Economic instruments in Water Management and desiccation in the Netherlands

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This report describes the economic aspects of the Dutch water problems and focuses on the economic impacts of groundwater management on agricultural production and nature conservation. Desiccation can be seen as an externality arising from among others draining of large agricultural areas. Microeconomic analyses are carried out to find the most optimal groundwater table (social optimum) for both agriculture (in-stream use) and nature (off-stream use) in a study area. To achieve this social optimal groundwater table, the size of the losses to agriculture is relatively small (about 0.5 to 4% of the agricultural optimal production value). The study investigates the potential role of economic instruments in water management

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Summary

Desiccation of natural areas became a serious environmental problem in the Netherlands during the last decade. The main factors that are causing the problem are hydrological measures for the improvement of the drainage system beneficial for agriculture, and groundwater extractions by agriculture, industries and water companies. Hydrological measures contribute with 60% and groundwater extractions contribute with 30% to desiccation. Rearrangements of the hydrological system are supposed to be the major strategy to reduce desiccation, whereas reduction of groundwater extractions is only seen as a secondary option. However, on certain locations, where large amounts of groundwater are extracted from the same spot, extraction activities have a significant impact on desiccation. The circumstances and causes of the desiccation problem can hence differ from location to location, which implies that anti-desiccation strategies need a region specific approach.

The Netherlands is characterized by its high population density and economic activity. Many different users with different concerns about water quality and groundwater level compete for the resource on a spatially limited area. Compared to other OECD countries the withdrawal of freshwater per capita per year is relatively low in the Netherlands. This could be an indication for a rather efficient use of water. However, high population density and economic activity forces people to treat groundwater resources even more efficiently than is already done.

The fact that many different users compete for the resource points out that water is applicable in many divers ways. This special characteristic of water makes it difficult to attach a proper price for water use. Instream uses, where water is used directly for consumption or for a production process, are easier to evaluate than offstream uses, such as fishery, nature conservation, navigation or recreation. The problem of finding a proper price for water resources shows its consequences in externalities arising from economic activities that make use of water resources. As a matter of fact, desiccation can be seen as an externality arising from agricultural activities that do not seem to pay the proper price for the drainage and discharge of water. Due to inadequate prices for water resources the market fails to allocate the resource in an optimal way. As a result, overuse and waste of water are inevitable.

Economic instruments can contribute to a correction of the market failure. In international literature several economic instruments can be found that are applied to economize water use. Economic instruments can be categorized roughly into market-based and nonmarket-based incentives. The market-based incentives aim at the resource itself by increasing its economic value in order to approach an optimal allocation. The most important market-based instruments are prices, tradable rights, effluent and pollution charges, subsidies and taxes. Nonmarket-based instruments have a more dictating and compulsory character. The most important nonmarket-based incentives are restrictions, quotas, licenses and public information and education.

The examples of economic instruments found in international literature come from regions of absolute water scarcity. In the Netherlands a lot of effort is put into getting rid of superfluous water. The Dutch water problem is hence not a case of absolute water scarcity. Difficulties arise with the availability of good quality water. Good quality water is economically scarce because the treatment of surface water is still rather expensive, at least more expensive than the extraction of groundwater. The poorer the quality of surface water the higher the costs for its purification. This indicates that quality and quantity aspects of water are closely related to each other.

If economic instruments are to be used for the reduction of desiccation, they should be applied to both hydrological measures and groundwater extraction. Since the reduction of desiccation demands a region-specific approach, there is no nationwide solution to the problem. A first attempt at applying economic instruments to stimulate rearrangements of the hydrological system is done in the quantitative part of this report.

The quantitative part describes the conflict between agriculture and nature and their competing interests concerning the groundwater table in a simplified model. Five functions for five different crops (grassland, maize, potatoes, sugar beets and grain) that describe the relationship between crop yields and groundwater table are estimated. The functions exhibit yield depressions due to water overload and due to drought. By maximizing total agricultural revenue, which is the sum of revenues of the five different crops, the model calculates the optimal groundwater table for agriculture. With the introduction of a value-of-nature function that describes the value-of-nature with respect to the groundwater table, an optimal combined groundwater table for both, agriculture and nature, can be obtained. A sensitivity analysis on the valuation of the natural area and the specification of the value-of-nature function shows that the optimal combined groundwater table depends strongly on these two aspects. The numeric results of this quantitive model have to be interpreted as the outcomes of an example to illustrate the applied methodology.

It is proposed that economic instruments, such as taxes or charges aiming at farmers who prefer a lower groundwater table than the combined one, could be introduced. The agricultural losses occurring due to the optimal combined groundwater table that is higher than the optimal groundwater table for agriculture, give an indication of the proper tax rates/heights of charges. In order to be effective, tax rates/charges have to be higher than agricultural losses. Since the optimal combined groundwater table varies according the different specifications of the value-of-nature, losses to agriculture vary and likewise the proper tax rates/heights of charges.

If economic instruments are to be applied to hydrological measures, the valuation of the natural area under consideration plays an important role. The valuation of nature depends on several factors, such as the quality of the specific ecosystem, the attractiveness for recreation activities or the distance to cities. These factors differ from region to region, which is again an indication for the region-specific approach that has to be taken in anti-desiccation strategies.

A successful strategy against desiccation has to consider the special circumstances and causes of the problem that are different from location to location. This requires an intensive knowledge of hydrological, biological and ecological processes in order to detect the most successful measures for reaching the target of desiccation reduction. An interdisciplinary approach is hence required.

1. Introduction

1.1 Definition of the problem

This report deals with problems around water management in the Netherlands with special attention to the desiccation of natural areas due to decreasing groundwater tables. The central point is the question if economic instruments can make a positive contribution to mitigate the desiccation problem. Economic instruments play an important role in controlling environmental degradations arising from economic activity. Some famous examples are pollution taxes or tradable rights for the emission of polluting elements. In countries where the management of water scarcity is a traditional problem, economic instruments have been introduced in order to stimulate users to a more conscience application of water. A further concern in this report is to what extent the water problem in these countries is comparable to the Dutch situation.

Although the Netherlands are known as the country that has to make a lot of effort to pump away superfluous water in order to keep the land dry, problems arise with respect to water scarcity. The shortage of water is becoming most evident in the problems around desiccation. The general definition of desiccation as it is found throughout the literature in the Netherlands says that an area is characterized as 'desiccated' if its groundwater level is not high enough to fulfil and maintain all natural functions that are combined within this area. Moreover, an area with *nature* as its main function is seen as desiccated if for compensation purposes non-local surface water of less quality that does not meet the quality demand of the local ecosystem has to be provided.

Desiccation is caused by *man-induced changes* of the natural hydrological system that entails a lowering of the original groundwater table. The most important impact arises from land consolidation and drainage and discharge of water for agricultural benefits. These activities cause 60% of the desiccation problem. Other causes are the extraction of groundwater for drinking water and industry as well as diverse actions such as the expansion of coniferous forests, the increase in evapotranspiration of crops due to intensified agricultural production, and the growth of urbanized area. Groundwater extraction causes further 30% of the problem whereas the remaining 10% arise from the divers actions (Ministry of Transport and Public Works, 1996; Feddes et al., 1997).

In 1996 the total desiccated area in the Netherlands was estimated at about 630,000 ha (Ministry of Transport and Public Works, 1996). This is about 18.5% of the total surface of the Netherlands, which is 34,000 km². Desiccation does not have the same characteristics and degree of severity in all affected areas. The consequences of the problem depend much on the type of soil, the geographical setting, and the sensitivity of the local ecosystem. As an example, the damage is especially severe along the coastal dunes and on areas with sandy soil. Figure 1.1 shows a map of the desiccated areas in the Netherlands. The main context in which this research takes place is depicted in figure 1.2. The figure shows the groundwater table as the central point with different influencing factors around it. Agriculture, industry and water supply companies represent the group of extractors. Next to extraction activities, agriculture has an impact on the groundwater table through hydrological regulation, such as drainage, and increased evapotranspiration of plants due to intensified production. Through their influence on the groundwater table, all factors have an impact on the biodiversity of nature.

Figure 1.1 Desiccated Areas in the Netherlands (Situation in 1994)
Source: Beugelink et al., 1995.

The center of attention in the discussion around desiccation is the conflict between agriculture and nature. On the one hand, agriculture benefits from a lowering of the groundwater table because drained fields attain higher yields. On the other hand, adjoined natural areas suffer damage to their ecological diversity if the groundwater level is too low to fulfill all ecological functions. During the last decades the natural hydrological system in the Netherlands has been adapted to the demands of an intensifying agricultural sector. The improvement of the drainage and discharge system had been initiated by an inventory of the hydrological situation in the Netherlands in 1958 (Feddes et al., 1997). At that time it appeared that 60% of the agricultural area had a crop yield decrease due to water excess, whereas 40% had a yield decrease due to dryness.

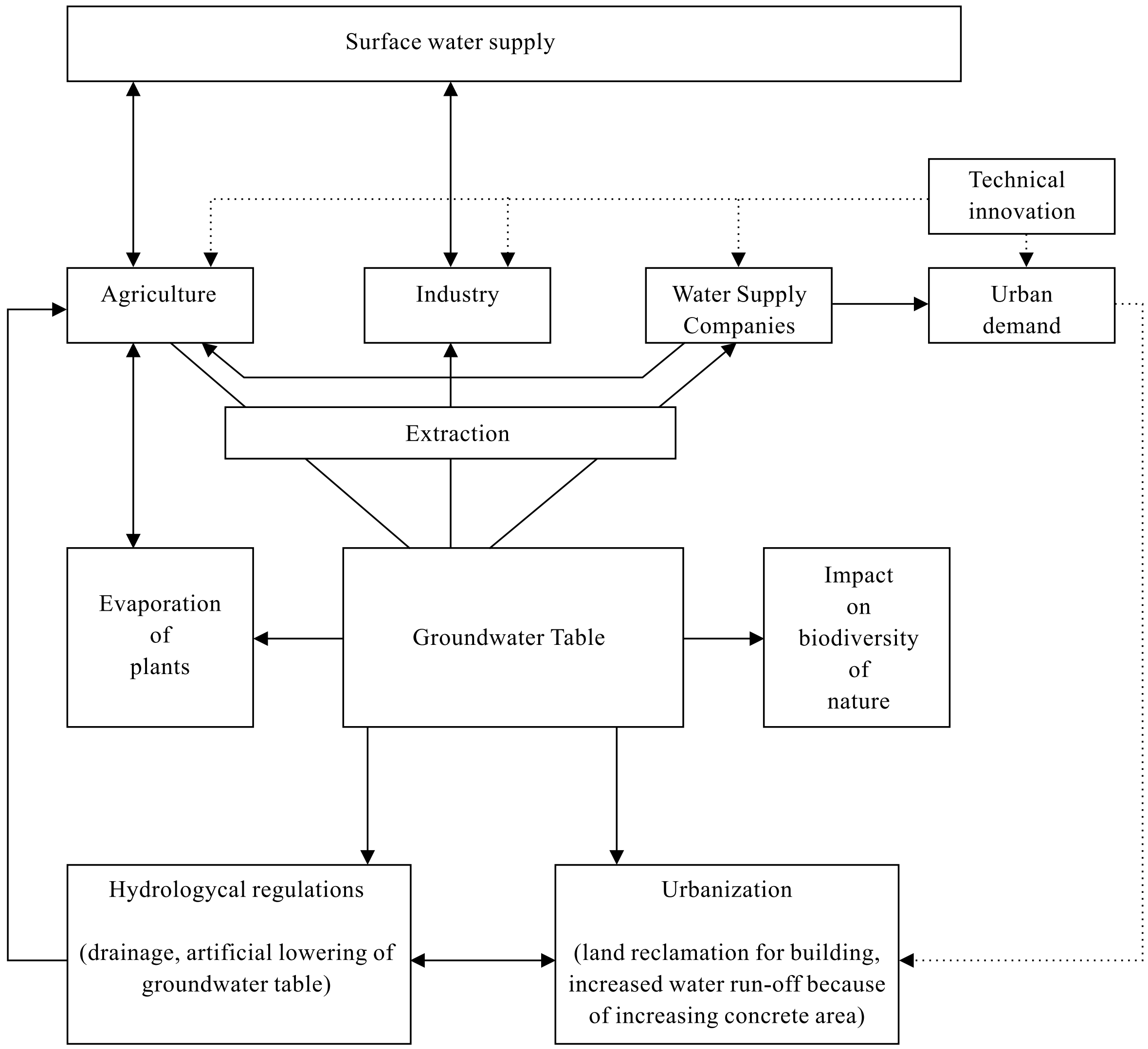

Figure 1.2   Factors Influencing the Groundwater Table

A method to quantify the conflict between agriculture and nature will be presented in a model that calculates the optimal groundwater table from a social point of view. Important elements in this model are the relationship between the groundwater table and agricultural crop yield and the valuation of natural areas. Attention is also paid to the role that economic instruments could play in the determination of the optimal groundwater table.

1.2 Motivation

Problems around environmental sound water management are not only occurring in the Netherlands. During the last decades increasing demand accompanied by pollution of good-quality water resources has become a familiar picture all over the world. In some areas water scarcity is seen as a major reason for future wars and conflicts. Several causes for this development can be mentioned. Increasing consumption and growing world population induced the increase of water use in agriculture, industry, and households. Especially in developing countries population growth brought about the conversion of land of minor quality into agricultural land, applying intensive irrigation in order to make this land suitable for agriculture. In contrast to this, as in the case of the Netherlands agricultural land needs to be drained or has to be provided with an artificial lowering of the groundwater level for cultivation. Drainage implies that water is carried away quickly to waterways and therefore percolation to recharge groundwater aquifers is interrupted. Increasing urbanization has similar effects: expansion of concrete areas and sewage systems takes more water to the big rivers and thus interrupting the natural cycle.

The countries where water management became an important governmental task are mainly situated in the arid regions of the world where absolute water scarcity is apparent. In this countries different economic instruments have been introduced in order to find a way out of the problem of decreasing water resources. The motivating question is now if these instruments are also applicable to the Dutch situation and to the special circumstances that are ruling in the Netherlands.

1.3 Objectives

The main objective in this report is as follows:

What is the role of economic instruments in Dutch water management and to what extent can they contribute to a reduction of desiccation?

In order to get insight into this main objective, some sub-questions have to be answered.

- What is the situation of desiccation in the Netherlands? Are there any specialties with respect to water in the Netherlands that have to be taken into account in management strategies? What is the situation of the different water users in the Netherlands?
- what are the special economic characteristics of water as a natural resource?

- what can be found about managing water scarcity through the introduction of economic instruments in international literature? Are there any differences in the water problem between other countries and the Netherlands?
- the quantitative part of this thesis illuminates the competing relationship concerning the groundwater table between agriculture and nature. The following objectives are put for the quantitative analysis;
- finding a function that describes the relationship between agricultural crop yield and the groundwater table;
- finding the optimal groundwater level for agricultural production and indicating losses to agriculture that occur through higher groundwater tables;
- finding a function that describes the value of nature with respect to the groundwater table;
- how can an optimal groundwater table for both, agriculture and nature, be obtained?
- can economic instruments be introduced to reach this optimal groundwater table?
- how sensitive is the optimal combined groundwater table with respect to the value of nature?.

1.4 Methodology

Different methodologies are used to find answers to the questions that are listed above. Extensive literature research is used to find out some facts about desiccation, the situation of water in the Netherlands and economic instruments in water management. For the characteristics of the water problem in the Netherlands domestic literature is the main source of information. Additionally, readings, discussions and debates about desiccation that took place on the 'Kennismarkt' (market of knowledge) in Wageningen on April, the17th and 18th 1998, contributed much to the clarification of the problem. For the explanation of the economic attributes of water and the different economic instruments that are used in water management international literature about environmental economic issues in general and the economics of natural resources has been consulted.

In order to get insight into the applicability of economic instruments to the water problem in the Netherlands, qualitative analysis with the help of (+, -)-tables is used. The economic instruments are tested on their impact on different criteria that have to be regarded if these instruments were to be implemented. The different criteria are effectiveness, equity, acceptability, financial impact, controllability, interregional acceptability, behavioral changes and environmental impact.

For the relationship between the groundwater table and crop yields the estimation technique of regression analysis is used. Five different crops are taken into account in the analysis, namely, grassland, maize, potatoes, sugar beets and grain. Since the relationship between crop yields and the groundwater table is supposed to describe a parabolic shape, curve estimations with quadratic and cubic functional forms are carried out. The computer program SPSS provides the proper software for the estimation procedures.

The five different functions resulting from the regression analysis are used for finding the optimal groundwater table for agricultural production. The optimal groundwater table is obtained by maximizing total revenue, which is the sum of the revenues of the five different crops. The revenues of the five different crops are calculated by multiplying the respective yield, price and hectares cultivated land. The optimization program GAMS serves for the calculations.

An optimal combined groundwater table for both, agriculture and nature, can be obtained in two ways. One way is to equate marginal costs for agriculture and marginal benefits for nature due to higher groundwater tables and the other one is to maximize the revenue of agriculture and nature together. Both ways will lead to the same results. The calculations in connection with equalizing marginal costs and benefits and the sensitivity analysis are also carried out with the computer program Matlab.

1.5 Structure of the report

The following chapter, chapter 2, serves to understand the prevailing circumstances of the water problem in the Netherlands. Different topics are illuminated in this chapter. Firstly, some aspects about the desiccation problem, which include soil chemistry, differences between the eastern and western part of the country, the involvement of the government, and options against the problem, are discussed. Secondly, a short overview about the availability of water in the Netherlands is given. Thirdly, the different user groups of water resources in the Netherlands are described, and lastly, some facts about the special circumstances of high density of economic activity in the Netherlands are mentioned.

Chapter 3 points out the economic attributes that are connected with water as a natural resource. The focus is put on the optimal allocation and extraction of resource, the externality problem, the special characteristics of water, and the theory about the optimal water pricing.

In chapter 4 different instruments about managing water scarcity as it is found in the international literature are reviewed. Chapter 4 also pays attention to several criteria that have to be considered while applying economic instruments. Furthermore, the pros and cons of the different instruments will be examined.

In chapter 5 different economic instruments are tested for the application to the Dutch situation. The instruments that have been selected are prices, tradable rights, effluent charges, subsidies, taxes and restriction and quotas. The tests have been carried out on water use/extraction of households and agriculture. Furthermore, the application of instruments on hydrological measures is discussed.

Chapter 6 presents a quantitative specification of the competing interests between agriculture and nature. It shows the estimation of the functions for five different crops that describes the relationship between the crop yield and the groundwater table. Subsequently, the optimal groundwater table for agriculture is calculated. Furthermore, a function for the calculation of value of nature with respect to the groundwater table is introduced. For finding an optimal groundwater table for both, agriculture and nature, the method of equalizing marginal costs and benefits is used.

Chapter 7 completes with conclusions and recommendations.

2. The water problem in the Netherlands

2.1 Introduction

The aim of this chapter is to get familiar with the special characteristics of the water problem in the Netherlands of which the desiccation problem is certainly a major element. Section 2.2 pays attention to the causes of desiccation, the chemical processes in the soil that create its symptoms, the different characteristics of desiccation in the eastern and western part of the country, governmental involvement, and to measures that can mitigate the problem. The ambiguity about real water scarcity in the Netherlands is discussed in section 2.3, where some facts and opinions about the availability of water are noted.

Many users with different interests are competing for water resources. On the one hand there are *offstream users* who are withdrawing ground and surface water for agricultural and industrial production processes and for municipal water supply. On the other hand there are *instream users* who are interested in the maintenance of stream flows such as for fishery, nature conservation, aesthetic values, navigation, hydropower, or waste water dilution. A description of all different user categories in the Netherlands is given in section 2.4.

It is well known that there is high density of population and economic activity in the Netherlands. Section 2.5 surveys some indicators about the problem of limited space in connection with Dutch water management. Finally, section 2.6 gives some concluding remarks.

2.2 Desiccation

The activities that cause desiccation are already mentioned in the introduction. As a reminder they are summarized in table 2.1. Additionally, the table shows the average groundwater table lowering induced by the different activities.

Table 2.1 Different cctivities with their impact on groundwater table lowering and contribution to desiccation

Activities	Groundwater table lowering (cm)	Contribution (%)
Land consolidation		
Drainage and discharge of water	35	60
Groundwater extraction for drinking water and industry	10 - 100	30
Increase in crop evapotranspiration		
Expansion of coniferous forests		
Expansion of urbanized area	20	10

Source: Feddes et al, 1997; own adaptations.

Table 2.1 indicates that groundwater extractions can generate an enormous lowering of the groundwater table. This is especially the case on certain spots where water demanding industries are established or where large amounts of drinking water have to be provided. As it is described further down in this section, the impact of extractions is only important on local level.

Chemical processes in the soil

Ecosystems that are especially sensitive to desiccation are characterized by upward seepage of mineral-rich and nutrient-poor groundwater. Upward seepage occurs mainly in the transitional regions between the high and low parts of the Netherlands (Feddes et al., 1997). It is the end product of the rainwater that infiltrated into the soil on the high-situated parts after purification and mineralization processes on the passage trough the soil. Desiccation means that the moisture content of the soil declines. This, in turn, entails an increase of temperature and oxygen concentration, which activates nitrogen mineralization and phosphate availability. The result of these processes is eutrophication. Another consequence of a lowering of the groundwater table is the decrease in upward seeping mineral-rich groundwater. Now, infiltrating rainwater, which has the opposite characteristics than upward seepage, namely mineral-poor and nutrient rich, let the pH-value of the soil decline and makes it to turn acid. The damage that is generally ascribed to desiccation is thus actually the result of a combination of desiccation, eutrophication and acidification (Feddes et al., 1997).

Differences between the Western and Eastern part of the country

The effects of a lowering of the groundwater table as it is described in the preceding paragraph are mainly a problem in the eastern and southern parts of the country with their sandy soils and their vulnerable high peat reserves. The main problems that occur in the western part of the country are of a different character. Here, the decreasing pressure of fresh water that is accompanied by a decreasing groundwater table brings about that salt water from the sea and brackish water from the rivers intrudes into the groundwater reservoirs. This has negative effects for the drinking water extraction in this area. Furthermore, a decreasing groundwater table induces a decline of the soil, which has destructive consequences for the foundation of buildings. This dilemma turns out to be a vicious circle because the soil decline implies that the groundwater table gets again closer to the surface. This, in turn, creates the need of a further lowering of the groundwater table.

The area in the western part of the country where desiccation is mainly caused by the extraction of groundwater is the area of the dunes. The groundwater reservoirs under the dunes serve as freshwater supply for the big cities in the 'randstad'. Runhaar et al. (1997), refering to Leeflang, mention that desiccation in the area of the dunes was already observed at the end of the 19^{th} century when groundwater was found to be a good water supply for the big cities.

Governmental actions

As a consequence of an extreme dry summer period in 1976 the Dutch government acknowledged desiccation as a serious problem (Raad voor verkeer en waterstaat et al., 1996). Therefore, the government took up desiccation in its plan for environmental policy. The intentions are to reduce the area suffering from desiccation with 25% in the year 2000 and with 40% in the year 2010 with respect to the year 1985. In the meantime, however, it is realized that the target reduction of 25% in 2000 cannot be reached. The actual decrease of desiccation attainable in 2000 is estimated at 5-6% whereas a 25% reduction is only viable in 2015 (Ministry of Transport and Public Works, 1996).

As mentioned in the introduction the characteristics and the degree of seriousness of desiccation are not uniform in all affected areas. Therefore, the provinces play an important role in controlling desiccation.

An important step is the establishment of the desired ground and surface water situation. The desired ground and surface water situation is to be determined by negotiations between the provinces, the water boards and the people that administrate or make use of the considered land, for instance environmental organizations and farmers.

Options against desiccation

Having in mind the activities that cause desiccation it is obvious that countermeasures to these activities have to be taken. The options for controlling the problem are listed below (Feddes et al., 1997; Projectteam Vierde Nota Waterhuishouding, 1996).

