	17538	41	0	0	0	0	17018	32	0	0	0	0	0	0	447
TOTAL IJpolders	94498	12311	8681	0	7789	17668	36597	698	628	6963	2360	169	6	24	604
NATIONAL TOTALS	2073104	1270107	61388	71692	28784	141000	288263	91558	13754	56885	30339	5308	4620	3292	6114

Table B.6

PRIMARY IRRIGATION DATA
(ha)

		GRASS				ARABLE CROPS				HORTICULTURE			
		SPRINKLE		IRRIGATE		SPRINKLE		IRRIGATE		SPRINKLE		IRRIGATE	
REGION	TOTAL	SURFACE	GROUND	SURFACE	GROUND	SURFACE	GROUND	SURFACE	GROUND	SURFACE	GROUND	SURFACE	GROUND
Humsterland	438	334	0	35	0	51	0	6	0	12	0	0	0
Hogeland	803	472	0	39	0	287	0	0	0	5	0	0	0
Centrale Bouwstreek	496	484	0	7	0	1	0	0	0	4	0	0	0
Oost-Fivelgo	24	19	0	5	0	0	0	0	0	0	0	0	0
Niew-Oldambt	47	37	0	10	0	0	0	0	0	0	0	0	0
Oud-Oldambt	122	56	0	23	0	14	0	0	0	29	0	0	0
Centrale Wiedestreek	878	835	0	43	0	0	0	0	0	0	0	0	0
Zuid. Westerkwartier	464	382	0	62	0	20	0	0	0	0	0	0	0
Goorecht	10	10	0	0	0	0	0	0	0	0	0	0	0
Westerwolde	797	380	95	60	0	205	51	6	0	0	0	0	0
Woldstreek	252	171	0	17	0	55	0	9	0	0	0	0	0
Veenkolonien	313	148	16	38	0	59	7	0	0	40	5	0	0
TOTAL Groningen	4644	3328	111	339	0	692	58	21	0	90	5	0	0
Het Bildt	2960	1200	0	57	0	1595	0	15	0	89	0	4	0
Weide-en Bouwstreek	4638	2650	0	723	0	1180	0	27	0	58	0	0	0
Kleiweidestreek	6509	4620	0	1540	0	318	0	20	0	11	0	0	0
Veenweidestreek	5057	1980	0	3076	0	0	0	1	0	0	0	0	0
Eilanden	0	0	0	0	0	0	0	0	0	0	0	0	0
De Wouden	5700	2947	328	2289	0	110	12	5	0	8	1	0	0
TOTAL Friesland	24864	13397	328	7685	0	3203	12	68	0	166	1	4	0
Weidegebied Noorverve	80	17	17	35	0	3	3	0	0	2	2	1	0
Centraal Zandgebied	2967	752	251	0	1354	276	92	0	223	11	4	0	4
Dieverderdingspel	997	211	211	0	528	10	10	0	27	0	0	0	0
Hoogeveen	219	14	3	0	202	0	0	0	0	0	0	0	0
Zuidwest Weidegebied	515	134	0	380	0	0	0	1	0	0	0	0	0
Hondsrug	632	242	81	89	0	135	45	25	0	11	4	0	0
Veenkolonien	767	308	34	154	0	230	26	14	0	1	0	0	0
Smilde	225	69	23	92	0	29	10	2	0	0	0	0	0
TOTAL Drenthe	6402	1747	620	750	2084	683	186	42	250	25	10	1	4

Table B.6 (continued)

REGION	TOTAL	GRASS				ARABLE CROPS				HORTICULTURE			
		SPRINKLE		IRRIGATE		SPRINKLE		IRRIGATE		SPRINKLE		IRRIGATE	
		SURFACE	GROUND	SURFACE	GROUND	SURFACE	GROUND	SURFACE	GROUND	SURFACE	GROUND	SURFACE	GROUND
Oist en Wijhe	1636	897	598	0	51	28	19	0	7	13	9	0	14
Westelijk Weidegebied	11201	4940	260	5802	0	101	5	2	0	86	5	0	0
Oostelijk Weidegebied	1783	413	1239	76	0	10	29	0	0	4	12	0	0
Giethoorn Steenwijkerwol	807	398	100	281	0	10	2	6	0	8	2	0	0
Zand-en Veengebied	931	327	399	15	0	70	85	14	0	9	12	0	0
Salland en Twente	5627	2579	2579	0	57	190	190	0	6	13	13	0	0
TOTAL Overijssel	21985	9554	5175	6174	108	409	330	22	13	133	53	0	14
Westelijke IJsselstreek	1775	477	886	101	0	62	114	0	0	47	87	1	0
Oostelijke IJsselstreek	1246	0	1080	0	0	0	155	0	0	0	11	0	0
Lijmers	1474	0	948	0	40	0	131	0	8	0	280	0	67
Oostelijke Betuwe	915	125	293	0	38	19	43	0	2	83	195	0	117
Midden-Betuwe	12010	7416	824	0	695	611	68	0	12	1554	173	0	657
Westelijke Betuwe	5970	3088	163	2017	0	83	4	23	0	313	17	262	0
Bommerelerwaard	5633	2803	495	1357	0	203	36	14	0	545	96	84	0
Land van Maas Waal-Noord	3191	1636	289	0	580	71	13	0	7	339	60	0	196
Land van Maas Waal-Zuid	2218	1303	230	434	0	60	11	0	0	101	18	61	0
Noordelijke Veluwe	618	313	209	88	0	4	3	1	0	0	0	0	0
Westelijke Veluwe	533	227	227	0	27	10	10	0	0	16	16	0	0
Oostlijke Veluwe	1301	783	261	117	0	33	11	1	0	34	11	50	0
Veluwezoom	1053	351	429	0	5	81	99	0	0	32	39	0	17
Noordelijke Achterhoek	6880	1601	4803	25	0	91	272	0	0	22	66	0	0
Zuidelijke Achterhoek	3089	142	2706	4	0	9	176	3	0	2	47	0	0
Oude IJssel-Gebied	2308	0	1995	12	0	0	292	0	0	0	9	0	0
Rijk van Nijmegen	1077	209	487	0	53	58	134	0	1	35	81	0	19
TOTAL Gelderland	51291	20474	16325	4155	1438	1395	1572	42	30	3123	1206	458	1073
Kromme Rijn-Streek	4277	2830	314	0	90	181	20	0	8	552	61	0	221
De Ronde Venen	782	543	0	206	0	13	0	0	0	20	0	0	0
Veenweidegebied	1099	845	0	160	0	0	0	0	0	61	0	33	0
Gebied van IJssel Oude R	1069	1024	0	9	0	0	0	0	0	18	0	18	0
Lopikerwaard	1519	1051	0	435	0	4	0	0	0	5	0	24	0
Eemland	234	67	0	152	0	3	0	0	0	8	0	4	0
Zandgbied	667	235	156	0	222	13	8	0	5	5	4	0	19
Heuvelrug	1093	272	504	134	0	30	57	5	0	23	42	26	0
TOTAL Utrecht	10740	6867	974	1096	312	244	85	5	13	692	107	105	240

Table B.6 (continued)

REGION	TOTAL	GRASS				ARABLE CROPS				HORTICULTURE			
		SPRINKLE		IRRIGATE		SPRINKLE		IRRIGATE		SPRINKLE		IRRIGATE	
		SURFACE	GROUND	SURFACE	GROUND	SURFACE	GROUND	SURFACE	GROUND	SURFACE	GROUND	SURFACE	GROUND
Amsteldieppolders	2879	1044	0	10	0	1249	0	0	0	576	0	0	0
Wieringermeerpolder	3225	461	81	12	0	1964	347	0	0	306	54	0	0
Haarlemmermeer IJ-Polder	1368	109	0	9	0	1125	0	0	0	125	0	0	0
Aalsmeer	69	16	0	0	0	18	0	0	0	35	0	0	0
Amstelland	359	213	0	71	0	59	0	0	0	16	0	0	0
Land van Zijpe	3017	1631	0	344	0	234	0	32	0	741	0	35	0
Noord. West-Friesland	6220	5004	0	45	0	240	0	0	0	925	0	6	0
Waterland	1831	1099	0	653	0	21	0	0	0	58	0	0	0
Droogmakerijen	3677	2921	0	301	0	397	0	0	0	49	0	9	0
't Gein	594	463	0	123	0	1	0	0	0	5	0	2	0
Texel en Wieringen	677	559	0	31	0	87	0	0	0	0	0	0	0
Gooiland	103	84	0	0	0	3	0	0	0	16	0	0	0
Noord-Kennemerland	1001	418	139	0	39	36	12	0	2	173	58	0	124
Zuid-Kennemerland	177	87	10	0	17	0	0	0	0	52	6	0	5
Geestmerambacht	1073	409	0	0	0	137	0	0	0	527	0	0	0
Randgebied Geestmeramba	2221	1115	0	0	0	342	0	0	0	761	0	3	0
Zuidelijk West-Friesland	1335	894	0	87	0	27	0	0	0	327	0	0	0
Bangert	1954	1419	0	6	0	29	0	0	0	497	0	3	0
Oostelijk West-Friesland	5310	1744	0	0	0	133	0	0	0	3420	0	13	0
TOTAL N. Holland	37090	19690	230	1692	56	6102	359	32	2	8609	118	71	129
Droogmakerijen	1391	525	0	23	0	675	0	0	0	153	0	15	0
Rozenburg-Oost.Voorne	657	432	0	8	0	136	0	0	0	81	0	0	0
Voornse Duinstreek	431	166	0	0	0	40	0	0	0	225	0	0	0
IJsselmonde	1756	561	0	3	0	412	0	0	0	780	0	0	0
Hoeksche, Dordsche Waard	3938	1106	0	40	0	1926	0	6	0	794	0	66	0
Goeree en Overflakkee	960	113	0	0	0	313	0	0	0	512	0	22	0
De Vennen	1789	1024	0	484	0	254	0	0	0	27	0	0	0
Rijnland	2108	1306	0	591	0	91	0	0	0	120	0	0	0
Boskoop	231	8	0	0	0	0	0	0	0	223	0	0	0
Land van Gouda Woerden	1546	1177	0	332	0	3	0	0	0	34	0	0	0
Delf-en Schieland	2370	1967	0	112	0	140	0	1	0	150	0	0	0
Krimpenerwaard	1120	137	0	976	0	0	0	0	0	4	0	3	0
Alblasserwaard	1633	536	0	1065	0	11	0	1	0	20	0	0	0
Vijfheerenlanden	2067	995	0	666	0	190	0	0	0	195	0	21	0
Bollenstreek	1279	676	0	185	0	6	0	0	0	411	0	1	0
Westland	617	166	0	10	0	262	0	0	0	179	0	0	0
TOTAL Z. Holland	23893	10895	0	4495	0	4459	0	8	0	3908	0	128	0

Table B.6 (continued)

		GRASS				ARABLE CROPS				HORTICULTURE			
		SPRINKLE		IRRIGATE		SPRINKLE		IRRIGATE		SPRINKLE		IRRIGATE	
REGION	TOTAL	SURFACE	GROUND	SURFACE	GROUND	SURFACE	GROUND	SURFACE	GROUND	SURFACE	GROUND	SURFACE	GROUND
Schowen en Duiveland	10	5	3	0	0	0	0	0	0	0	0	0	2
Sint Philipsland	0	0	0	0	0	0	0	0	0	0	0	0	0
Tholen	62	6	4	0	6	0	0	0	0	4	2	0	40
Noord-Beveland	4	0	0	0	0	0	0	0	0	0	0	0	4
Walcheren	37	0	0	0	2	0	0	0	0	12	8	0	15
Zuid-Beveland	81	0	0	0	1	0	0	0	14	0	0	0	66
West Zeeuwsch-Vlaanderen	56	28	18	0	0	2	2	0	0	0	0	0	6
Oost Zeeuwsch-Vlaanderen	86	0	0	0	21	17	11	0	6	5	3	0	23
TOTAL Zeeland	336	39	25	0	30	19	13	0	20	21	13	0	156
Noordwesthoek	3744	690	77	0	22	1723	191	0	7	869	97	0	68
Westelijke Langstraat	947	537	28	0	0	247	13	0	0	116	6	0	0
Biesbosch	687	210	0	0	0	392	0	0	0	85	0	0	0
Oostelijke Langstraat	775	527	59	0	0	94	10	0	0	76	9	0	0
Land van Altena	2362	1874	0	21	0	339	0	0	0	128	0	0	0
Maaskant	1491	883	98	276	0	135	15	34	0	28	3	19	0
Land van Bergen op Zoom	349	29	115	0	0	16	63	0	0	25	101	0	0
Noordweste. Zandgronden	4719	1015	1885	0	61	222	411	0	18	378	702	0	27
Land van Breda	3249	454	1362	0	182	71	214	0	41	231	692	0	2
Westelijke Kempen	2340	89	1698	0	26	16	300	0	4	10	197	0	0
Meijerij	6221	1068	3203	0	332	154	462	0	75	229	688	0	10
Oostelijke Kempen	4920	196	3725	0	67	38	731	0	23	7	128	0	5
Noordelijk Peelgebied	4842	386	3478	0	70	64	579	0	15	24	218	0	8
Zuidelijk Peelgebied	3230	614	1841	0	19	114	343	0	2	70	210	0	17
Land van Cuyk	1504	102	918	0	23	28	255	0	10	17	151	0	0
TOTAL N. Brabant	41380	8674	18487	297	802	3653	3587	34	195	2293	3202	19	137
Zuid-Limburg	828	229	57	0	342	69	17	0	53	36	9	0	16
Westelijk Noord-Limburg	7430	1095	2555	0	330	648	1511	0	118	336	783	0	54
Noordelijke Maasvallei	7163	2094	1396	52	0	1306	871	20	0	838	559	27	0
Land van Montfort	1629	302	561	0	0	210	390	0	0	58	108	0	0
TOTAL Limburg	17050	3720	4569	52	672	2233	2789	20	171	1268	1459	27	70
Noordoostpolder	14411	4789	0	259	0	8082	0	45	0	1230	0	6	0
Oostelijk	3639	1363	151	80	0	1714	191	70	0	63	7	0	0
Zuidelijk Flevoland	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL IJpolders	18050	6152	151	339	0	9796	191	115	0	1293	7	6	0
TOTAL NATION	257725	104537	46995	27074	5502	32888	9182	409	694	21621	6181	819	1823

