ILRI WORKSHOP: GROUNDWATER MANAGEMENT: SHARING RESPONSIBILITY FOR AN OPEN ACCESS RESOURCE

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PREFACE

Several reasons have motivated the choice to organize a workshop on groundwater.
The first of these stems from the nature of groundwater itself, and, more particularly, from what people do with groundwater. Groundwater has been labelled as one of the last of the earth's resources to be fully exploited. Nevertheless, at the rate at which the earth's people are now using groundwater, we can say that they are quickly making up for lost time.

In many countries of the world, groundwater is an important resource for human activities. This has been so for decades in the developed countries. Now groundwater is quickly becoming an important resource in many emerging countries. In the arid and semi-arid regions of these countries, groundwater is already being used intensively. But because such technical implements as pumps and well-drilling equipment are readily available to many users, the supplies of groundwater are being over-exploited, as is the case with so many other natural resources. In addition, the policies, rules, and regulations that are required to govern the use of groundwater are not yet in place. The right equipment in the hands of many users and the lack of restrictions on extraction have made groundwater an open-access resource: all who wish to do so can pump groundwater for their own use.

This situation has already led to unwanted consequences: groundwater levels have dropped, seawater has intruded further inland, groundwater supplies have been contaminated with waste products, and so on. These consequences have led to ecological disasters and near-disasters, and they have depleted groundwater supplies, creating problems for cities that rely on groundwater for drinking water.

The other side of the coin is that groundwater brings many blessings. Particularly in the arid and semi-arid areas of the world, groundwater is a highly reliable source of water - indeed, it is often the only source of water - as rainfall is notoriously erratic and insufficient, and as surface streams usually do not exist. For generations, the farmers in these areas have felt that water is the limitation to further development. Now they are thrilled that they can finally have as much water as they please. Their happiness will be only temporary, however, if nothing is done to regulate groundwater use. Sooner or later the groundwater economies on which these farmers depend, will collapse unless the groundwater resources are managed wisely.

The second reason for organizing a workshop on groundwater is that on missions abroad ILRI staff have seen for themselves the seriousness of these and other groundwater problems. Often these problems appear to be related to irrigation and drainage, the traditional core concerns of ILRI. While working out the interrelations between these subjects and the implications of their management, we have found that groundwater management questions, especially, have received only limited attention thus far.
By bringing together people with experience in groundwater management in a workshop, we hope to contribute to the understanding of groundwater management. We opted for a broad approach, bringing together experts from different disciplines and with experience from different geographical regions. This may not make the task of formulating conclusions on groundwater management issues easy, but I believe that we have succeeded, not in the last place because of the contributions of those who presented papers or contributed to the discussions.

The third reason for holding a workshop had to do with the next World Water Day, which will be held on March 21, 1998, and which will have groundwater as its theme. By organizing the workshop of which the proceedings are now in front of you, we felt that we could prepare ourselves better for World Water Day. We hope that this applies also for the participants to the workshop.

The workshop is presented as a triple double-u workshop. In this case, W W W does not stand for 'World Wide Web'. Although the workshop has been announced on the web, and it has attracted the attention of quite a number of people. W W W in our context stands for 'Wageningen Water Workshop.' ILRI is planning to organise triple double-u workshops annually. Each of these will focus on a subject related to water. ILRI will take the initiative in these workshops, but it will not necessarily take a leading role. It will seek the cooperation of other institutions, in Wageningen or elsewhere, to jointly organise the triple-double-u workshops.

I wish to thank all people, from both outside and inside ILRI, who have contributed to make the workshop a success.

Wageningen, December 1997

M.J.H.P Pinkers
Director ILRI

ACKNOWLEDGEMENTS

One of the first steps in preparing the workshop on Groundwater Management was to define the workshop's objective and its focus. Subsequently, the subject was broken down into a number of separate themes. The next step was to identify experts in the field of groundwater management who could contribute to the themes and then to approach them with the request whether they would be willing to present a paper and participate in the discussions. We feel extremely pleased that, with the exception of two experts who could not be in Wageningen at the time of the workshop, all who were approached agreed enthusiastically to cooperate. They have not disappointed us. Their contributions were interesting and informative and helped much to feed the discussions during the workshop. Their papers are included in these proceedings.

Equally important in bringing the workshop to a success was the input of the participants. About one-third of them came from developing countries, the countries that were at the focus of the workshop. Their experiences and insights were heard during the working-group sessions and at the plenary sessions at the end of days 1 and 2. We wish to thank them all for the interest shown in the workshop and for their willingness to share their thoughts with us and contribute to the further development of the field. After all, this was what the workshop was all about: to contribute to the understanding of the many factors that have an impact on proper groundwater management.

Once again, we would like to take the opportunity to express our gratitude to the ILRI colleagues who have been working hard and with dedication to set the stage for the workshop to take place: Mr Johan van Manen, who organized the logistics of the workshop, Mrs Elizabeth Rijksen, who did the public relations of the workshop as well as many other things, Mrs Kitty Moors, who was responsible for all correspondence, and Mrs Elly Verschoor-Visser, who was always willing to do the things that others for one reason or another could not do at that time. We also wish to thank Mrs Meredith Naeff-Snyder and Mrs Margaret Roche, who edited the text of the proceedings, Mr Joop van Dijk for his work on the drawings for the proceedings, and Mr Stefan Nortier for finalizing the lay-out of the proceedings.