- Hydrological measures:
- conservation of water inside a region by active water management;
- temporary storage of precipitation surplus;
- reduction of drainage capacity;
- re-meandering of brooks;
- allowing more vegetation growth in ditches.
- Reduction and reallocation of groundwater extractions for drinking water and industries.
- Substitution of groundwater with surface water for drinking water supply;
- Replacement of dark coniferous forests with broad-leaf-wood.

From debates among experts (Wageningse Kennisdagen, 1998) it becomes clear that hydrological measures that imply a reduction of drainage capacity and the conservation of water in its original area are the dominant strategies in the discussion around desiccation. On the other hand, reduction in groundwater extraction takes only a minor position.

The same opinion is shared by the association of Dutch drinking water suppliers (VEWIN) who reveals their opinion about the relationship between municipal water use and desiccation in the journal Duurzaam Bouwen (1998). Since groundwater extraction for drinking water causes only 10% of the problem it is somewhat doubtful whether a reduction in municipal use of drinking water will have a significant contribution to the reduction of desiccation. They argue that the problem is mainly the result of the polder creation. Originally, rainwater that infiltrated on the hills near Utrecht seeped to the area that was then characterized by upward seepage because it was the lowest point in the region. The creation of the polders in the Ijsselmeer entails that the lowest point was moved. Consequently, the flowing groundwater passes its original destination and ends up in the polders.

Another study supporting the attitude that reduction of groundwater extraction is not a proper measure against desiccation is done by Van Ee and Pakes (1994). They investigate the benefit for nature as a result of a reduction in groundwater extraction in eastern Brabant. Their main results are that a reduction of ten million m^3 water induce an increase in the value of nature with 0.3%. The costs for the water works sector that are combined with this reduction are about 170 million guilders. Because the increase in the value of nature is only marginal whereas the costs are very high, they conclude that it would be advisory to think about measures with respect to changes in the water control system. The evaluation of nature in this study is somehow questionable. They would probably come to other results if they would take other standards or methods to find a value for nature.

The most recent study about anti-desiccation strategies is reported by Baltissen and Van Der Sluis (1998). The results of this research indicate that in 69% of the research area hydrological measures recovered more than 50% of the target situation. It is expected that through a stop of groundwater extractions on specific places another 5% of recovery of nature can be reached. An important point that was detected in this study is that a stop of groundwater extraction is an additional option and only useful if hydrological rearrangements run parallel to it. A stop of groundwater extraction without reducing the water discharge capacity of the drainage system in the natural area does not have any effect on mitigating desiccation. Other measures such as the replacement of coniferous forest through broad-leaf-wood and the depoldering of Flevoland only seem to give a restricted contribution.

Another option against desiccation that is often mentioned in the literature is the infiltration of non-local surface water on desiccated areas. This measure turned out to be not effective because the quality of that water does not meet the demands of the desiccated areas' ecosystem.

2.3 Availability of water

The OECD (1995) mentions in its report about environmental performances of its member countries that the Netherlands are subject to both, an abundance and a shortage of freshwater resources. 70% of total fresh water supply is provided by the rivers Rhine and Meuse. Most of this water is needed to flush out brackish groundwater and to push back the intrusion of salt water from the sea. The other 30% are provided by precipitation and little streams and brooks. The average amount of precipitation in the Netherlands is about 796 mm per year which is not enough to prevent water deficit during summer (OECD, 1995). Blumenthal (1988) summarizes that the main water management problem in the Netherlands is to get rid of excess rainfall in winter and to distribute the available river water over the country in summer, taking care that good quality of both surface and groundwater is maintained.

Among the experts of the Dutch water sector rather different opinions can be found about the degree of seriousness of water scarcity. The most contradictory judgements are certainly done by Cals, who is the manager of the association of Dutch drinking water suppliers (VEWIN), and by Saeijs, who is professor for water quality policies and sustainability at the Erasmus University in Rotterdam. Cals expresses himself positive about the fresh water situation. According to him drinking water is by no means a scarce commodity. He builds his conclusion on the fact that drinking water consumption is stabilized at a level of about 130 liters per capita per day since 1990. Additionally, he is pointing out that there is no question about intensifying the extraction of groundwater. Due to technical innovation, so Cals, it will get more favorable to purify surface water which is surly an inexhaustible resource in the Netherlands (NRC, 20-11-97). Saeijs (1995) represents the other extreme. In his inaugural speech in September 1995 he determined that the Netherlands belong with respect to fresh water resources to the poorest countries in the world. He based his statement on the definition of the poverty line for fresh water that was established on the Environmental Top Conference in Rio de Janeiro in 1992. This poverty line is set at 1,000m^3 per capita per year. He reasons further that the annual amount renewable water from own sources per capita available in the Netherlands is only 680m^3 and therefore beneath the poverty line. Moreover, the Netherlands are importing fresh water and are thus not self-sufficient which means that they depend on foreign countries.

These two different views illustrate the wide range of attitudes towards this question and it is obvious that they depend heavily on the academic background of the respective person. Without doubt, every expert is able to defend his or her position. However, for a sustainable development of the Dutch water resources integrated policy measures have to be introduced.

Sustainability and integrated water management are also the main objectives in the fourth policy document on water management in the Netherlands. The sustainability item corresponds with the national environmental policy plan, which has the target that environmental problems ought to be manageable by the year 2010 (Raad voor verkeer en waterstaat et al., 1996). Integrated water management implies that every function of water has to be taken into account equally. As far as possible, it should create adequate conditions for the different user groups with their competing interests about the quality and quantity of water to act next to or even with each other. Certainly, in some cases a combination of different functions of water is not possible, which means that the presence of one user group excludes the presence of another user group. The different user groups of water resources in the Netherlands are described in the following section.

2.4 Different functions of water

Although this study is focusing on water quantity items it has to be stressed that an economically efficient water management system has to integrate quantity as well as quality issues (Howe et al., 1986). This statement is even more important in a situation such as the Netherlands where the space limit forces high density of economic activity with competing purposes of water use. Figure 2.1 shows all the different user groups that benefit from the multifunctional character of water (Ministry of Transport and Public Works, 1996). The dashed lines between the categories of use are supposed to indicate their overall interrelationship meaning that every activity has effects on other activities. While discussing the different user categories remarks are made about their effects on desiccation.

Nature

The category *nature* represents all functions that are important for the continuation of biodiversity and the preservation of the natural composition of water, soil, and air. Because all other categories are originated by human activity which is never without consequences for the natural material cycle it can be stated that *nature* is the main opponent of all other categories. Focusing on desiccation, water control measures for the benefit of *agriculture*, *urbanization*, and *security* and groundwater extraction of *agriculture, industry* and *drinking water companies* are known to be the most important items that have to be taken under consideration. With its recent 'Note on Environment and Economy the Dutch' government shows its intention for the development of a sustainable economy in which economic growth is supposed to go hand in hand with decreasing pressure on the environment (VROM et al., 1997). The sustainable development issue is also found back in the 'National Policy Document on Water Management', which put the ecological development of water systems such as the sustained use of it by man, preservation of natural production, and diversity of species as its main target (Ministry of Transport and Public Works, 1989).

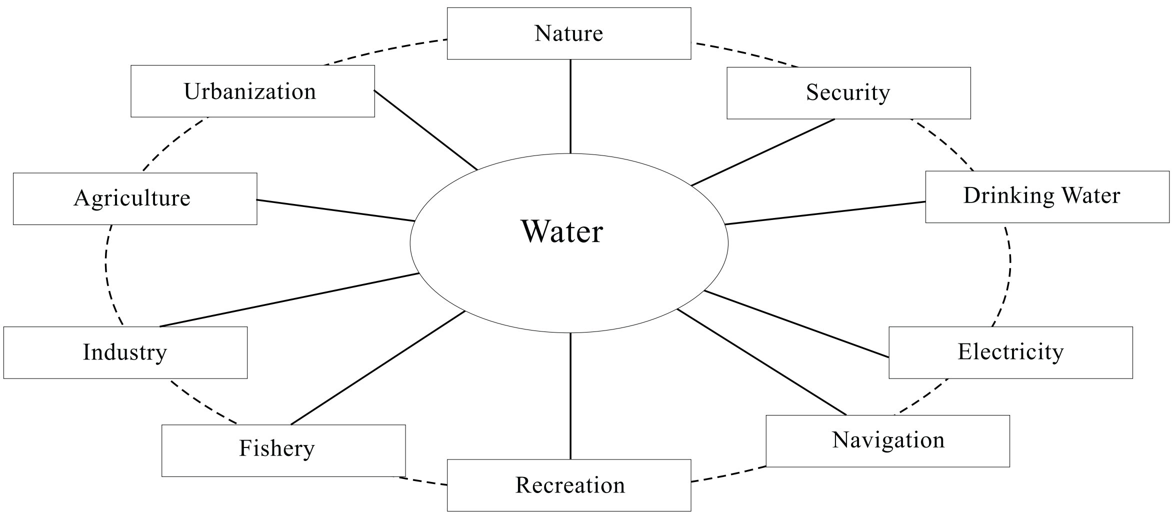

Figure 2.1 Different user categories of water in the Netherlands

Security

From a historical point of view *security* has always been the most important topic in Dutch water management. To protect people from floods and extreme high tides it is necessary to care for high enough dikes at river- and seaside and a fast enough run-off of superfluous water. After the floods in 1993 and 1995 and with view on the rising sea level due to climatic changes the *security* item is still an emerging point on the agenda. For instance, in the 'Exploration of Water Systems 1996' the Ministry of Transport and Public Works set *security* as a definite starting point in water policy measures. Traditional water engineering takes straightening, broadening and deepening of rivers and streams to increase discharge capacity as the most appropriate way to provide flood protection. Under the overall target policy of a sustainable development of the Dutch economy new strategies of flood protection have became a point of discussion. The most important strategies to approach a more ecological way of dealing with water superfluity are spatial rearrangements that tend to conserve water in order to reduce peaks of discharge. Such spatial rearrangements are the re-meandering of rivers and streams, the transformation of agricultural land into natural area, and the creation of buffer zones and inundation polders along water courses (VROM, 1997). Conserving water for a longer time is also known as being a substantial contribution to the reduction of the desiccation problem (VROM, 1997).

Urbanization

Water overload of rivers and streams is partly caused by increasing *urbanization*. The extension of cities and urban area entails an increase in concrete area that makes sure that rain water is quickly led away through the canalization to the bigger rivers and streams. Next to water overload *urbanization* contributes to the desiccation problem because rainwater that runs away through the sewage system does not have enough time to percolate through the soil to replenish the groundwater reservoir.

Agriculture

Agriculture makes use of water in nearly all-possible ways. Firstly, it demands special management of water control. In springtime the groundwater level has to be low enough such that the soil can provide the necessary bearing strength for heavy machines that are needed for land cultivation. Secondly, water is needed for irrigation in summer time in order to save the crops from drought damage and for the cattle. This two purposes demand high quality water especially with respect to salt contents and toxic elements. Thirdly, *agriculture* is putting much pressure on water quality by leftovers of fertilizer and pesticides that are washed out of the soil into groundwater reservoirs or that end up in ditches. Through the extensive network of ditches, brooks and channels it cannot be avoided, that unwanted elements in surface water spread out over the area very easily. The need of low as well as high groundwater tables and the demand for high quality water on the one hand and the pollution of water on the other hand makes it obvious that even inside one sector there are many contradictory interests. A more detailed description of the role of water in *agriculture* can be found in chapter 6.

Drinking water

The main competitors of *agriculture* on quality level as well on quantity level are certainly *drinking water companies*, *nature*, *fishery*, and *recreation*. All of them are interested in water of good quality. *Drinking water companies* have to bear the costs of purification, which are substantially influenced by the pollution of pesticides and nitrate. The costs of purification of pesticides are estimated to be about 200 million guilders per year and that of nitrate about 75-130 million guilders per year (Ministry of Transport and Public Works, 1996).

Currently, 33% of drinking water is supplied by surface water and 67% is extracted from groundwater (Ministry of Transport and Public Works, 1996). Regarding desiccation and increasing demand for drinking water until the year 2000 it is planned that in the near future more surface water will be used as substitution for groundwater supply. Because of higher costs of purification that are connected with the supply of surface water it is predicted that the price of drinking water will rise.

Industry

Industry needs water as instream uses such as for production processes, for the products themselves, and for cooling and as offstream uses such as for the dilution of waste water. Total water use of *industry* decreases between 1986 and 1991 with 28% from 4,300 million m^3 to 3,100 million m^3 (CBS, 1986 and 1991). This can be explained by the strict policy of the 'Pollution of Surface Water Act' from the late 80s which uses licensing and inspection of discharges, combined with sanctions and penalties to improve water quality in order to induce firms to treat and reuse waste water (OECD, 1995). However, groundwater extractions of many industrial firms, especially in food industry, are to large extent responsible for desiccation on local scale. This is because large amounts of groundwater are extracted from the same spot.

Electricity

Electric power plants and *industry* uses most of the surface water for cooling purposes. The pollution of surface water with warm water can have considerable effects on the living conditions of local water life and therefore be harmful to *nature, fishery* and *recreation*. The consequences of the warming of surface water are a decrease of the oxygen level, an intensified growth of algae, and botulism, which can all lead to mortality of fishes. A system of licenses and norms are established for the discharge of cooling water that should care for the avoidance of such negative effects. Anyway, it is still a problem to handle hot and dry periods where the water run-off of the rivers is not strong enough to washout and dilute cooling water (Ministry of Transport and Public Works, 1996).

Fishery

For *fishery* quantity and quality of water are the most essential inputs. Water pollution from *agriculture* and *industry* has negative effects on the health condition of the fish stock. The straightening and deepening of rivers and streams deteriorated the settlement possibilities of migratory fishes such that they became very scarce or that they disappeared totally from their original habitats. The spatial rearrangement measures to provide flood control discussed above would surely have positive consequences for the variety of fish species, which in turn would be beneficial for *fishery* provided that harvesting takes place in a sustainable way.

Navigation

Navigation makes demand of an appropriate wide and deep enough waterway with a water flow that should neither be too high or too low. The Ministry of Transport and Public Works (1996) expects an increase in *navigation* with bigger ships in the near future. Although *navigation* is by comparison with road and air transport regarded as being a rather clean way of conveyance, the water pollution, especially of oil discharge and antifouling coating should not be underestimated. These negative effects for *fishery, recreation* and *nature* have to be taken into account while planning integrated water management.

Recreation

Recreation is an increasing sector in the Dutch economy. Water is needed for swimming, sailing, fishing, and ice-skating or just as an element that cannot be missed in the typical Dutch landscape enjoyed by walkers or bikers. Water quality aspects are certainly the most important items in recreation because it directly effects the health of human beings enjoying water activities or because an abnormal smell would be inconvenient for people. Quantity aspects become a point of discussion when talking about the extension of protected area for special animals and plants that would be harmed by recreational activity in such areas.

2.5 The problem of limited space

The Netherlands are known for their high population density and agglomeration of economic activity. This entails in many cases an additional pressure on environmental resources. The question is now if limited space could be an extra obstacle that impedes the development of an integrated plan for water management. Table 2.2 shows some general indicators for environmental pressure in the Netherlands in comparison with European OECD countries and all OECD countries.

From the figures in table 2.2 it becomes obvious that in the Dutch situation all indicators that are reported per square kilometer reach a very high score compared to the average value of other OECD countries. The density of economic activity is reflected in population and GDP per km^2, which are both more than four times higher than the average. The three indicators representing agricultural activity, cattle and pigs, and use of fertilizer and pesticides, indicate intensive production methods which are famous for being relevant contributors to many water related environmental problems. The road vehicle stock and the road network length show that transport facilities take an important role and may also be an indicator of the degree of society's mobility, which is known to be quite high in the Netherlands. Furthermore, also in waste per km^2 and energy consumption (toe/1,000 US$ per unit GDP), the Netherlands take the leading position. With regard to the space problem it is not amazing that the percentage of forest area is rather modest in contrast to the fellow OECD members. On the other

Table 2.1 Indicators for environmental pressure in the Netherlands

Indicators for environmental pressure (1990-1992)	Netherlands	OECD (Europe)	OECD
Population (inhabitants/km^2)	407	98	27
GDP (million $/km^2)	6.7	1.4	0.5
Cattle and pigs (head/km^2)	549	52	15
Use of nitrogen fertilizer (tons/km^2 of permanent crop land)	41.5	9.7	5.9
Use of pesticides (tons of active ingredients per km^2 of permanent crop land)	1.8	0.5	0.3
Road vehicle stock (vehicles/km^2)	182	40	15
Road network length (km/km^2 of land area)	3.5	0.8	0.4
Waste (tons/km^2)	205	36	13
Energy consumption (toe/1,000US$ per unit GDP)	0.26	0.19	0.24
Forest area (% of total area)	9.9	33.4	33.2
Major protected area (% of total area)	9.5	6.9	7.8
Indicators for environmental pressure (1990-1992)	Netherlands	OECD (Europe)	OECD
Withdrawal of freshwater resources (m^3/capita/year)	517	628	1,073

Source: OECD Environmental Performance Review: The Netherlands, Paris, 1995.

hand the relative high percentage of major protected area indicates a strong interest in nature conservation. However, Verbruggen (1995) mentioned that the absolute area of nature in the Netherlands is not only small compared with other OECD countries but also very fragmented and in a worrisome condition. As a matter of fact, the disintegrated structure of the natural area is a major obstacle in curing desiccation (Baltissen and Van Der Sluis, 1998).

The last indicator noted in table 2.2 points out that the withdrawal of cubic meters freshwater per capita per year is actually lower than the average. In connection with the high population density this relative low level of water use is compensated by 407 inhabitants per km^2. It is therefore not difficult to conclude that high pressure is put on the Dutch freshwater resources. (It should be mentioned that the high average value of all OECD countries, 1,073 m^3/capita/year, is mainly influenced by the United States that have a withdrawal of freshwater resources of 1,875 m^3/capita/year.)

Limited space brings about that all the different users with their competing interests are spatially very close to each other, which increases the severity of external effects produced by one user on his/her competitors. A successful plan for integrated water management certainly needs obligingness of all competitors and participation of society to take into account all concerns and objectives.

2.6 Conclusions

In this chapter the role of water in the Netherlands has been explored. Desiccation is a major reason why traditional management of the hydrological system, which implies high drainage capacities for the benefit of agriculture, is called in question. The most important option against the desiccation problem is hence the rearrangement of the hydrological system such as the conservation of water inside a region or the reduction of drainage capacity. The recovery of the hydrological system is a measure that has an impact on regional scale. Among experts, the reduction of groundwater extraction activities is only taken as a secondary option against desiccation. However, on local scale, groundwater extraction can cause a groundwater table lowering down to one meter below the original level and is therefore quite significant on specific locations. A successful policy against desiccation certainly has to consider that circumstances and causes of the problem can differ from location to location. This implies that there is no overall solution to the problem and that anti-desiccation strategies have to be adapted to the local situation.

While talking about water scarcity in the Netherlands it is important to define the type of water scarcity beforehand. The effort that has been put into getting rid of superfluous water shows that there is no absolute water scarcity in the Netherlands. A problem appears with respect to quality issues, which means that fresh groundwater resources are getting scarce. Good quality water is scarce from an economic point of view because the purification of surface water is still very expensive, at least more expensive than the extraction of groundwater, which costs do not yet include the external effects that occur by the extraction and that become visible as desiccation.

A special characteristic of the Netherlands is the high density of economic activity. Several in- and offstream users with different demands on quality and quantity of water compete for the resource on a spatially limited area. This could imply that external effects produced by the different users on their competitors are more severe. With respect to the withdrawal of freshwater per capita per year the Netherlands lie under the average of the other OECD countries. This could be an indication that compared to the other OECD countries efficiency of use is already relatively high in the Netherlands. However, the fact that a limited area has only a limited underground area and therefore less space available for the storage of groundwater in combination with high population density forces people to treat groundwater resources even more efficiently as it is done already.

For a better understanding of the efficient use of water and the efficient allocation of water among users the following chapter will describe some economic issues around water as a natural resource.

3. The economics of water

3.1 Introduction

In this chapter some basic principles about treating water as an economic good are explained. Section 3.2 shows the concept of the optimal allocation of scarce resources and the theory of the *Hotelling Rule* as a guideline for an optimal extraction of environmental resources. It was already shown in the preceding chapter that the purposes of water use are manifold. Section 3.3 and 3.4 take up again this special characteristic of water and additionally pay attention to the dilemma why water fails to be allocated in an optimal way. Section 3.5 gives some ideas about the optimal pricing of water services. Section 3.6 finishes this chapter with some concluding remarks.

3.2 The optimal allocation and extraction of water

There are two concepts that are important while talking about the optimal allocation of resources: the concept of efficiency and the concept of optimality (Perman et al., 1996). Efficiency is described by Vilfredo Pareto in 1897, who introduced the Pareto-criterion: a particular allocation of resources is Pareto efficient if it is not possible to make anyone better off without making at least one other person worse off. This implies that in a Pareto inefficient situation, positive gains to any person are possible without losses to others. An optimal situation can be described as the state with the highest social welfare or in which the corresponding social welfare function is maximized. An optimal arrangement is therefore necessarily an efficient one. The crucial point is that the reverse is not true: An efficient allocation is not automatically an optimal one. This is because there are numerous potential Pareto-efficient allocations, all of them dependent on a certain initial distribution of factor endowments.

For social welfare to be maximized, an economically efficient resource allocation requires that marginal net benefits are equalized across all different users. An optimal allocation of water resources is also established in the Dutch groundwater law (Van Staalduinen et al., 1996). The marginal net benefit curve is defined as the vertical distance between the demand curve for water and the marginal costs of extracting and distributing that water as it is depicted in figure 3.1 (Tietenberg, 1992).

Water use can be classified in different economic terms. On the one hand, water offers benefits through direct use in final consumption such as in households or for environmental and recreational purposes. On the other hand, it is used as an intermediate good in a production process, e.g. irrigation, hydropower or cooling (Gibbons, 1986). In the latter application the value of water has to be derived from the value of the final good. An optimal allocation of water in different production processes can be achieved if its value of marginal product is equalized over all processes. Hence, the demand for water is a derived demand and depends on the value of the good produced (Bogess et al., 1993). This relationship is presented in Figure 3.2.

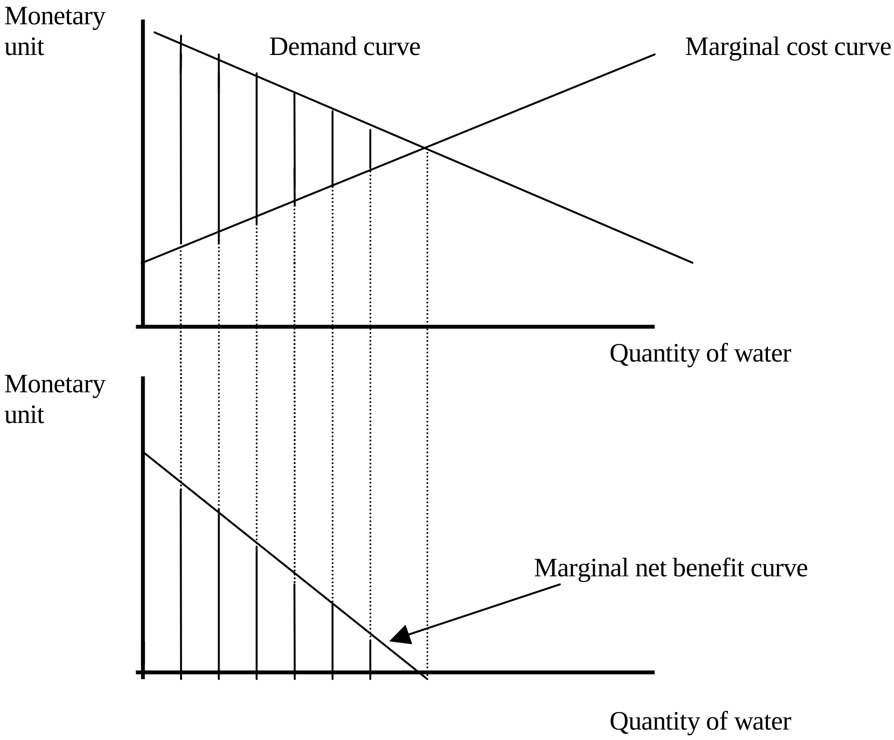

Figure 3.1 Derivation of marginal net benefit curve

While talking about the optimal allocation of water it is important to distinguish between surface water and groundwater. Surface water has the characteristics of a renewable resource and its future supply depends mainly on natural phenomena whereas the future supply of groundwater is dominantly influenced by current withdrawal and the aspect of intertemporal allocation has to be taken into account as well (Tietenberg, 1992). Depletion of groundwater occurs when the extraction rate continuously exceeds the recharge rate. A groundwater aquifer can become irreversibly used up if the geological pattern of its supply channels is such that they need a certain minimum water level to keep on functioning and the provision of this minimum level is not guaranteed because of excessive withdrawal (Neher, 1990).