Table B.7

PERCENTAGE OF AGRICULTURE REGIONS IN PAWN DISTRICTS

PAWN Region: North

Districts:

Agricultural region	1 FRIELAND			2 HETBILDT			3 LAUWMEER			4 UITHUIZN			5 EEMSKANN			6 OLDAMBT			7 WESTWOLD		
Gr Humsterland	30	30	25	.	.	.	50	50	50	.	.	.	.	.	.	.	.	.	.	.	.
Hogeland	.	.	.	.	.	.	60	60	80	20	20	.	20	20	20	.	.	.	.	.	.
Centrale Bouwstreek	.	.	.	.	.	.	70	70	70	.	.	.	30	30	30	.	.	.	.	.	.
Oost-Fivelgo	.	.	.	.	.	.	.	.	.	.	.	.	50	50	100	50	50	.	.	.	.
Niew-Oldambt	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100	.	.	.
Oud-Oldambt	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	70	70	.	30	30	100
Centrale Wiedestreek	.	.	.	.	.	.	50	50	40	.	.	.	20	20	45	.	.	.	.	.	.
Zuid. Westerkwartier	30	30	20	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Westerwolde	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100
Woldstreek	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100	.	.	.	.	.	.
Veenkolonien	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	10	.	.	90	100	100
Fr Het Bildt	.	.	.	100	100	100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Weide-en Bouwstreek	80	80	80	.	.	.	20	20	20	.	.	.	.	.	.	.	.	.	.	.	.
Kleiweidestreek	100	100	100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Veenweidestreek	100	100	100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
De Wouden	100	100	100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

PAWN Region: North (cont)

Districts:

Agricultural region	8 NWDRENTE			9 WESKWART			13 VOLENHOV			14 NEPOLDER			15 MASTBROK		
Gr Humsterland	.	.	.	20	20	25	.	.	.	.	.	.	.	.	.
Centrale Wiedestreek	.	.	.	30	30	15	.	.	.	.	.	.	.	.	.
Zuid. Westerkwartier	.	.	.	70	70	80	.	.	.	.	.	.	.	.	.
Goorecht	90	90	.	10	10	100	.	.	.	.	.	.	.	.	.
Dr Weidegebied Noorverve	20	100	.	80	.	100	.	.	.	.	.	.	.	.	.
Centraal Zandgebied	20	20	.	10	.	5	.	.	.	.	.	.	.	.	.
Dieverderdingspel	.	.	.	.	.	.	30	30	20	.	.	.	.	.	.
Zuidwest Weidegebied	.	.	.	.	.	.	20	20	50	.	.	.	.	.	.
Hondsrug	70	80	.	.	.	.	.	.	.	.	.	.	.	.	.
Veenkolonien	10	30	.	.	.	.	.	.	.	.	.	.	.	.	.
Ov Westelijk Weidegebied	.	.	.	.	.	.	40	40	30	.	.	.	50	50	70
Oostelijk Weidegebied	.	.	.	.	.	.	.	.	.	.	.	.	70	70	80
Giethoorn Steenwijkerwol	.	.	.	.	.	.	100	100	100	.	.	.	.	.	.
IJ Noordoostpolder	.	.	.	.	.	.	.	.	.	100	100	100	.	.	.

Table B.7 (continued)

PAWN Region: Northeast Highlands

Districts:

Agricultural region	10 NEDRENTE			11 SEDRENTE			12 SWDRENTE			16 OVIJVECT		
Dr Centraal Zandgebied	.	.	.	30	30	75	40	50	20	.	.	.
Dieverderdingspel	.	.	.	.	.	.	70	70	80	.	.	.
Hoogeveen	.	.	.	10	10	10	60	60	60	30	30	30
Zuidwest Weidegebied	.	.	.	.	.	.	80	80	50	.	.	.
Hondsrug	10	.	25	10	10	65	10	10	10	.	.	.
Veenkolonien	60	.	70	30	70	30	.	.	.	.	.	.
Smilde	.	.	.	.	.	.	100	100	100	.	.	.
Ov Zand-en Veengebied	.	.	.	.	.	.	10	10	.	90	90	100
Salland en Twente	.	.	.	.	.	.	.	.	.	6	6	15

PAWN Region: Northeast Highlands (cont)

Districts:

Agricultural region	17 DINKEL			18 TWENTHE			19 SALLAND			20 TWENTKAN			21 SHIPBEEK			24 BERKEL			25 OUDEIJSL		
Ov Oist en Wijhe	.	.	.	.	.	.	100	100	100	.	.	.	.	.	.	.	.	.	.	.	.
Westelijk Weidegebied	.	.	.	.	.	.	10	10	.	.	.	.	.	.	.	.	.	.	.	.	.
Oostelijk Weidegebied	.	.	.	.	.	.	30	30	20	.	.	.	.	.	.	.	.	.	.	.	.
Salland en Twente	12	12	.	40	40	15	12	12	40	20	20	15	10	10	15	.	.	.	.	.	.
Ge Oostelijke IJsselstreek	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	25	25	25	75	75	75
Lijmers	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	70	70	40
Noordelijke Achterhoek	.	.	.	.	.	.	.	.	.	10	10	30	5	5	.	80	80	70	5	5	.
Zuidelijke Achterhoek	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	30	30	100	70	70	.
Oude IJssel-Gebied	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100

Table B.7 (continued)

PERCENTAGE OF AGRICULTURE REGIONS IN PAWN DISTRICTS

PAWN Region: IJsselmeerpolders and Veluwe

Districts:

Agricultural region	22 IJSELGEB			23 NEVELUWE			26 ARNHEM			27 SEVELUWE			28 SWVELUWE			29 NWVELUWE			30 FLEVLAND		
Ge Westelijke IJsselstreek	50	50	80	50	50	20	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Noordelijke Veluwe	.	.	.	20	100	20	.	.	.	.	.	.	.	.	.	80	.	80	.	.	.
Westelijke Veluwe	.	.	.	.	.	.	.	.	.	10	.	.	50	100	.	40	.	100	.	.	.
Oostlijke Veluwe	30	30	30	70	70	70	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Veluwezoom	.	.	.	10	50	50	40	.	.	40	.	.	10	50	50	.	.	.	.	.	.
Ut Eemland	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100	.	.	.	.	.	.
Zandgbied	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100	.	.	.	.	.	.
Heuvelrug	.	.	.	.	.	.	.	.	.	.	.	.	30	30	40	.	.	.	.	.	.
NH Gooiland	.	.	.	.	.	.	.	.	.	.	.	.	30	30	30	.	.	.	.	.	.
IJ Oostelijk	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100
Zuidelijk Flevoland	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100

PAWN Region: North Holland

Districts:

Agricultural region	31 WIERGMER			32 AMSTLMER			33 MEDMBLIK			34 HOORN			35 SCHERMER			36 WATRLAND			37 NZKANGEB		
NH Amsteldieppolders	.	.	.	100	100	100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Wieringermeerpolder	100	100	100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Haarlemmermeer IJ-Polder	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20	20	20
Land van Zijpe	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100	.	.	.	.	.	.
Noord. West-Friesland	.	.	.	40	40	40	60	60	60	.	.	.	.	.	.	.	.	.	.	.	.
Waterland	.	.	.	.	.	.	.	.	.	.	.	.	55	55	55	25	25	25	20	20	20
Droogmakerijen	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100	.	.	.	.	.	.
Texel en Wieringen	.	.	.	20	20	20	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Noord-Kennemerland	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100	.	.	.	.	.	.
Zuid-Kennemerland	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20	.	20
Geestmerambacht	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100	.	.	.	.	.	.
Randgebied Geestmeramba	.	.	.	30	30	30	.	.	.	.	.	.	70	70	70	.	.	.	.	.	.
Zuidelijk West-Friesland	.	.	.	.	.	.	.	.	.	70	70	70	30	30	30	.	.	.	.	.	.
Bangert	.	.	.	.	.	.	30	30	30	70	70	70	.	.	.	.	.	.	.	.	.
Oostelijk West-Friesland	.	.	.	.	.	.	90	90	90	10	10	10	.	.	.	.	.	.	.	.	.

Table B.7 (continued)

PAWN Region: Midwest and Utrecht

Districts:

	Agricultural region	38 RIJNLAND			39 AMSTLAND			40 GOOI			46 SCIELAND			47 DELFLAND		
Ut	De Ronde Venen	.	.	.	100	100	100	.	.	.	.	.	.	.	.	.
	Veenweidegebied	.	.	.	20	20	20	50	50	50	.	.	.	.	.	.
NH	Haarlemmermeer IJ-Polder	80	80	80	.	.	.	.	.	.	.	.	.	.	.	.
	Aalsmeer	100	100	100	.	.	.	.	.	.	.	.	.	.	.	.
	Amstelland	20	20	20	80	80	80	.	.	.	.	.	.	.	.	.
	't Gein	.	.	.	50	50	50	50	50	50	.	.	.	.	.	.
	Gooiland	.	.	.	.	.	.	70	70	70	.	.	.	.	.	.
	Zuid-Kennemerland	80	100	80	.	.	.	.	.	.	.	.	.	.	.	.
ZH	Droogmakerijen	30	30	30	.	.	.	.	.	.	70	70	70	.	.	.
	De Vennen	90	90	90	10	10	10	.	.	.	.	.	.	.	.	.
	Rijnland	100	100	100	.	.	.	.	.	.	.	.	.	.	.	.
	Boskoop	100	100	100	.	.	.	.	.	.	.	.	.	.	.	.
	Land van Gouda Woerden	40	40	40	.	.	.	.	.	.	.	.	.	.	.	.
	Delf-en Schieland	10	10	10	.	.	.	.	.	.	15	15	15	75	75	75
	Bollenstreek	100	100	100	.	.	.	.	.	.	.	.	.	.	.	.
	Westland	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100

PAWN Region: Midwest and Utrecht (cont)

Districts:

	Agricultural region	41 KROMRIJN			42 LEIDRIJN			43 WOERDEN			44 LOPIKWAR			45 KRIMPWAR		
Ut	Kromme Rijn-Streek	100	100	100	.	.	.	.	.	.	.	.	.	.	.	.
	Veenweidegebied	.	.	.	10	10	10	20	20	20	.	.	.	.	.	.
	Gebied van IJssel Oude R	25	25	10	60	60	60	5	5	10	10	10	20	.	.	.
	Lopikerwaard	.	.	.	.	.	.	30	30	30	70	70	70	.	.	.
	Heuvelrug	70	70	60	.	.	.	.	.	.	.	.	.	.	.	.
ZH	Ijsselmonde	.	.	.	.	.	.	.	.	.	.	.	.	20	20	20
	Land van Gouda Woerden	.	.	.	.	.	.	60	60	60	.	.	.	.	.	.
	Krimpenerwaard	.	.	.	.	.	.	.	.	.	10	10	10	75	75	75

Table B.7 (continued)

PAWN Region: Lower rivers and Northern Delta

Districts:

Agricultural region	48 VOORNE			49 GOEREE			50 IJSLMOND			52 DORDRECT			53 ABLASWAR			55 TIELWARD			57 BETUWE			59 RECMAASN		
Ge Lijmers	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	30	30	60
Oostelijke Betuwe	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100	.	.	.
Midden-Betuwe	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	40	40	40	60	60	60	.	.	.
Westelijke Betuwe	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100	.	.	.	.	.	.
Rijk van Nijmegen	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	30	30	.
ZH Rozenburg-Oost.Voorne	80	80	80	.	.	.	20	20	20	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Voornse Duinstreek	100	100	100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ijsselmonde	.	.	.	.	.	.	50	50	50	30	30	30	.	.	.	.	.	.	.	.	.	.	.	.
Hoeksche, Dordsche Waard	20	20	20	.	.	.	30	30	30	20	20	20	.	.	.	.	.	.	.	.	.	.	.	.
Goeree en Overflakkee	20	20	100	40	40	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Krimpenerwaard	.	.	.	.	.	.	.	.	.	.	.	.	15	15	15	.	.	.	.	.	.	.	.	.
Alblasserwaard	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100	.	.	.	.	.	.	.	.	.
Vijfheerenlanden	.	.	.	.	.	.	.	.	.	.	.	.	10	10	10	90	90	90	.	.	.	.	.	.