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MANAGING AN OPEN-ACCESS RESOURCE: GROUNDWATER

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Introduction

Since time immemorial, people have been using groundwater. At first, they used it only for drinking. A simple rope-and-bucket system, installed above a dug well, hauled up water from its underground hiding place. With this technique, shallow groundwater layers became accessible. A slightly modified, but basically the same system, used animals to lift water that could be applied to irrigate fields. The quantities of water that could be brought to the surface in this way were limited, and only fields in the immediate surroundings of a well could be irrigated. More impressive examples of techniques of ancient groundwater extraction include the tunnel systems that have been constructed - sometimes more than 1,000 years ago - in countries like Pakistan, Yemen, and Indonesia (van Steenbergen 1996; van der Gun and Abdul Aziz Ahmed 1995; own observations, island of Bali).

Throughout the centuries, groundwater use has been extensive; in all these cases, the natural recharge exceeded the extractions. A more intensive use of groundwater became possible when new technologies were invented. In particular, the development of mechanical pumps brought an important change. For the first time, the capacity to withdraw groundwater exceeded the natural recharge. In principle, the need to manage groundwater resources was thereby created.

This chapter, after presenting some examples of groundwater use in different countries and in different contexts, will focus on the advantages that groundwater brings to its users and on the disadvantages of intensive groundwater use. Today, groundwater is put to many uses. In developing countries, it is the agricultural sector that brings most of the groundwater to the surface. In the industrialized countries, it is the drinking water sector. The benefits to both farmers and citizens are many. The resource has become so popular in many areas that groundwater levels are dropping. In addition, some groundwater resources are becoming increasingly contaminated.

This chapter will continue with a discussion of groundwater management. A conceptual model will be presented that relates three elements to one another: the groundwater resource itself, groundwater managers (users and others), and groundwater management institutions. Together, these elements constitute what could be referred to as the `resource management triangle'. Each of these elements will be explained in detail.

The basis has then been set for the identification of a set of groundwater management issues. Eight such issues will be presented. These issues are at the core of the papers contributed by the respective authors; the issues also constituted the topics around which the workshop discussions were centered. The eight topics will appear again in the last chapter of this book, when the conclusions of the workshop are presented.

Finally, this chapter will introduce a number of new concepts and terms: 'physical integrity' and 'resource manager', for instance. These are explained in their proper places. The terms are also explained in a glossary.

Groundwater development : an overview

Industrialized countries

In industrialized countries like The Netherlands and Denmark, the intensive use of groundwater started in the second half of the nineteenth century, and accelerated further at the beginning of the twentieth century. Groundwater was brought to the surface to supply drinking water to the countries' increasingly urbanized populations. Today, the populations of both these countries rely on groundwater for, respectively, 65% and 98% (!) of their drinking water (van Soest 1991; Anderson and Thomsen 1991). In addition, the industrial sector started to use groundwater as a resource. The main industrial consumers of groundwater in these countries are the electricity plants; they use groundwater as a cooling agent. Groundwater use for irrigation is of a more recent date. In The Netherlands, it started only a few decades ago and is basically meant to overcome dry spells during the summer.

The Las Vegas Valley, Nevada, U.S.A., is another interesting example of early - intensive - groundwater exploitation. This Valley, which combines an extremely arid climate with a rich aquifer system, started using groundwater intensively as early as 1850 (Morris *et al.* 1997). Agricultural crops in the Las Vegas Valley have been irrigated with groundwater since before 1900.

The first regulations on groundwater in the Las Vegas Valley date from 1866 (Morris *et al.* 1997). Remarkably, these early regulations were meant to stimulate the use of groundwater, rather than to restrict its use and to protect the resource. Regulations to protect groundwater resources were formulated several decades later. Not until 1934 - or almost three quarters of a century after the intensive use of groundwater started in the Las Vegas Valley - did the focus shift to preserving groundwater and to protecting the existing groundwater resource.

Also in Denmark and The Netherlands, groundwater management started long after groundwater resources became intensively used. In Denmark, the first regulation on groundwater use was a decree that all new wells had to be registered and that information on the properties of the pumps had to be registered as well (Andersen and Thomsen 1991). This decree was issued in 1926, or about half a century after the start of intensive groundwater exploitation. This was the first action in that country to bring groundwater extraction under the control of an overseeing authority. The policy to concentrate on wells and pumps was a lucky one. As a result, Denmark now has an excellent database showing the location and other relevant details of every single extraction point in the country. Today, these data are used as the basis for a zoning policy, restricting groundwater exploitation in some areas and allowing it in others.

Another twenty years passed before more detailed regulations were issued in Denmark and a shift was made in the direction of a more integrated water management. In 1950, the Danish authorities issued more detailed regulations on groundwater. In the decades that followed, the authorities established rules and regulations that covered important matters like decision-making levels, instructions on maintaining the physical integrity of groundwater resources, and the involvement in decision-making by groundwater users.

In The Netherlands, the first regulations focussing on groundwater protection were passed in 1940, and were further elaborated in the fifties. As in Denmark, more comprehensive groundwater management was given shape in subsequent years. The papers by Pellenbarg and by Romijn in this volume give further details.

In both Denmark and The Netherlands, groundwater has gradually changed from an open-access resource (uncontrolled exploitation) into a common-pool resource (shared and controlled exploitation). Today, groundwater management in most western countries is characterized by a large degree of control over both groundwater extractions and groundwater quality. Public participation is another phenomenon that characterizes groundwater management in these countries, as is decentralized decision-making. This is not to say that groundwater management in western countries must be considered optimal. It is not! To give just two examples, groundwater extraction in the Las Vegas Valley still exceeds the recharging capacity by a factor 1.5, and this has been going on since as long ago as 1946 (Morris *et al.* 1997, p. 190). From a resource management perspective, this is hardly acceptable. And in parts of The Netherlands, groundwater quality has become seriously contaminated with agricultural chemicals and industrial waste.