3.2.1 The optimal extraction of exhaustible resources

A rule for the intertemporally efficient extraction of exhaustible resources under the assumption of maximization of social welfare was developed by Hotelling in 1931 (Perman et al., 1996). It states that the rate of change of the resource's shadow price has to be equal to the social utility discount rate. In mathematical form it can be expressed as:

$$\frac{dP_t / dt}{P_t} = \rho \tag{3.1}$$

Where: P_t = shadow price of the resource at time t
ρ = social utility discount rate.

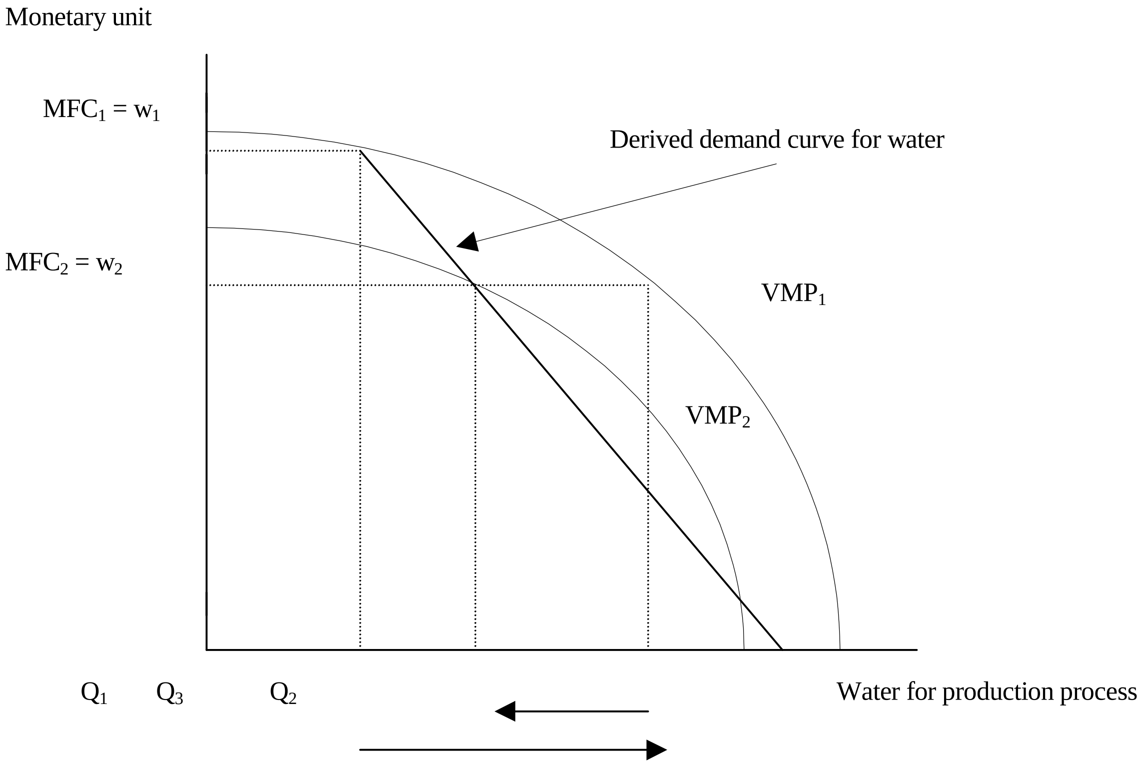

Figure 3.2 The Demand for water in a production process
Source: Bogges et al., 1993.

VMP_1 is the initial value of marginal product curve and depicts the demand for water at different prices. Microeconomic theory says that in a profit maximizing enterprise the value of marginal product equates marginal factor costs ($p^*\partial y/\partial q = \partial C/\partial q$). If the enterprise is a price taker, marginal factor costs correspond to the price of one unit of the resource that is used as input ($p^*\partial y/\partial q = \partial C/\partial q = w$). This means that the value of the additional production caused by one more unit of input matches the additional costs that arise from the use of one more unit of input respectively its price. In figure 3.2, w_1 is the original input price with the corresponding demand for water Q_1. After a price decrease to w_2 the producer will expend his/her demand to Q_2. If the reduced price is available to many producers of the same good and they will all increase their production, the extended supply will induce a decline in output price, which in turn has an effect on the value of marginal product. The new VMP is lower than in the initial situation and in the figure it is represented by VMP_2. With the new input price w_2 and the new value of marginal product VMP_2, the producers will adjust their input demand to the quantity Q_3. The derived demand curve for water after one adjustment is shown in the figure. It may have another non-linear form if more adjustments, which depend on various aspects such as elasticity of supply or price flexibility, would take place. (The derivation of Hotelling's Rule can be found in appendix A.)[1]

The price is the net price that means after subtracting costs of extraction and purification. After rearranging and integrating (3.1), another form of Hotelling's Rule can be obtained:

$$P_t = P_0 e^{\rho t} \qquad (3.2)$$

Formula 3.2 shows more clearly that the current price P_t rises at a rate equal to the social discount rate ρ. The rising price of the resource reflects the increasing scarcity of the declining stock. If the price reaches the point where it is cheaper to use a substitute, the extraction of the resource might be ceased before it is fully depleted. The substitute is called the backstop technology and the price at which it is introduced is the choke price because at this point resource extraction is choked off (Perman et al., 1996).

3.2.2 The optimal extraction of renewable resources

In the case of renewable resources Hotelling's Rule needs some modification (Perman et al., 1996). Here the growth or, with respect to water, recharge rate has to be considered as well. It is assumed that the amount of growth/recharge Ω is a function of the current stock level S_t, hence $\Omega(S_t)$. The supplemented Hotelling rule can be described by:

$$dP/dt = \rho P - P\Omega_S \qquad (3.3)$$

Where: $\Omega_S = d\Omega/dS$.

In words, Ω_S is the rate of change in growth/recharge with respect to a change in the resource stock. While extracting or harvesting a renewable resource a steady-state should be reached. A steady-state means that all stocks and flows of the renewable resource remain constant over time which implies that the rate of extraction should always be equal to the growth/recharge rate. Additionally, in a steady-state demand for the resource is constant over time and therefore, with a constant rate of extraction, the price will stay unchanged as well. Hence, in (3.3) dP/dt becomes zero and (3.3) reduces to

$$\rho = \Omega_S \qquad (3.4)$$

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[1] If the assumption is not the maximization of social welfare but maximization of private profit the social utility discount rate is replaced by the market interest rate i. These two rates are in fact identical if profit maximization takes place under the assumption of perfect competition and if the area under the demand curve is identified as gross benefit (see Perman et al., 1996, p. 152).

This equality says that extraction of the resource should be such that the growth/recharge rate matches the social utility discount rate.

It should be mentioned that the conditions that are presented in equation (3.1)-(3.4) are most basic specifications. Variations such as population growth, technical progress, extraction and damage costs can be introduced in order to approach a more complex reality.

3.3 Water: a common property resource

Water has characteristics that prevent an optimal allocation. The most important one is certainly that it belongs to the common property resources and experiences therefore the treatment that is known as the tragedy of the commons. In the case of groundwater, Gisser and Sanchez (1980) classified the pumping of an aquifer between the harvesting of privately owned timber and the exploitation of fishing grounds. Privately owned timber, where non-owners are excluded, will be cut in such a way that profit is maximized over time, taking into account the discounted value of future timber cutting. On the other hand, the non-exclusiveness of fishing grounds implies that everyone wants to harvest the fish before anyone else does it and this leads to dissipation of rent and inefficient application of effort over time. A groundwater aquifer is to some extent attached with exclusiveness because only the users that are situated above this aquifer are able to extract from it. However, this sort of exclusiveness does not prevent the users from disregarding the value of water in situ because conservation of one person does not have any effect if the others continue extracting.

Market forces can only attain an optimal allocation if property rights are fully assigned and if all goods and services are private. Furthermore, the use of water produces externalities whose costs are not incorporated in the price and are therefore passed on to society. The social costs of water use are therefore higher than the private costs. This is portrayed in figure 3.3 at the hand of an example of a private producer who is using water as input for production.

As mentioned above the private producer will demand the quantity of water that corresponds to a situation where the price of water is equal to the private marginal costs. Say that the water price is established at P*, then the producer will demand the quantity Q^P. If the same condition shall hold for social marginal costs (P* = SMC), the quantity demanded has to be reduced to Q^S. The triangle a-b-c is the amount of external environmental costs that have to be borne by the society. The implications for the introduction of the optimal environmental tax will be discussed further down in section 4.4.7.

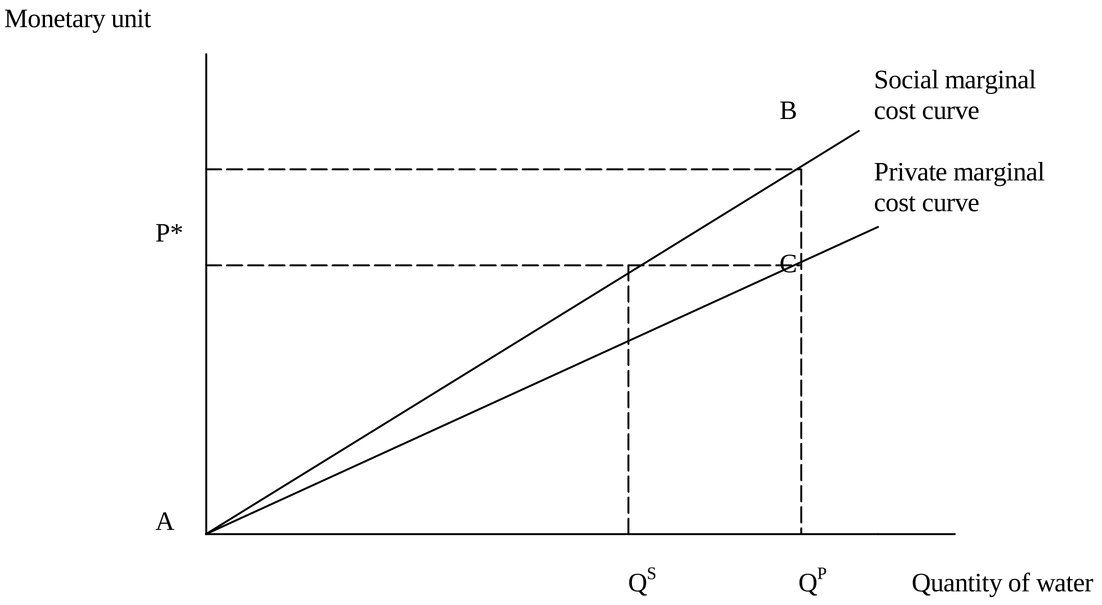

Figure 3.3 Social and private marginal costs

3.4 The special characteristics of water

Young (1986) summarizes some supply and demand characteristics that distinguish water from other commodities:

– *mobility:* since water flows, evaporates, seeps, and transpires it is difficult to identify and measure. This makes the establishment of property rights problematic;
– *economies of large scale:* due to large storage and distribution systems water supply has a large fixed costs component and is hence predestined for being a natural monopoly;
– *uncertainty in supply:* water supply depends on stream flows and precipitation and is variable in time, space and quality. It is therefore not foreseeable in a precise way. In general, supply peaks do not coincide with periods of high demand;
– *assimilating and absorbing capacities:* water does also serve as a host for waste water and pollutants. The assimilative capacity of a water body could therefore be seen as an additional commodity itself. This characteristic reminds that quality and quantity items are very close connected to each other;
– *diversity of use:* water is used for numerous purposes in different user categories. For some uses it is difficult to establish an economic value, which complicates the derivation of utility that different users gain from different forms of water application.

3.5 Water pricing

In accordance with Randall (1981) water can be defined in terms of resource costs, opportunity costs or social costs. Resource costs reflect the provision of water as, for instance, pumping or distribution costs; opportunity costs represent the value of that water in its best alternative use; and social costs are costs that society has to bear such as costs arising from externalities. In an efficient situation the three marginal costs are equalized and at the same time they are pointing out the proper price. Randall's recommendation corresponds to the fundamental concept of economically efficient use of resources, the marginal costs pricing system (Frederick and Kneese, 1995). Because of increasing marginal costs in most common situations the marginal costs pricing system needs a progressive tariff structure which implies higher charges at higher units of consumption (Winpenny, 1994). At present however, the opposite, namely special-offer charges for bulk users, is in many cases a matter of course.

The OECD (1987) suggests that marginal cost pricing under the User-Pays Principle (UPP) would be the proper charging system to prevent inefficiency. The UPP is analogous to the well-known Polluter-Pays Principle (PPP). Whereas under the PPP the polluter has to pay for the external costs that he/she enforces upon society, the UPP prescribes that the users of the services have to bear the full costs of the service collectively. Subsequently a charging system that reflects quality and quantity items will divide full costs among all users. The UPP certainly implies the abolition of subsidies to users of the water service.

Unfortunately, the marginal costs pricing system is not found in practice. In general, water companies apply a system to recover the costs of treatment and delivery (Randall, 1981; Tietenberg, 1992; Winpenny, 1994; Rosegrant, 1997), which means that they only take into account the resource costs (see above). The rate-setting structure often takes the form of average cost pricing, where the water service is charged at average costs, or flat rate tariffs, where the price is not directly based on the quantity of water used but on, for instance, number of residents, number of tabs, size of inflow pipe or the property value. (For further details of rate-settings, see OECD (1987); They give a very clear and detailed description of the different price and tariff structures that are found in the water service sector).

Tietenberg (1992) mentions the consequences of inappropriate water pricing for migration. He notes that tariffs that are set too low would make arid region financially more interesting to new residents than they really are. An increase in population in such areas would put even more pressure on the limited water resources. The question arises if this statement counts for independent private people and if they would make the price of water as an important criterion of their decision to move to an arid region. In most cases people migrate because of reasons of employment. Therefore, the settlement of industries and big employers should be aggravated in such areas.

3.6 Conclusions

Water belongs to the common property resources and experiences the tragedy of the commons. An important characteristic of water is its diversity of use. Water fulfils numerous functions for different economic activities. Externalities that arise from the use of water by these activities indicate that the price for water use paid by the different users does not enclose the full costs. As a consequence, the market fails to allocate water in an optimal way and overuse and waste of water are inevitable.

The following chapter describes several economic instruments that assist in internalizing external effects and correcting market failure. Research on these instruments has been carried out by consulting international literature about managing water scarcity.

4. Economic instruments for managing water scarcity

4.1 Introduction

This chapter presents several economic instruments that are applied to economize water use in countries where water shortage has become a serious problem. The objective of economic instruments is to influence the demand behavior of water users. They are hence aimed at the demand side of the water chain. Section 4.2 gives insight into the differences between supply and demand management and the theory that demand management is an inevitable consequence of supply management. Next, section 4.3 presents an overview of different policy measures and different criteria that have to be taken into account while applying these measures. The following sections (4.4, 4.5, 4.6 and 4.7) explain the different policy measures that are introduced in section 4.3 in further detail. Special attention is paid to section 4.5. This section describes the markets-based incentives for saving water. Market-based incentives are those instruments that use market forces to approach an optimal allocation. Finally, section 4.8 gives some concluding remarks.

4.2 Demand versus supply management

In literature the problem of water shortage is in general approached in two different ways: 1) through supply management or 2) through demand management. Rosegrant (1997) defines supply and demand management as follows: *'Supply management, which involves activities to locate, develop and exploit new sources of water, and demand management, which addresses the incentives and mechanisms that promote water conservation and efficient use of water'*. Supply management is thus focusing mainly on quantity and quality of water at the entry point of the distribution system while demand management applies to actions that influence the use or wastage of water on the other side of the distribution system. Winpenny (1994) uses the term supply augmentation instead of supply management. He argues that supply-side solutions are unsustainable because they are increasingly costly and are going to face hydrological, environmental and financial limits sooner or later. In other words, it is not possible to fight a cause with its own symptom. A shift towards demand management, which induces treating water more like a commodity and not like an automatic public service, is therefore inevitable. Randall (1981) interprets supply and demand management as two different segments of a continuum. He introduced the term of maturing water economies, which includes two phases: the expansionary and the mature phase. The expansionary phase refers to supply management and is characterized by a policy that is concerned about an appropriate rate of expansion and subsidization of the water economy. Generally, during this stage long-run water supply is elastic, competition among different users of water is minimal, delivery systems are in good condition, externality problems are not striking and social costs of subsidizing increased water use are fairly low. As the water economy is moving towards the mature phase these features are changing. Long-run water supply becomes inelastic, competition among different users is increasingly intense, delivery systems are aging and in need of expensive repairs and renovation, externality problems are getting urgent and social costs of subsidization are high and even rising. Due to this changes the value of water increases and benefits can be achieved by reallocating water resources. In the mature phase of the water economy supply management transformed into demand management.

Putting more emphasis on demand management does not mean that supply management should be totally ignored. According to Alfred Marshal who is cited by Winpenny (1994), '*supply and demand are the two blades of a pair of scissors*'. In many situations new supply schemes have to be introduced, but it is always important to take the demand management policies equivalently into account in order to avoid the mistakes from the past, where supply side approaches dominated water resource practices (FAO, 1995).

In the following sections different policy measures for tackling the problem of water scarcity are described. The focus is put on the demand management side because this is where efficiency improvements through economic instruments can be achieved.

4.3 Different policy measures: an overview and criteria

Based on Rosegrant (1997) and Winpenny (1994) the following scheme of policy instruments for managing the demand of water has been developed.

Table 4.1 Different policy measures for water management

Enabling conditions (4.4)	Market-based incentives (4.5)	Non-market-based incentives (4.6)	Direct interventions (4.7)
Institutional and legal changes Reform of water rights Privatization of utilities Macroeconomic and sectoral policy	Pricing reform (4.5.1) Tradable rights and Water markets (4.5.2) Effluent or pollution charges (4.5.3) Water banks (4.5.4) Auctions (4.5.5) Subsidies (4.5.6) Taxes (4.5.7)	Restrictions (4.6.1) Quotas and Licences (4.6.2) Public information and education (4.6.3)	Conservation programs Leak detection and repair programs Water efficient user appliances Industrial recycling

Source: Winpenny, 1994; own adaptations.

Before describing especially the market and non-market based policy measure in detail it should be mentioned that a certain instrument does not have to be taken as a single choice. Anderson et al. (1977) brought up that any environmental control strategy has to be concerned about conflicting interests in society and has to be aware of the ups and downs of a modern mixed economy. Every control strategy can therefore be subject to criticism for many reasons. Bressers (1989) recommended that instruments should consider the purposes, the information and the power of the government agency and should regard the addressed target group. They are only able to contribute to a better environment if they are adjusted to the circumstances under which they are applied. The different instruments are therefore not different option but have to be combined to reinforce each other. This implies that an optimal policy mix has to be constructed conforming to the particular circumstances and economic situations in the various countries, such as the level of economic development, institutional capability, relative water scarcity and level of agricultural intensification (Rosegrant, 1997).

Furthermore there are some criteria that have to be taken into account while choosing the best way of water planning (Winpenny, 1994).

Efficacy/effectiveness

This criterion can be seen as the elasticity of response to different instruments. A combination of measures, such as higher charges joined with campaigns of public information and education and subsidies for the introduction of water saving technologies, will be in most cases the most effective.

Efficacy is associated with the criterion of acceptability (which will be discussed under point 7 in this section) because policy measures will have the highest pay-off if society accepts them.

Economic efficiency

For a policy measure to be efficient it is required that its discounted economic benefits exceed its discounted costs. The efficiency principle was already discussed in 2.2 but it is worth to mention again that the re-allocation among users such that water moves to higher-value uses is essential to gain an optimal solution.

Equity and distributional effects

Equity can be reached in an undistorted market through trading from lower to higher-value applications. As soon as the market gets distorted through for instance subsidized inputs or protectionism in crop prices, equity is not guaranteed any longer. Instruments should be fair with respect to their impacts on the various socio-economic groups. It is often recognized that groups with less influence get low priority in the provision of public water services. The equity criterion is often contradictory to the economic efficiency criterion, which is only concerned with the magnitudes of benefits and costs and not their distribution (Colby Saliba, 1987). Although, in theory, efficiency improvement through reallocation should lead to a higher net social benefit, some groups that do not have anything to trade with (money, water rights, political power and legal power to impose transaction costs) will suffer losses if no compensation payments are taking place.

Colby Saliba (1987) also enters upon third-party impacts, instream flow uses and water quality considerations. She argued that policies that take these features into account are indubitably expensive and their costs must be deliberated against the value of what these particular policies want to achieve. However, the valuation of consumptive uses is much easier than evaluating instream flows and quality changes and policy makers incline to favor water uses whose values can be easily assessed.

Public health and nutrition

The World Bank warned that over one thousand people are in need of safe water supply and proper sanitation (FAO, 1995). Hundreds of million of people who suffer from intestine diseases due to lack of hygiene would benefit if a general improvement in water supply and sanitation would take place. Especially in developing countries where the infrastructure of the water system is not as obvious as in the developed (industrialized) countries, this criterion is very important.

With respect to the national nutrition level in developing countries, it could be well advised to introduce policy measures supporting local irrigated farming in order to enhance food security of the local population.

Environmental impact

Consideration of the environmental criterion got more importance in the recent years only. The increasing significance of environmental impacts is the reason why demand management measures are getting more popular. They reduce the environmental costs arising from the development of supply projects, which used to be favored in water management decisions.

Fiscal impact

It is beyond question that every policy measure should have a positive net impact on the finances of the central or local government, the water utilities and the irrigation agencies. For instance, positive effects such as taxes, higher water prices and charges should more than outweigh negative effects such as subsidies or tax relief.

Political and public acceptability

As already mentioned under 1) acceptability is combined with efficacy. The factors that determine acceptability are the distribution of costs and benefits, the severity of the problem, the educational level of the population, the role of prominent political and community figures and the readiness for behavioral change in society. A policy measure that gets support from the target groups involved is more likely to be implemented than one that run into severe resistance of the affected parties.

Sustainability

The most sustainable policies are those that have an increasing positive long-run effect. They consist of elements that reinforce each other such that their impact is continuos and growing over time.

Short-term measures have a strong instantaneous effect. They are introduced in a case of emergency such as a drought when quick action is required. They loose their impact when emergency is over.

Administrative feasibility

This criterion refers to the government's capability to administer, enforce and monitor its chosen policy measure. In the case of water pricing for instance, it has to be kept in mind that it requires quite a lot of staff and organization that is connected with the metering and the collection of revenues. Moreover, there must be a willingness and ability to prosecute non-payers.

Macroeconomic environment

Agricultural and food policy measures on macroeconomic level can be supporting as well as discouraging for water conservation policies. If, for instance, prices of water intensive crops are subsidized and protected, it will be more difficult to let farmers' behavior change towards crops that use water more efficiently. Therefore, liberalization could have in many cases a positive effect on water policies.

4.4 Enabling conditions

The term 'enabling conditions' or 'enabling environment' describes the creation of a general basis for encouraging a more economically rational use of resources through a change in the institutional, legal and economic framework within which this resource is supplied (Winpenny, 1994). According to Young (1986) the surrounding circumstances should not be underestimated. He proclaims that the choice of institutions to co-ordinate economic activity is among the most fundamental of social decisions.