PAWN Region: West Brabant and Southern Delta

Districts:

Agricultural region	51 HOLNDIEP			54 BIESBOSH			74 MARK			75 ROSENDAL			76 ZOOM			77 SCHOUWEN		
ZH Hoeksche, Dordsche Waard	20	20	20	10	10	10	.	.	.	.	.	.	.	.	.	.	.	.
Goeree en Overflakkee	.	.	.	.	.	.	.	.	.	.	.	.	20	20	.	20	20	.
Ze Schouwen en Duiveland	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100
Sint Philipsland	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100	.	.	.
Tholen	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100	.	.	.
Zuid-Beveland	.	.	.	.	.	.	.	.	.	.	.	.	40	.	40	.	.	.
NB Noordwesthoek	60	60	60	.	.	.	.	.	.	40	40	40	.	.	.	.	.	.
Westelijke Langstraat	10	100	20	90	.	80	.	.	.	.	.	.	.	.	.	.	.	.
Biesbosch	.	.	.	100	100	100	.	.	.	.	.	.	.	.	.	.	.	.
Oostelijke Langstraat	.	.	.	50	.	40	.	.	.	.	.	.	.	.	.	.	.	.
Land van Altena	.	.	.	40	40	40	.	.	.	.	.	.	.	.	.	.	.	.
Land van Bergen op Zoom	.	.	.	.	.	.	.	.	.	30	100	100	70	.	.	.	.	.
Noordweste. Zandgronden	30	30	50	.	.	.	30	30	50	40	40	.	.	.	.	.	.	.
Land van Breda	.	.	.	.	.	.	100	100	100	.	.	.	.	.	.	.	.	.
Westelijke Kempen	.	.	.	.	.	.	30	30	30	.	.	.	.	.	.	.	.	.

Table B.7 (continued)

PAWN Region: Southeast Highlands

Districts:

Agricultural region	56 DENBOSCH			58 MAASWAAL			61 MASKANTE			62 MASKANTW			70 MDOMMEL			71 WDOMMEL			72 NDOMMEL			73 DONGE		
Ge Bommerelerwaard	100	100	100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Land van Maas Waal-Noord	.	.	.	100	100	100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Land van Maas Waal-Zuid	.	.	.	100	100	100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Rijk van Nijmegen	.	.	.	30	30	40	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
NB Oostelijke Langstraat	50	100	60	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Land van Altena	60	60	60	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Maaskant	.	.	.	.	.	.	.	.	.	100	100	100	.	.	.	.	.	.	.	.	.	.	.	.
Westelijke Kempen	5	5	5	.	.	.	.	.	.	.	.	.	.	.	.	30	30	65	5	5	.	30	30	.
Meijerij	15	15	50	.	.	.	.	.	.	6	6	45	10	10	.	.	.	.	27	27	.	.	.	.
Oostelijke Kempen	.	.	.	.	.	.	.	.	.	.	.	.	35	35	.	35	35	100	.	.	.	5	5	.
Noordelijk Peelgebied	.	.	.	.	.	.	60	60	.	10	10	15	.	.	.	.	.	.	.	.	.	.	.	.
Land van Cuyk	.	.	.	.	.	.	100	100	100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

PAWN Region: Southeast Highlands (cont)

Districts:

Agricultural region	60 RECMAASM			63 AA			64 DEPEEL			65 RECMAASS			66 ROERMOND			67 SLIMBURG			68 MLIMBURG			69 EDOMMEL		
Ge Rijk van Nijmegen	40	40	60	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
NB Meijerij	.	.	.	27	27	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	5	.
Oostelijke Kempen	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	25	25	.
Noordelijk Peelgebied	.	.	.	30	30	85	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Zuidelijk Peelgebied	.	.	.	90	90	100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	10	10	.
Li Zuid-Limburg	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100	.	.	.	.	.	.
Westelijk Noord-Limburg	.	.	.	7	7	10	45	45	60	.	.	.	.	.	.	.	.	.	40	40	30	8	8	.
Noordelijke Maasvallei	10	10	15	.	.	.	30	30	25	40	40	10	.	.	.	.	.	.	20	20	50	.	.	.
Land van Montfort	.	.	.	.	.	.	.	.	.	.	.	.	100	100	100	.	.	.	.	.	.	.	.	.

Table B.8

INITIAL DEFINITIONS OF SUBDISTRICTS

PAWN Region: North

DISTRICT	SUBD	FRAC	ROOT ZONE SOIL TYPE	SUBSOIL TYPE	LANDFORM
1 FRIELAND	1	0.300	Loamy medium coarse sand	Loamy medium coarse sand	Lowlands
	2	0.250	Basin clay	Basin clay	Lowlands
	3	0.150	Light clay	(Hum. loamy med. coarse sand)	Lowlands
	4	0.130	Peat	Peat	Lowlands
	5	0.120	Basin clay	Peat	Lowlands
	6	0.050	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
2 HETBILDT	7	1.000	Loam	(Light loamy med. coarse sand)	Lowlands
3 LAUWMEER	8	1.000	Light clay	(Hum. loamy med. coarse sand)	Lowlands
4 UITHUIZN	9	1.000	Loam	(Light loamy med. coarse sand)	Lowlands
5 EEMSKANN	10	0.700	Light clay	(Hum. loamy med. coarse sand)	Lowlands
	11	0.300	Hum. loamy med. coarse sand	Hum. loamy med. coarse sand	Lowlands
6 OLDAMBT	12	0.800	Silty clay	Silty clay	Lowlands
	13	0.200	Hum. loamy med. coarse sand	Hum. loamy med. coarse sand	Lowlands
7 WESTWOLD	14	1.000	Hum. loamy med. coarse sand	Hum. loamy med. coarse sand	Lowlands
8 NWDRENTE	15	0.550	Loamy medium coarse sand	Loamy medium coarse sand	Lowlands
	16	0.450	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
9 WESKWART	17	0.750	Loamy medium coarse sand	Loamy medium coarse sand	Lowlands
	18	0.250	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
13 VOLENHOV	24	0.700	Peat	Peat	Lowlands
	25	0.150	Loamy medium coarse sand	Loamy medium coarse sand	Lowlands
	26	0.150	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
14 NEPOLDER	27	1.000	Sandy clay loam	(Hum. loamy med. coarse sand)	Lowlands
15 MASTBROK	28	0.400	Loamy medium coarse sand	Loamy medium coarse sand	Lowlands
	29	0.400	Light clay	(Hum. loamy med. coarse sand)	Lowlands
	30	0.200	Peat	Peat	Lowlands

Table B.8 (continued)

PAWN Region: Northeast Highlands

DISTRICT	SUBD	FRAC	ROOT ZONE SOIL TYPE	SUBSOIL TYPE	LANDFORM
10 NEDRENTE	19	1.000	Hum. loamy med. coarse sand	Hum. loamy med. coarse sand	Lowlands
11 SEDRENTE	20	0.400	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	21	0.600	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
12 SWDRENTE	22	0.400	Loamy medium coarse sand	Loamy medium coarse sand	Lowlands
	23	0.600	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
16 OVIJVECT	31	0.250	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	32	0.750	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
17 DINKEL	33	0.250	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	34	0.750	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
18 TWENTHE	35	0.350	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	36	0.650	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
19 SALLAND	37	0.650	Loamy medium coarse sand	Loamy medium coarse sand	Lowlands
	38	0.350	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
20 TWENTKAN	39	0.700	Light loamy med. coarse sand	(Light loamy med. coarse sand)	Lowlands
	40	0.100	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	41	0.200	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
21 SHIPBEEK	42	1.000	Light loamy med. coarse sand	(Light loamy med. coarse sand)	Lowlands
24 BERKEL	47	0.250	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	48	0.750	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
25 OUDEIJSL	49	0.350	Light clay	(Hum. loamy med. coarse sand)	Lowlands
	50	0.650	Loamy medium coarse sand	Loamy medium coarse sand	High highlands

PAWN Region: Flevoland & Veluwe

DISTRICT	SUBD	FRAC	ROOT ZONE SOIL TYPE	SUBSOIL TYPE	LANDFORM
22 IJSELGEB	43	1.000	Light clay	(Hum. loamy med. coarse sand)	Lowlands
23 NEVELUWE	44	0.250	Light clay	(Hum. loamy med. coarse sand)	Lowlands
	45	0.250	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	46	0.500	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
26 ARNHEM	51	1.000	Light clay	(Hum. loamy med. coarse sand)	Lowlands
27 SEVELUWE	52	0.300	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	53	0.700	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
28 SWVELUWE	54	0.600	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	55	0.400	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
29 NWVELUWE	56	0.700	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	57	0.300	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
30 FLEVLAND	58	1.000	Sandy clay loam	(Hum. loamy med. coarse sand)	Lowlands

Table B.8 (continued)

PAWN Region: North Holland

DISTRICT	SUBD	FRAC	ROOT ZONE SOIL TYPE	SUBSOIL TYPE	LANDFORM
31 WIERGMER	59	1.000	Light clay	(Hum. loamy med. coarse sand)	Lowlands
32 AMSTLMER	60	1.000	Light clay	(Hum. loamy med. coarse sand)	Lowlands
33 MEDMBLIK	61	1.000	Light clay	(Hum. loamy med. coarse sand)	Lowlands
34 HOORN	62	1.000	Light clay	(Hum. loamy med. coarse sand)	Lowlands
35 SCHERMER	63	0.300	Peat	Peat	Lowlands
	64	0.300	Peat	Peat	Lowlands
	65	0.200	Basin clay	Basin clay	Lowlands
	66	0.200	Light loamy med. coarse sand	(Hum. loamy med. coarse sand)	Lowlands
36 WATRLAND	67	1.000	Peat	Peat	Lowlands
37 NZKANGEB	68	0.650	Silty clay	(Hum. loamy med. coarse sand)	Lowlands
	69	0.350	Peat	Peat	Lowlands

PAWN Region: Midwest and Utrecht

DISTRICT	SUBD	FRAC	ROOT ZONE SOIL TYPE	SUBSOIL TYPE	LANDFORM
38 RIJNLAND	70	0.500	Silty clay	(Hum. loamy med. coarse sand)	Lowlands
	71	0.400	Peat	Peat	Lowlands
	72	0.050	Coarse sand	Coarse sand	Lowlands
	73	0.050	Basin clay	Peat	Lowlands
39 AMSTLAND	74	0.650	Peat	Peat	Lowlands
	75	0.350	Basin clay	Peat	Lowlands
40 GOOI	76	1.000	Peat	Peat	Lowlands
41 KROMRIJN	77	0.600	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
	78	0.400	Light clay	(Hum. loamy med. coarse sand)	Lowlands
42 LEIDRIJN	79	1.000	Basin clay	(Silty clay)	Lowlands
43 WOERDEN	80	1.000	Peat	Peat	Lowlands
44 LOPIKWAR	81	0.400	Basin clay	(Silty clay)	Lowlands
	82	0.300	Basin clay	Peat	Lowlands
	83	0.300	Light clay	(Hum. loamy med. coarse sand)	Lowlands
45 KRIMPWAR	84	0.800	Peat	Peat	Lowlands
	85	0.200	Loam	(Light loamy med. coarse sand)	Lowlands
46 SCIELAND	86	0.500	Peat	Peat	Lowlands
	87	0.500	Silty clay	(Basin clay)	Lowlands
47 DELFLAND	88	0.650	Basin clay	Peat	Lowlands
	89	0.250	Light loamy med. coarse sand	(Light loamy med. coarse sand)	Lowlands
	90	0.100	Silty clay	(Basin clay)	Lowlands

Table B.8 (continued)

PAWN Region: Large Rivers & Northern Delta

DISTRICT	SUBD	FRAC	ROOT ZONE SOIL TYPE	SUBSOIL TYPE	LANDFORM
48 VOORNE	91	1.000	Loam	(Light loamy med. coarse sand)	Lowlands
49 GOEREE	92	1.000	Loam	(Light loamy med. coarse sand)	Lowlands
50 IJSLMOND	93	1.000	Loam	(Light loamy med. coarse sand)	Lowlands
52 DORDRECT	95	1.000	Loam	(Light loamy med. coarse sand)	Lowlands
53 ABLASWAR	96	0.550	Basin clay	Peat	Lowlands
	97	0.250	Basin clay	(Silty clay)	Lowlands
	98	0.200	Peat	Peat	Lowlands
55 TIELWARD	102	0.500	Light clay	(Hum. loamy med. coarse sand)	Lowlands
	103	0.500	Basin clay	(Silty clay)	Lowlands
57 BETUWE	107	1.000	Light clay	(Hum. loamy med. coarse sand)	Lowlands
59 RECMAASN	109	0.300	Light clay	(Hum. loamy med. coarse sand)	Lowlands
	110	0.700	Loamy medium coarse sand	Loamy medium coarse sand	High highlands

PAWN Region: West-Brabant & Southern Delta

DISTRICT	SUBD	FRAC	ROOT ZONE SOIL TYPE	SUBSOIL TYPE	LANDFORM
51 HOLNDIEP	94	1.000	Loam	(Light loamy med. coarse sand)	Lowlands
54 BIESBOSH	99	0.400	Loam	(Light loamy med. coarse sand)	Lowlands
	100	0.300	Loamy medium coarse sand	Loamy medium coarse sand	Lowlands
	101	0.300	Light clay	(Hum. loamy med. coarse sand)	Lowlands
74 MARK	137	0.150	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	138	0.850	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
75 ROSENDAL	139	0.350	Loam	(Light loamy med. coarse sand)	Lowlands
	140	0.650	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
76 ZOOM	141	0.900	Loam	(Light loamy med. coarse sand)	Lowlands
	142	0.100	Loamy medium coarse sand	Loamy medium coarse sand	Lowlands
77 SCHOUWEN	143	1.000	Loam	(Light loamy med. coarse sand)	Lowlands

Table B.8 (continued)