Developing countries

In the arid and semi-arid zones of developing countries, the intensive use of groundwater started roughly a century later than in industrialized countries. In countries like Yemen, Kenya, and Egypt, farmers started installing pumps on a large scale in the late sixties (van der Gun and Abdul Aziz Ahmed 1995; also Negenman, this volume). Today, aquifers in Yemen are being depleted faster than anywhere else in the world. Over a 25-year period - from 1960 to 1985 - groundwater use by farmers in Pakistan increased from 8% to 40% of total supplies (van Steenbergen, this volume). Data from West Africa show that pump-lift irrigation there started later still. In Nigeria, for example, the increase occurred in the eighties: in the period 1983-90 the number of pumps increased from a low 50 to as many as 15,000 (Sonou 1994).

The example of groundwater extraction in the State of Uttar Pradesh, which has the largest groundwater potential in India, is illustrative. Uttar Pradesh is an interesting example, because it is both unique and in line with the general pattern. Groundwater extraction in Uttar Pradesh started at a relatively early date. Already in the thirties of this century, pumps had been installed (Alberts 1997). These were deep tubewells and they were constructed by the then-colonial government. They were meant to irrigate the fields of small peasant farmers, who were believed not to have the means to develop the groundwater resource themselves. By 1960, some half a million ha were under these public groundwater irrigation schemes.

From then onwards, Uttar Pradesh started to show the same development pattern that can be observed in so many other arid regions in developing countries. Groundwater resources were soon being intensively exploited. By 1982, the area under groundwater irrigation had increased more than ten-fold, to 5.4 million ha. Seven years later, the area had increased almost two times again, to 8.8 million ha. By now, the balance had shifted in favour of private tubewells: 86% of the area under groundwater irrigation in Uttar Pradesh is covered by private pumps. The State of Uttar Pradesh is one of the many states in India that has exploitable groundwater reserves. Many of India's groundwater reserves are already intensively used, yet in many areas they have potential to irrigate considerably larger areas still (Tushaar Shah 1993).

In the arid and semi-arid zones of developing countries, groundwater development differs in several ways from groundwater development in countries like Denmark and The Netherlands. The relatively recent moment in time when people in developing countries started to use groundwater has already been mentioned. The much dryer climate of arid and semi-arid regions as compared with the climates in the industrialized countries is an important reason why groundwater in (semi-)arid areas is used for irrigation in the first place and for drinking water in the second. In Denmark and The Netherlands, this is the other way around. Here, groundwater is exploited to provide drinking water to its citizens. This has an important management implication. Controlling a limited number of large specialized exploiters of groundwater like drinking water companies requires an essentially different set of policy instruments than controlling countless private small-holders. A further difference concerns the pace at which developments have taken place. Within the short time span of a few decades, literally thousands of powered pumps have been installed in countries like Pakistan, Yemen, Egypt, and India. Finally, the governments of Denmark and The Netherlands have a much firmer grip on resource use than the governments of most developing countries.

The large numbers of users and the pace at which developments have unfolded add to the complexity of groundwater management in developing countries. The users are numerous farmers, whose behavioural patterns are ill-understood, who understand little of the effects of their collective behaviour on the resource they tap, yet who have an interest in pumping ever more water to the surface. In many regions, the impact on groundwater resources is dramatic: groundwater levels are dropping fast. Even acute water shortages occur from time to time (Negenman, Bakker, this volume). Remedial actions are required. What is needed are effective groundwater management institutions, but in developing countries, these are virtually absent.

Groundwater in developing countries still has all the characteristics of an open-access resource; people extract from the resource without feeling - or being - restricted. And it is the yield of the pump that concerns them most. The evolution towards regarding groundwater as a common-pool resource is only in its infancy. Under common-pool management, the continued future use of the resource is an important objective, shared by both groundwater managers and users.

Positive and negative effects

For farmers in arid and semi-arid zones in developing countries, access to groundwater means having access to a reliable source of water. Compared with surface irrigation - the other source of irrigation water available to them - the advantages are many. Once a pump of sufficient capacity has been installed, farmers can irrigate their fields effectively: not only can they supply as much water as they please, but they can also supply it when they want it and as regularly as they want it. They are in control of their own water supply. For farmers in such regions, for whom water has always been the major limiting factor in increasing the production of their fields, groundwater must come as a 'gift from heaven'.

If compared to the situation before pumps were installed and surface irrigation water became available, the differences are even more dramatic. Farmers in arid and semi-arid areas were always dependent on extremely limited and erratic rains. With time, they developed strategies that were characterized by risk-avoidance. Under the prevailing farming systems, farms were large, labour input per unit of land was kept low, cash inputs were minimized, a variety of crops were cultivated, and crops were, in the first place, meant for home consumption. In addition, farmers in such regions usually kept several kinds of livestock, which served as an extra source of income and as a buffer in case rains - and thus harvests - failed.

Even where irrigation from surface water is supplied, groundwater is a welcome and often an essential supplementary source of water. Many irrigation systems do not provide sufficient supplies, and do not provide water at timely and regular intervals. With the exception of farmers whose fields are close to an intake, individual farmers depending on surface irrigation are not in control of their supply of water. They are dependent on either the supplying agency, which in most cases is a slowly-reacting government institution, or on farmers upstream in the system, or on both. Even large, influential farmers are at the mercy of conditions beyond their control.

The example of farmers in the Punjab in Pakistan and India is illustrative. The large irrigation systems in these areas were developed as "protective" irrigation systems: they supply just enough water to prevent crop failures because of failing or erratic rains (Jurriëns *et al.* 1996). Farmers are restricted to growing the same low-water-demanding crops that they would have grown under rain-fed conditions. Recently, farmers have started to pump up the water that has seeped into the ground through the canal bottoms. They use this to supplement the irrigation water provided by the surface irrigation system (conjunctive use of canal water and groundwater; see Murray-Rust and van der Velde 1992; Jasveen Jairath 1991; O'Mara 1988; Vincent 1991). With this extra supply, they have enough water to grow high-water-demanding crops. Such crops are usually cash crops that they can sell at a profit at nearby markets. A recent survey has shown that groundwater supplies, in minutes, are at least ten times more important than surface irrigation water supplies (Schrevel and Kaul 1997).