Enabling conditions build in most cases the conditions that are necessary for the introduction of other instruments. For instance, in the literature about the introduction of water markets in several countries it becomes obvious that the government has to check in what way its new policy conforms to the existing legislature and to what extent a law making process has to be carried out. Some examples of legal issues that are important for water markets are the security of water rights, certain rules in case of a conflict, the question whether water rights may be transferred separately from land, or the management of third party effects, which are return flows, changed groundwater levels and changed water quality (FAO, 1995). A further explanation of water markets can be found below in section 4.5.2.

Since water supply systems have a high fixed-costs-component, they have the characteristics of a natural monopoly and are therefore predestined to be in public hands. However, different forms of privatization of which total private ownership is the most extreme one are alternatives to increase efficiency. An often-used example of privatization is the French water sector (Dijkgraaf et al., 1997). In the French model two different forms of contracts between the authority and private firms exist. One is the *lease contract* where only the operational tasks such as extraction, purification, wastewater treatment and discharging are privatized but the waterworks system and the installations are still property of the authority who is also responsible for necessary investments. Lease contracts are short-term contracts and are the most common.

The other form is called *concession contracts*. They are long-term contracts and are more rare than lease contracts. They can last up to 50 years and the private company is fully responsible for maintenance and investments. After expiration of the contract all property rights go to the government and the private owner gets a compensation payment if the investments are not depreciated. A reason why these contracts are less frequent is that they can only be done when new installations or waterworks systems have to be built. A major disadvantage of this system is that the controlling and regulating parties are widely spread over different levels of administration, such that the introduction of country wide standard regulations as, for instance, prices or environmental issues, might cause some problems with respect to organization and costs.

4.5 Market-based incentives

4.5.1 Pricing reforms

As already mentioned in section 3.4, a marginal cost pricing system would contribute to an efficient allocation of water. The introduction of marginal cost pricing implies that users have to pay a higher price, which is also reflecting opportunity and social costs. The effect of a price increase on water demand depends on its price elasticity. Pricing measures can only have a positive influence on water conservation if the elasticity of demand is significantly different from zero and negative. Several estimates about price elasticities can be found literature and it becomes obvious that they vary widely according to sector (industry, agriculture and municipalities), utilization (indoor or outdoor), country and season (Gibbons, 1986; OECD, 1987). They are mainly situated in the inelastic range of the demand curve, which means that they have values between zero and minus one. It is a wide spread opinion that the pricing instrument is not very effective because of the low price elasticity water demand, which implies a minor response to price changes. For example, Martin and Kulakowsi (1991) conclude on the base of an empirical research on urban water use in Tucson, Arizona, that the water price would have to be raised by the rate of inflation plus the rate of change in income each year if water use were to remain constant instead of increase. The problem with their argument is that it is based on estimations calculated from existing water prices, which are obviously too low. Estimation based on higher prices that reflect the real costs of supply, would probably show that the demand curve would become more elastic.

In order to be able to register and control consumption of the different users an essential condition for water tariffs being a successful instrument for water conservation is metering. Young and Haveman (1985), refering to estimates of Mexican irrigation water of Schramm and Gonzales and of urban water use of Hanke and Gysi, point out that the introduction of a metering system combined with volumetric charges has significant impacts on consumption. A similar result is found by the OECD (1987) in its examination of pricing of water and related services, which declares that the introduction of volumetric charges create notable reductions in demands and consequently economic and environmental benefits. However, the OECD (1987) concludes that the final decision of introducing a metering system will depend on its costs and benefits. Therefore the OECD introduced in the same publication a metering decision rule:

The costs of metering (M) consist of the provision of the installation, the maintenance and the additional reading, billing and collection costs on top of the existing charging system. It is assumed that consumers reduce their water use as a consequence of metering. Therefore, another cost component is the value of consumption of water forgone (U), which is equal to the area under the demand curve. The benefits (B) are calculated by means of the annual reduction in water demands by the users (R) multiplied by the marginal costs of supply and disposal (C). Furthermore it is assumed that metering of all users will provide useful information with respect to the improvement in demand forecasting and wastewater reduction techniques (I). With these variables the metering decision rule can be defined:

$$M + U < B + I \qquad (4.1)$$

Where: $B = R*C$

Obviously, it will be worth to introduce metering if its costs plus the forgone benefit of water consumption are smaller than the benefits plus the value of the additional information. By means of the metering decision rule the influence on the water-planing criterion of *fiscal impact* can be calculated.

With respect to *equity* the pricing instrument can be approached from two sides (OECD, 1987). On the one hand metering is recognized as fair because everyone pays exactly the amount that he/she used. On the other hand it is criticized that poorer members of the society are at disadvantage because they have to spend relatively more of their income on water, which is, as stated by the United Nations, a basic need and everyone should have the right to its provision. To guarantee *equity* it is important to develop a charging system that considers income classes, disadvantaged regions and user categories (OECD, 1987). The danger of the complexity of such a charging system is that it may become too difficult for consumers to understand. This may have consequences on *public acceptability* with negative effects on the *effectiveness* of price measurements.

Without a doubt, the introduction of an effective metered charging system needs a lot of research, planning and investment. But for an efficient market where prices are supposed to be a signal of real scarcity, the effort that has to be made in the beginning will be worthwhile in the future.

4.5.2 Tradable rights and water markets

Tradable rights and water markets emerged in areas where water scarcity became very severe and new supplies were not so easy to discover. A fair amount of literature is published on this topic of which most cases are situated in the southwestern part of the United States, Australia, Chile and the Middle East. Becker (1995) reports from Israel that the stimulus to introduce a water market arose from the fact that investments in institutional changes that are necessary for a proper functioning of the market appear to be cheaper than investments in developing new supplies such as import or desalination installations. The most important condition to be introduced for a successful working of a water market is that property rights are secure and well established (Gazmuri Schleyer and Rosegrant, 1996).

If water becomes a marketable good, a transfer of water from lower to higher value application will be set in motion. It will stop if the marginal benefit of all applications is equal. This mechanism is illustrated in figure 4.1.

Say that the total amount of water that can be traded is 1,000m^3 and that the initial distribution of water rights is set at point I, where user A owns 300 units of water rights and user B owns 700 units of water rights. In this situation the marginal benefit of user A (λ_A) exceeds the marginal benefit of user B (λ_B) by the distance λ_A-λ_B. If B offers A one more unit of water rights at a price that is higher than λ_B but lower than λ_A, both users would gain. A would gain the difference between its own marginal benefit curve and any price between λ_B and λ_A. The same counts for B. This procedure can be continued until point E is reached where marginal benefit of A and B are at the same level. E is also the point where joint benefit of both users is maximized. In the initial situation A's total benefit is the quadrangle a-b-I-c, B's total benefit is the quadrangle d-f-g-I and joint total benefit is the area a-b-d-f-g-c. Moving towards the optimal situation at point E let joint benefit increase by the shaded triangle b-E-d.

In this simple example with only two participants overall benefit can be maximized by trading. In reality, however, it is often criticized that water markets will have negative effects on third parties. The problem of the third party effects was already taken up while discussing the *equity* criterion. It is remarked that instream uses that are difficult to evaluate are often neglected because its interest groups do not have enough purchasing power.

Gazmuri Schleyer and Rosegrant (1996) who investigated the Chilean water market demonstrate an example of a good functioning water market. They emphasize that the positive picture of the Chilean water market owes much to its legal and institutional framework. It is found that there are strict laws for the protection from adverse third-party effects, for water user organizations and for solving conflicts if these cannot be solved by the organizations themselves. Another success supporting item is the decoupling of water from land. This regulation makes it possible for the farmers to sell water to urban users. This is a quite lucrative trade for the farmers and it stimulates them even more to increase efficiency in their production processes.

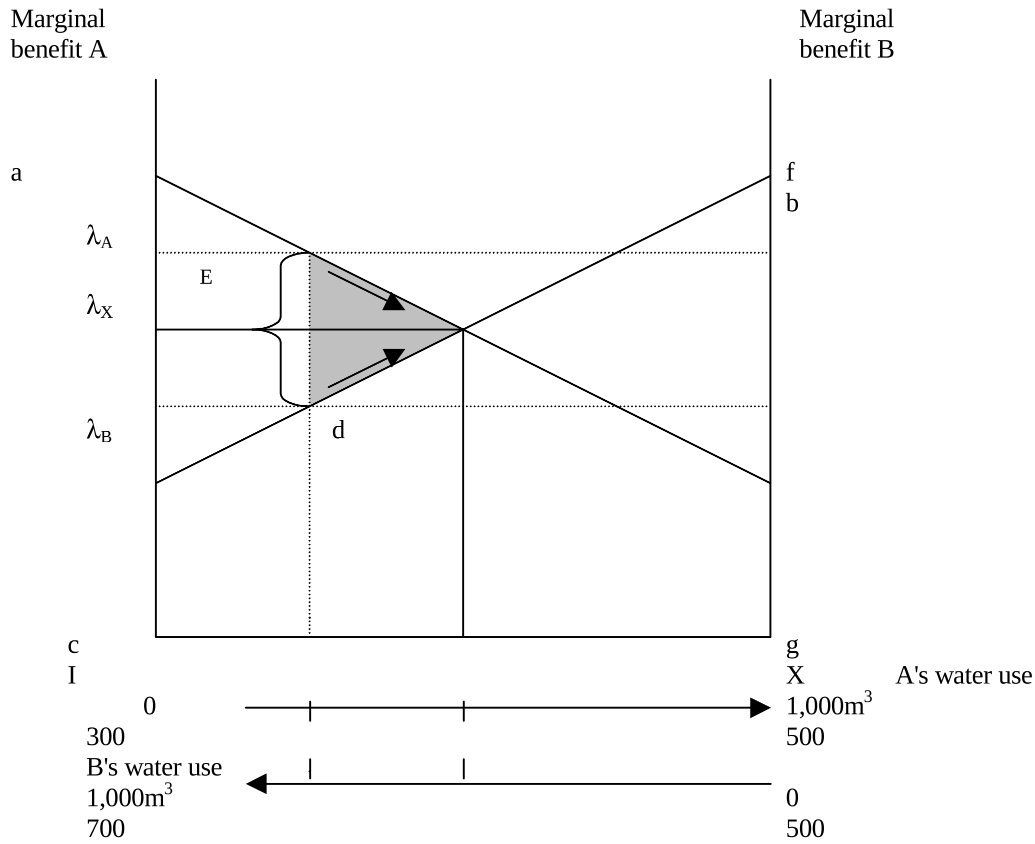

Figure 4.1 The mechanism of tradable rights
Source: Perman et al., 1996, adapted to water rights.

Because of the fact that water is a heterogeneous good, water markets have to be diversified with respect to different qualities and different purposes of use. Spulber and Sabbaghi (1994) state that water can be seen as a group of differentiated products for different purposes traded in different markets at different prices. Such a system would give complete information to all market participants and authorities. Colby et al. (1993) also enters upon price dispersion in water markets. On the base of empirical analysis they conclude that the price of water rights additional to the heterogeneity criterion is closely related to the geographic area and the characteristics of the local market, the size of the transaction, the number and size of potential traders and the information and searching costs that are involved in the transaction.

The high demand for regulatory and administrative institutions is often criticized to be a major disadvantage of water markets. However, if a supporting institutional framework is guaranteed, water markets with secure property rights can be a good approach to achieve an efficient allocation and to stimulate investments in water-saving technologies (Gazmuri Schleyer, Rosegrant, 1996).

In order to bring water markets into line with modern forms of communication, internet and e-mail can surly not be left out of consideration in the future. Olmstead et al. (1997) report about the application of WaterLink, the first electronic water market system. This pioneer system has been established in the Westlands Water District in California and it enables water users to buy and sell water rights with their home computers. WaterLink contains weekly and seasonal market statistics on the number and volume of transactions, the average trading price, rainfall summaries and water storage levels. Olmstead et al. conclude that electronic water systems will definitely improve the efficiency of water markets because they are able to reduce the high information, searching and negotiation costs that are often criticized as being a major obstacle in water trading.

4.5.3 Effluent or pollution charges

Although this instrument is actually placed in the category of water quality improvement it also has influence on the quantity of water used. Effluent and pollution charges are imposed to internalize the costs arising from the environmental damage caused by the discharge of (industrial) wastewater. If these charges are set high enough, industries are encouraged to invest in their own wastewater treatment and recycling plants in order to reduce costs. Recycling and reuse of wastewater consequently implies that the demand for fresh water decreases. If this measure were combined with higher water prices for industries or subsidies for the installation of recycling plants the incentive to reuse wastewater would be even stronger. It should be mentioned that attention should be paid to the distribution of subsidies. In some cases subsidies could cause inefficiently working companies to stay in business. (More about subsidies can be found in section 3.4.6.).

4.5.4 Water banks

A bank is an institution where goods that are abundant at present can be stored for future use. Water banking in its simplest form means that surface water that is not needed now is conducted to an area where it can percolate to recharge an aquifer. In times when surface water is scarce this groundwater can be pumped up again in order to meet demand (Winpenny, 1994). The most mentioned example of water banking is that of the establishment of a water bank in California in 1991 as a consequence of the latest drought where the state had the major responsibility for water transfers. According to Keller et al., who is cited by Winpenny (1994) a water bank is an effective short-term emergency instrument. The long-term effects of water banking are not very clear because there is not yet enough experience in this field. The observations made in California show that next to the state-controlled water banks there are also a lot of private-controlled water transfers taking place which may appear to be more appropriate ones (Isreal and Lund, 1995).

Using water banking as an instrument against desiccation is dubious because it implies that non-local water is infiltrated into a groundwater aquifer whose water may have different characteristics.

4.5.5 Auctions

Water auctions are not very common. Some examples can be found in the USA (Victoria State), Spain and Australia (Winpenny, 1994). It is exclusively used for the distribution of water among farmers. For an auction to be sensible it is necessary that the water under consideration is fully controlled by the water authority and that no other users can dispose of it. In an auction a minimum price is established and subsequently the person who can bid the highest price for a specific amount of water will have it at his/her disposal. Theoretically, this mechanism could lead to an efficient allocation of that water but in practice it is often realized that part of the bidders made engagements with each other beforehand such that the allocative mechanism was undermined by monopsonistic behavior (Winpenny, 1994).

4.5.6 Subsidies

In the framework of water management measures there are two ways of dealing with subsidies. Firstly, there are the subsidies on water consumption that fail to give a clear sign of real scarcity to consumers with the result of excessive consumption and secondly there are the subsidies that intent to support firms in the investment of water saving technologies. Beyond dispute, the subsidies in the first case have a negative effect on an efficient allocation of water. Subsidized water can be found in all user categories. Especially in developing countries the basic-need criterion of water causes that municipal water facilities are highly subsidized, such that water can be provided at a lower price. Subsidized irrigation water in agriculture leads to uneconomic applications on low value crops and it raises the possibility that farmers irrigate just to calm their conscience. This fact will be supported if recent investments in irrigation installations with high fixed costs have been made and variable costs are low due to the subsidization of water.

The second application of subsidies is a bit ambiguous. On the one hand they are supposed to have a positive effect on water conservation because they should encourage firms to invest in water saving technologies (including wastewater treatment facilities for recycling and reuse as mentioned earlier). On the other hand there is also substantial criticism attached to this kind of subsidies. Baumol and Oates (1975) point out that uncontrolled granting of subsidies would attract new firms into a business which would more than off-set the reduction of water use that is attained by single firms. Another item is noted by Hommes and van 't Hof (1989). It describes that the subsidized technologies are in many cases end-of-pipe technologies that only shift the environmental problem to another level. In the example of waste water treatment plants, unwanted substances are accumulated in the sludge. Instead of investing in end-of-pipe technologies, more effort should be spent on solutions that try to avoid environmental problems before they actually arise. This notion is also remarked by Anderson et al. (1977). They said that if there were no subsidies to support the improvement of process related innovations, investment decisions of firms would tend to be in favor of wastewater treatment facilities only.

However, it cannot be concluded that subsidies in water management should not be introduced in general. It is only a warning that attention has to be paid to the negative side effects that can come up if a subsidy scheme is not well planned and difficult to control.

4.5.7 Taxes

As already stated in section 3.3, taxes have to be levied for equalization of social and private marginal costs in order to internalize external effects that arise from water use. The optimal tax level can be added to figure 3.3, which is depicted in figure 4.2.

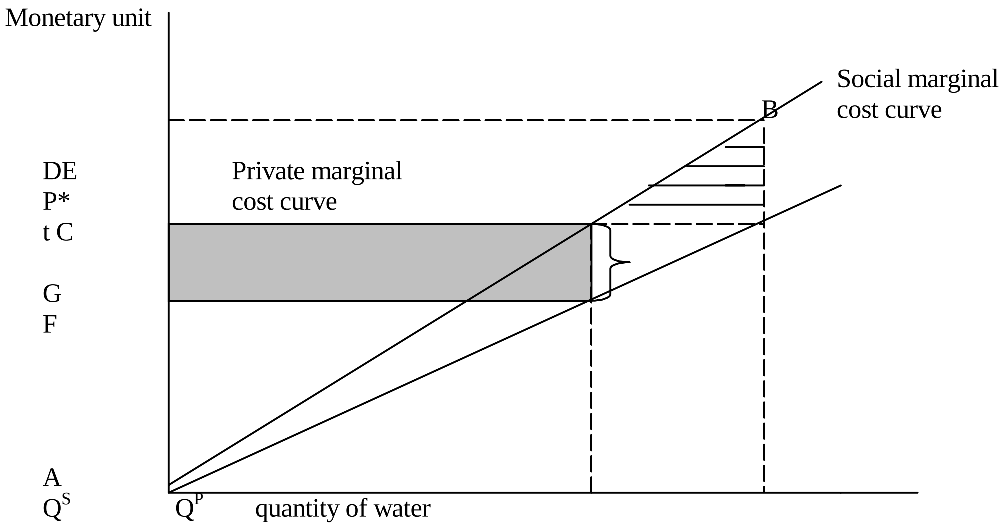

Figure 4.2 Social and private marginal costs and the optimal tax level

At the existing price P*, the distance t is the optimal tax level because this amount has to be added to private marginal costs to incorporate social marginal costs. The tax revenue that is received by the government is equivalent to the shaded rectangle D-E-F-G. Originally, the costs that had to be borne by society were shown by the triangle A-B-C. After the introduction of the tax these costs are internalized. The remaining area E-B-C-F can be divided into two parts: one is the triangle E-C-F that describes part of the forgone benefit to the private producer and the other is the striped triangle B-C-E that expresses social welfare gain.

The theoretical framework of the optimal tax level is clear but some difficulties emerge if a proper tax level has to be determined in reality. In most cases it is hard to attach an objective monetary value to the damage arising from the excessive use of a natural resource. The perpetrators of the exernalities usually evaluate the damage less severe than other interest groups. Whether the imposition of a certain tax is accepted by the society, depends heavily on the group that managed to have the most influence.

4.6 Nonmarket-based incentives

4.6.1 Restrictions

A common situation in which restrictions are imposed is at times of unusual dry periods such as droughts or seasonal water shortages. The restrictions may consist of prohibiting irrigation, municipal outdoor uses (lawn sprinkling or car washing) or of industrial production constraints. A major disadvantage of this instrument is its dependence on monitoring and execution, which may turn out to be too expensive. In cases where the administration is subject to corruption and bribery performed by bulk users even more pressure is put on small-scale users. A restriction scheme can only be successful if it is fair to all groups of the society and the need of it is clear to all consumers.

4.6.2 Quotas and licenses

Quotas and licenses are based on quantity control. They are divided among different users with the intention to allocate a restricted amount of supply in a most efficient and equitable way (Winpenny, 1994). Penalties have to be introduced for those users who exceed their assigned quota. This, in turn, means that it is dependent on monitoring and control.

There are different ways to determine the distribution of quota among the different users. Rosegrant (1997) mentions two possibilities: firstly the assignment of the quota in proportion to the water that was extracted by each users in a certain base period and secondly, in the case of groundwater extraction in agriculture, the appropriation on the base of the land that is owned above an aquifer.

According to Arlosoroff who is cited by Winpenny (1994), quotation and licensing attained great success in the Israeli industrial sector. Within 20 years, between 1962 and 1982, the average water consumption (per unit value of output) was reduced with 70%. In that case, the quotas are delivered according to the norms of the best-practice technology in combination with the specific circumstances of each firm.

4.6.3 Education and persuasion

It is doubtful whether the instrument of education and persuasion has influence on consumer behaviour if it is introduced on its own. Winpenny (1994) notes that it could be used as an announcement for a price increase to 'soften up' consumers. Martin and Kulakowski (1991) concluded on the base of an empirical research on urban water use in Tucson, Arizona, that without an increase in price at the same time, information and education do not seem to have a significant effect on water consumption.

Nieswiadomy (1992) found a positive effect of education programs, conservation and education on urban water demand in the United States. His calculations show that only in the West, public education has a significant effect on the reduction of water consumption but not in other parts of the country. As a possible explanation of this phenomenon he mentions the already existing awareness of water scarcity in the West which makes education programs more effective.

4.7 Direct interventions

Measures of direct intervention can have a supporting and reinforcing effect in combination with the other economic instruments discussed above. In the case of direct interventions the government plays an active role in the development and execution of the programs, whereas in the case of market and non-market based instruments its main duty is to build a suitable framework in which the individual users behave in their own best interest (Winpenny, 1994). For instance, conservation programs, water efficient user application and industrial recycling projects are useful if they are introduced together with price increases because it makes users more aware of the possibilities of saving water.

Important direct intervention measure are leak detection and repair programs. The costs of these measures are rather high and an involvement of the government is hence necessary. Especially in developing countries technical losses due to leaks and deteriorated infrastructure can be quite substantial, such that the costs of the programs are lower than the value of the water saved and lower than the costs of the creation of new supplies (Winpenny, 1994).

Another typical situation for a direct involvement of the government is in cases of emergency such as droughts or floods. These measures are mainly short-term interventions and will stop when the state of emergency is over.

4.8 Conclusions

Chapter 4 presented several economic instruments that are supposed to stimulate a more conscious use of water. It is striking that most of the examples of economic instruments found in international literature stems from arid regions where absolute water scarcity is evident and where water is the limiting factor. Knowing Dutch weather conditions and Dutch history that is characterized by fighting against water for land reclamation it becomes obvious that absolute water scarcity is not the actual problem in the Netherlands. The effort that is put in getting rid of water proves that water in general is abundant in the Netherlands. The basic problem lies in the minor quality of surface water, which implies high costs for its treatment and purification. Minor quality of surface water entails that good quality groundwater is used for low-value applications such as the irrigation of grassland. This indicates that the quality and quantity of water is closely related to each other, which means that research on the quantity of water should necessarily take quality issues into account as well.

The following chapter will discuss the applicability of economic instruments to the Dutch situation with special attention to desiccation.

5. The applicability of economic instruments to Dutch water management

5.1 Introduction

This chapter gives a first attempt of testing economic instruments for the application to Dutch water management with special attention to the desiccation problem. The main focus is put on the instruments that belong to the market-based incentives as it is categorized in the previous chapter. Five instruments have been selected from market-based incentives, namely prices, tradable rights, effluent charges, subsidies and taxes. One instrument has been selected from non-market based incentives, namely restrictions and quotas. The selected instruments have been tested with respect to the following criteria: *Effectiveness, equity, acceptability, financial impact, controllability, interregional applicability, behavioral changes* and *environmental impact*. The interpretation of these criteria is given in section 5.2.

The desiccation problem is an important reason why the water issue has become a hot topic in scientific as well as in administrative circles and a lot of effort is put into research about the clarification of all connections and interrelationships within the complex system of ground and surface water. Knowledge of the actual reasons for desiccation is imperative for the effective application of economic instruments. Since these reasons are rather diverse and can differ locally as mentioned in chapter two, there cannot be one overall solution to the problem. The economic instruments as they are found in international literature focus mainly on the extraction and use of water. However, a reduction in extraction and use of water is only on some specific places an adequate contribution to a reduction of desiccation and hence not the main strategy for mitigating the problem. This does not mean that no attention should be paid to the extraction and use of water in the Netherlands. As mentioned above high-quality water is not at all abundant in the Netherlands. Within the framework of the sustainable economy target of the Dutch government, water savings and a more conscious use of water are binding.