PAWN Region: Southeast Highlands

DISTRICT	SUBD	FRAC	ROOT ZONE SOIL TYPE	SUBSOIL TYPE	LANDFORM
56 DENBOSCH	104	0.500	Light clay	(Hum. loamy med. coarse sand)	Lowlands
	105	0.150	Loamy medium coarse sand	Loamy medium coarse sand	Lowlands
	106	0.350	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
58 MAASWAAL	108	1.000	Light clay	(Hum. loamy med. coarse sand)	Lowlands
60 RECMAASM	111	1.000	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
61 MASKANTE	112	0.200	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	113	0.800	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
62 MASKANTW	114	0.500	Light clay	(Hum. loamy med. coarse sand)	Lowlands
	115	0.200	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	116	0.300	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
63 AA	117	0.250	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	118	0.750	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
64 DEPEEL	119	0.150	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	120	0.850	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
65 RECMAASS	121	0.250	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	122	0.750	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
66 ROERMOND	123	0.100	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	124	0.900	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
67 SLIMBURG	125	1.000	Clay loam	(Loamy medium coarse sand)	High highlands
68 MLIMBURG	126	0.200	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	127	0.800	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
69 EDOMMEL	128	0.250	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	129	0.750	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
70 MDOMMEL	130	0.200	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	131	0.800	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
71 WDOMMEL	132	1.000	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
72 NDOMMEL	133	0.150	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	134	0.850	Loamy medium coarse sand	Loamy medium coarse sand	High highlands
73 DONGE	135	0.250	Loamy medium coarse sand	Loamy medium coarse sand	Low highlands
	136	0.750	Loamy medium coarse sand	Loamy medium coarse sand	High highlands

Table B.9

SUBDISTRICT CROP/IRRIGATION DATA
(ha)

PAWN Region: North

DISTRICT	SUBD	NATURE	-------GRASS-------			-------------------ARABLE CROPS-------------------								-------OPEN AIR HORTICULTURE--------					
			TOTAL	SW	GW	CONP	MILLP	SEEDP	SBEET	CEREA	CORN	SW	GW	BULB	VEG	FRUIT	TREES	SW	GW
1 FRIELAND	1	14007	62000	4259	0	0	547	733	484	1283	361	0	0	0	0	0	46	0	0
	2	11673	55000	6570	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	7003	22692	4023	0	743	0	2009	2467	3759	0	1438	0	80	366	88	0	68	0
	4	6069	28000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	5603	26000	5080	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6	2335	11000	0	328	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2 HETBILDT	7	3928	4318	1257	0	344	0	1573	1725	2387	0	1610	0	25	458	100	0	93	0
3 LAUWMEER	8	18896	24585	1962	0	1276	75	3016	4728	14250	160	500	0	23	459	81	5	24	0
4 UITHUIZN	9	3602	2176	0	0	343	0	794	1210	3544	41	0	0	0	106	20	0	0	0
5 EEMSKANN	10	2420	7183	583	0	401	0	872	1572	6303	131	122	0	0	195	21	0	0	0
	11	1037	3386	273	0	0	3224	0	647	4985	0	0	0	0	0	0	0	0	0
6 OLDAMBT	12	4032	4131	47	0	118	0	315	2220	15044	858	0	0	0	646	47	0	0	0
	13	1008	0	0	0	0	4015	0	750	2600	0	0	0	0	0	0	133	0	0
7 WESTWOLD	14	4082	6285	705	111	89	17577	230	5557	13252	268	284	58	0	110	6	188	72	5
8 NWDRENTE	15	9264	16575	0	413	0	2571	0	0	0	464	0	0	3	0	0	42	0	0
	16	7580	0	0	0	179	6457	561	3623	5192	0	0	122	0	86	0	0	0	21
9 WESKWART	17	13297	20961	679	0	137	0	279	0	811	0	48	0	0	32	17	0	0	0
	18	4433	4208	0	0	0	1395	0	754	811	214	0	0	10	0	0	11	0	0
13 VOLENHOV	24	11523	20637	3223	0	0	0	0	0	0	0	0	0	0	48	16	16	34	15
	25	2469	4503	978	0	0	0	89	0	0	0	49	0	0	0	0	0	0	0
	26	2469	2619	0	425	66	1161	0	155	731	467	0	0	0	0	0	0	0	0
14 NEPOLDER	27	5862	7051	5048	0	3485	0	5334	9333	7538	441	8127	0	587	4081	1412	34	1236	0
15 MASTBROK	28	2715	12259	330	997	66	50	0	0	153	528	80	38	0	0	0	0	0	0
	29	2715	13000	7580	0	0	0	0	0	0	0	0	0	0	69	16	0	63	0
	30	1357	6500	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0
TOTAL		149379	365069	42597	2274	7247	37072	15805	35225	82643	3933	12258	218	728	6656	1824	489	1590	41

Table B.9 (continued)

PAWN Region: Northeast Highlands

DISTRICT	SUBD	NATURE	GRASS			ARABLE CROPS								OPEN AIR HORTICULTURE					
			TOTAL	SW	GW	CONP	MILLP	SEEDP	SBEET	CEREA	CORN	SW	GW	BULB	VEG	FRUIT	TREES	SW	GW
10 NEDRENTE	19	4988	2489	406	0	0	9339	142	3694	5118	134	211	0	0	251	0	0	0	0
11 SEDRENTE	20	3751	12167	919	0	0	0	612	0	0	0	384	0	0	166	0	0	37	0
	21	5626	1258	0	533	155	9054	0	3427	4933	555	0	117	0	0	0	12	0	0
12 SWDRENTE	22	8184	24928	779	0	0	0	932	0	0	0	111	0	0	85	0	0	0	0
	23	12275	19106	0	1514	296	9581	0	3203	5408	1290	0	206	0	0	0	30	0	0
16 OVIJVECT	31	2826	6922	733	0	103	0	65	0	0	0	112	0	0	60	0	0	0	0
	32	8477	12659	0	579	0	3775	0	1137	2260	1608	0	88	0	0	8	19	0	12
17 DINKEL	33	2232	3500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	34	6694	8324	0	316	87	234	16	0	385	1348	0	0	0	5	0	11	0	0
18 TWENTHE	35	9930	16230	387	0	0	0	53	0	0	0	28	0	0	17	0	0	0	0
	36	18442	23184	0	1055	288	780	0	355	1282	4492	0	102	6	0	0	31	0	0
19 SALLAND	37	6544	20947	2026	0	162	0	0	250	0	0	106	0	0	22	137	29	19	29
	38	3523	8714	0	1363	0	309	23	0	570	1963	0	59	0	0	0	0	0	0
20 TWENTKAN	39	18822	16825	674	707	185	0	48	267	887	1900	56	66	0	20	0	25	13	21
	40	2689	2864	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	41	5378	4406	0	300	0	416	0	0	0	898	0	0	0	0	0	0	0	0
21 SHIPBEEK	42	11323	12048	387	504	92	208	0	0	443	1399	28	34	0	0	0	13	0	0
24 BERKEL	47	4084	13224	1296	0	0	0	87	0	0	0	76	0	0	0	15	0	15	0
	48	12254	30257	0	4924	421	313	0	505	2690	5728	0	309	0	91	0	64	0	70
25 OUDEIJSL	49	5782	13159	0	1631	0	0	0	550	1000	1500	0	0	0	290	281	0	0	296
	50	10739	23619	0	4000	394	0	117	494	2389	3914	0	643	0	0	0	48	0	0
TOTAL		164563	276830	7807	17426	2183	34009	2095	13882	27365	26729	1112	1624	6	1007	441	282	84	428

PAWN Region: Flevoland & Veluwe

DISTRICT	SUBD	NATURE	GRASS			ARABLE CROPS								OPEN AIR HORTICULTURE					
			TOTAL	SW	GW	CONP	MILLP	SEEDP	SBEET	CEREA	CORN	SW	GW	BULB	VEG	FRUIT	TREES	SW	GW
22 IJSELGEB	43	12432	9471	732	521	128	33	0	142	491	699	59	60	4	55	83	15	64	47
23 NEVELUWE	44	7137	5570	271	658	212	0	0	0	250	447	78	0	0	65	122	0	49	80
	45	7137	4257	731	0	0	0	0	0	0	0	0	0	12	0	0	31	37	0
	46	14275	6920	0	394	0	100	0	185	671	673	0	117	0	0	0	0	0	0
26 ARNHEM	51	4142	1638	0	0	59	90	0	0	377	230	0	0	0	11	41	10	0	0
27 SEVELUWE	52	3174	1700	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	53	7407	2725	0	0	81	110	0	0	458	462	0	0	0	11	43	15	0	0
28 SWVELUWE	54	29439	20183	817	0	198	0	0	0	0	0	71	0	0	0	119	0	73	0
	55	19625	10529	0	1001	0	237	0	99	679	2124	0	90	19	17	0	96	0	80
29 NWVELUWE	56	23508	13505	547	0	118	0	0	0	0	0	0	0	0	21	0	0	0	0
	57	10075	4298	0	0	0	0	0	0	386	1039	0	0	0	0	0	23	0	0
30 FLEVLAND	58	38325	5260	1443	151	5196	0	2455	8335	29059	257	1784	191	41	2882	948	135	63	7
TOTAL		176676	86056	4541	2725	5992	570	2455	8761	32371	5931	1992	458	76	3062	1356	325	286	214

Table B.9 (continued)

PAWN Region: North Holland

DISTRICT	SUBD	NATURE	GRASS			ARABLE CROPS								OPEN AIR HORTICULTURE					
			TOTAL	SW	GW	CONP	MILLP	SEEDP	SBEET	CEREA	CORN	SW	GW	BULB	VEG	FRUIT	TREES	SW	GW
31 WIERGMER	59	3476	1338	473	81	1521	0	1800	4034	5619	77	1964	347	406	498	0	15	306	54
32 AMSTLMER	60	3108	9902	3526	0	350	0	1398	1498	2356	68	1465	0	1922	843	127	0	1177	0
33 MEDMBLIK	61	2854	10877	5027	0	422	0	416	182	282	30	272	0	1775	2814	583	0	3798	0
34 HOORN	62	1746	4210	1858	0	66	0	85	0	0	0	52	0	460	470	549	0	922	0
35 SCHERMER	63	4948	14009	2267	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	64	4948	14009	2267	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	65	3299	3842	1284	0	841	0	990	1353	2119	0	1100	0	0	0	194	0	0	0
	66	3299	4313	2244	178	0	0	0	0	0	142	0	0	2284	2496	0	11	2199	182
36 WATRLAND	67	1405	4738	438	0	24	0	0	28	58	0	5	0	31	15	0	0	15	0
37 NZKANGEB	68	5146	1995	391	0	392	0	0	707	1222	0	229	0	120	125	27	7	47	0
	69	2771	2500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL		37000	71733	19775	259	3616	0	4689	7802	11656	317	5087	347	6998	7261	1480	33	8464	236

PAWN Region: Midwest and Utrecht

DISTRICT	SUBD	NATURE	GRASS			ARABLE CROPS								OPEN AIR HORTICULTURE					
			TOTAL	SW	GW	CONP	MILLP	SEEDP	SBEET	CEREA	CORN	SW	GW	BULB	VEG	FRUIT	TREES	SW	GW
38 RIJNLAND	70	12217	7746	962	0	2132	0	293	4079	6802	203	1473	0	571	1527	157	0	399	0
	71	9773	18044	2100	0	0	0	0	0	0	0	0	0	0	0	0	912	300	0
	72	1222	0	0	0	0	0	0	0	0	0	0	0	3108	0	0	0	350	0
	73	1222	2500	2101	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39 AMSTLAND	74	3272	9000	500	0	0	0	0	0	0	0	0	0	0	0	0	27	0	0
	75	1762	3788	1121	0	205	0	0	296	588	58	86	0	55	70	35	0	58	0
40 GOOI	76	9080	10842	855	0	21	0	0	0	95	139	6	0	11	53	58	47	62	0
41 KROMRIJN	77	9164	6854	0	757	0	0	0	0	280	819	118	68	0	0	424	33	0	311
	78	6108	7000	3177	0	93	0	0	0	0	0	93	0	0	32	1500	0	585	0
42 LEIDRIJN	79	3763	5324	720	0	0	0	0	0	0	70	0	0	0	32	330	6	31	0
43 WOERDEN	80	4520	10984	1656	0	0	0	0	0	0	0	0	0	0	30	194	30	52	0
44 LOPIKWAR	81	1860	3798	570	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	82	1395	2850	425	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	83	1395	2426	363	0	0	0	0	0	0	0	0	0	0	0	359	0	28	0
45 KRIMPWAR	84	2016	7242	836	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	85	504	971	112	0	112	0	0	123	228	0	82	0	0	303	75	0	161	0
46 SCIELAND	86	1828	4179	696	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	87	1828	0	0	0	443	0	281	1213	1971	96	493	0	7	574	57	33	140	0
47 DELFLAND	88	2431	11430	1735	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	89	936	0	0	0	0	0	0	0	0	0	0	0	47	659	0	0	292	0
	90	374	0	0	0	214	0	46	243	662	78	368	0	0	0	33	20	0	0
TOTAL		76670	114978	17929	757	3220	0	620	5954	10626	1463	2719	68	3799	3280	3222	1108	2458	311

Table B.9 (continued)