Without much exaggeration, one could say that, in the Indian and Pakistan Punjab, a groundwater economy has come into existence. Groundwater economies have come into being in other arid regions as well. In Balochistan, Pakistan, orchards are being supplied with groundwater as the only or major source of water (van Steenbergen 1996). The density populated areas of Yemen are another example (van der Gun and Abdul Aziz Ahmed 1995). In Mendosa, Argentina, the area under groundwater exceeds the area under groundwater and surface water (Querner, this volume). If groundwater were no longer available, these groundwater economies would collapse. This would have severe consequences for the incomes of the people concerned.

In many of these areas - the Punjab is an exception - the sharp increase in volumes of groundwater extracted over the last two to three decades has resulted in a drop of groundwater tables. The cases described later in this volume are all illustrations of this phenomenon. Groundwater must be taken from ever deeper layers, which means higher extraction costs. In the end, it will only be those users who command more capital (i.e. rich farmers) who will be able to continue to bring water to the surface. Farmers will continue to pump water for as long as they find markets for their products. Considerations regarding the damage their actions are bringing to the resource they are exploiting do not bother them.

Environmental considerations are not reflected in the price that farmers receive for their products.

A falling groundwater table is but one of the consequences of increasing groundwater extraction. A related problem is land subsidence (i.e. the land sinks). Land subsidence may result in costly damage to roads, structures, and public and private utilities (Tuinhof 1994, p. 103; Morris *et al.* 1997). Intensive groundwater exploitation can also lead to land degradation. Where groundwater infiltrating into the ground and pumped up for supplementary irrigation is not properly drained off, watertables do not drop but rise. Locally, this will result in waterlogging. In arid environments, waterlogging will eventually be followed by salinisation (see van Steenbergen, this volume).

In coastal areas, sea water replaces the fresh water that has been pumped to the surface. The intrusion of salt water will negatively affect the quality of groundwater. In densely populated and industrialized areas, the quality of groundwater may also be affected by effluents of industrial waste. This constitutes a threat to public health. The case of The Netherlands is an example (Tuinhof 1994). It is for this reason that drinking water in The Netherlands today is increasingly being taken from surface water reserves. Groundwater in general is further affected by chemicals wasted by the agricultural sector.

Groundwater management conceptualized

Land, forests, fishing grounds, grazing pastures, surface water, and groundwater are all examples of natural resources. Each of these natural resources has unique properties that call for unique management approaches.

Fishing grounds, for example, or more accurately schools of fish, cannot be controlled directly. Putting a fence around schools of fish is not possible. This property requires the resource to be managed indirectly; measures are meant to affect the behaviour of users of the resource, and thereby - and in an indirect way - the resource itself. It is not the fish, but the users that are managed. The catch quota system as applied in the countries of the European Union and other western countries is the indirect way in which fish resources are managed today. The catch quota system is based on a thorough understanding of the resource itself, its magnitude, and its capacity to regenerate itself (resilience capacity). Institutes are called into being to determine the annual catch quota. Fishermen have organized themselves in interest groups to lobby for better incomes. This resource management system has evolved over the last decades as a reaction to serious threats to the future of fish resources. It is a typical example of exploiting a resource to the maximum extent possible. Yet, the long-term sustainability of the resource is the primary objective. The resource is being harvested, rather then mined.

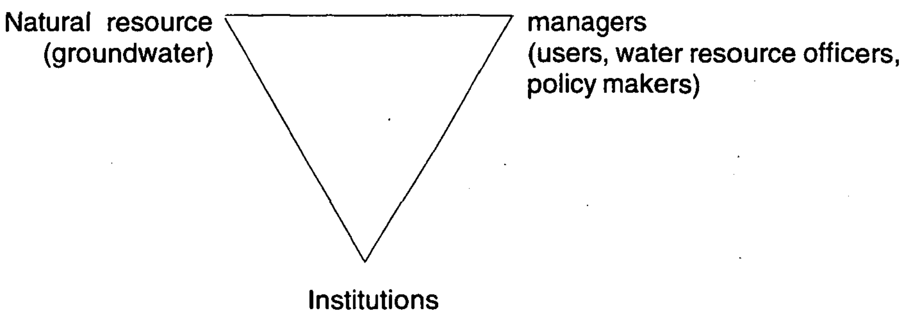
The sophisticated catch quota system should be compared with more traditional ways of managing fishing resources. Traditional ways of managing fish resources usually consisted of restrictions on catching fish during certain periods of the year. Managers and users are not organized. Their understanding of the resource is limited.

Forests are an example of resources that can be fenced off. These fences can be controlled. This is indeed how many forest resources are being managed. In developing countries, however, fencing off forest reserves and controlling the fences is not practical. The areas to be guarded are too extensive; the controlling agencies are not well enough equipped for their task; and the pressure to enter the forests and use its products is too high. Alternative managing regimes have evolved, based on the direct involvement of local people and less intensive control.

Like fishing grounds and forest reserves, groundwater too has distinct properties that call for distinct management approaches. And it is precisely these groundwater management characteristics that are at the focus of the workshop that preceded the publication of this volume.

The examples above showed that each resource management system in principle has three components: (i) the resource itself, (ii) the resource managers, and (iii) the management institutions or organizations. These components relate to each other as shown in Figure 1.

Figure 1. The three components of natural resource management systems



Resource management systems are usually not static. A change in one component triggers off changes in one of the other components. The real-world situations described in the preceding sections contained multiple examples of this. We shall now turn to a discussion of the three components of the resource management model. The focus will again be on groundwater.