Since 60% of the desiccation problem is caused by the 'improvement' of the drainage system, the question arises if the selected economic instruments are also appropriate for managing the hydrological system. Managing the hydrological system means influencing the groundwater table by rearranging the surface water system such as reducing drainage capacity, building controllable barrages or reducing the depths of ditches. Section 5.4 presents the test of the selected instruments on hydrological measures. Finally, section 5.4 gives some concluding remarks.

The testing has a rather general character. The impact on the tested criteria depends on many conditions and circumstances, which certainly need further investigation. This could not be carried out due to the time constraint of this project. The test results indicated in the tables are hence open to debate.

5.2 Interpretation of criteria

The tests have been carried out with the aid of (+, -)-tables with five different categories. '+ +' stands for a definite positive impact on the respective criteria, '+' stands for positive impact, '- -' stands for a definite negative impact and '-' stands for a negative impact, '+/-' indicates the possibility of positive as well as negative impact. '+(-)' [-(+)] means a mainly positive [negative] impact with negative [positive] exceptions.

Effectiveness

This criterion indicates to what extent the introduced instrument can reach its objective or the response of the affected parties to the introduced instrument. '+' notes that the instrument definitely reaches its objective and '-' notes that the instrument is less effective.

Equity

This criterion shows if the (financial) impact of the introduced instrument on the affected parties is balancing. '+' means that the instrument is fair towards all effected parties, whereas '-' means that the instruments is advantageous for some special parties and disadvantageous for the other parties.

Acceptability

This criterion shows if users accept the implemented instrument. '+' notes that they accept it and '-' notes that they do not accept it.

Financial impact

This criterion is subdivided into users, water company and administration for the test on extraction. Financial impact means the costs (-) and incomes (+) that occur to these different parties by implementing the instrument.

Controllability

This criterion indicates the effort that the supervising agency has to put into controlling the respective instrument and the actions of the users. Controllability includes also sensitivity to fraud. '+ ' means that the instrument is easy to control and hence not sensitive to fraud. '-' means that controlling the instruments is more complicated and committing fraud becomes easier.

Interregional applicability

This criterion signifies if it is possible and useful to implement an instrument nationwide. '+' means that it is applicable nationwide and '-' means the opposite.

Behavioral changes

This criterion indicates if the respective instruments induce changes in the use patterns of the water user (e.g. reducing the time for showering from 10 to 5 minutes). '+' notes changes and '-' notes no changes in behavior.

Environmental impact

Obviously, this criterion focuses mainly on the instruments' impact on the reduction of desiccation. '+' notes a significant contribution and '-' notes no significant contribution to a reduction of desiccation.

5.3 Application of instruments to extraction

The parties that are taken into account for water use are households and agriculture. Agriculture can directly extract groundwater, whereas households can only buy water from the water company. Since the water use pattern of these parties are rather different, they are tested separately. The (+, -)-tables are placed as a summary at the end of the section. It has to be mentioned that the industrial sector also extracts large amounts of groundwater, which is on some specific places a major cause of the desiccation problem. Due to time constraints, industries had to be left out.

5.3.1 Prices

At present, prices for drinking water vary widely from region to region in the Netherlands. The differences in prices are caused by the of use surface water as a source for drinking water in some regions. The use of surface water entails higher costs for both transport and treatment. Consumers in different parts of the country have therefore different expenses for water services. In the frame of anti-desiccation projects the objectives of Dutch water supply companies is to use more surface water instead of groundwater all over the country. This implies that the water prices in the regions with groundwater as main supply for drinking water will rise and hence may approach the same level as the water prices in regions where surface water is used already. The prices for drinking water from groundwater do not include the external costs that arise through desiccation. If these costs would be internalized into the existing costs of supply, the price for drinking water from groundwater would rise as well.

Households

The *effectiveness* of the price instrument depends on the price elasticity of water demand because it shows consumers' response to price increases. The price elasticity of water use in Dutch households has been estimated by Kooreman (1993) and Linderhof (1997). Kooreman found a value of -0.10 with a significance level of 90% at a water price of 116 ct/m^3. Linderhof's result is a price elasticity of -0.7 with a significance level of 95%. Although these estimations are rather low, they could have a substantial effect in physical terms. Linderhof gives an example. He illustrates that a 10% price increase of the average water price of 135 ct/m^3 would (with the average water consumption of 130m^3 per capita per year) result in a reduction of water use of 0.91m^3 per capita per year. According to the studies by Kooreman and Linderhof, there are some indications that the price instrument could have a positive influence on the reduction of water use in households.

The price instrument requires metering. According to the VEWIN (information supplied by telephone) the metering percentage in the Netherlands will reach 100% in the next few years.[1] *Interregional applicability* is hence guaranteed.

A price reform that encloses an increase in prices due to the substitution of groundwater by surface water and due to the internalization of external effects gets a high score concerning *equity*. Firstly, with respect to the equalization of the price differences, secondly, with respect to nature, that presently has to suffer losses due to groundwater extraction activities and thirdly, as a result from the previous point, with respect to society that has to bear less costs for anti-desiccation activities. Furthermore, a metered system makes sure that everyone only has to pay the amount of water that he actually consumed. A fair instrument will also be widely *accepted*. Exceptions may be found in areas where users have to pay their water use according to the number of taps. A payment according to liters used would entail a significant increase of the water bill.

The *financial impact* on users is negative. (Water saving activities that might be carried out as a reaction to higher prices might have a compensating effect. This implies that the water bill might reduce again to its original level or even to a lower one.) Water companies have a positive financial impact because of increased incomes.

Provided that the water meters are sealed such that it is not possible for the users to manipulate the counter, the price instrument is not sensitive to fraud and easy to control.

Behavioral changes means in what way consumers consciously change their use patterns. If it is noticeable on the water bill that fair amounts of water can be saved with the help of water saving technologies only, behavioral changes might not be significant. People that cannot afford water saving technologies have to change their behavior towards water use if they want to see a positive effect on their water bill.

The extraction of groundwater for domestic drinking water use causes only 10% of the desiccation problem. A reduction in domestic water consumption has therefore only a minor effect on the reduction of desiccation and hence a minor *environmental impact.*

A positive side effect of a reduction in domestic water consumption is a reduction in energy use. Energy is saved because half of the water that has been saved would have been heated and also does not need to be transported by the water company.

[1] Big cities that have to been metered in the past years are Groningen, Rotterdam and Amsterdam. The city of Groningen just finished the installation of water meters in all households. In Rotterdam, the installation is in progress and in Amsterdam it is just starting.

Agriculture

The testing for agriculture is based on the current situation, which means that farmers are still allowed to build their own wells.

Up to now, in the agricultural sector a pricing reform had an adverse effect. A raise of the water price entails that farmers build their own wells instead of buying water from the water company. Van Staalduinen et al. (1996) report advantageous points for farmers to build their own well. Firstly, the costs that are occurring to the farmer include only the investment costs of the well and a groundwater tax of 0.17 guilders per m^3 (water companies have to pay a groundwater tax that is twice as much, namely 0.34 guilders per m^3). Secondly, private persons only have to register if the extraction capacity of the well exceeds $10m^3$ per hour. Thirdly, farmers are released from groundwater taxes for the first $40{,}000m^3$ groundwater per year that are used for irrigation. Fourthly, a nil-tariff has to be paid if the extracted groundwater infiltrates back to its original water system.

Water consumption might increase because the investment in the well needs to be earned back. *Effectiveness* is therefore not guaranteed in this case and the *environmental impact* is negative as well. If farmers can avoid paying higher prices for water, they do not have any incentives to change their behavior towards water use.

A higher price for water is not *accepted* among farmers. Otherwise the increasing amount of private wells cannot be explained.

The *financial impact* for farmers is positive because the extraction from a private well is cheaper than buying water from the water company. The *financial impact* for the water companies is hence negative, firstly, because of reduced revenues and secondly because of the occurrence of costs due to overcapacity.[1] Costs are also occurring to the administration because of increasing requests for private wells.

For a successful implementation of the price instrument in agriculture, legislation concerning the building of private wells has to be changed beforehand. If it stays possible for farmers to avoid paying higher prices for water, they do not have any incentive to think about saving activities.

5.3.2 Tradable rights

The tradable rights that are meant here, are tradable rights for groundwater extraction. Since households do not extract themselves it is not applicable in this case.

Agriculture

The following situation is assumed:

- the farmers are situated in the same area, in which their extraction activities have a negative impact on the nearby natural area. (Hence, no *interregional applicability*);
- trade can take place between farmers;

[1] Due to the increasing amount of private wells from farmers, the annual sales of water companies in the province Limburg have decreased with 8% in recent years (Intermediar, 29-09-1997).

- trade can also take place between the administration and farmers. The administration in this case represents interests for nature conservation. In the frame of an anti-desiccation program the administration can buy groundwater extraction rights in order to keep farmers from extraction;
- the price the administration pays to the farmers is high enough to compensate farmers for possible damage to crops due to lack of irrigation.

The mobility of the water market depends much on the farmers' attitude towards risk. Farmers are not likely to sell their water rights to other farmers if they do not want to run the risk of too much damage to their crops in cases of droughts. If the administration decides to buy groundwater extraction rights, it can be effective for a reduction of desiccation. The problem of how much the farmers will receive as compensation (the price for the water rights) can be big. Costs for administration are quite high in any case. Firstly, because they have to buy rights if groundwater extraction by farmers has to be reduced. Secondly, because the introduction of water rights requires a lot administrational work, which includes also that all farmers have to be controlled if they actually extract the amount that they are entitled to by their rights only (negative score on *controllability*).

This measure can be summarized as being effective with a positive environmental input at high costs for administration.

5.3.3 Effluent charges

Households

Effluent charges have an indirect effect on water use. In order to make consumers conscious of the connection between use of drinking water and effluent charges, the Dutch water sector is discussing the introduction of the so-called 'Waterspoor'. 'Waterspoor' implies that the sewage charges are paid as a percentage of drinking water use. In this way users have more influence on sewage charges and water bill. A reduction in water use has therefore a double saving effect, which probably makes this instrument especially efficient. A variation of 'Waterspoor' is the broad 'Waterspoor', which includes also purification taxes in the charging system. Estimations hint that 20% of present drinking water consumption could be saved by introducing the broad 'Waterspoor' (Kiewiet and Van Dam, 1998). The broad 'Waterspoor' is in fact a policy mix of pricing reforms, sewage charges and taxes. It is a promising move towards users' involvement into the working of the water chain and their alerting about the increasing scarcity of good quality fresh water. This could entail *behavioral changes*. 'Waterspoor' is a rather new item in the water sector and acceptability and income effects on users has not been tested yet. If policy makers succeed in giving clear and understandable information about the tariff structure in 'Waterspoor' to all users, *acceptability* can be high because users realize saving potentials in their water consumption.

The other criteria are comparable to the price instrument.

Agriculture

Effluent charges for farmers are not likely to have the same effect as for consumers: only a small part of the water used by farmers is discharged as effluent into the sewage system. Therefore this measure has limited applicability.

5.3.4 Subsidies

Households

It is assumed that subsidies for households are realized by low prices for water saving technologies, such as water saving shower heads, toilet flushing systems, washing machines etc. It has to be mentioned that subsidies are closely related to the price of water. It will partly depend on the time of amortization if consumers make use of subsidies or not.

Subsidies get a very high score with respect to the following criteria: *Effectiveness*, because water can be saved without even changing behavior, e*quity*, because everyone has the right to make use of them, *acceptability*, because consumers are supported, *controllability*, because if the subsidy is put on the price of the water saving technologies, they cannot be abused, *interregional applicability*, because water saving technologies can be bought all over the country. The *financial impact* on users is neutral: some investment by the users is still necessary, which is often earned back over an extended period of time. Subsidies are negative for the government (administration) because it provides the price support for water saving technologies.

Behavioral changes might occur because consumers become more aware of the water problem. On the other hand, possibly no bevavioral change will occur, because buying subsidized water saving technologies may be considered as sufficient personal contribution.

As already mentioned above, the contribution of households to the desiccation problem is only 10%. Water saving in this category therefore has a minor positive environmental impact.

Agriculture

It is assumed that subsidies are given for the introduction of water saving technologies. The saving effect resulting from this measure might only consist of the water saved by the new technology because farmers tend to irrigate more than is actually needed in order to be on the safe side, which means that they will not change their behavior because of subsidized water saving technologies. Another reason for the mediocre effectiveness of subsidies is the fact that farmers still have to invest some of their own money. This money has to be earned back as soon as possible (*financial impact* negative in the beginning, later positive because of savings of irrigation water). With the believe of more irrigation resulting in higher yields even more irrigation water will be used in order to obtain higher revenues. If the subsidies are connected to the price of water saving technologies, they are relatively easy to control.

5.3.5 Taxes

Households

It is assumed that taxes are put on the consumption of water and not on the extraction. The impact of taxes on the different criteria is comparable to the price instrument. An exception is the financial impact on water companies and administrations (government). Taxes are a source of income for the government, Hence, *financial impact* for the government is positive and neutral for water companies.

Agriculture

Higher taxes that are put directly on extraction of groundwater (for example, the same tax rate as other extractors have to pay) have a negative *financial impact* on farmers. This could induce saving activities (*behavioral changes)* by farmers, which in turn has positive environmental effects. The building of private wells is still rather attractive because farmers only have to pay the tax to the administration (positive *financial impact*) and not the price for water to the water company (negative *financial impact*). *Controllability* remains difficult.

5.3.6 Restrictions and quotas

Households

Restrictions or quota for households would only be acceptable in situations of emergency, as, for instance, in a very dry summer. In such a situation low value applications such as lawn sprinkling or car washing could be prohibited.

Agriculture

Restrictions and quota are forcing instruments and it is assumed that the penalty that has to be paid if the restricted amount of groundwater extraction is exceeded, is rather high. This would make this instrument effective with a positive environmental effect. The instrument scores negative in acceptability, controllability and, in cases of violation of the restricted amounts, in *financial impact* on users. This, in turn, implies positive *financial impact* on the administration.

Table 5.1a The impact of selected economic instruments aimed at the use/extraction of water on different Criteria for households

	Households					
	price reforms	tradable rights a)	effluent charges/ 'waterspoor'	subsidies	taxes	restrictions b)
Effectiveness	+	n.a.	++	++	+	l.a.
Equity	++	n.a.	++	++	++	l.a.
Acceptability	+(-)	n.a.	+	++	+(-)	l.a.
Financial Impact						
User	-	n.a.	-	+(-)	-	l.a.
Water Company	+	n.a.	+	+(-)	+(-)	l.a.
Administration	+/-	n.a.	+(-)	-	++	l.a.
Controllability	++	n.a.	++	++	++	l.a.
Interregional Applicability	++	n.a.	++	++	++	l.a.
Behavioral Changes	+/-	n.a.	+	+(-)	+(-)	l.a.
Environmental Impact	+	n.a.	+	+	+	l.a.

a) n.a.: not applicable.
b) l.a.: limited applicability.

Table 5.1b The impact of selected economic instruments aimed at the use/extraction of water on different criteria for agriculture

	Agriculture					
	price reforms	tradable rights	effluent charges a)	subsidies	taxes	restrictions and quota's
Effectiveness	--	+	l.a.	+	+	++
Equity	-	+	l.a.	+	++	+/-
Acceptability	--	-	l.a.	+	-	-
Financial Impact						
User	+	+/-	l.a.	-/+	-	- (+/-)
Water Company	--	+/-	l.a.	+/-	-	+/-
Administration	-	--	l.a.	-	+	+
Controllability	-	--	l.a.	+	-	-
Interregional Applicability	+	-	l.a.	++	++	+
Behavioral Changes	--	+/-	l.a.	-	+	+/-
Environmental Impact	--	+	l.a.	+	+	+

l.a.= limited applicability.

5.4 Application of instruments to hydrological measures

Hydrological measures as they are defined here are rearrangements of the surface water system that influence the groundwater level. The main hydrological measures are the reduction of drainage capacity on agricultural land, the building of controllable barrages and the reduction of the depths of ditches. The main objective of the implementation of economic instruments is the reduction of desiccation. Mitigating desiccation depends heavily on the understanding of the impact of the hydrological system on the vegetation at a local level (Jalink and Meeuwissen, 1998). This implies that anti-desiccation strategies can and must differ locally. For instance, the removal of the drainage system is the best measure on some places, whereas on other places a reduction in the depth of ditches is the most successful strategy. Successful anti-desiccation program needs hence a region specific approach.

The question is now if economic instruments are applicable to stimulate the introduction of the hydrological measures described above. Agriculture benefits from the current situation of water drainage. The party that is mainly affected by a change of this situation is hence agriculture, which implies that the instruments have to aim at farmers. Hydrological measures need to be applied to the whole area under consideration in order to be effective. This implies that the introduction of hydrological measures affects several farmers at the same time. The instrument must therefore be applied to groups of farmers.

The problem is that the farmers have little advantage to gain from the introduction of techniques to lower the drainage capacity: a certain minimum drainage capacity is needed to make sure no water overload occurs. Subsidies for anti-drainage techniques would not work in such a case.

Lowering the drainage capacity entails lower crop yields for farmers. By whichever technique the lowering of the drainage capacity is introduced, the farmers will in any case demand to be compensated for their financial losses. At the moment compensation payments to farmers are the main strategy in the discussion around the reduction of desiccation. A possible situation would be where groups of farmers reach an agreement with the water boards and the administration about the introduction of anti-drainage techniques. The administration would need to bear the costs for these operations and somehow compensate the farmers in the future for financial losses. In chapter 6 a model is presented with which the compensation payments to farmers can be estimated.

However, the strategy of compensation payments is rather in favor of the agricultural sector. Another strategy could be the introduction of taxes or charges that farmers have to pay for a groundwater level that is optimal for agriculture. This is a rather theoretical approach and more practical insight would be needed in order to evaluate them. A first move towards such an idea is done also in the chapter 6. There, it is assumed that the optimal groundwater table from a social point of view is in that point where marginal costs to agriculture due to higher groundwater tables equal marginal benefits to nature. This specific groundwater table could be reached with the help of economic instruments such as taxes or charges.

5.5 Conclusions

The applicability of economic instruments to reduce desiccation is ambiguous. Several instruments have been found to be effective with respect to extraction activities. However, extraction activities contribute with only 30% to the desiccation problem. This does not mean that economic instruments should not be applied to extraction (and in fact some of them are currently being applied in the Netherlands): it alerts people about the value of water in general and stimulates creative water recycling technologies.

It has been mentioned several times in this report that hydrological measures are the major remedy against desiccation and that they are the most effective in mitigating the problem. Effective solutions for the desiccation problem seem to be situated on the technical level. Examples are the fine-tuning of water discharge or changes in land use. Fine-tuning of water discharge means sufficient water discharge in springtime such that farmers are able to cultivate their land and conservation of water as soon as the cultivation is done. This might even be advantageous for farmers because it might reduce drought damage in the summer, which implies that irrigation costs could be saved.[1] Changes in land use mean that areas that are especially sensitive to desiccation are destined to be natural conservation territory only and agriculture is moved to areas of less ecological value that are destined to be agricultural area only.

In the current discussion around the desiccation problem, compensation payments to farmers for agricultural losses due to higher groundwater tables seem to have the major attention. An alternative approach could be the introduction of taxes or charges paid by farmers if they want to have a groundwater table that is optimal for agricultural production but below the social optimum. A first attempt of the estimation of compensation payments and the determination of taxes or charges on an artificially low groundwater table is presented in the following chapter.

[1] A test farm in the province Noord-Brabant made good experiences with saving irrigation costs by conserving water in the ditches. The water level in the ditches influences the groundwater level, which is controlled on a weekly basis and is kept on 50 cm below the soil surface. This strategy saved the farm about 50 mm irrigation water per hectare, which is 150 guilders per hectare per year in monetary terms (Agrarisch Dagblad, 8-01-1998).

6. Desiccation and agriculture: how to find the optimal groundwater table?

6.1 Introduction

The central point in this chapter is the competing interest concerning the groundwater level between an agricultural and a natural area. The agricultural area benefits from a low groundwater table and the natural area benefits from a high groundwater table. Two policy measures are dealt with in this chapter: compensation payments to farmers for agricultural losses due to higher groundwater tables and taxes and charges that farmers have to pay for a groundwater table adjusted to agriculture.

The relationship between the groundwater level and agricultural crop yields is discussed in section 6.2. First of all, the paragraph 6.2.1 gives some theoretical background about this issue. The subsequent paragraphs describe the estimation of five functions, namely for five different crops, that describe crop yields with respect to groundwater table. Paragraph 6.2.2 presents a description of the study area. The chosen study area is the Eastern Cattle Area, which is situated in the eastern part in the Netherlands, where desiccation plays an important role. Paragraph 6.2.3 explains the attainment and construction of the data set that serves as the base for the estimations. The estimations are carried out by means of regression analysis. The last paragraph in section 6.2 gives a first attempt of a validation of the estimation results.

The results found in section 6.2 serve as input for the optimization model presented in section 6.3 that is used to illustrate the competing interests between agriculture and nature. First of all, paragraph 6.3.1 shows the optimal groundwater table for agriculture. Next, in paragraph 6.3.2, a value-of-nature function is introduced in the analysis. The value-of-nature is expressed as index and also as monetary value. With the help of the model, losses to agriculture respectively to nature at different groundwater levels can be calculated. The losses to agriculture can be used as an indication for the amount of compensation payments for farmers.

Taxes and charges are applied in order to reach on optimal solution from society's point of view. The optimal solution for the heights of the groundwater table is found by equalizing marginal costs and benefits or by maximizing combined revenue of agricluture and nature. Both methods result into the same outcomes. This is shown in section 6.3.3. The optimal groundwater table is at that point where marginal costs for agriculture arising through yield losses due to a higher groundwater table and marginal benefits for nature are equal. Since the monetary value-of-nature is rather debatable, the last paragraph in section 6.3 presents a sensitivity analysis on the value-of nature function. This chapter finishes off with section 6.4, which gives some concluding remarks.

6.2 The influence of the groundwater table on crop yields

The relationship between groundwater level and crop yield is very complex. Feddes and Van Wijk (1976) stated that this relationship is only indirect because crop yield is actually dependent on soil moisture that is in turn determined by the groundwater level. Furthermore, the influence of other factors, such as climate, precipitation, humidity, or fertilization, is certainly substantial. However, for the purpose of this study it is suitable to abstract the problem to the influence of the groundwater level only and to illuminate a few different aspects.

6.2.1 Physical and agrotechnical aspects

A depression in crop yield can occur if the groundwater table is either too high or too low. In the first case, air conditions, nitrogen supply and soil temperature could be suboptimal, whereas in the second case, water supply might not be sufficient to guarantee an optimal growth of the plant.

While describing the influence of the groundwater table on crop yield, it is useful to divide the vegetation period into three different stages. Feddes and Van Wijk (1976) present a division into winter and spring conditions, growing season-, and autumn conditions for arable and grassland.

a) Winter and spring conditions

This period is determined by the seed bed preparation and the start of the growing season. A groundwater table that is too high has negative effects on the following aspects (Werkgroep HELP, 1987).

Workability and cultivation of the soil
For the activities of arable farming in the springtime it is important that the soil guarantees enough bearing strength for the heavy machines to carry out cultivation, fertilization, sowing and planting. A crucial point in time is the sowing date because it determines the length of the growing season. An influential source of yield losses is therefore a delay in the sowing date, which entails that plant growth lags behind. Werkgroep HELP (1987) cites Wind who found out that the magnitude of yield depression due to delayed sowing is about 0.5 to 1% per day.

Schothorst, who is cited by Feddes and Van Wijk (1976) has shown for grassland that the soil has enough bearing strength if the groundwater table is not higher than 30 cm below the soil surface.

Air conditions in root zone
High soil moisture can be the cause of an insufficient exchange between the atmosphere and the air in the soil, which will lead to oxygen deficit in the root zone. As a consequence respiration of the roots is decreasing such that the transportation of water and nutrients constrains, which favors the formation of toxic elements. Inadequate ventilation of the soil due to a high groundwater level in spring is therefore disadvantageous for the development of the root system. This implies a restricted capability to absorb water and nutrients also in the remaining

vegetation period. In extreme cases of water overload the roots loose their ability to absorb water totally and will consequently fade.