PAWN Region: Large Rivers & Northern Delta

DISTRICT	SUBD	NATURE	GRASS			ARABLE CROPS								OPEN AIR HORTICULTURE					
			TOTAL	SW	GW	CONP	MILLP	SEEDP	SBEET	CEREA	CORN	SW	GW	BULB	VEG	FRUIT	TREES	SW	GW
48 VOORNE	91	7093	6231	865	24	2560	0	102	2896	5000	420	848	0	110	1763	350	0	996	2
49 GOEREE	92	3253	0	0	0	1357	0	0	1259	2012	0	0	0	190	1300	100	0	0	0
50 IJSLMOND	93	3208	2664	714	0	1750	0	0	2004	3537	163	813	0	0	1402	377	0	664	0
52 DORDRECT	95	2584	1166	398	0	1016	0	0	1146	2022	83	510	0	0	830	232	0	406	0
53 ABLASWAR	96	2842	10636	1404	0	18	0	0	22	49	0	31	0	0	17	243	0	43	0
	97	1292	4993	530	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	98	1034	3980	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0
55 TIELWARD	102	5203	11518	3000	771	242	0	0	757	1112	536	521	0	0	123	2500	112	797	349
	103	5203	15439	6566	0	0	0	0	0	0	0	0	0	0	0	1367	0	594	0
57 BETUWE	107	9053	15224	4575	1242	224	12	0	833	1414	551	386	93	27	243	3515	155	1015	810
59 RECMAASN	109	696	825	0	0	66	0	0	268	519	0	0	82	0	0	149	0	0	76
	110	1624	3692	0	458	0	0	0	0	0	436	0	0	0	78	0	14	0	58
TOTAL		43085	76368	18052	2495	7233	12	102	9185	15665	2189	3109	175	327	5756	8833	289	4515	1295

PAWN Region: West-Brabant & Southern Delta

DISTRICT	SUBD	NATURE	GRASS			ARABLE CROPS								OPEN AIR HORTICULTURE					
			TOTAL	SW	GW	CONP	MILLP	SEEDP	SBEET	CEREA	CORN	SW	GW	BULB	VEG	FRUIT	TREES	SW	GW
51 HOLNDIEP	94	8311	8006	1258	671	3025	0	640	4279	7593	1229	1580	261	167	3154	689	118	905	324
54 BIESBOSH	99	1446	1992	431	0	1191	0	0	1761	3130	0	624	0	0	993	0	0	246	0
	100	1084	5991	425	0	0	6	0	0	0	725	0	0	10	0	0	17	0	0
	101	1084	2108	867	0	618	0	0	1198	1861	0	332	0	0	615	407	0	100	0
74 MARK	137	2374	3733	988	0	367	0	0	0	0	0	187	0	0	600	0	0	423	0
	138	13450	17634	0	2645	0	0	64	1188	1107	3739	0	475	24	1793	191	758	0	972
75 ROSENDAL	139	2019	1000	305	0	1079	0	447	1812	3068	0	705	0	104	1401	410	0	373	0
	140	3749	6636	0	933	600	0	0	866	1549	1321	0	314	0	1029	0	75	0	459
76 ZOOM	141	9381	3040	0	0	4120	0	206	4775	8853	0	0	0	413	2543	1656	37	0	48
	142	1042	858	0	0	0	0	0	0	834	873	0	0	0	461	0	0	0	0
77 SCHOUWEN	143	5158	2062	0	0	3043	0	81	3297	7273	316	0	0	260	2043	299	10	0	0
TOTAL		49098	53060	4274	4249	14043	6	1438	19176	35268	8203	3428	1050	978	14632	3652	1015	2047	1803

Table B.9 (continued)

PAWN Region: Southeast Highlands

DISTRICT	SUBD	NATURE	GRASS			ARABLE CROPS								OPEN AIR HORTICULTURE					
			TOTAL	SW	GW	CONP	MILLP	SEEDP	SBEET	CEREA	CORN	SW	GW	BULB	VEG	FRUIT	TREES	SW	GW
56 DENBOSCH	104	5043	9270	5456	0	862	0	92	826	1214	0	555	177	33	490	694	0	866	0
	105	1512	4085	696	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	106	3529	7057	0	1170	0	0	0	0	0	2093	0	0	0	297	0	83	0	219
58 MAASWAAL	108	4139	12328	3457	1261	91	0	17	386	854	457	154	71	0	88	1125	22	515	304
60 RECMAASM	111	4420	3259	447	355	201	0	0	543	835	389	234	141	0	366	118	78	151	96
61 MASKANTE	112	2527	5291	0	0	0	0	29	0	0	0	28	0	40	0	0	0	0	0
	113	10108	12505	0	3070	711	0	0	1991	1489	3959	0	621	0	414	151	202	0	287
62 MASKANTW	114	3694	5428	1159	0	182	0	0	674	984	0	248	107	0	0	114	0	54	0
	115	1477	2850	538	0	0	0	0	0	0	0	0	0	0	100	0	0	100	0
	116	2216	2630	0	665	0	0	0	0	0	1676	0	0	0	66	0	41	0	67
63 AA	117	8753	10740	1207	0	372	0	0	0	0	0	241	0	0	300	0	0	152	0
	118	26257	21145	0	3895	372	0	0	1938	1668	7397	0	748	54	1018	352	190	0	519
64 DEPEEL	119	2678	2132	1193	0	900	0	0	0	0	0	720	0	0	1000	0	0	418	0
	120	15175	10500	0	1717	275	0	54	3128	3600	2993	0	994	96	1325	459	267	0	544
65 RECMAASS	121	2719	2500	214	0	200	0	0	0	0	0	133	0	0	300	0	0	87	0
	122	8157	2166	0	558	400	0	0	1598	2127	910	0	348	29	1073	276	252	0	224
66 ROERMOND	123	681	571	302	0	270	0	0	0	0	0	210	0	0	100	0	0	58	0
	124	6128	2735	0	561	0	0	37	2010	2721	523	0	390	14	256	156	24	0	108
67 SLIMBURG	125	21619	17271	229	399	1652	0	12	4969	7278	2774	69	70	7	230	2306	46	36	25
68 MLIMBURG	126	3003	2635	1401	0	945	0	0	0	0	0	857	0	0	800	0	0	534	0
	127	12015	7816	0	1433	0	0	0	2514	2845	2509	0	826	82	1038	362	196	0	447
69 EDOMMEL	128	2844	4105	0	600	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	129	8530	6229	0	942	478	0	0	941	1055	2904	0	380	23	495	103	59	0	158
70 MDOMMEL	130	2074	3537	0	524	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	131	8300	8170	0	1157	481	0	0	782	937	3282	0	318	11	326	70	71	0	117
71 WDOMMEL	132	14770	12709	254	1844	470	0	0	904	1060	3641	48	355	10	264	55	41	13	106
72 NDOMMEL	133	2003	2592	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	134	11352	10402	0	1041	224	0	0	397	396	2597	0	160	10	397	115	120	0	199
73 DONGE	135	2894	3760	0	350	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	136	8682	7224	0	710	204	0	0	478	500	2471	0	183	0	248	72	61	0	135
TOTAL		207299	203642	16553	22252	9290	0	241	24079	29563	40575	3497	5889	409	10991	6528	1753	2984	3555

Table B.10

IRRIGATION WEIGHTS FOR DEFINING PLOTS

ROOT ZONE SOIL TYPE	ARABLE CROPS						HORTICULTURE			
	CONSPOT	MILLPOT	SEEDPOT	SUGARBT	CEREALS	CUTCORN	BULBS	VEGOPEN	FRUIT	TREES
Loamy medium coarse sand*	5	3	10	3	1	0	8	9	7	8
Light clay*	1	0	2	0	0	0	8	9	7	8
Loam	1	0	2	0	0	0	8	9	7	8
Peat	1	0	2	0	0	0	8	9	7	8
Basin clay*	1	0	2	0	0	0	8	9	7	8
Sandy clay loam	1	0	2	0	0	0	8	9	7	8
Hum. loamy med. coarse sand*	1	0	2	0	0	0	8	9	7	8
Light loamy med. coarse sand*	5	3	10	3	1	0	8	9	7	8
Silty clay*	1	0	2	0	0	0	8	9	7	8

NOTE: Asterisks denote substitution soils. See note to Table 6.5.

Table B.11

AGRICULTURAL REGIONS AND AREAS
(ha)

Region: NorthSeaClay

1	FRIELAND	3	39484
2	HETBILDT	7	14876
3	LAUWMEER	8	67474
4	UITHUIZN	9	11842
5	EEMSKANN	10	19098
6	OLDAMBT	12	27412
		13	8513
AREA OF REGION			188699

Region: H-IJ Polder

14	NEPOLDER	27	45194
30	FLEVLAND	58	92887
31	WIERGMER	59	18882
32	AMSTLMER	60	21535
37	NZKANGEB	68	9746
38	RIJNLAND	70	36904
46	SCIELAND	87	6673
78	MARKWARD	144	47500
AREA OF REGION			279321

Region: SW Sea Clay

45	KRIMPWAR	85	2241
48	VOORNE	91	26659
49	GOEREE	92	9474
50	IJSLMOND	93	15193
51	HOLNDIEP	94	37352
52	DORDRECT	95	9121
54	BIESBOSH	99	10513
75	ROSENDAL	139	11340
76	ZOOM	141	57364
77	SCHOUWEN	143	23768
AREA OF REGION			203025

Region: River Clay

19	SALLAND	37	28214
22	IJSELGEB	43	23508
23	NEVELUWE	44	14002
25	OUDEIJSL	49	22624
41	KROMRIJN	78	14646
54	BIESBOSH	100	7863
		101	7918
55	TIELWARD	102	22267
		103	22009
56	DENBOSCH	104	18710
57	BETUWE	107	31623
58	MAASWAAL	108	19310
59	RECMAASN	109	2468
AREA OF REGION			235162

Region: Loess

67	SLIMBURG	125	58167
AREA OF REGION			58167

Region: NorthPasture

1	FRIELAND	2	66673
		4	34069
		5	31603
13	VOLENHOV	24	32169
15	MASTBROK	28	15655
		29	15715
		30	7870
AREA OF REGION			203754

Region: West Pasture

35	SCHERMER	63	18957
		64	18957
		65	12638
		66	12684
36	WATRLAND	67	6254
37	NZKANGEB	69	5271
38	RIJNLAND	71	28729
		73	3722
39	AMSTLAND	74	12466
		75	6741
40	GOOI	76	20340
42	LEIDRIJN	79	9707
43	WOERDEN	80	15784
44	LOPIKWAR	81	5658
		82	4245
		83	4191
45	KRIMPWAR	84	9291
46	SCIELAND	86	6446
47	DELFLAND	88	13861
		90	1493
53	ABLASWAR	96	13738
		97	6285
		98	5018
62	MASKANTW	114	11184
AREA OF REGION			253660

Region: North Sand

1	FRIELAND	1	79415
		6	13335
8	NWDRENTE	15	28922
		16	23768
9	WESKWART	17	35485
		18	11824
11	SEDRENTE	21	25032
12	SWDRENTE	22	34270
		23	51228
13	VOLENHOV	25	6972
		26	7602
16	OVIJVECT	31	9980
		32	29920
AREA OF REGION			357753

Region: East Sand

17	DINKEL	33	5732
		34	17002
18	TWENTHE	35	26160
		36	49035
19	SALLAND	38	15102
20	TWENTKAN	39	39028
		40	5553
		41	11098
21	SHIPBEEK	42	25422
24	BERKEL	47	17308
		48	52454
25	OUDEIJSL	50	41687
AREA OF REGION			305581

Region: Central Sand

23	NEVELUWE	45	11394
		46	22940
26	ARNHEM	51	6491
27	SEVELUWE	52	4874
		53	11246
28	SWVELUWE	54	50018
		55	33432
29	NWVELUWE	56	37131
		57	15802
41	KROMRIJN	77	17574
AREA OF REGION			210902

Region: South Sand

56	DENBOSCH	105	5597
		106	13059
59	RECMAASN	110	5752
60	RECMAASM	111	10250
61	MASKANTE	112	7818
		113	31751
62	MASKANTW	115	4427
		116	6532
63	AA	117	20234
		118	60438
64	DEPEEL	119	6710
		120	38143
65	RECMAASS	121	5719
		122	17143
66	ROERMOND	123	1622
		124	14534
68	MLIMBURG	126	7383
		127	29670
69	EDOMMEL	128	6949
		129	20763
70	MDOMMEL	130	5611
		131	22530
71	WDOMMEL	132	33831
72	NDOMMEL	133	4595
		134	26161
73	DONGE	135	6654
		136	19889
74	MARK	137	7074
		138	40099
75	ROSENDAL	140	15799
76	ZOOM	142	4068
AREA OF REGION			500805

Region: Peat

5	EEMSKANN	11	13286
7	WESTWOLD	14	47711
10	NEDRENTE	19	26202
11	SEDRENTE	20	16773
AREA OF REGION			103972

Region: Rest of NH

33	MEDMBLIK	61	20507
34	HOORN	62	7469
AREA OF REGION			27976

Region: Rest of SH

38	RIJNLAND	72	4330
47	DELFLAND	89	5237
AREA OF REGION			9567

Table B.12

ASSIGNMENT OF DISTRICTS TO WEATHER STATIONS
URBAN (SW), SURFACE WATER (SW) AND VEGETATION COVERED LAND (VEG) AREAS(ha)

Leeuwarden	URBAN	SW	VEG	TOTAL
1 FRIELAND	12708	12609	264579	
2 HETBILDT	438	683	14876	
TOTAL	13146	13292	279455	305893

Eelde	URBAN	SW	VEG	TOTAL
3 LAUWMEER	2460	5386	67474	
4 UITHUIZN	349	432	11842	
5 EEMSKANN	2425	2114	32384	
6 OLDAMBT	2105	1346	35925	
7 WESTWOLD	4074	1974	47711	
8 NWDRENTE	3336	1920	52690	
9 WESKWART	3623	1989	47309	
10 NEDRENTE	1929	1170	26202	
TOTAL	20301	16331	321537	358169