Management institutions and organizations

Resource management institutions are defined as all arrangements meant to govern a natural resource. Thus, resource management institutions include both agreements as well as associations of people (after Coward 1991).

Examples of resource management institutions are rules and regulations issued to control a resource, either directly or indirectly. Less formal arrangements, such as unwritten norms and behavioural patterns to which people adhere, are examples of institutions as well. For example, an agreement between users of a natural resource to respect each other's access rights, like an agreement among groundwater users to keep a minimum distance between wells, is an example of an institution as well. Even the culturally defined habit of initiating a well by means of an animal-slaughtering ceremony is an example of an institution.

Under this definition, the organizations called into being to rule over a natural resource (e.g. a natural water resource management agency) is an institution as well. Another example of an institution is a water users' association.

Groundwater managers

Resource managers are defined as private or public persons whose actions or decisions have an influence on the physical integrity of the resource (Blaikie and Brookfield 1987). Resource managers are thus both the users of a resource and the specialists with a mandate to govern a resource.

Users make decisions to use a resource. Groundwater users sink wells, install lifting devices, and lift water. By doing so, they extract water from the resource; they influence the physical quality of the groundwater resource.

Specialists governing a groundwater resource are the public servants working in a water resource management institute. Consultants on a groundwater project are also groundwater managers. One could even think of the experts within multilateral donor organizations like the World Bank and other development institutions as resource managers. Their decision to support or not to support a programme or project often has an important impact on a natural resource. Policy-makers in general are resource managers as well.

Even consumers of the products of a natural resource must be regarded as resource managers. If they stop buying the product - as happened when the Dutch public stopped buying the fur of wild animals - producers will not be able to sell and will stop producing. As a result, the resource will not be further depleted.

The difference between these different categories of resource managers lies in the impact they generate. This impact can be either direct or indirect, and can sometimes be so indirect that it can hardly be detected. In this chapter, we are only concerned with three types of resource managers: users, experts within the institutions called to govern groundwater resources, and policy-makers. For reasons of convenience, we shall refer to the second category of resource managers as `competent authorities'.

Users of a resource do not necessarily share the same interests. On the contrary, groundwater users, for example, are more likely to be each other`s competitors. In The Netherlands, drinking water companies compete with farmers for water. Environmentalists have entirely different interests in groundwater than either the drinking water companies or the farmers. Within a group of users who apply the source for the same purpose, like farmers, competition is the rule rather than the exception. It is for this reason that the first groundwater management rule that is usually formulated is that wells must be spaced at a certain distance from each other. Competition will be more severe if less of a resource is available, thus at times when demands are increasing and supplies diminishing. Competent authorities may have still other interests. Even within one and the same competent authority, different interests may occur.

This may be all too obvious. But a number of important questions remain. One of these is: who is to decide what the 'optimal' state of a resource is? If we look at groundwater, should it be the hydro-geological engineer? Or the farmer? Or the environmentalist? And should it be a rule to maintain groundwater tables and quality levels at their present levels? Or should groundwater tables be brought back to their `natural state'. What, then, is the natural state of a groundwater resource? Is this the state a resource had before people started to use it? In many cases, this situation is unknown; in other cases, it is it not preferred. If, in The Netherlands, groundwater was brought back to its `natural' state, half of the country would be flooded!

The point to make is that decisions concerning groundwater - and for that matter, natural resources in general - should be the outcome of processes of negotiation. Preferably all resource managers should take part in these negotiations and preferably all will be informed about relevant aspects. This principle is laid down here as an important principle of groundwater management (compare also the paper by Otto, this volume).

Farmers should not be looked at as an homogenous group, although they are often spoken about as such. Statistics that only show total groundwater consumption data by the agricultural sector are confusing and are in fact over-simplifications of what occurs in that sector.

Rural populations consist of different types of farmers. The most important differentiation is based on the area cultivated. Thus, one speaks about large farmers, middle-sized farmers, and small farmers. Larger farmers usually have more financial means at their disposal than smaller farmers. This rule is only true if farmers depend on the same sources of income, if land is the most important production factor, and if farmers have the same access to water. If farmers live near urban agglomerations, however, they may have other sources of income, and land area is no longer a good indicator of relative wealth (Schrevel 1993). Farmers whose household economies are subsidized with the earnings of an overseas family member also combine relatively high incomes with the possession of small areas of land. It should further be acknowledged that usually complex economic relationships exist between members of farming communities. Land and agricultural-product markets are usually well developed, with different constructions on how production costs and production are shared.

Little is known about groundwater use by different categories of users. It must be expected, however, that richer farmers are among the first to start using the resource. If this is true, they are also the first to reap the benefits of groundwater. Some evidence is available that richer farmers are also in a better position to absorb the consequences of falling watertables (van Steenbergen, this volume). They can afford to sink deeper wells and to install more powerful pumps to lift water from deeper layers. Poor farmers apparently also in this situation are the first to lose out. Moreover, where groundwater is available, groundwater markets quickly develop. In Uttar Pradesh, the Indian state discussed earlier, land-poor farmers appear to depend almost entirely on the purchase of groundwater from richer farmers (Pant 1985, 1991). Groundwater markets have also been the subject of a study by Meinzen-Dick (1997).

As these examples show, groundwater management has an important socio-economic dimension as well. The implication is that the internal structure of rural communities must be understood before effective strategies to influence groundwater use can be defined.

Groundwater properties

The third component of the management model described above constitutes the qualities inherent to the resource itself. Four properties of groundwater are discussed: its invisibility, the openness with which it can be accessed, the indivisibility of a groundwater resource, and the fact that groundwater, like many other resources, is finite. The third property, the indivisibility of groundwater, relates to the fact that a groundwater resource cannot be divided into smaller units to which individuals can have rights. This fact and the management problems that stem from it are further elaborated by Nibbering, under "Common Pool Theories and Concepts" (this volume).