Another difficulty that arises from insufficient ventilation is the inhibition of nitrogen mineralization and nitrification. In extremely wet circumstances even denitrification can take place, which means a loss of nitrogen. An additional application of nitrogen can partly compensate yield depressions due to high groundwater levels (Feddes and Van Wijk, 1976).

Soil temperature

Soil temperature has a strong influence on germination and hence on the beginning of the growing phase. According to Feddes who is cited by the Workgroep HELP (1987), the seed bed temperature at a high groundwater level is 1 to 2°C lower than at a deep groundwater level.

b) Growing season

During the growing season, the production of crop yield is directly determined by the magnitude of evapotranspiration (Feddes and Van Wijk, 1976). If the plant cannot evapotranspirate sufficiently due to lack of water there will be depression in yields. The depression in yields is actually a result of a decrease of the assimilation of CO_2. This is because evapotranspiration of water and assimilation of CO_2 are taking the same way out of respectively into the plant, namely through the stomas. If water supply is insufficient the plant will close its stomas in order to save water but at the same time CO_2 uptake is hindered. This leads to a decrease of photosynthetic activities and hence the growth of the plant is stopped (Wesseling, 1976).

c) Autumn conditions

The effects of a high water table under arable land in autumn are similar to that in spring time. Whereas in springtime it is advantageous to sow as early as possible, in autumn it is favorable to put off harvesting to a later date because it extends the length of the growing season. For a late harvest date it is necessary that the groundwater table is low enough such that the soil has sufficient bearing strength for heavy machines.

Next to these physical aspects, there are also issues with respect to farm management that determine the seriousness of water overload (Werkgroep HELP, 1987). Firstly, intensive and highly mechanized farm practices experience water overload more serious and therefore put higher demands on drainage. Secondly, the risk of water overload is more apparent at crops that need a long growing season, which implies that they have to be sown/planted early in spring and harvested late in autumn. Thirdly, in the case of grassland, damage due to water overload can be mitigated by organizational arrangements with respect to the grazing system. Epecially in areas with sandy soil where most farms have low as well as high fields at their disposal, it is possible to avoid the low fields in wet periods and use the higher fields instead.

6.2.2 Data

a) Description of the study area: the Eastern Cattle Area

The agricultural district 'Eastern Cattle Area' (from now on ECA) includes major parts of the provinces Gelderland and Overijssel and a small piece of the southern part of the province Drenthe. The ECA is depicted in figure 6.1.

As indicated in the name, the main agricultural activities in the ECA are dairy farming and cattle breeding. Therefore, the major part of the area is grassland. Table 6.1 on the following page shows the use of agricultural land in the ECA in 1993.

The crops that are taken into account for the quantitative analysis are grassland, maize, potatoes, sugar beets, and grain. Since the remaining crops that are shown in table 6.1 have only marginal contributions to land use, they are neglected in the analysis.

Physical yields and prices for grass, maize, potatoes, sugar beets, and grain for the ECA are shown in table 6.2 on the following page. The data are from the year 1992.

Figure 6.1 The Eastern Cattle Area
Source: LEI.

Table 6.1 Agricultural land use in the Eastern Cattle Area, 1993

Agricultural land use in 1993	in 1,000 hectare	in %
Grassland	200.1	65.8
Tillage	99.7	32.8
maize	72.4	23.8
potatoes	13.8	4.6
sugar beets	6.2	2.0
grain	5.5	1.8
others	1.8	0.6
Horticulture	3.2	1.1
open field	3.1	1.1
greenhouses	0.1	0.0
Fallow	0.8	0.3
Total	303.8	100

Source: Hoogeveen et al, 1996.

Table 6.2 Physical yields and prices of grass, maize, potatoes, sugar beets, and grain for the ECA in 1992

	Grass (kVEM)	Maize (kVEM)	Potatoes (kg)	Sugar beets (kg)	Grain (kg)
Physical yield per hectare9,260	11,830	46,000	60,900	4,590	
Price in guilders per kVEM resp. kg	0.31	0.31	0.115	0.099	0.46

Source: Hoogeveen et al., 1996.
(kVEM = kilo voeder eenheid melk (kilo gram feed unit milk)).

The information noted in table 6.2 is the basis for the construction of the data set, which is described in the following paragraph.

b) Construction and attainment of data

Depression tables

Werkgroep HELP (1987) published different tables in which percentage yield depressions due to water overload respectively drought, are noted. The depression tables are partly based on hydrological computer simulations and partly on practical experience from field tests. They are based on the principle of groundwater steps, which is a way of categorizing the situation of groundwater tables in the Dutch subsoil area. Every groundwater step has its specific 'averaged highest groundwater level (AHG)' and 'averaged lowest groundwater level (ALG)'. Table 6.3 shows these values for the different groundwater steps.

Table 6.3 Groundwater steps with corresponding AHG and ALG

Groundwater step	I	II	III	IV	V	VI	VII
AHG in cm below soil surface	5	10	15	50	25	60	100
ALG in cm below soil surface	30	70	105	110	140	170	200

Source: Beugelink and Claessen, 1995.

Table 6.3 clarifies that a groundwater step with a low respectively high value represents wet respectively dry soil conditions.

The depression tables are sorted by different types of soil. For every type of soil there is one table for grassland and one table for arable land. Since the ECA is mainly determined by sandy podzol soil (SC-DLO, 1997), the tables for this type of soil have to be the choice. The percentage depression values for yields on grassland and arable land that are taken from the depression tables by Werkgroep HELP are listed in table A (grassland) and table B (arable land) in appendix B.

The table for arable land gives average percentage values. To get the drought depression value for the different arable crops the average yield depression percentage value shown in the table has to be modified according to crop specific formulas. The percentage values for maize are taken as a reference and do not have to be modified. Table 6.4 shows the different formulas as they are noted in Werkgroep HELP (1987).

Table 6.4 Percentage yield depressions on arable land through lack of water per crop on sandy podzol soil

CROP	Percentage yield depressions through lack of water per crop (y) as a function of average depression percentage value (x) as noted in table B in appendix B
Maize	$y = x$
Potatoes	$y = 1.15x + 0.5$
Sugar beets	$y = 0.85x - 0.5$
Grain	$y = 1.05x - 2.5$

Source: Werkgroep HELP, 1987.

According to Van Wijk et al. (1988) and Feddes and Van Wijk (1976) it is assumed that the optimal groundwater level for grassland is at 60 cm below the soil surface and for arable crops at 100 cm below the soil surface. This is also indicated in table A and B in appendix B, where zero percent depression is noted at 60 cm below soil surface (table A for grassland) respectively at 100 cm below soil surface (table B for arable land). Because the present situation of water control is entirely attuned to agriculture (Ministerie van verkeer en waterstaat, 1996), it is assumed that the actual values of crop yield from 1992 (table 6.2) are optimal. This assumption implies that the yield of grass (9260 kVEM/ha) is harvested at a groundwater table of 60 cm below the soil surface whereas the yields of the arable crops (e.g. for maize: 11,830 kVEM/ha) are harvested at a groundwater table of 100 cm below the soil surface.

With the help of the percentage depression values from table A and B in appendix B and the physical yields that are shown in table 6.2 the percentage depressions due to water overload and drought for all different crops can be calculated. The depression values for drought damage on arable land are calculated according to the formulas in table 6.4. In order to obtain a continuous data set, the depression values that cannot be attained by means of the depression table, are calculated by linear interpolation. The constructed data set is presented in appendix C.

6.2.3 Regression Analysis

The function that describes the relationship between the groundwater table and crop yield is supposed to have a parabolic form. This is sensible because as mentioned above there is yield depression if the groundwater table is either too high or too low with the optimum somewhere in-between.

The functional forms that reflect a parabolic shape are quadratic and cubic functions. The quadratic function takes the form:

$$Y_x = \alpha + \beta_1 * GW + \beta_2 * GW^2 + \varepsilon \qquad (6.1)$$

The cubic function takes the form:

$$Y_x = \alpha + \beta_1 * GW + \beta_2 * GW^2 + \beta_3 * GW^3 + \varepsilon \qquad (6.2)$$

Where: Y_x = Yield of crop x;
GW = Groundwater table;
α = Constant;
β_x = Parameters;
ε = Error term.

With the help of the computer program SPSS, five estimations have been carried out, namely for the five different crops mentioned above. After running the estimation procedures for the quadratic and cubic form it becomes evident that the cubic form gives the best fit. This is demonstrated in figure 6.2 for the example of grassland.

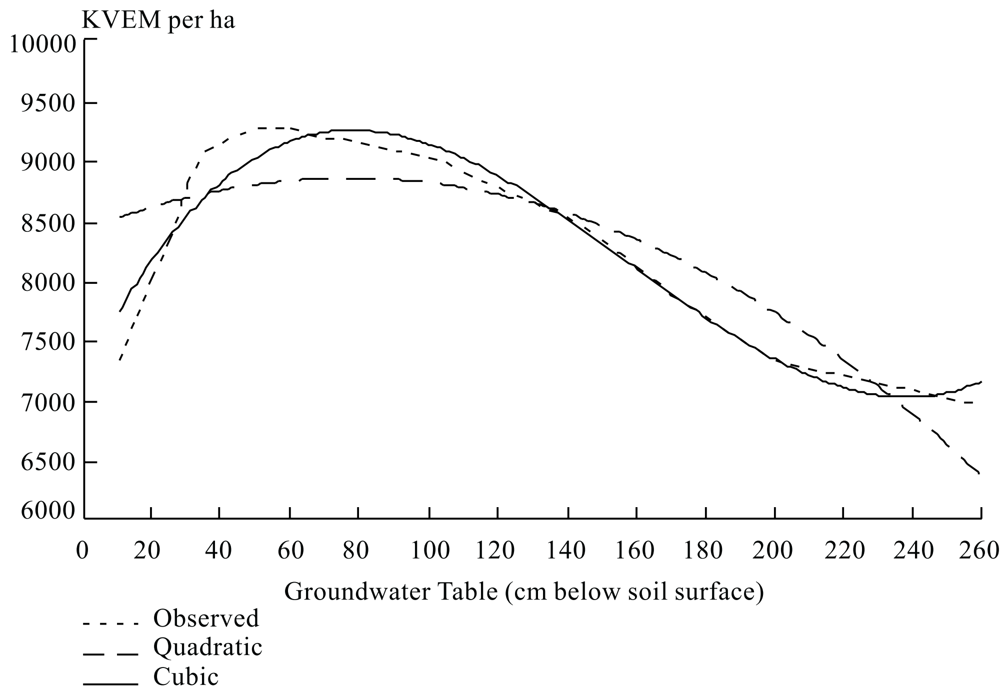

Figure 6.2 Curve estimations of quadratic and cubic functional form for the yield of grassland with respect to groundwater table

Figure 6.2 shows that the cubic form (black line) describes the observed data set (dotted line) better than the quadratic from (dashed line). The fact that the cubic form is moving upwards again at a groundwater table of 240 cm below soil surface is of no importance in this case because the range under consideration is situated below this value. The estimations for the other crops show similar results namely that the cubic function is preferred to the quadratic one. The figures of the curve estimations for the other crops are depicted in appendix D.

Table 6.5 Estimation results for the cubic function crop yield with respect to groundwater table

Crop	Constant	β_1	β_2	β_3	R^2
Grassland	7,172.987	59.795	-0.51	0.001	0.97
	(70.62)	(18.93)	(-19.06)	(16.5)	
Maize	7,487.919	112.811	-0.9	0.002	0.97
	(64.37)	(31.19)	(-29.33)	(25.18)	
Potatoes	28,822.508	456.818	-3.733	0.008	0.98
	(62.65)	(31.93)	(-30.78)	(26.58)	
Sugar Beets	38,936.056	556.699	-4.319	0.009	0.97
	(65.07)	(29.92)	(-27.38)	(23.33)	
Grain	2,884.929	44.129	-0.344	0.0007	0.98
	(75.36)	(37.07)	(-34.06)	(28.77)	

The estimation results of the cubic functions for the five different crops are shown in table 6.5. The t-values are noted in brackets.

With the estimated functions for the five different crops the specific groundwater tables that result in the maximum yields of the different crops can be calculated. The maximum yields per hectare with the related groundwater tables are listed in table 6.6.

Table 6.6 Different crops and the optimal groundwater table with related maximum yield per hectare (based on estimation results)

Crop	Optimal groundwater table (cm below soil surface)	Maximum yield per hectare
Grassland	75.3	9,210.76 kVEM
Maize	89.19	11,809.15 kVEM
Potatoes	83.72	45,596.94 kg
Sugar Beets	89.47	60,616.61 kg
Grain	87.52	4,581.41 kg

Appendix E shows a figure of the production values of the five different crops (physical yields multiplied by the respective prices) with respect to the groundwater table. The figure depicts that sugar beets produce at all groundwater levels the highest revenue. The order of the five crops starting with the one producing the highest revenue is sugar beets, potatoes, maize, grass, grain. This order remains the same at every groundwater level. This is an indication that at current prices for the different crops the cropping pattern does not change if the groundwater table changes. These findings are used in the following simplified model (section 6.3) as an assumption that land use does not change if the groundwater table increases.

6.2.4 Validation of results

Since the estimation results are based on a constructed data set, a validation of these results by means of empirical data is needed. Due to problems with respect to data availability and the time constraint of this research, a quantitative validation cannot be carried out. A rough indication about the verity of the estimation results is found in Brouwer et al. (1996). They give empirical data for the yield of grassland in kVEM per hectare with respect to four groundwater groups for the years 1992/1993 and 1993/1994. The categorization into groundwater groups is a simplification of the groundwater steps that are displayed in table 6.3. The groundwater steps with the corresponding groundwater groups and the referring average spring groundwater table are noted in table 6.7.

Table 6.7 Groundwater steps with corresponding groundwater group and average spring groundwater table

Groundwater step	Groundwater group	Average spring groundwater table (cm below soil surface)
I	A	15
II	A	27
III	B	40
IV	C	65
V	B	52
VI / VII	D	>90

Source: adapted from Brouwer et al. (1996) and Beugelink and Claessen (1995).

The four data points of grass yield with the respective groundwater group that are given in Brouwer et al. are shown in figure 6.3.

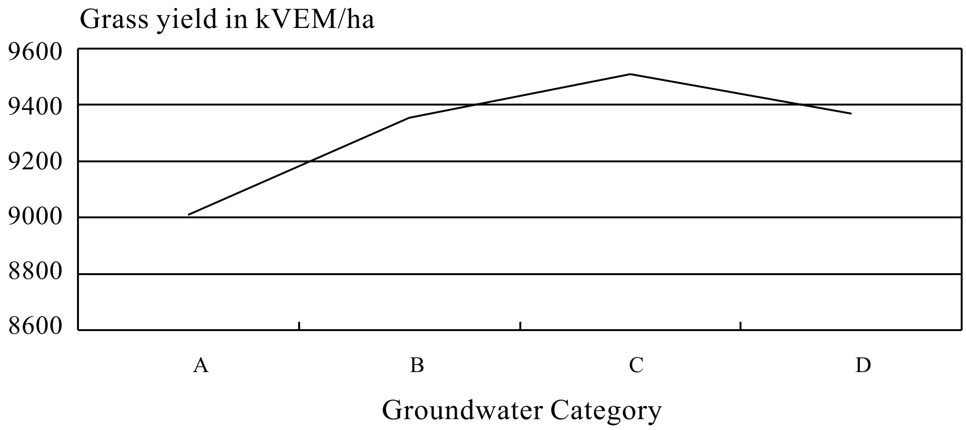

Figure 6.3 Grass yield with respect to groundwater category
Source: The data are taken from Brouwer et at., 1996.

Figure 6.3 indicates that the highest grass yield is obtained in groundwater category C and yield depressions for the categories A, B and D. Table 6.7 shows that category C corresponds with an average spring groundwater table of 65 cm below soil surface. The maximum grass yield in the constructed data set is assumed to be obtained at a groundwater table of 60 cm. The fact that the constructed data set is based on depression tables, which in turn are the result partly of hydrological computer simulations and partly of experiences from field tests explains the differences between empirical data and the estimation results from the analysis in this research. Furthermore, the aggregation into four groundwater categories implies losses in exactness. However, a parabolic shape of the function can be recognized in the empirical data for grass yield with respect to groundwater categories.

Empirical data for arable crops with respect to the groundwater table are not taken into consideration.

6.3 A simplified model

This section presents the model that describes the competing interest concerning the groundwater table between an agricultural area and a natural area. The areas have the same size and are situated next to each other such that the groundwater tables under both areas are at the same levels.

First of all, a method of calculating compensation payments to farmers for agricultural losses due to higher groundwater tables is proposed. Another approach explains how taxes or charges could theoretically contribute to reach a groundwater table that is optimal from a social point of view. This can be done by equalizing marginal costs to agriculture and marginal benefits for nature or by maximizing both revenues, that of agriculture and that of nature, jointly. Both methods will lead to the same results.

The following assumptions have been made in this simplified model:

- agricultural land use: 60% grassland, 25% maize, 5% potatoes, 5% sugar beets and 5% grain. These dimensions of agricultural land use are a rough indication of the agricultural land use in the ECA shown in table 6.1;
- agricultural land use does not change if the groundwater table increases (see above appendix E);
- the agricultural area and the natural area are both of the same size and are situated next to each other;
- the groundwater table has to be the same under both areas.

6.3.1 The optimal groundwater level for agriculture

The optimal groundwater level for agriculture is found by maximizing total revenue, which is the sum of the revenues of the five different crops.

$$TOTREV = REVG + REVM + REVP + REVS + REVGN \qquad (6.3)$$

Where: TOTREV = Total revenue;
REVG (M, P, S, GN) = Revenue of grassland (maize, potatoes, sugar beets, grain).

Revenues of the five different crops are calculated by multiplying yields, prices, and cultivated area respectively.

$$REVX = YX * PX * HAX \qquad (6.4)$$

Where: REVX = Revenue of crop X;
YX = Yield of crop X;
PX = Price of crop X;
HAX = Hectares of crop X.

The hectares that are engaged by the different crops are noted above and the prices of the crops are shown in table 6.2. The yields are calculated by the estimated functions with groundwater table as explanatory variable. The groundwater table variable has a lower limit of 30cm below soil surface. According to Schothorst who is mentioned by Feddes and Van Wijk (1976), the bearing strength of the soil tends to be adequate if the groundwater table is deeper than 30cm below soil surface. This implies that a groundwater level that is higher than 30cm below soil surface eliminates agricultural activities. The upper level is 200cm below soil surface. The Gams specification of the model is given in appendix F.

Results

The amount of maximized total revenue for 100 hectares agricultural area is 329150 guilders. The optimal groundwater level at this point is 81.86 cm below soil surface. The distribution of total revenue over the five different crops is shown in figure 6.4.

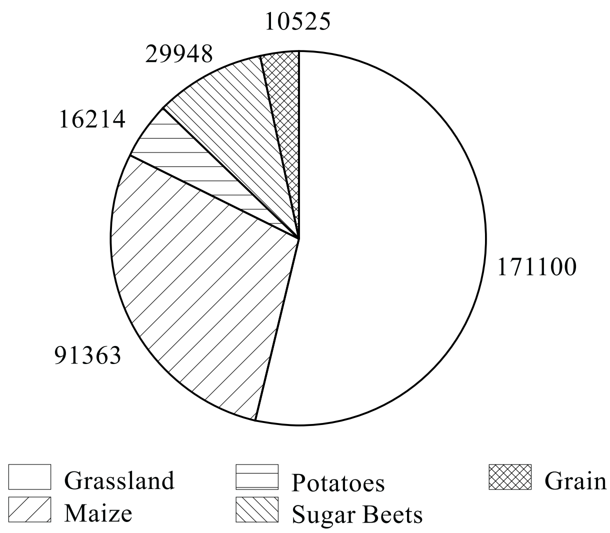

Figure 6.4 Revenue of crops distribution in guilders per 100 hectare agricultural area

For the further analysis it is more practical to use values per one hectare. Hence, the estimated total revenue of 100 hectare is divided by 100. In this way the proportional contributions of the different crops to total revenue stay the same and a weighted average of total revenue per hectare has been obtained. Maximized total revenue per hectare at a groundwater table of 81.86 cm below soil surface is hence 3,291.50 guilders.

Total revenue as a function of groundwater table

In order to obtain a curve for total revenue per hectare with respect to groundwater table, the model that is described above needs a slight modification. Instead of letting the model choose the optimal groundwater table, the groundwater table is set as a fixed parameter beforehand. In this way the different levels of groundwater table can be determined. Subsequently, the model calculates total revenue that is related to the determined groundwater table. The curve that is obtained by this procedure is shown in figure 6.5 in the next section.

A quantitative specification of this curve can be derived by the regression of the calculated total revenues per hectare on the groundwater table. The function for total revenue with respect to groundwater table is specified as follows.

$$TOTREV = 2339.025 + 26.269*GW - 0.215*GW^2 + 0.00045*GW^3 \qquad (6.5)$$

6.3.2 Introduction of the value-of-nature

In order to emphasize the competition between nature and agriculture a value-of-nature index is introduced. The formula for the value-of-nature index is adapted from s'Jacobs and Wilmar (1996). It has to be mentioned that this formula is only one example for the description of an index for the value of nature. This formula is the only one that has been come across in the studied literature and no specific investigations have been carried out in order to find other descriptions.

$$VNI = 100 * e^{(0.2 - GW/100)} \qquad (6.6)$$

Where: VNI: Value-of-nature index
GW: Groundwater table

In this function it is assumed that measurable damage to nature only occurs if the groundwater table gets lower than 20 cm below soil surface. Figure 6.5 shows the value-of-nature index (equation 6.6) and total revenue per hectare of agricultural production with respect to groundwater table (equation 6.5).

The different groundwater levels with the related value-of-nature index, total revenue of agricultural production and losses in total revenue of agricultural production are listed in table 6.8.

At groundwater table 81.86cm below soil surface where total agricultural revenue is maximized is the value-of-nature index 53.9%. The losses that occur to agricultural revenue if the groundwater table increases respectively decreases are listed in the last column. Through the quantification of the losses to agriculture the amount of compensation payment at different groundwater levels that has to be paid to the farmers, is indicated.

It was mentioned above that the bearing strength of the soil for agricultural production is only adequate at a groundwater level of 30 cm below soil surface. This explains that there is no production at a groundwater level of 20 cm. In this example with the assumed function for the value-of-nature index it is therefore not possible to continue with agricultural activities and at the same time keeping the value-of-nature index at 100%.