Hoorn N.H.	URBAN	SW	VEG	TOTAL
31 WIERGMER	263	793	18882	
32 AMSTLMER	1412	2110	21535	
33 MEDMBLIK	1834	1575	20507	
34 HOORN	1048	515	7469	
35 SCHERMER	7227	4802	63236	
36 WATRLAND	320	952	6254	
37 NZKANGEB	7039	2587	15017	
TOTAL	19143	13334	152900	185377

Lelystad	URBAN	SW	VEG	TOTAL
14 NEPOLDER	837	1986	45194	
30 FLEVLAND	2255	2664	92887	
78 MARKWARD	1150	1350	47500	
TOTAL	4242	6000	185581	195823

Dedemsvaart	URBAN	SW	VEG	TOTAL
11 SEDRENTE	2505	1277	41805	
12 SWDRENTE	3167	2439	85498	
13 VOLENHOV	1419	4474	46743	
15 MASTBROK	1958	1762	39240	
16 OVIJVECT	1562	1533	39900	
17 DINKEL	1268	407	22734	
18 TWENTHE	5815	1465	75195	
19 SALLAND	2483	1282	43316	
20 TWENTKAN	2890	930	55679	
21 SHIPBEEK	1882	457	25422	
TOTAL	24949	16026	475532	516507

Naaldwijk	URBAN	SW	VEG	TOTAL
38 RIJNLAND	15082	6520	73685	
39 AMSTLAND	3000	2482	19207	
42 LEIDRIJN	1278	561	9707	
43 WOERDEN	1701	1020	15784	
44 LOPIKWAR	1088	749	14094	
45 KRIMPWAR	2091	1389	11532	
46 SCIELAND	2263	1018	13119	
47 DELFLAND	5910	1001	20591	
48 VOORNE	1617	2464	26659	
50 IJSLMOND	1511	929	15193	
TOTAL	35541	18133	219571	273245

De Bilt	URBAN	SW	VEG	TOTAL
22 IJSELGEB	1648	492	23508	
23 NEVELUWE	3615	910	48336	
26 ARNHEM	1024	175	6491	
27 SEVELUWE	2247	289	16120	
28 SWVELUWE	8256	1811	83450	
29 NWVELUWE	4152	1121	52933	
40 GOOI	4179	1458	20340	
41 KROMRIJN	5622	841	32220	
TOTAL	30743	7097	283398	321238

Winterswijk	URBAN	SW	VEG	TOTAL
24 BERKEL	2870	1155	69762	
25 OUDEIJSL	4615	1503	64311	
TOTAL	7485	2658	134073	144216

Andel	URBAN	SW	VEG	TOTAL
52 DORDRECT	2621	613	9121	
53 ABLASWAR	2600	1620	25041	
55 TIELWARD	2842	2101	44276	
57 BETUWE	2852	1169	31623	
58 MAASWAAL	2318	1145	19310	
59 RECMAASN	1438	445	8220	
TOTAL	14671	7093	137591	159355

Vlissingen	URBAN	SW	VEG	TOTAL
49 GOEREE	399	620	9474	
76 ZOOM	2416	2114	61432	
77 SCHOUWEN	971	1172	23768	
TOTAL	3786	3906	94674	102366

Oudenbosch	URBAN	SW	VEG	TOTAL
51 HOLNDIEP	2078	1724	37352	
54 BIESBOSH	2446	1696	26294	
73 DONGE	3780	463	26543	
74 MARK	4738	863	47173	
75 ROSENDAL	2666	1033	27139	
TOTAL	15708	5779	164501	185988

Gemert	URBAN	SW	VEG	TOTAL
56 DENBOSCH	4066	2226	37366	
61 MASKANTE	2398	810	39569	
62 MASKANTW	2597	610	22143	
63 AA	6602	1537	80672	
69 EDOMMEL	2628	733	27712	
70 MDOMMEL	5001	670	28141	
71 WDOMMEL	2482	654	33831	
72 NDOMMEL	2864	736	30756	
TOTAL	28638	7976	300190	336804

Venlo	URBAN	SW	VEG	TOTAL
60 RECMAASM	1323	288	10250	
64 DEPEEL	2993	648	44853	
65 RECMAASS	2727	498	22862	
68 MLIMBURG	2329	1134	37053	
TOTAL	9372	2568	115018	126958

Beek Z.L.	URBAN	SW	VEG	TOTAL
66 ROERMOND	1190	573	16156	
67 SLIMBURG	11796	1382	58167	
TOTAL	12986	1955	74323	89264

Appendix C

LOWLANDS UNDERGROUND WATER AS A PHYSICOCHEMICAL SYSTEM

by J. C. De Haven

C.1. INTRODUCTION

As mentioned in Chap. 7, DISTAG may underestimate drainage in the lowlands, because its calculations are based on Darcy's law using only gravitational head differences. In this appendix, we wish to draw attention, more explicitly than in the past, to a possible alternative sink for fresh water in the Netherlands. This possible loss of fresh water does not appear to be accounted for in the water balance analyses for the Netherlands that I have seen. In particular, I believe that there may be a significant, dynamic flux of fresh water across the underground freshwater/saltwater boundary, driven by large physicochemical forces. The upper water layer cycles out to sea on top of the lower, more concentrated saltwater layer which is also continuously renewed from the sea and moves inland. These dynamic processes, ultimately involving underground movement of fresh water to the sea, should contribute significantly to the steady state hydrological situation of the lowlands. Inasmuch as the lowlands are hydrologically connected with the higher lands, uncounted water loss in the former should be reflected in uncounted percolation from the latter areas.

Present models of freshwater/saltwater interactions in coastal regions will be briefly reviewed along with some of their inherent assumptions which may have caused this infiltration water loss to be underestimated in the lowlands areas. An attempt is made to evaluate the effects of the postulated osmotic phenomena on the predicted magnitude of this freshwater movement. Tentative results indicate that the net downward freshwater flux in the lowlands may be over thirty times as large as that computed from conventional physical head differences.

C.2. MODELS AND ASSUMPTIONS ABOUT FRESH-SALT INTERACTIONS IN COASTAL AREAS

As might be expected, the first investigator to formalize coastal water relations was a Dutchman, Badon-Ghyben, in 1889. This was followed shortly later by the treatment of the German, Herzberg. Currently applied models are dynamic extensions of these studies. Water flows are assumed to be steady and two-dimensional, and to obey Darcy's law that stipulates that the velocity of flow is proportional to the potential gradient in the flow direction. Boundaries between fresh and salt water are assumed to be impenetrable, and the forcing potential is assumed to be hydrologic pressure. The several underlying water pools--brackish and saltwater--are assumed to be stagnant with respect to exchanges with each other and with the sea, though their boundaries with each other and with fresh water may move one way or another in response to hydrologic pressure changes [C.1-C.5]. As may be expected from these assumptions, models incorporating them would predict essentially zero underground percolation loss of fresh water to the sea in the lowlands.[1]

Models incorporating these assumptions may yield qualitatively acceptable predictions of freshwater movements in coastal regions where the land elevations are high with respect to sea level, and where, therefore, hydrological pressure heads are important driving potentials. It is questionable, however, if such models may not seriously underpredict freshwater infiltration and subsequent flow to the sea in lowlands delta regions such as exist in much of the Netherlands. An attempt will be made here to indicate how these assumptions may need to be modified to more correctly predict freshwater flow in these latter circumstances. The modified assumptions involve complex physicochemical phenomena whose implications for hydrology are just beginning to be recognized.

An important reason why the questionable assumptions mentioned above have been employed is that no satisfactory models incorporating these more complex phenomena have yet been constructed. An attempt will be made in this appendix to describe these complexities as they may affect water losses for the lowlands and to use best available data to make estimates as to the magnitude of the corrections that should be applied to infiltration losses in water balance calculations.

C.3. SOME PHENOMENA THAT SHOULD BE TAKEN INTO ACCOUNT IN COMPUTING WATER BALANCES

In computing water balances of lowlands areas, inland from the seas, Dutch hydrologists have properly attempted to compute the total flows into each separate area from hydrologically upstream areas, and net flows out of the areas in terms of surface and underground flows, withdrawals, net precipitation, and infiltration of water from upper to lower zones (e.g., Ref. C.6). Computation of this latter infiltration amount, as presently accomplished, may be subject to an error that could have a significant influence on water balance determinations. The possible sources of this error will be explored here.

In areas for which water balances are to be determined, a number of bore holes of different depths are constructed to measure physical water heights and to take undisturbed sediment samples for laboratory determination of vertical resistance to water movement. This vertical resistance factor is also computed indirectly by the residual water flow required for obtaining balance. It is assumed here that factors determining the other water flows are better known (e.g., horizontal underground flows through test-well measurements). However resistance is determined, vertical water flow is computed as

$$v_z = \Delta h/c \tag{1}$$

where v_z is vertical flow in meters per day, Δh is the measured difference in heights of water in steel-lined bore holes having inlet slots at different depths (m - NAP), and c is resistance (in days). Volume of flow is determined by multiplying v_z by the appropriate hydrologic area. In lowlands areas an unusual phenomenon appears in that the water levels in the test tubes extending to great depths may be close to or higher than the water levels in tubes extending a shorter distance into water-bearing strata. As a consequence, vertical infiltration computed from Eq. (1) is very small or even upward in flow (seepage). A conventional explanation for these high water levels from deep tubes is that they reflect high hydraulic pressures from distant, higher land and aquifers that are separated horizontally and continuously by impenetrable layers from the upper aquifers and phreatic water. An alternative explanation, developed here, is that these high tube water levels reflect interference with the complex osmotic phenomena of the measuring bore tube. As a result of these phenomena, the undisturbed and effective water heads are much different from those currently measured between the underlying fresh and deeper brackish water. Thus, a much larger effective Δh must be used to compute the actual vertical water leakage downward. The Δh must reflect both the physical difference in water potential and the chemical water potential difference between the upper and lower layers. The latter potential operates by reason of the semipermeable nature of the sedimented aquifer soils and the difference in the chemical potential of water between relatively low-salinity upper layers and high-salinity lower layers. Drilling test holes through the sedimented aquifer structure short-circuits one basis for the osmotic phenomena, the semipermeable membrane, and allows water height to reflect only the small Δh represented by physical forces.

Generally, the semipermeable nature of sedimented aquifer structures is not taken into account in studies of hydrodynamic dispersion (e.g., Bear in Ref. C.7). Semipermeable means that the membrane or other structure is more permeable to water than to other substances such as electrolytes or organic substances. In fact, measurement methods conventionally used to study hydrodynamic movements in aquifers are such that these chemical influences on water movements will not be sensed. The incorrectly low water potential difference measured by test bore holes has already been mentioned. Other misleading measuring devices are the use of dissolved electrolytes or organic dyes as tracers to measure water flow in soils and aquifers. These substances are not true tracers of water movement, but will yield low results because, in comparison with water, they are selectively retained on the soil and sediment structures. An adequate tracer of water flow must be very water-like in chemical nature. Tracers such as deuteria or tritia may fit this requirement. There may be others.

In laboratory model studies of interactions between fresh and salt waters in aquifers, care must be taken that the porous medium used is not an inert material like washed quartz [C.8], but materials at least treated to reflect the semipermeable nature of the in situ sediments.

Also, in these studies, purified water must not be used, but, rather, water having the complete chemical nature of the raw water is necessary. The need for these characteristics will become clear from a description of sediment-like semipermeable membranes in the following section.

C.4. THE SEMIPERMEABLE NATURE OF SEDIMENTS

The implications of sediments as semipermeable membranes were first impressed on the present author by papers on so-called dynamically formed membranes used for hyperfiltration or reverse osmosis. In these processes, fresh waters may be produced by forcing solutions, even sea water, through semipermeable membranes at high pressures.[2] The dissolved substances remain on the solution side, and fresh water appears on the other side of the membrane. Highly successful membranes for this purpose have been made from porous tubes of highly inert substances such as sintered glass or porcelain. These inert tubes are treated with very small amounts of one or a combination of substances such as iron or aluminum hydrous oxides, clays, humic acid, and other organic compounds [C.9], to develop their highly successful semipermeable characteristics. In practice, these doctoring substances are added to the input water flows, and the membranes become self-healing. The resemblance of these dynamic semipermeable membranes to the natural, unconsolidated sediments of aquifers is remarkable. One should note that the natural waters flowing through these structures contain hydrous metal oxides, humic acids, clays, and organic compounds, all substances found by experience to be effective in maintaining semipermeability.[3]

The detailed mechanisms of these membranes operating to separate water and dissolved substances under potential differences is not known. They are not simple sieving mechanisms because the pore diameters of useful membranes are much larger than the diameters of the dissolved substances that are retained. It is believed that processes such as selective adsorption or repulsion within the membrane pores, as well as chemical activity differences caused by high pressure gradients, are involved in the separation of water and dissolved substances.

The phenomena involved may be more apparent if one considers an inverted glass U-tube with the ends sealed, containing in one leg concentrated salt solution and in the other an equal amount of dilute salt solution. Bridging the two solutions in the tube is saturated water vapor. Temperature is everywhere equal and maintained so by heat transfer with the environment. This system is, of course, highly out of equilibrium because the escaping tendency (or almost equivalently the vapor pressure, or the activity) of water in the dilute solution is higher than that of the concentrated solution. This system will attempt to reach equilibrium by means of water evaporating from the dilute solution and moving through the vapor phase of the semipermeable membrane to condense in the concentrated solution. Ultimately, at equilibrium, both solutions will be at equal concentration, but the formerly concentrated side will have increased in volume as the result of water movement to it from the now smaller, dilute side.