Groundwater is invisible. This simple fact has been observed by many, but the management implications require attention as well. Because groundwater is invisible, users often have little understanding about the physics of groundwater. For example, in 1940, after roughly one hundred years of intensive groundwater use, users in the Las Vegas Valley, Nevada, U.S.A., still thought of the resource in terms of an enormous underground lake (Morris *et al.* 1997). Users sometimes believe that the resource is infinite, and that, if watertables have dropped, they only have to dig deeper to get access to water. The notion that eventually the bottom is a hard rock layer does not always exist (van Steenbergen 1996). As if the earth is a balloon filled with water!

It is not only users who have incorrect notions about groundwater; competent authorities are not always well informed either. Underestimates of potentially hazardous developments seem to be a common problem. Groundwater managers in developing countries seem to be more concerned with obtaining maximum yields from the resource and less with protecting and preserving it. This could very well be a result of the invisibility of groundwater: what the eye does not see, the heart does not grieve.

A related problem is that almost never do adequate sets of data on groundwater resources exist, on the basis of which sensible management decisions can be made. Such data have not been collected because the resource, being invisible, has been neglected, both by users and by competent authorities. Complete sets of data are required according to some; estimates or assumptions regarding volumes of aquifers are clearly insufficient (Tuinhof 1994).

The open-access character of groundwater management is as much a result of the properties of the resource as it is an expression of the strength of management regimes. Groundwater is relatively easy to obtain. All that anyone needs to do is to sink a well and tap into an existing groundwater layer. It is important to realize that users can access groundwater directly from their fields; they do not have to go to some shared intake point to get their water. In other words, groundwater can be accessed from multiple access points - or from multiple extraction points, depending on one's point of view. Of course, this is only true in alluvial plains with shallow watertables (e.g. valley floors and coastal plains). But, as it happens, it is on the plains and in the valleys that the highest concentrations of populations live.

In contrast, surface water systems (e.g. rivers, canals, or reservoirs) have to be accessed at one point. A user will always have to transport water over some distance to bring it from an intake point to his fields. Only farmers who have their fields at the intake will have direct access. Yet, in most cases, regulations will restrict such farmers. Surface water systems combine indirect access with access from one extraction point.

Because of the easy access to groundwater, its users do not suffer from a number of disadvantages that are inherent to surface water supply systems. Thus, the notoriously difficult problem of head-enders who take water before tail-enders does not trouble groundwater users. Neither is the problem of getting right-of-way for a canal or structure known to groundwater users.

Although access to groundwater is relatively easy for users, it is difficult for competent authorities to exercise control over the resource. Not one extraction point needs to be governed, but multiple extraction points. In fact, as many extraction points need to be controlled as there are users. Ultimate control over groundwater requires either ultimate control over the users or ultimate control over the land area where access to the groundwater is possible. Only indirect control is possible.

The direct accessibility of groundwater allows efficiency in use. The (vertical) distance over hich groundwater is transported is relatively short. To this can be added that the owner, the operator, and the user of a pump is usually one and the same person. As a direct relationship exists between operating costs, water yields, yields of irrigated crops, and incomes from agriculture, it is in the interest of the groundwater user to use his pump cost-efficiently. This relationship is distorted when pump operating costs are subsidized through subsidies on energy. This is the usual practice in many countries; but it encourages inefficiency in groundwater use (Tuinhof 1994; van der Gun and Abdul Aziz Ahmed 1995).

The properties of groundwater as a resource require that active management regimes be in place to govern the resource. If not, the resource will be exploited, or to use another term, mined. Once the resource is depleted, it is of no further use. This property minimally asks for a conscious decision to be made between controlled exploitation on the one hand, in which case a management regime of some kind is required, and mining on the other.

The conceptual framework presented above has a further practical implication. It makes us aware of the fact that groundwater use should not be looked at from a mono-sectoral, purely hydro-geological, perspective. It is important to understand not only the changes that take place in groundwater resources as these occur under the influence of natural or man-made processes, but also their causes. And these causes are economic and sociological. As a consequence, not only data on the resource itself need to be collected, but also data on the users of the resource. The factors that motivate users to act as they do need to be understood.

It is this 'resource management triangle', which consists of the resource itself, its users, and the institutional and organizational arrangements, that always needs to be considered.

Groundwater management issues

From the above analyses and fom the literature on resource management, a number of groundwater management issues can be deduced. A total of eight such issues will be presented here. While some are concerned with understanding groundwater as a physical resource, others are concerned with managing the users of a resource, including the aspect of costs.

As was explained in the Introduction, the eight management issues come into the picture again in the last chapter of this book, which presents the conclusions of the workshop participants regarding the resource management issues. The issues also receive attention in the various papers contributed by the experts on groundwater management. Under the eight sub-headings that follow, the issues that were selected as focal points during the workshop are discussed.

Objectives of groundwater management

Discussions on how a resource should be managed should always start with the question: "What objective is to be served?" An example will explain this.

It makes a difference, of course, whether a resource is to be used as intensively as possible - in which case the swift degradation or depletion of the resource is accepted - or whether the sustainable use of the resource is the aim. An example of the first case is a metal ore resource that is required for some strategic purpose. In that situation, users who can bring in the heavy machinery needed will be invited to participate. In the other case, the quantities extracted and probably the timing of extraction become important considerations.

In many developing countries, the choice often needs to be made between the sustainable use - from an ecological point of view - and resource exploitation to feed expanding populations.