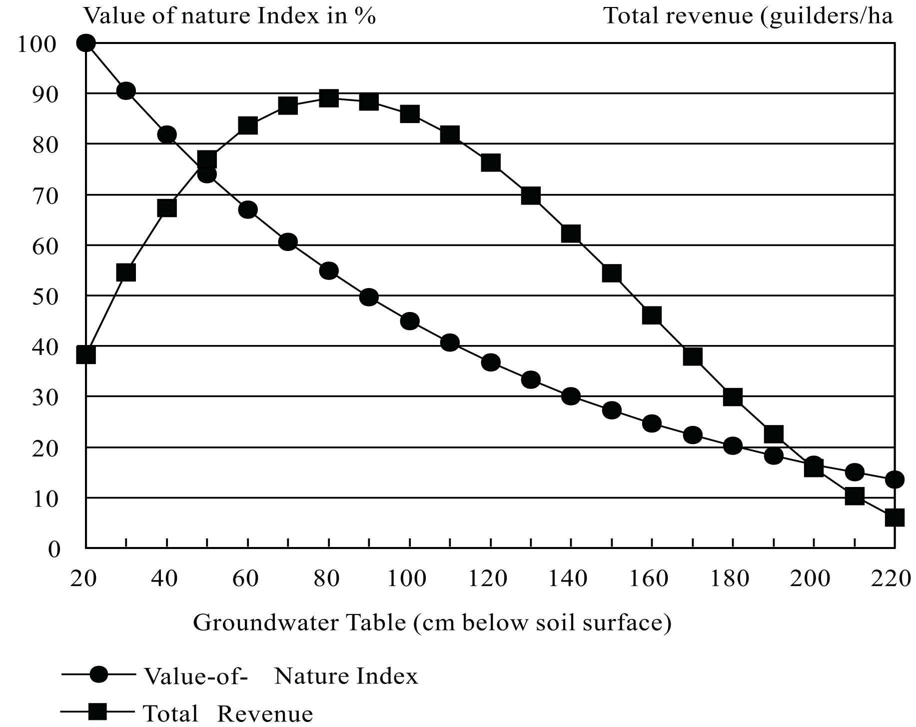

Figure 6.5 Value-of-nature index and total revenue of agricultural production

Table 6.8 Value-of-nature index, total revenue of agricultural production (guilders/ha), and losses in total revenue of agricultural production (guilders/ha) with respect to groundwater table

Groundwater table in cm below soil surface	Value-of-nature index in %	Total revenue of agricultural production (guilders/ha)	Losses in total agricultural revenue (guilders/ha)
20	100	no production	3,291.5
30	90.5	2,945.4	346.1
40	81.9	3,073.9	217.6
50	74.1	3,169.9	121.6
60	67	3,236.4	55.1
70	60.6	3,275.9	15.6
80	54.9	3,291.1	0.4
81.86	53.9	3,291.5	0
90	49.6	3,284.8	6.7
100	44.9	3,259.5	32
110	40.6	3,218	73.5
120	36.8	3,163	128.5
130	33.3	3,097.2	194.3
140	30.1	3,023.2	268.3

Monetary value-of-nature

According to social welfare theory, the optimal groundwater level is at the point where the losses to total agriculture revenue equal the gains for nature while changing the groundwater level by one unit which is one centimeter. This condition requires a monetary valuation of nature. Several techniques for the economic valuation of natural areas and biodiversity have been developed. The most popular examples are the *Contingent Valuation Method*, the *Hedonic Pricing Method*, and the *Travel Cost Method*. (For a detailed description of different valuation techniques see, for example, Perman et al. (1996), and Pearce and Moran (1994)). For further analysis it is assumed that one hectare of natural area is valuated with 500 guilders. This value is taken from the estimation of the willingness to pay for the preservation benefits of a blanket bog area in Scotland that has been carried out by Hanley and Craig (Pearce and Moran, 1994). They revealed a value for the willingness to pay of 164.68 pounds per hectare, which are approximately 500 guilders per hectare. Blanket bog belongs to the ecosystem type of wetlands and is therefore a reasonable approach to the type of ecosystem that is found in the desiccated natural areas in the Netherlands.

It has to be emphasized that the valuation of natural area with 500 guilders per hectare is only an assumption. A valuation of the affected natural areas in the Netherlands ought to be carried out beforehand in order to obtain reliable results. The assumption that the natural area is evaluated with 500 guilders per hectare serves mainly as an illustration for the method that is used in the analysis.

Furthermore it is assumed that the value-of-nature index that is shown in equation 6.6 can be replace by the monetary valuation. This means that a value-of-nature index of 100% corresponds to 500 guilders per hectare, which implies that this is the value that is attached to an intact natural area. Equation 6.6 can hence be transformed into the following equation.

$$MVN = 500 * e^{\left(0.2 - GW/_{100}\right)} \qquad (6.7)$$

Where: MVN = Monetary value-of-nature;
GW = Groundwater table.

By using equation 6.7 the monetary value-of-nature can be calculated for different groundwater tables. At a groundwater table of 81.86 cm below soil surface, where total revenue of agricultural production is maximized, the monetary value-of-nature is 269.35 guilders per hectare. The losses to nature are at that point 230.65 guilders per hectare. These two key numbers are listed in table 6.9 further down.

6.3.3 Equalizing marginal benefit and marginal costs

In order to reach a situation that is optimal from society's point of view, taxes or charges could be introduced. Farmers have to pay taxes or charges on a groundwater table that would be optimal for agricultural production but below the social optimum. The social optimum is there where the losses to agriculture are equal to the gains for nature or where the marginal costs for agriculture are equal to the marginal benefits of nature. This point can be derived by equalizing the absolute values of the slopes of the functions for total agricultural revenue (equation 6.5) and for the monetary value-of-nature (equation 6.7). In mathematical terms, it is equalizing the absolute values of the first derivatives of these functions with respect to the groundwater table:

$$\left|\frac{\partial TOTREV}{\partial GW}\right| = \left|\frac{\partial MVN}{\partial GW}\right| \tag{6.8}$$

The first derivatives of the two functions are as follows:

$$\frac{\partial TOTREV}{\partial GW} = 26.269 - 0.43 * GW + 0.00135 * GW^2 \tag{6.9}$$

$$\frac{\partial MVN}{\partial GW} = -\frac{1}{100} * 500 * e^{(0.2 - GW/100)} \tag{6.10}$$

The absolute values of these two first derivatives are depicted in figure 6.6.

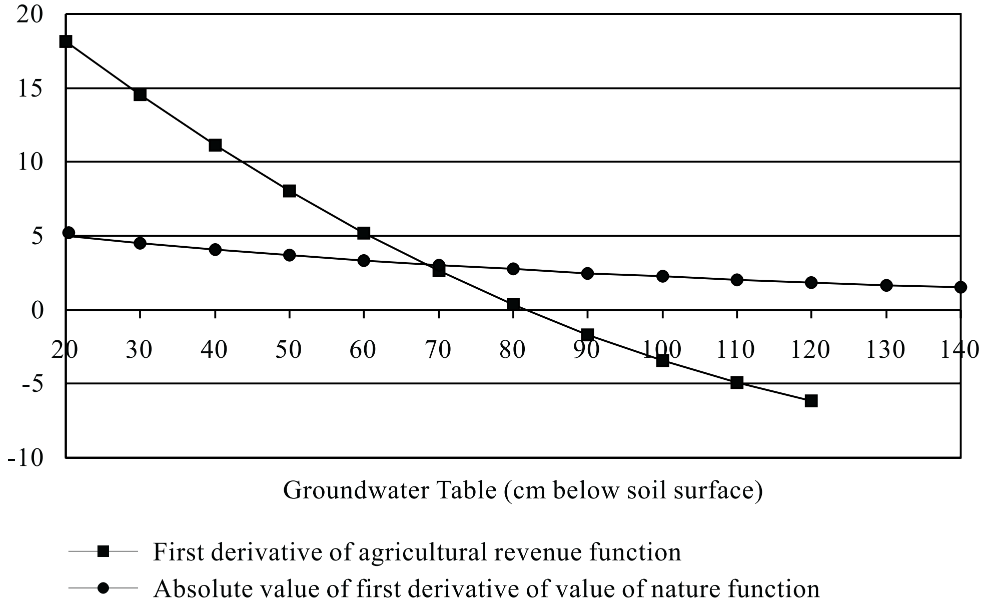

Figure 6.6 First derivatives of total agricultural revue function and absolute values of monetary value-of-nature function

The groundwater table where losses to agriculture equal gains for nature can be obtained by solving equation 6.8. The optimal combined groundwater table is in this case 68.4 cm below soil surface. The marginal losses to agricultural respectively the marginal gains to nature that occur by changing the groundwater level by one cm at that point are 3.08 guilders. Agricultural revenue at 68.4 cm below soil surface amounts to 3,273.94 guilders per hectare. With the maximum total revenue of 3,291.5 guilders per hectare, this implies absolute losses to agricultural of 17.56 guilders per hectare. The monetary value-of-nature at 68.4 cm below soil surface is 308.16 guilders per hectare. With the maximum value-of-nature of 500 guilders per hectare, this implies absolute losses to nature of 191.84 guilders per hectare. These key numbers are summarized in table 6.9 further down. Losses to agriculture are 17.56 guilders per hectare. In the case of taxes and charges, the tax rate respectively the heights of the charges must lie above the amount of losses to agriculture in order to stimulate farmers to refrain from a lowering of the groundwater table. The tax rate/heights of charges must hence lie above 17.56 guilders per hectare. The same results are obtained with the maximization of joint revenue of agriculture and nature.

The optimal combined groundwater table and hence the proper tax rate/heights of charges varies according to the monetary value-of-nature. A sensitivity will give insight into the range of variation of the optimal combined groundwater table if the monetary value-of-nature changes.

Sensitivity analysis

It was mentioned above that the valuation of the natural area is an assumption only. The monetary value of a natural area will differ anyway dependent on the respective valuation method used. In order to get an idea about the scope of variation of the results due to changes in the valuation of nature, a sensitivity analysis has been carried out with respect to the specification of the monetary value-of-nature function. Four different variations of the monetary value-of-nature function used for the analysis above have been tested. The variations only describe a higher valuation of the natural area. Lower valuations are not taken into account.

1. The monetary value of an intact natural area is 750 guilders per hectare instead of 500 guilders per hectare:

$$MVN = 750 * e^{(0.2 - GW/100)} \tag{6.11}$$

2. The monetary value of an intact natural area is 1,000 guilders per hectare instead of 500 guilders per hectare:

$$MVN = 1000 * e^{(0.2 - GW/100)} \tag{6.12}$$

3. The value-of-nature decreases at a faster rate as the groundwater table decreases:

$$MVN = 500 * \left(e^{(0.2 - GW/100)} \right)^2 \tag{6.13}$$

4. The monetary value of an intact natural area is 750 guilders per hectare instead of 500 guilders per hectare and the value-of-nature decreases at a faster rate as the groundwater table decreases:

$$MVN = 750 * \left(e^{(0.2 - GW/100)} \right)^2 \qquad (6.14)$$

The results of the sensitivity analysis are summarized in table 6.9. (Recall that the optimal groundwater table for agricultural production is 81.86 cm below soil surface).

The figures in table 6.9 show a clear variation in the different key numbers with respect to the different specifications of the monetary value-of-nature function. Losses to nature at an optimal groundwater level for agriculture range from 230.65 guilders per hectare to 532.35 guilders per hectare. This is a difference of 301.7 guilders per hectare.

Table 6.9 Results of the sensitivity analysis on the specification of the monetary value-of-nature function

Key numbers	Specification of monetary value-of-nature function				
	$v * e^{(0.2-GW/100)}$			$v * \left(e^{(0.2-GW/100)} \right)^2$	
	v = 500 (reference)	v = 750	v = 1,000	v = 500	v = 750
MVN at gw 81.86 cm bss in guilders/ha	269.35	404.02	538.7	145.1	217.65
Losses to nature at 81.86 cm bss in guilders/ha	230.65	345.98	461.3	354.9	532.35
Combined optimal gw in cm bss	68.4	61	53.1	64.3	48.9
Marginal losses/gains in guilders/ha	3.08	4.98	7.18	4.2	8.41
Agric. revenue at combined optimal gw in guilders/ha	3,273.94	3,243.56	3,195.07	3,258.84	3,162.09
Losses to agriculture in guilders/ha	17.56	47.94	96.43	32.66	129.41
Value-of-nature at combined gw in guilders/ha	308.16	497.49	718.33	206.25	421.06
Losses to nature inguilders/ha	191.84	252.51	281.67	293.75	328.46

Abbreviations: mvn = monetary value-of-nature; gw = groundwater table; bss = below soil surface.

The point where marginal losses to agriculture equal marginal gains to nature, is here described as the optimal combined groundwater table. As the monetary value-of-nature per hectare increases respectively the value-of-nature decreases at a faster rate, the optimal combined groundwater table increases. The optimal combined groundwater table varies from 68.4 cm below soil surface to 48.6 cm below soil surface.

According to the variation of the optimal combined groundwater table, losses to agriculture and nature are changing. Losses to agriculture vary from 17.56 guilders per hectare to 129.41 guilders per hectare. This is a variation of 111.85 guilders per hectare. Losses to nature range from 191.84 guilders per hectare to 328.46 guilders per hectare, which is a difference of 136.62 guilders per hectare.

According to the wide range of variation of losses to agriculture the optimal tax rate/heights of charges has to vary as well if farmers are stimulated to refrain from a lowering of the groundwater table. The optimal tax rate/heights of charges always has to lie above the losses to agriculture.

6.4 Concluding Remarks

The sensitivity analysis shows that the monetary valuation of the natural area plays an important role in the determination of the groundwater table that is optimal from the point of view of social welfare theory. Losses to agriculture are especially important for the introduction of taxes and charges. The wide range of losses to agriculture, namely from 17.56 guilders per hectare to 129.41 guilders per hectare, shows that the determination of the value-of-nature is quite substantial for the introduction of the proper tax rate/heights of charges.

The highest optimal combined groundwater table calculated with the different specifications of the monetary value-of-nature function is 48.9 cm below soil surface. It is uncertain if this if sufficient for an appropriate reduction of desiccation. With the method of finding the optimal combined groundwater table by equalizing marginal costs and marginal benefits a higher monetary valuation of nature is needed in order to reach a higher optimal combined groundwater table.

The valuation of a natural area is region specific. This means that it depends on several factors. Some of these factors are the value of the respective ecosystem, the attractiveness for recreation activities, the distance to cities or the valuation technique applied. The value of natural areas might hence differ from region to region, which is again a sign for the region specific approach that has to be taken in anti-desiccation projects.

Improvements for the model

The estimations of the functions for crop yields due to the groundwater table are based on a data set constructed with the help of depression tables. In order to improve the persuasiveness of the model, validations by means of empirical data should be carried out. Furthermore, the estimations only include groundwater level as an explanatory variable. Other influencing factors on crop yields such as fertilization, sort of crop (brand) or weather conditions have not been taken into account. In the frame of an empirical estimation of the yield functions, these other explanatory factors should be considered as well.

The costs arising for agriculture due to an increase of the groundwater table only include pure losses to crop yields that can be calculated with the estimated function of the regression analysis. It should be mentioned that there are more costs that may arise due to higher groundwater tables. A decline of the bearing strength of the soil in springtime implies that cattle have to stay in the shed for a longer time. This means that farmers need more feed, which can be provided either by purchasing or by buying more land for silage.

The monetary value-of-nature is an important factor in the determination of the optimal combined groundwater table. A valuation of the desiccated areas in the Netherlands by means of established valuation techniques (Willingness To Pay, Contingent Valuation Method, Hedonic Pricing Method, Travel Cost Method) would increase the reliability of the results.

7. Conclusions and recommendations

7.1 Introduction

The final chapter of this report presents conclusions and recommendations. The conclusion will be given as answers on the questions that are put as objectives in the introductory chapter 1. The main objective was:

What is the role of economic instruments in Dutch water management and to what extent can they contribute to a reduction of desiccation?

Before coming to the main objective, answers will be given on the sub-questions.

The recommendations do partly refer to bottlenecks encountered during the research and will give some indications for further research. The recommendations follow directly on the conclusions under the different sub-questions.

What is the situation of desiccation in the Netherlands? Are there any specialties with respect to water in the Netherlands that have to be taken into account in management strategies? What is the situation of the different water users in the Netherlands?

Discharge and drainage of superfluous water cause 60% of desiccation, groundwater extraction 30% and other reasons 10%. Desiccation is a major reason why traditional management of the hydrological system, which is mainly adjusted to benefits for agriculture, is called in question. On regional scale, rearrangements of the hydrological system are seen as the most important measure against desiccation, whereas reduction in groundwater extraction activities seems to take a minor position. However, on local scale groundwater extraction can have an important impact on desiccation. A successful policy against desiccation certainly has to consider that circumstances and causes of the problem can differ from location to location. Solutions are hence region specific, which means that there is no nation wide solution to the problem.

The water problem in the Netherlands is contradictory. On the one hand, much effort is put in getting rid of superfluous water and on the other hand problems are coming up with water scarcity. The problem lies in the scarcity of good quality water. Good quality water is scarce from an economic point of view because the treatment of surface water is still expensive, at least more expensive than the extraction of groundwater, which costs do not yet include the external effects that occur by the extraction of groundwater and that becomes visible as desiccation.

A special characteristic of the Netherlands is the high density of economic activity. Many users of water resources with different demands on quality and quantity items of water compete for the resource on a spatially limited area. This is an indication that external effects produced by different users on their competitors are more evident. The fact that a limited area has only a limited underground area and hence less space available for the storage of groundwater in combination with high population density puts additional pressure on scarcity of good-quality water.

What are the special economic characteristics of water as a natural resource?

Water belongs to the common property resources and experiences the tragedy of the commons. An important characteristic of water is its diversity of use. The diversity of use becomes also obvious in the Netherlands where many users have different demands on the quality and quantity of water. The manifold application possibilities of water make it difficult to attach a proper value to water resources. Instream uses, where water is used directly for consumption or for production processes are easier to evaluate than offstream uses, such as fishery, nature conservation, navigation or recreation. The problem of attaching a proper value to water resources entails the production of externalities arising from economic activities that make use of water resources. Desiccation can be interpreted as an externality arising from agricultural activities that do not seem to pay the proper price for draining the fields.

An optimal allocation of natural resources is at that point where marginal net benefits are equal across all users. This is also established as the main objective in the Dutch groundwater law. If marginal net benefit has to be equalized in order to reach a social optimum, the key problem is thus to identify the actual marginal net benefit of all different users of groundwater. A reliable identification of the actual marginal net benefit of all different users in the Netherlands is still lacking. This is mainly due to the absence of dependable data of consumption of private extractors and to the low price that private extractors have to pay for the water. Intensified research on these topics would be advisable to find the actual marginal net benefits of the different user categories in order to be able to determine an optimal allocation of the water resource.

What can be found about managing water scarcity through the introduction of economic instruments in international literature? Are there any differences in the situation of water between other countries and the Netherlands?

Several instruments to economize water use can be found in international literature. The instruments that are especially interesting are those that are based on market forces. These instruments are pricing reforms, tradable rights, effluent and pollution charges, subsidies and taxes. These instruments aim at the resource itself by increasing its economic value in order to approach an optimal allocation. The introduction of economic instruments demands the proper enabling conditions, which means that it harmonizes with the organizational and administrative conditions. A policy mix of the different economic instruments is in many cases more effective than the introduction of a single one. While introducing economic instruments or policy mixes, it is important to take into account the prevailing social, economical and political circumstances in the respective country.

It is striking that most of the examples of economic instruments found in international literature stem from arid regions where absolute water scarcity is evident and where water is the limiting factor. Knowing Dutch weather conditions and Dutch history that is characterized by fighting against water for land reclamation it becomes obvious that absolute water scarcity is not the actual problem in the Netherlands. The effort that is put in getting rid of water proves that water in general is abundant in the Netherlands. The basic problem lies in the minor quality of surface water, which implies high costs for its treatment and purification. Minor quality of surface water entails that good quality groundwater is used for low-value applications such as the irrigation of grassland. This indicates that the quality and quantity of water is closely related to each other, which means that research on the quantity of water should necessarily take quality issues into account as well.

The following sub-questions refer to the quantitative part of this report.

Finding a function that describes the relationship between agricultural crop yields and the groundwater table.

Five different functions for five different crops (grassland, maize, potatoes, sugar beets and grain) have been estimated. The relationship between crop yields and groundwater table can be described with a cubic functional form. The crop with the lowest optimal groundwater table is grassland with 75.3 cm below soil surface (followed by potatoes, then grain, then maize and finally sugar beets with the highest optimum of 89.47 cm below soil surface). The functions indicate that a higher groundwater table than the optimum has a more negative effect on crop yields than a groundwater table that is lower than the optimum.

Finding the optimal groundwater level for agricultural production and indicating losses to agriculture that occur through higher groundwater tables.

In this simplified model the optimal groundwater table for agricultural production that is calculated by maximizing total agricultural revenue is 81.86 cm below soil surface. The function that describes total revenue of all crops with respect to groundwater table exhibits losses to agriculture and hence the costs that occur to agriculture due to higher groundwater tables than the optimum. These losses can be taken as an indication for compensation payments for farmers if agreements have been made about an increase of the groundwater table.

The costs that are calculated in this model do only include pure losses to crop yields. Other cost items such as the additional amount of feed for the cattle needed because of a longer shed period should be taken into account as well.

How can an optimal groundwater table for both, agricultural and nature, be obtained?
Can economic instruments be introduced to reach this optimal combined groundwater table?

Theory says that social optimum is at that point, where marginal costs equal marginal benefits. Hence, for the attainment of an optimal combined groundwater table the method of equalizing marginal costs to agriculture and marginal benefits for nature is used. The objective of economic instruments is to approximate an optimal allocation of resources in order to maximize social welfare. Theoretically, economic instruments, as for instance taxes or charges, could be put on a lowering of the groundwater table below the social optimum. The instruments would have to aim at farmers because they benefit from the groundwater table lowering. In order to be effective, taxes or charges have to be higher than the losses to agriculture.

In the hypothetical model in chapter 6, the optimal combined groundwater table lies, with the monetary value-of-nature of 500 guilders per hectare, at 68.4 cm below soil surface. Agricultural losses are at this point 17.56 guilders per hectare. An effective tax rate or heights of charges has therefore to exceed 17.56 guilders per hectare.

How sensitive is the optimal combined groundwater table with respect to the value of nature?

The monetary valuation of nature plays an important role in the determination of the optimal combined groundwater table. The level of the optimal combined groundwater table determines losses to agriculture and hence the proper tax rate/heights of charges. The sensitivity analysis on the monetary value-of-nature for this hypothetical model shows that the optimal combined groundwater table increases if the value-of-nature per hectare increases respectively the value-of-nature per hectare decreases at a faster rate as the groundwater table falls. In the example the optimal combined groundwater table ranges from 68.4 cm below soil surface to 48.9 cm below soil surface. Accordingly, losses to agriculture vary from 17.56 guilders per hectare to 129.41 guilders per hectare. The wide range of losses to agriculture gives an indication of the importance of the value-of-nature on the proper tax-rate/heights of charges.

Since the valuation of nature in the model is an assumption only, a valuation of the desiccated areas in the Netherlands by means of established valuation techniques (Willingness To Pay, Contingent Valuation Method, Hedonic Pricing Method, Travel Cost Method) would definitely contribute to an approach of the 'real world' situation. The valuation of a natural area can differ from region to region. This means that it depends on factors such as the biological value of the specific ecosystem, the attractiveness for recreation activities, the distance to cities or the valuation technique applied. This is again an argument for the region specific approach that has to be taken in the reduction of the desiccation problem.

Answer to the main objective

What is the role of economic instruments in Dutch water management and to what extent can they contribute to a reduction of desiccation?

Desiccation can be interpreted as an externality arising from intensive drainage and discharge of water and extraction of groundwater. Economic instruments can be used to internalize externalities by increasing the economic value (costs) of water discharges respectively groundwater extraction/use.

The application of economic instruments to water use/extraction can be promising in the Netherlands. With respect to the fact that the metering percentage of Dutch households will be 100% in the near future, especially the price instrument and the instrument 'Waterspoor', which is a combination of prices and sewage charges, could be effective to stimulate a more conscious use of water. In the case of agriculture, the successful application of economic instruments needs some juridical changes beforehand. The increase of water prices stimulates farmers to build private wells in order to avoid higher charges. This advantage and the fact that actual water consumption of farmers is not easy control, implies that without changing these conditions, the price instrument is not very effective.

However, groundwater extraction causes only 30% of the desiccation problem and it is even expected that reductions or stops of extractions only have a minor effect if drainage capacities remain high in the same area. This does not mean that economic instruments should not be applied to extraction/use: it alerts people about the real value of water and about increasing water scarcity also on worldwide level that will play an very important role in the near future.

The application of economic instruments to stimulate higher groundwater tables would have to occur through hydrological measures. Hydrological measures as they are defined here are rearrangements of the surface water system that influence the groundwater level. The main hydrological measures are the reduction of drainage capacity on agricultural land, the building of controllable barrages and the reduction of the depths of ditches. The introduction of hydrological measures can affect a whole area, which implies that several farmers are affected at the same time. The instrument must therefore be applied to groups of farmers.