Consider now the effects of relaxing the equal temperature constraint in this conceptual U-tube system. Imagine that the temperature of the originally more concentrated solution side is maintained at a somewhat higher level than the dilute side. What now is the effect upon the differential chemical potentials of water in the two sides and on the direction of water flow? Rather amazingly. the escaping tendency of water is very sensitive to small differences in temperature. For example, if our two solutions have concentrations of 5000 ppm and 200 ppm Cl- at equal temperatures, the driving water potential from the dilute to the more concentrated solution will be about 7.20 atmospheres (74.4 m water height). If, however, the temperature of the concentrated solution is held one degree centigrade hotter than the dilute solution, then the water-driving potential will be reversed and the net water potential in the direction of the dilute solution will be approximately 100 atm - 7.20 atm = 92.8 atm (960 m water height).[4] The dilute solution will now increase in size as water moves to it from the concentrated solution. The new steady state will occur when the latter solution becomes very concentrated (128,000 ppm sodium chloride).

It will be recalled that without input of energy, in both the inverted U-tube and in the real hydrologic system, the several gradients and net water flows would come to equilibrium with zero net water flows and no concentration or temperature gradients. The energy to drive the real hydrologic system and maintain it in disequilibrium comes ultimately, of course, from the sun through its chemical unmixing of salt and water in evaporating sea water, and the subsequent precipitation of fresh water on the land surface.

In the uniform temperature inverted U-tube, steady state could be maintained by continuously introducing fresh water to the dilute side and removing brackish water from the other leg. The continuous introduction of fresh water by percolation is an obvious characteristic of the natural system. Not so obvious is the apparently complex circulation of brackish and more concentrated salt water that appears to occur at higher and lower depths in lowlands near the sea. Physical model results [C.8] and direct observation [C.10] indicate that the upper less-salty water flows outward to the sea on top of a more salty lens that intrudes landward from the sea. The initial intrusion from the sea appears to be mediated by tidal action. Unless the salty intrusion is greatly reinforced by the described osmotic forces, the intrusion distance would be short.

The U-tube physical model becomes more realistic if the tube is firmly packed with aquifer sediment over its entire length. Fresh water still enters in one leg and salt water exits from the other. The sediment is wetted and water moves from one leg to the other. The packed sediment is not as perfect a semipermeable membrane as is the previous water vapor phase. Some salt will begin to move from the concentrated solution side toward the dilute leg, even in the uniform temperature case. However, the salt moves more slowly than does the water in the opposite direction. There is cross coupling between the water and salt flows so that at steady state there will be a constant band of decreasing salt concentration rising above the concentrated solution within the sediment, as well as a constant net flow of fresh water to the saltier leg.

Nonuniform temperatures, with the concentrated side being hotter, should importantly alter this pattern. Now, the net flow of water is reversed. This reversal should positively couple the salt and water movement in the same direction so that the salt-concentration gradient should widen and rise. Flow-out of the saltier leg should be reduced, and water levels should rise in the fresh side. In the real lowlands, the tendency toward such a change of states should be observable between summer and winter. The deeper waters tend to change less in temperature with seasons than does the near-surface water. Thus, in winter, the deep water may be somewhat warmer than surface water. As described above, this should result in a decrease or reversal in net vertical water flow, reduced underground flow out of the hydrologic unit, a rise in salt concentration in lower waters, and a widening of the underground concentration gradient band. As a result of these phenomena, increased pumping should be required in polders in winter. This increased pumping requirement should be above the additional water present in the winter because of the reduced evapotranspiration losses.

Equation (1), above, which defines vertical seepage, must be modified to account for the effects of the additional groundwater potential gradients described. A possible modification is as follows:

$$v_s = (\Delta h_g + \Delta h_c + \Delta h_t)/c$$

where v_s and c are as previously defined, and

Δh_g = conventional hydraulic potential difference due to gravity

ΔH_c = water potential difference due to concentration (salinity) difference

Δh_t = water potential difference due to temperature difference.

Because these potentials are algebraically additive, care must be taken to see that signs for the several Δh are consistent. In Ref. C.6 where Eq. (1) is presented, the convention is that Δh is the difference in water height below sea level. Here Δh is positive (and v_s is positive downward) when the lesser height below sea level is subtracted from the greater height below sea level. This is usually the bore-hole height of the upper level water subtracted from the level in the bore hole to the lower level. To be directionally consistent, Δh_c should be the water-height equivalent of the upper water potential subtracted from the lower water potential equivalent when each are computed as described here.[5] A similar convention should be used for computing Δh_t.

The following methodologies for computing osmotic influences are based on some simplified assumptions relating to the phenomena involved. More rigorous models are not warranted at present because of the sparsity of the required data. For example, computation of the escaping tendency of water from solutions requires knowledge of the nature and amount of the dissolved substances. For many underground waters in the Netherlands, only dissolved chloride ion concentrations are given. An approximation for converting the difference between two solutions given in parts per million (or its equivalent, mg/l) of Cl to ppm of total dissolved substance is to multiply the former by 1.50.[6] We are still confronted by a weight measure of average dissolved substance which has little import for computing chemical effects on water activity. We must assume some chemical form for the solute--this is chosen as sodium chloride having a molecular weight of 58.45 grams per mole, and completely ionized to yield an ideal solution. Further, one osmolar (1/2 molar) solution of sodium chloride is assumed to have an osmotic pressure of 23.22 atmospheres at 10C. These assumptions combine to yield a conversion factor of 0.0082, which may be used to multiply differences of concentrations in ppm (or mg/l) of Cl^- to give Δh_c in meters of water-height difference.

Computation of Δh_t requires a knowledge of the pressure-difference equivalent of a temperature gradient on water activity. From Table 2.2 and App. 4 of Ref. C.11, we find that a difference of 1C (in the vicinity of 10C) alters the escaping tendency (activity) of water by about the same amount as a pressure difference of 100 atmospheres, or equivalently a water height of 1034 m. Measurements of the in situ temperature difference between deep underground water and near surface water are required. These data do not appear to be widely available.

C.5. MEASUREMENT DIFFICULTIES

Previously it was noted that conventional test bore holes filled with water tend to mask the upper and lower level pressure differences caused by salinity and temperature gradients, particularly as the water in the tube becomes mixed. Measurement of in situ water activity at depths in aquifers presents problems. Perhaps after the appropriate sensing or sampling devices are installed in a newly drilled or driven test hole the tube could be refilled with the sediment that was removed (or equivalent material), and raw surface water allowed to seep continuously down the filled tube in an attempt to maintain the original conditions. Total water activity effects might be measured by vapor pressure sensing (differential thermometry). For measurement of salinity effect alone, conductivity or freezing-point depression should be suitable. Measurement of Cl- concentration alone is not satisfactory because there is a different relation between Cl- and total dissolved solids for each water.

In an attempt to compensate for the lack of temperature gradient measurements, one might assume as a first approximation that over a four-season year the temperature gradients change in a pattern that just compensates vertical water losses and gains through this influence. We are left then with the salinity gradient influences for which at least some Cl- concentration measurements are available (e.g., Ref. C.6). These might be converted and used to correct the present infiltration-loss estimates.

C.6. COMPUTATIONS OF WATER BALANCES THAT INCLUDE OSMOTIC POTENTIAL GRADIENTS

Reference C.6 contains information about the midwest Dutch lowlands that can be used to check the reasonableness of the assumptions presented here as well as to derive some correction factors. As example, Ref. C.6 contains data on the Cl- concentration at different depths for a number of test borings in the Haarlemmermeerpolder. This is an important subbasin of the midwest Netherlands lowlands region. Figure 38 from Ref. C.6 is reproduced here (Fig. C.1) to show these data.

Before making use of these data, it is necessary to eliminate some because of known peculiarities in the location of the test bores. Test holes G96 and G95 shown to the left in this figure are in a region of strong lateral, underground, freshwater flow and are not typical. Test holes G98, G99, and G104 penetrate regions in which strongly impenetrable layers separate upper and lower aquifers. Vertical water movement is thereby locally limited by the physical barrier. These test-hole data are also not used in the following quantitative analysis. Four test holes remain in the data. These are G97, G100, G101, and G109, which are located variously to cover the subbasin area. A first task is to convert parts per million of Cl- to osmotically meaningful units. We wish the water-escaping tendency or osmotic pressure to be in units of hydraulic water head. For this purpose the following equation is used:

$$m_{H_2O} = 0.0084 \text{ (ppm + 210)}.^7$$

There are 36 measurements of Cl- concentration given for the four test bores. These concentration measurements, converted to equivalent osmotic water heights by the above formula, are compared with the actual measured depths for each measurement point by linear regression. The straight line best expressing the relation between estimated osmotic water height and actual water height above the measurement point is

$$y = -10.92 + 1.13x$$

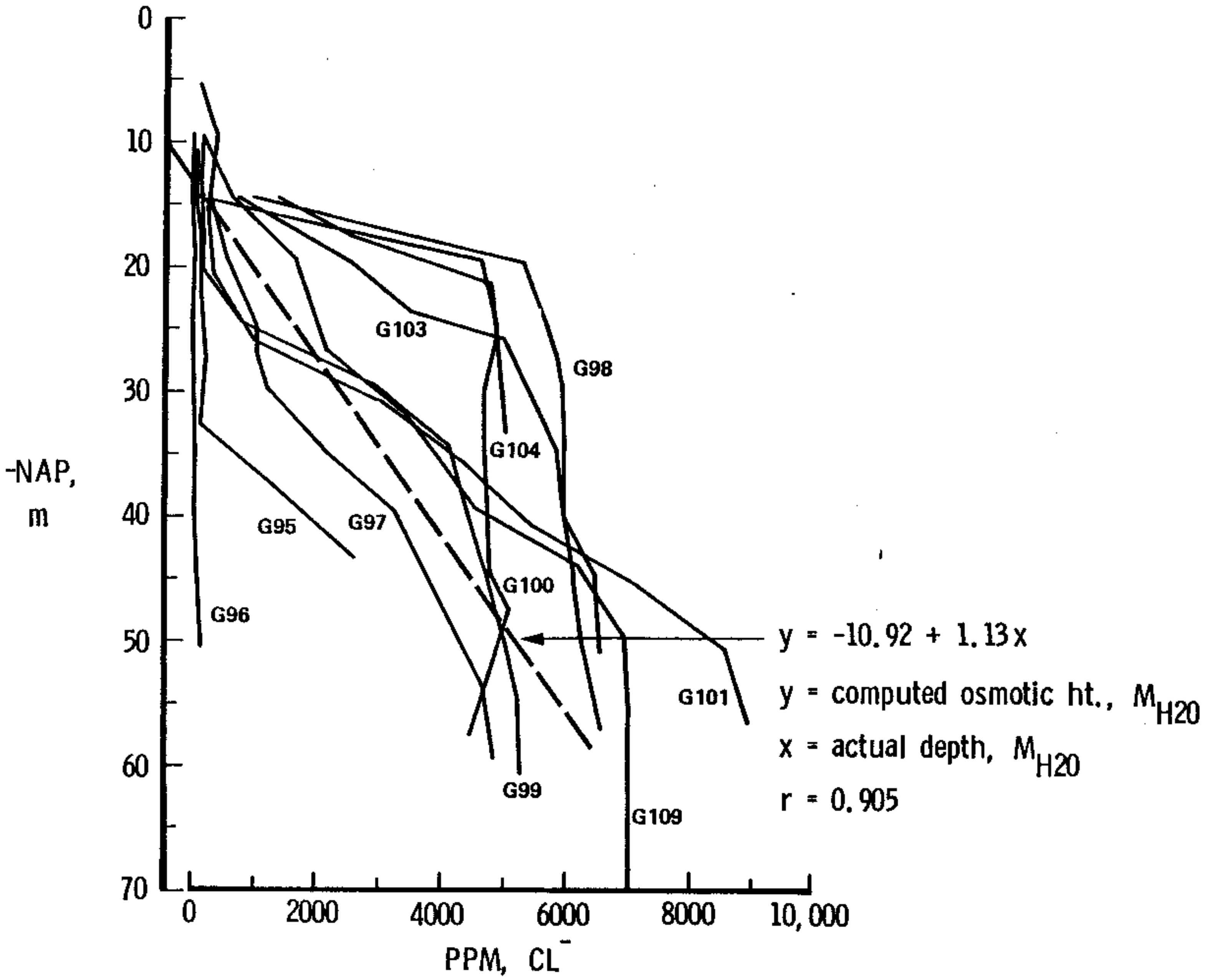

Fig. C.1--Osmotic relations in polder groundwater where y is computed osmotic height and x is measured water depth to the point. The correlation coefficient, r = 0.905, indicates a relatively good fit. This relation indicates that for locations in the lowlands where anomalous intrusions of fresh water or impervious layers do not occur locally, the escaping tendency of the underground water, as indicated by the concentration of dissolved substances, is well correlated with the overlying water pressure head. Conversely, one may make a pretty good prediction of total dissolved substance at any depth in such regions. The line of best fit is shown dashed in Fig. C.1.

The average relations described above mask another related phenomenon. That is, if one looks at the Cl- concentration of the lower points reported in the above figure and the distance inland for the acceptable test bore holes,[8] one notes the tendency for the holes toward the sea to have higher bottom concentrations than those farther inland. Even the test bore holes that are distorted by the impervious layer appear to have bottom concentrations that move toward this pattern as sample points move downward from the shadow of the impervious intrusion. Of the acceptable test bores, C10 is the nearest to the sea and G97 is farthest inland in this subbasin. Data from these bore holes will be used in simple models from which an attempt will be made to compute net average downward water flow for the region.