Required levels of decision-making

National resources can be managed at different levels. The lowest is the local level, or even the level of the individual resource user. The highest is the central government. International resources (e.g. oceans) are sometimes managed by supra-national bodies. If individual users are completely in control, one speaks of an open-access situation. As soon as agreements of some kind control the actions of users or are issued by a competent authority, some degree of controlled access exists. Which level is the most appropriate depends on a number of factors, including the physical characteristics of groundwater resources.

Noteworthy is the statement by the World Bank that resources should be managed at their "lowest appropriate level" (World Bank 1993). Although this gives direction in the discussion about which of two decision levels is the most appropriate - the higher or the lower - it does not say that decisions should always be made at low levels. Some decisions are better made at higher levels.

Good governance, law, and administration

When the most appropriate level (or levels) of management has been established, the actions of both users and managers still need to be regulated. How this should be done, and how it is done best, are particularly important questions. Relevant issues to be decided upon in every resource management situation include rights of access, conditions for access, competencies of authorities, costs and cost recovery mechanisms, responsibilities, and accountabilities.

Economic and other policy instruments

Among the policy instruments that governments can put into action, economic policy instruments are among the more effective. In theory, the demand for a resource will be reduced if the costs of acquiring it are increased by imposing a tax. The same effect occurs if the costs of acquiring a substitute resource are reduced. For example, if surface irrigation water can be made available at a lower cost to the farmer and with the same degree of efficiency (sufficient, timely, and predictable supplies), the demand for groundwater will be less. In addition to economic policy instruments, other instruments exist (e.g. licensing and the obligation to have pumping installations registered).

Roles of users, politicians, and groundwater experts

As was explained above, users, politicians, and also groundwater experts like hydro-geologists, are all resource managers. Users directly influence the resource; the actions of politicians and hydro-geologists have a more indirect impact. What should be the roles, responsibilities, obligations, and rights of each of these resource managers? How much responsibility should be left to the users? What should they be allowed to decide on? And the politicians? And the groundwater experts?

Today, it is generally accepted that users should be involved in decision-making. This is partly a negative choice. After so many years of relying on competent authorities to set and implement policies, results have been generally disappointing (World Bank 1992). The allocations of means has generally been inefficient and natural resources have frequently been put to inefficient uses. Development institutions like the World Bank, UNDP, and also *DGIS*, now advocate the participation of resource users in the management of their resource, in the hope and expectation that that resource will be used in a more sustainable way.

Data collection and monitoring

Because groundwater is invisible, effective groundwater management is not possible without information on the quantity, quality, and changes in quantity and quality of the resource. What exactly has to be known is still unclear.

It is also important to understand the factors that influence the resource. In the case of groundwater, not only the geology of an area should be understood, but also the behaviour and motivations of users. As changes in groundwater resources are more and more the result of human interference, the actions of users and managers become more and more relevant.

Data on socio-economic factors should include data on groundwater use by different categories of users and data on agricultural markets. Categories of users can be farmers, drinking water companies, and factories. Sub-categories are large and small farmers, farmers cultivating certain crops (e.g. high-profit crops), farmers concentrated in areas with distinct groundwater characteristics, and possibly female farmers.

Preferable management regimes

Groundwater can be managed under different institutional arrangements. At one extreme, they can be open-access regimes, where no restrictions exist on who may use groundwater; access to water is free to all. At the other extreme, access to groundwater is restricted to one party only; say to an agent appointed by the government with a task and mandate to distribute water to consumers. In between these two extremes, other management regimes can be thought of. The most obvious is groundwater managed by sets of laws, rules, and regulations; the government allows private parties to extract groundwater, but effectively controls the quantities extracted.

The question is which of these or other management regimes is the most appropriate for developing countries, such countries almost always having partly ineffective governmental institutions. The matter is further complicated because different types of groundwater systems demand different management regimes. Geographically confined aquifer systems in narrow valley floors, for example, demand a basically different solution than aquifer systems in large plains. The sheer number of people involved is the critical factor here.

Training and dissemination of information

Training means transferring knowledge or improving skills. Dissemination information means regularly transferring information on some issue in a standard form to receivers who know how to interpret the information. Both processes are potentially relevant in groundwater management.

Important questions are whether groundwater users should be trained in understanding the qualities and dynamics of the resource they depend on, and whether they should be regularly informed about changes in the resource. It could be argued that users need to understand their resource, that this is a condition for more protective behaviour. Equally important are the questions whether groundwater managers in competent authorities should receive training and whether the skills and knowledge of groundwater specialists in groundwater institutes need to be upgraded. To some extent, the answers to these questions depend on choices made in other management questions discussed above.

At a more detailed level, answers are required to the questions of what kind of information transfer is needed and which skills are in need of improvement. A provisional conclusion is that, at the very minimum, training in understanding users' behaviour is required.

Epilogue

The time has now come to see what the experts on groundwater management say about the eight groundwater management issues and what conclusions could be drawn from the discussions among the participants of the workshop.

The papers presented during the workshop and in these proceedings can be divided into three groups:

Group 1:
Two papers discuss groundwater management from a theoretical point of view. One is the paper by Otto, who looks at the juridical and development administration aspects of groundwater management; the other is the paper by Nibbering, who discusses groundwater management from the perspective of the common-pool resource management theory. Fortunately, these papers are not purely academic exercises, but manage to translate theoretical findings into practical implications. This makes these papers particularly interesting.

Group 2:
This group of papers deals with groundwater management in The Netherlands. Pellenbarg gives a broad picture of groundwater reserves in The Netherlands, and explains how water management evolved over the last centuries until now, including the Groundwater Act, 1984.
Details about groundwater quality problems and control in The Netherlands are described in the paper by Arnold.
Romijn, in his paper, focuses on the situation in one of the provinces of The Netherlands, the Province of Gelderland. He explains the process of formulating the Provincial Water Policy Plan in Gelderland.
Together, these three papers give an excellent overview of groundwater management in practice in The Netherlands and how this evolved after the first regulations were issued early this century.