Chapter 6 showed a theoretical approach to the introduction of taxes or charges on a lowering of the groundwater table. I expect that in practice administrative and organizational problems may come up with the introduction of economic instruments to hydrological measures. Difficulties could come up in negotiations with whole groups of farmers, the fair value attached to natural areas and the determination of the proper tax rate/heights of charges. Despite the possible obstacles, it would be interesting to start a test project in which economic instruments are applied to hydrological measures. Such a test project would require precise knowledge of the hydrological system, the biological circumstances of the ecosystem, the role of the different users of water resources and the technical possibilities to reduce desiccation in the test area beforehand.

Final remark

Especially in the quantitative part of this report it became clear that a pure economic approach to the questions around the desiccation problem is difficult. All aspects concerning changes in the hydrological system require a clear and intensive knowledge of the processes of groundwater in the soil and the complex system between surface water and groundwater. Furthermore, the impacts of the changes in the hydrological system on agricultural yields as well as biodiversity have to be identified. This demands a deep insight into the sensitivity of agricultural crops to water supply and the biological relationships of the different ecosystems. For a successful and reliable strategies against desiccation an interdisciplinary approach with hydrologists, soil scientists, crop scientist and biologist is therefore strongly recommended.

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Appendix A List of abbreviations

AHG	Averaged Highest Groundwater Level
ALG	Averaged Lowest Groundwater Level
BSS	Below Soil Surface
ECA	Eastern Cattle Area
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GW	Groundwater Table
HA	Hectare
kVEM	kilo Voeder Eenheid Melk (kilo feed unit milk)
MFC	Marginal Factor Costs
MVN	Monetary Value-of-Nature
OECD	Organization for Economic Cooperation and Development
P	Price
PPP	Polluter-Pays-Principle
Q, q	Quantity (input of water)
REVG	Revenue of Grassland
REVM	Revenue of Maize
REVP	Revenue of Potatoes
REVS	Revenue of Sugar Beets
REVGN	Revenue of Grain
RIVM	Rijksinstituut voor volksgezondheid en milieu (National Institute of Public Health and the Environment)
SMC	Social Marginal Costs
TOTREV	Total Revenue

UPP	User-Pays-Principle
VEWIN	Vereniging van exploitante waterleidingsbedrijfen in Nederland (Association of Dutch Drinking Water Supplier)
VMP	Value of Marginal Product
VNI	Value-of-Nature Index
VROM	Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieu (Ministry of Housing, Physical Planning and Environment)
Y	Yield

Appendix B Derivation of hotelling's rule

(Based on Perman, 1996, p. 138)

The Hotelling's Rule can be derived by applying the current valued Hamiltonian to maximize the social welfare function where utility depends on consumption. For simplicity only the resource stock constraint is introduced. Capital and consumption constraints are ignored. The function to be maximized is:

$$W = \int (C_t)\, e^{-\rho t}\, dt \qquad \text{(a)}$$

Where: W Social welfare
U: Utility
C: Consumption at time t
ρ: Social utility discount rate

Subject to the constraint:

$$\frac{dS}{dt} = -R_t \qquad \text{(b)}$$

which means that the decrease in the stock at time t is equal to the extraction at time t.
The objective function of the current valued Hamiltonian is for this maximization problem is

$$H_t = U(C_t) + P_t(-R_t) \qquad \text{(c)}$$

The first order conditions for the current valued Hamiltonian are:

1) Derivation with respect to the control variable C

$$\frac{\partial H_t}{\partial C_t} = 0 \qquad \text{(d)}$$

2) Derivation with respect to the state variable S

$$\frac{\partial H_t}{\partial S_t} = \rho P_t - \frac{dP}{dt} \qquad \text{(e)}$$

Because $\partial H_t/\partial S_t = 0$, (e) becomes $\rho P_t = dP/dt$, and after rearranging we get

$$\frac{dP_t / dt}{P_t} = \rho \qquad \text{(f)}$$

which is formula (2.1), the Hotelling's Rule, in the main text.

Appendix C   Depression tables

Table A   Percentage depression values for yields on ***grassland*** *with respect to the groundwater table*

Groundwater table (cm below soil surface)	Yield depression (in %)	Type of depression
10	21	Water overload
15	17	Water overload
25	10	Water overload
30	5	Water overload
35	2	Water overload
50	0	Optimal
55	0	Optimal
60	0	Optimal
70	1	Drought damage
75	1	Drought damage
105	3	Drought damage
110	4	Drought damage
140	8	Drought damage
150	10	Drought damage
170	15	Drought damage
200	21	Drought damage
260	25	Drought damage

Table B   Percentage depression values for yields on ***arable land*** *with respect to the groundwater table*

Groundwater table (cm below soil surface)	Yield depression (in %)	Type of depression
10	31	Water overload
15	27	Water overload
20	23	Water overload
25	15	Water overload
35	9	Water overload
50	6	Water overload
60	2	Water overload
100	0	Optimal
105	4	Drought damage
110	4	Drought damage
140	9	Drought damage
150	12	Drought damage
170	16	Drought damage
200	23	Drought damage
260	26	Drought damage

These tables are derived from the depression tables that are given in Werkgroep HELP (1987). Table A is based on HELP-code H2b, number 61 in depression table G7. Table B is based on HELP-code H2b, number 61 in depression table B7. HELP-code and number is information about the characteristics of the soil.

Appendix D Constructed data set

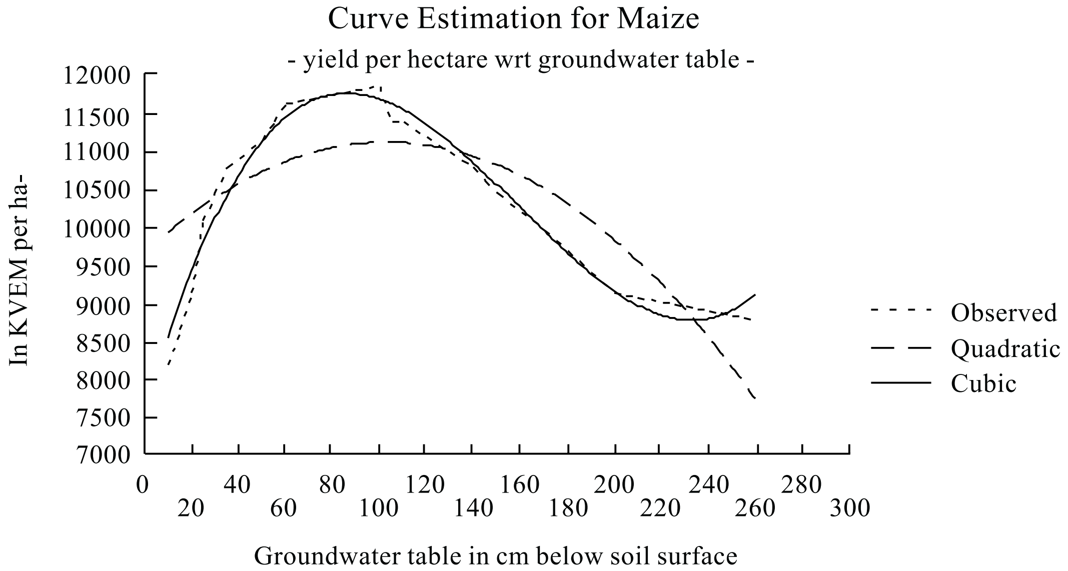
(kVEM = kilo voeder eenheid melk (kilo feed unit milk))

Groundwater table (cm below soil surface)	Grass (kVEM/ha)	Maize (kVEM/ha)	Potatoes (kg/ha)	Sugar beets (kg/ha)	Grain (kg/ha)
10	7,315.4	8,162.7	31,740	42,021	3,167.1
15	7,685.8	8,635.9	33,580	44,457	3,350.7
20	8,009.9	9,109.1	35,420	46,893	3,534.3
25	8,334	10,055.5	39,100	51,765	3,901.5
30	8,797	10,410.4	40,480	53,592	4,039.2
35	9,074.8	10,765.3	41,860	55,419	4,176.9
40	9,136.5	10,883.6	42,320	56,028	4,222.8
45	9,198.3	11,001.9	42,780	56,637	4,268.7
50	9,260	11,120.2	43,240	57,246	4,314.6
55	9,260	11,356.8	44,160	58,464	4,406.4
60	9,260	11,593.4	45,080	59,682	4,498.2
65	9,213.7	11,622.98	45,195	59,834.3	4,509.68
70	9,167.4	11,652.55	45,310	59,986.5	4,521.15
75	9,167.4	11,682.13	45,425	60,138.8	4,532.63
80	9,136.5	11,711.7	45,540	60,291	4,544.1
85	9,105.7	11,741.28	45,655	60,443.3	4,555.58
90	9,074.8	11,770.85	45,770	60,595.5	4,567.05
95	9,043.9	11,800.43	45,885	60,747.8	4,578.53
100	9,013.1	11,830	46,000	60,900	4,590
105	8,982.2	11,356.8	43,654	59,133.9	4,511.97
110	8,889.6	11,356.8	43,654	59,133.9	4,511.97
115	8,827.9	11,258.22	43,213.17	58,702,5	4,471.81
120	8,766.1	11,159.63	42,772.3	58,271.2	4,431.65
125	8,704.4	11,061.05	42,331.5	57,839.8	4,391.48
130	8,642.7	10,962.47	4,1890.7	57,408.4	4,351.32
135	8,580.9	10,863.88	41,449.83	56,977	4,311.158
140	8,519.2	10,765.3	41,009	56,545.7	4,270.99
145	8,426.6	10,587.85	40,215.5	5,5769.2	4,198.7
150	8,334	10,410.4	39,422	54,992.7	4,126.41
155	8,218.25	10,292.1	38,893	54,475.1	4,078.22
160	8,102.5	10,173.8	38,364	53,957.4	4,028.01
165	7,986.75	10,055.5	37,835	53,439.8	3,976.3
170	7,871	9,937.2	37,306	52,922.1	3,933.63
175	7,778.4	9,799.18	36,688.83	52,318.2	3,877.4
180	7,685.8	9,661.17	36,071.7	51,714.3	3,821.18
185	7,593.2	9,523.15	35,454.5	51,110.3	3,764.95
190	7,500.6	9,385.13	34,837.3	50,506.4	3,708.72
195	7,408	9,247.12	34,220.17	49,902.5	3,652.49
200	7,315.4	9,109.1	33,603	49,298.6	3,596.27
205	7,284.6	9,079.53	33,470.75	49,169.1	3,584.22

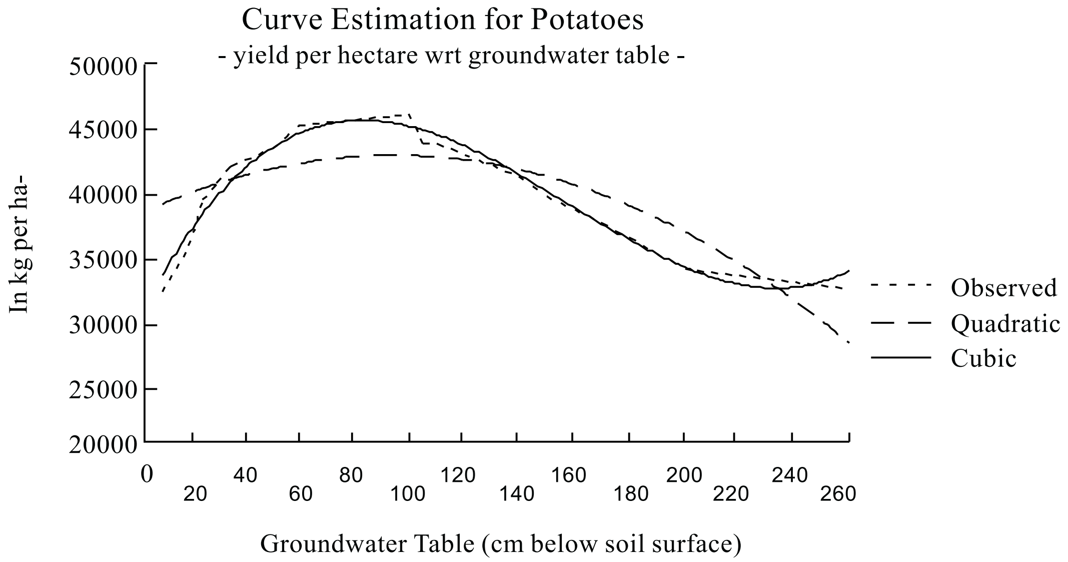
Groundwater table (cm below soil surface)	Grass (kVEM/ha)	Maize (kVEM/ha)	Potatoes (kg/ha)	Sugar beets (kg/ha)	Grain (kg/ha)
210	7,253.7	9,049.95	33,338.5	49,039.7	3,572.17
215	7,222.8	9,020.38	33,206.25	48,910,3	3,560.12
220	7,191.9	8,990.8	33,074	48,780,9	3,548.07
225	7,161.1	8,961.23	32,941.75	48,651.5	3,536.02
230	7,130.2	8,931.65	32,809.5	48,522.1	3,523.97
235	7,099.3	8,902.08	32,677.25	48,392.7	3,511.92
240	7,068.5	8,872.5	32,545	48,263.3	3,499.88
245	7,037.6	8,842.93	32,412.75	48,133.8	3,487.83
250	7,006.7	8,813.35	32,280.5	48,004.4	3,475.78
255	6,975.9	8,783.78	32,148.25	47,875	3,463.73
260	6,945	8,754.2	32,016	47,745.6	3,451.68

Appendix E Curve estimations for maize, potatoes, sugar beets and grain

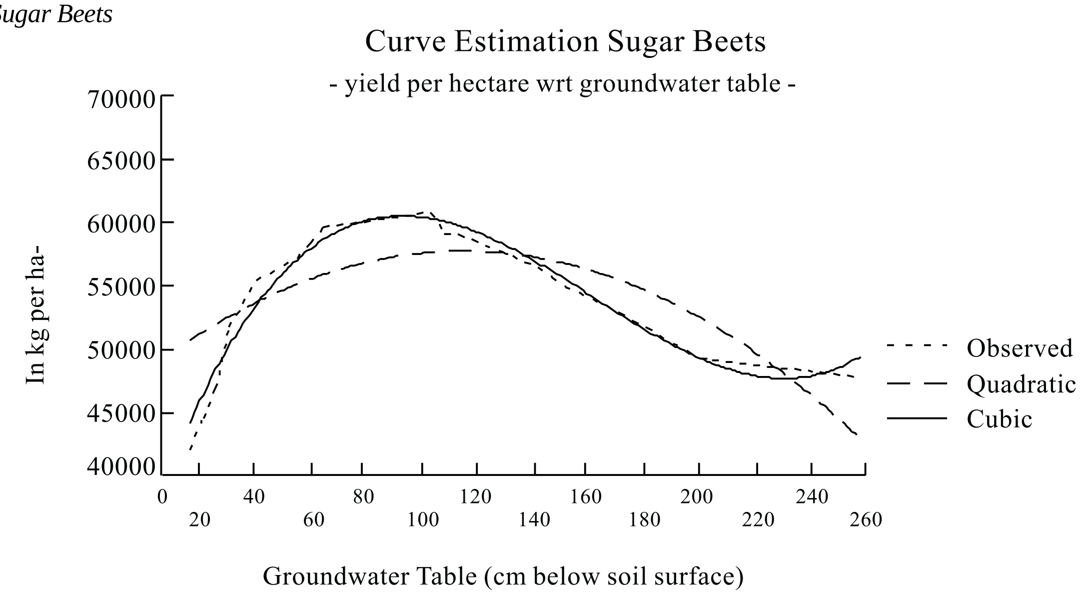
a) Maize



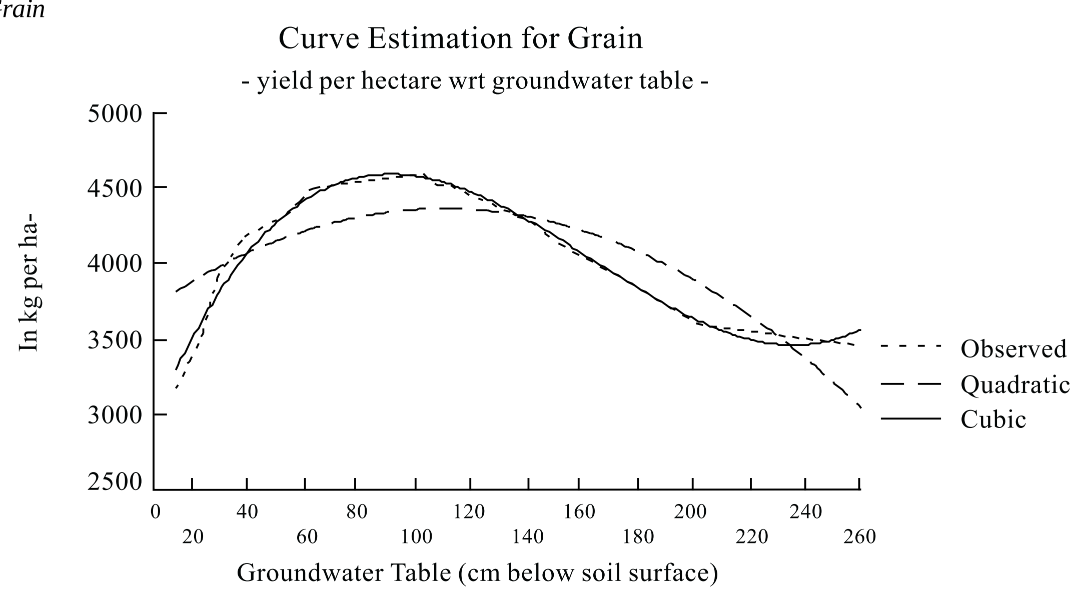
b) Potatoes



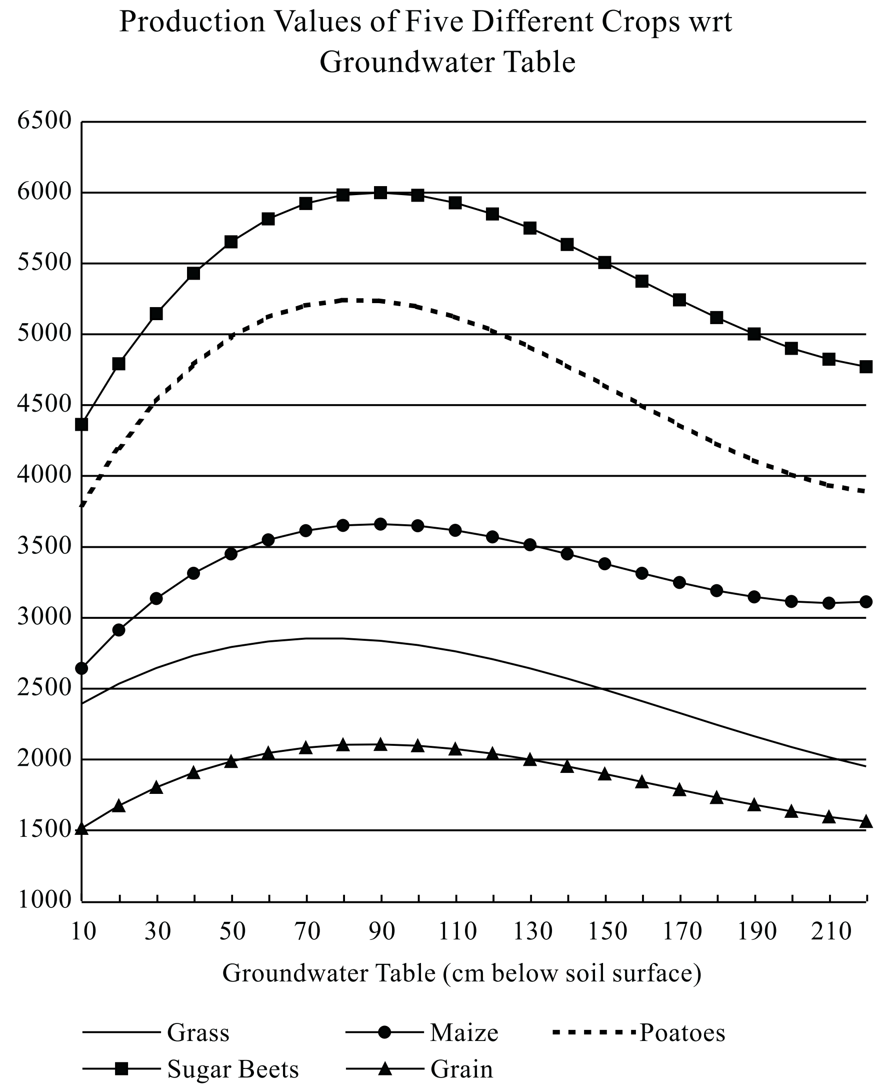
c) Sugar Beets



d) Grain



Appendix F Production values of crops



Appendix G Gams specification

Model for finding the optimal groundwater level while maximizing total agricultural revenue

Scalar

PG	price of grass per kVEM	/0.31/
PM	price of maize per kVEM	/0.31/
PP	price of potatoes per kg	/0.115/
PS	price of sugar beets per kg	/0.099/
PGN	price of grain per kg	/0.46/
HAG	hectares of grass	/60/
HAM	hectares of maize	/25/
HAP	hectares of potatoes	/5/
HAS	hectares of sugar beet	/5/
HAGN	hectares of grain	/5/;

Variables

YG	yield of grass per hectare
YM	yield of maize per hectare
YP	yield of potatoes per hectare
YS	yield of sugar beets per hectare
YGN	yield of grain per hectare
REVG	revenue grass
REVM	revenue maize
REVP	revenue potatoes
REVS	revenue sugar beets
REVGN	revenue grain
TOTREV	total revenue
VNI	value of index of nature;

Positive variables

GW	groundwater table
TAA	total agricultural area;

GW.LO=30;
GW.UP=250
TAA.UP=100;

Equations

```
YYG       yield of grass
YYM       yield of maize
YYP       yield of potatoes
YYS       yield of sugar beets
YYGN      yield of grain
TTAA      total agricultural area
RREVG     revenue grass per hectare
RREVM     revenue maize per hectare
RREVP     revenue potatoes per hectare
RREVS     revenue sugar beets per hectare
RREVGN    revenue grain per hectare
TTOTREV   total revenue
VVNI      value of nature index;

VVNI..    VNI =E= 100*(2.72**(0.2-(GW/100)));
YYG..     YG =E= 7172.987+(59.795*GW)-(0.51*(GW**2))+(0.001*(GW**3));
YYM..     YM =E= 7487.919+(112.811*GW)-(0.9*(GW**2))+(0.002*(GW**3));
YYP..     YP =E= 28822.508+(456.818*GW)-(3.733*(GW**2))+(0.008*(GW**3));
YYS..     YS =E= 38936.056+(556.699*GW)-(4.319*(GW**2))+(0.009*(GW**3));
YYGN..    YGN=E= 2884.929+(44.129*GW)-(0.344*(GW**2))+(0.0007*(GW**3));
TTAA..    TAA=E= HAM+HAG+HAP+HAS+HAGN;
RREVG..   REVG =E= YG*PG*HAG;
RREVM..   REVM =E= YM*PM*HAM;
RREVP..   REVP =E= YP*PP*HAP;
RREVS..   REVS =E= YS*PS*HAS;
RREVGN..  REVGN=E= YGN*PGN*HAGN;
TTOTREV   TOTREV =E= REVG+REVM+REVP+REVS+REVGN;

model model /all/
solve model using dnlp maximizing TOTREV;
```

Modifications for the calculation of optimal combined groundwater table and for the sensitivity analysis:

Monetary valuation of nature:

```
1) VVNI.. VNI =E= 500*(2.72**(0.2-(GW/100)));
2) VVNI.. VNI =E= 750*(2.72**(0.2-(GW/100)));
3) VVNI.. VNI =E= 1,000*(2.72**(0.2-(GW/100)));
4) VVNI.. VNI =E= 500*((2.72**(0.2-(GW/100)))**2);
5) VVNI.. VNI =E= 750*((2.72**(0.2-(GW/100)))**2);
```

Maximizing combined revenue:

```
COMBREV combined revenue (agriculture + nature);
CCOMBREV COMBREV =E= (TOTREV/100)+VNI;
        :
        :
solve model using dnlp maximizing COMBREV.
```