C.7. MODELS AND COMPUTATIONS

Figure C.2 is a schematic showing conceptual water movements within and between water layers having the osmotic properties indicated by test bores G101, G97, and the averages for all of the acceptable bores. First, there appear to be two different layers of underground water--an upper and lower parcel--that have different characteristics. The upper layer appears not to exhibit osmotic head differences in the horizontal direction, so it should be driven in the seaward direction by the conventional hydraulic gravitational forces as applied in Ref. C.6. From both the chemical composition of the water and the nature of the sediments as presented in this reference, the upper layer appears to be about 25 m thick, and the bottom layer about 35 m.

The lower layer appears to have a quite different osmotic nature. Data from bores G101 and G97 indicate that the water at the bottom has osmotic water-head equivalents of 77.36 m seaward and 39.96 m landward. This potential gradient suggests that this lower layer moves landward as suggested (but not quantified) by several of the previous references for such seacoast regions.

There is another disequilibrium apparent in the data for this lower layer. The computed average value for the osmotic water head at 60 m depth is 56.88 m or 6562 ppm Cl-. However, these values in the landward G97 bore are 35.96 m or 4500 ppm Cl-. Water moving into this zone should move upward in the layer, in comparison to the net downward cycle of water in the seaward portion. Quantitative

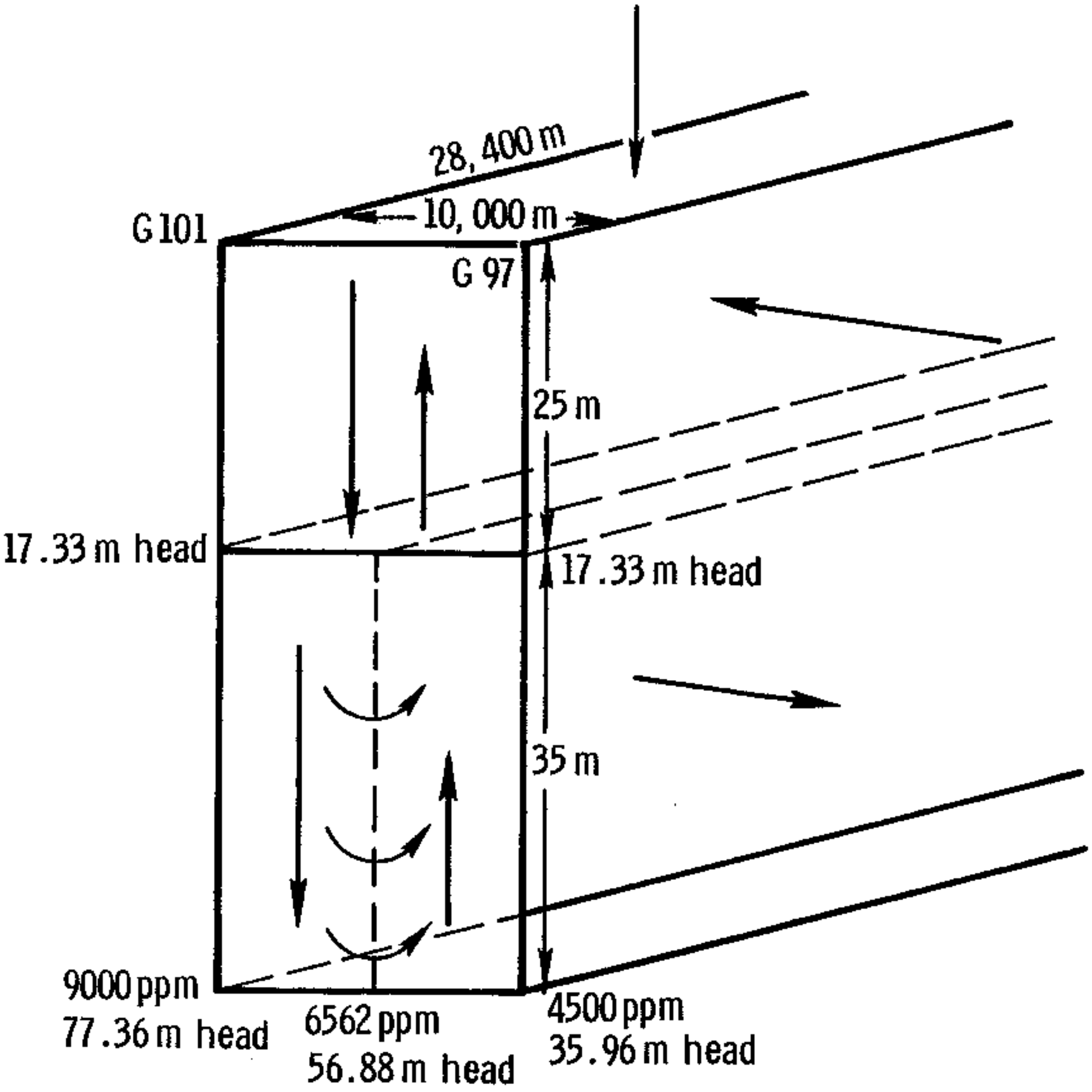

Fig. C.2--Model of conceptualized movements in overlying and underlying water parcels in the lowlands as influenced by osmotic forces (dimensions highly distorted) differences between these two water fluxes should give the net water movement as the layer traverses this subbasin.[9]

This net downward water movement may be computed from the indicated differences in osmotic heads in the vertical direction and the reported vertical resistance factor for this subbasin. The net movement $q_1 - q_2$ may be computed as follows:

$$q_1 = F_1 v_{z1},$$

$$q_2 = F_2 v_{z2},$$

where q_1 is downward flux in the seaward half of the parcel, q_2 is upward flow in the landward half; further,

$$v_{z1} = (h_1 - h_2)/c, \text{ and}$$

$$v_{z2} = (h_2 - h_3)/c,$$

where h_1 and h_3 are the seaward and landward effective osmotic heights and h_2 is the predicted osmotic height for 60 m depth, c is the vertical resistance factor of the subbasin, here 3200 days, and F_1 and F_2 are the specific areas involved, here 1.42×10^8 m^2 for each half of the parcel. Because the movement from the downward moving half to the upward moving half of the parcel could take place anywhere along their vertical interface, the arithmetic average of the osmotic head differences is used to compute the vertical water movements. Given the above assumptions and data,

$$q_1 - q_2 = 4.54 \times 10^5 \text{ m}^3/\text{day} - 3.84 \times 10^5 \text{ m}^3/\text{day}$$

$$= 70{,}000 \text{ m}^3/\text{day}$$

The conventional physical head differences were ignored in making these calculations because they are small (~1/2 m) with respect to the osmotic heads. The downward water movement computed in Ref. C.6 for this subbasin is 2248 m^3/day, or about 3.2 percent of the 70,000 m^3/day computed here using osmotic heads.

C.8. AN ALTERNATIVE MODEL

For those who are uncomfortable with the use of osmotic heads and countermoving vertical water currents as mechanisms for explaining and computing net vertical water movements, the following, alternative model is based primarily on mass balances and conventionally computed movement of the upper layer. We have now the upper layer flowing seaward to the extent of 99,000 m^3/day.[10] The depth of this upper layer in this subbasin is about 25 m; the average salinity is about 500 ppm Cl- ((200 + 1000)/2). The lower layer is moving landward through this subbasin and has an average thickness of 35 m and an average salinity of 3875 ppm Cl- ((9000 + 4500)/2 = 6750, 6750/2 = 3875 ppm Cl-). In each subbasin between the sea and the landward extent (30 to 40 km) of this osmotically driven counterflow, each upper unit volume of water will be exchanging with the lower layer in attempting to reach osmotic equilibrium. At some inland extent, osmotic forces will become smaller than physical forces and the latter will dominate underground flow conditions. Until this inland position is reached, however, water from the upper layer will have a net movement downward. The osmotic potential for this movement will be greater near the sea and become much less in the landward direction as the intruding seawater becomes diluted by the vertical-moving fresh water.[11] For the present purpose of computation, the subbasin described is assumed to represent an average state between other water subbasins landward and seaward from it. The average salinity concentration of the upper layer reflects, therefore, 11 water exchanges that have occurred upstream (landward), and the salinity concentration in the lower layer reflects all exchanges that have occurred upstream (seaward) of this average subbasin position.

To compute the freshwater exchange in this subbasin 1, we note that there is a concentration gradient in the lower layer, from sea to landward. The average concentration in the seaward boundary is 5000 ppm ((9000 + 1000)/2), and the average concentration in the landward boundary is 2750 ppm ((4500 + 1000)/2). All of the water for diluting the average cubic meter moving landward in the lower layer must come from the upper layer and its inputs. The upper layer does not change concentration in moving seaward; therefore, downward water losses must be compensated for as the upper layer moves through the subbasin. To reduce the lower layer concentration from 5000 ppm to 2750 ppm in steady state requires 0.82 m^2 of water to be added to each average daily m^3 in the lower layer, and a similar amount of water to be delivered from each average daily m^3 of the upper layer.[12] The net freshwater movement downward should thus be 0.82 × 99,000 m^3/day, or 81,180 m^3/day. This value compares favorably with 70,000 m^3/day computed on the basis of osmotically induced fluxes and the previous model. These computed downward water movements are 31 to 36 times the movements computed on the basis of physical pressure heads in Ref. C.6.

C.9. CONCLUSIONS

The author wishes to emphasize the tentative nature of these conclusions. They are based on scanty data that may have been measured in a manner that distorts, upward or downward, the importance of the described phenomena. The diffusive water movements discussed here seem to be universally dismissed as unimportant in the hydrology literature. Indeed, they may be unimportant in most inland regions where physical gradients promoting horizontal flow overwhelm those diffusive movements. In flat seacoast regions it appears, however, that the osmotic potentials and diffusive flows should be considered in water balance analysis. Seasonal changes in these osmotic potentials and their induced hydrologic flows, as mediated by temperature changes, may be especially important.[13] Such unmeasured temperature effects may, indeed, nullify the conclusions on vertical flow described here. Very little theoretical treatment of the influence of temperature gradients on transport of water exists in the literature. The most complete treatment known to the author is by D. C. Spanner in Ref. C.16.

NOTES

1. Dutch hydrologists include vertical movements in computing water balances, but retain the assumption that the driving forces are purely physical in nature (e.g., Ref. C.6).
2. The potential difference between pure water and seawater is about 27.5 atmospheres. Consequently, pressures higher than this must be applied to the seawater side of a membrane to force pure water from the seawater. In practical devices, pressures in excess of 80 atmospheres are used to yield high flows.
3. Water used in physical models of these phenomena should also contain these substances, as noted above. Other deficiencies in the physical models, upon which the idea of the unimportance of vertical diffusive movements of water are based, are as follows: the models are very shallow ($h \underline{1}$ m) so that the important pressure effects on water activity are only minutely operating; some models were operated for too short a period (2 hr) for diffusive forces to show up at these low potential differences; and temperatures of freshwater and seawater inputs were not controlled. The physical models of Nomitsu et al. Ψ0[12], as well as others Ψ0[8], exhibited these deficiencies. Nomitsu et al. Ψ0[12] in 1927 developed dynamic mathematical models for hydraulic flows near the coast which are essentially equivalent to the currently used models. These authors make the following statements based on these inadequate physical experiments: "According to our experiments, fortunately the diffusion velocity is negligibly slow compared with the velocity of the groundwater. If the diffusion velocity were tolerably great compared with that of the freshwater current, the boundary curve would be so much disturbed that our theory would be dealt a fatal blow." The present author proposes that this latter condition pertains for the Dutch lowlands.
4. In anticipation of large gasps of disbelief at the magnitude of such forces operating in infiltration and the implications for water loss through this pathway, one must recall that the vertical resistance to vertical movement is very large. This resistance to flow attenuates drastically the impacts of large net driving potentials. For example, present estimates of

underground percolation loss to the sea from the Netherlands are on the order of 0.1 percent of input water using the small hydraulic potentials. The potentials described here might increase these movements by one to two orders of magnitude from a loss of 1 to 10 percent, depending upon season.

5. Some confusion can occur about signs because of the conventions used. Thus, osmotic pressure is usually defined as the hydrostatic pressure required to prevent the entrance of the pure solvent (water) through the membrane and into the solution. We are concerned here with the negative of this effect, i.e., the relative escaping tendency of water from two solutions of unequal concentration.
6. The basis for this conversion is described in Refs. C.13 and C.14. The factor 1.50 is for groundwater.
7. This equation is derived from measurements made in Dutch groundwaters and reported in Ref. C.13, plus the following additional factors to convert pressure equal to 0.36×10^{-3} micromhos; one atmosphere equals 10.34 m water height. The formula from Ref. C.13 is (ppm + 210) 2.25 = micromhos.
8. These positions are shown in Fig. 1 of Ref. C.6.
9. The water at a salt concentration of 4500 ppm could indeed have the same in situ activity as water at a salt concentration of 6562 if the temperature of the 4500-ppm volume were somewhat higher than that for the 6562-ppm volume. It is assumed in the following calculations that laboratory salinity measurements were made on sampled water and that all salinity measurements were made at equal temperatures at the surface.
10. Ref. C.6, p. 32.
11. The initial force driving seawater inland is thought to be tidal action $\Psi 0^{12}$\ $\Psi 0^{15}$. This force is believed to extend directly inland only a few thousand meters or less. However, the osmotic forces described here could cause an extension of this movement inland of 30 to 40 km.
12. Because of the difference in volumes between upper and lower layers, this assumption requires that the flow rate through the lower layer is about 0.71 of the upper layer.
13. Seasonal changes in temperature gradients may also be an important force in determining nutrient movements between sedimented bottoms and bulk water in Dutch freshwater lakes.

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