Group 3:
The five papers of this group are all case studies from arid or semi-arid countries in the developing world. Negenman writes about the country of Yemen, where groundwater management is slowly but surely moving in the direction of more control and more effective management and less careless exploitation and mining. Much still needs to be done, however.
Bakker explains the groundwater management situation in Kenya. In that country, competition for groundwater is becoming more severe, particularly in the highlands, and although groundwater management practices are being adapted to the new situation, the process is again a slow one.
Van Steenbergen writes about the different groundwater situations in three provinces in Pakistan, and explains the management conditions in these provinces. They differ from one province to the other, but in none of them does the situation appear to be effectively under control.
After having read these three papers, the conclusion is unavoidable that management conditions are in urgent need of improvement. Improvements are being realized, often with assistance from foreign experts, but the rate at which things change is slow in relation to the steadily increasing pressure on groundwater reserves.
The case of the Mendosa province, Argentina, is described by Querner. Apparently, groundwater management institutions in Mendosa have developed more than in Yemen, Kenya, or Pakistan. Querner presents an integrated water resources simulation model and explains the benefits of such a model for policy-makers. Finally, the contribution by Hoencamp focuses on groundwater quality management in both Egypt and The Netherlands.

The last chapter in this book presents the conclusions of the workshop participants after two days of discussions. The eight management issues are the focal points of the results.

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Glossary of terms

access point	location from where a user has access to a resource; in this case, access to a surface water resource or to a groundwater resource (compare extraction point)
common-pool resource	resource that is used by a collection of private or public persons who cooperate in its management and use
competent authorities	(government) authorities with a mandate to perform distinct tasks; in this case, to govern a groundwater resource or groundwater resources
direct-access resource	resource that can be directly accessed without permission of any kind being required (open access)
extensive groundwater use	state of groundwater use where the sum of extractions is less than the sum of natural and artificial recharges
extraction point	location from where a resource is tapped; in this case, water from a surface or groundwater resource (compare: access point)
indirect-access resource	resource that can be accessed only after some kind of permission has been obtained
intensive groundwater use	state of groundwater use where the sum of extractions is higher than the sum of natural and artificial recharges (over-exploitation)

open-access resource	resource is in use, but extractions are not yet regulated, let alone controlled
physical integrity	the state - of a groundwater water resource - at which it continues to possess its present properties
resilience capacity	capacity for a resource to have its original qualities restored; this can take a short or a long time
sensitivity	degree to which the physical qualities of a resource change under some external influence

GROUNDWATER AND COMMON POOL THEORY. CONSIDERATIONS FOR EFFECTIVE GROUNDWATER MANAGEMENT IN (SEMI)ARID AREAS

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Introduction

Historically, common property or common pool[1] resource management regimes have been quite general and seem to have worked reasonably well for long periods of time without destroying the underlying natural resource base. An example is provided by the *marke* communities that existed since the Middle Ages until well into modern times in the eastern part of the Netherlands and north west Germany and regulated agricultural and pastoral land use, while ensuring exclusive usufruct rights for their members (Slicher van Bath 1963). During the last two decades the developing world has shown a remarkable interest in common property resource management due to a growing concern for the sustainability of the exploitation of natural resources and the high costs involved in privatization or the establishment of state property regimes in (local) resource management. Local management of natural resources is also strongly advocated as local user groups are supposed to have a long term interest in the sustainability of local resources and command the knowledge systems and enforcement mechanisms required for optimal natural resources management. Moreover, joint management is considered to be worthwhile, for it can be superior to individual and competitive action. However, whereas common pool regimes may have performed well in the past, present day projects set up on the basis of collective management are often fraught with difficulties.

The increased interest in common pool management has evoked and has at the same time been fostered by an upsurge of conceptual and theoretical thinking on common pool resource management. Various common pool resources have already been tackled with the aid of these new theoretical insights, such as pastoral systems (Livingstone 1986), forestry schemes (Thomson *et al.* 1992), irrigation (Ostrom and Gardner 1993) and soil conservation (White and Runge 1994). Groundwater, however, which clearly shares the characteristics of common property resources with these other natural resources, has only quite recently received explicit attention in this respect (cf. van Steenbergen 1997). This is obviously due to the fact that depletion of groundwater caused by large scale groundwater development has also become manifest relatively recently.

1 See the annex at the end of this paper for a glossary of terms used in this paper. The terms 'common pool' and 'common property' are used interchangeably in this paper.

Likewise, the problems groundwater use is confronted with, particularly in arid and semi-arid areas of the developing world, are typical of common pool resources. Therefore, it seems worthwhile to assess the usefulness of common pool theory for analysing groundwater management and for finding solutions for its manifold problems. In what follows we will explain the main concepts and theories pertaining to common pool resources. Then, actual groundwater management situations and trends in the rural areas of South and South West Asia are characterized using concepts from common pool theory. The emphasis will be on hardrock areas facing lowering water tables. The paper continues with reflections on conditions to be met and problems to be solved in groundwater management under a common property regime. It is hoped that this principally theoretical contribution will provide useful insights and give rise to new ideas on groundwater management during this workshop.

Common pool concepts and theories

Concepts and theories on the use of common property resources, are in this paper designated as 'common pool theory'. This is done merely for practical reasons and is not meant to suggest that there is anything like one coherent theoretical body on common pool resource management. Various different sources of theoretical thinking have contributed to common pool theory, including game theory (von Neumann and Morgenstern 1947; Nash 1951; Thomas 1986; Rasmusen 1989), institutional analysis (Kiser and Ostrom 1982; Oakerson 1986) and transaction economics Williamson, 1975, 1985, 1986). These theories all have in common that they study decision making processes and their outcome where individuals weigh costs and benefits of their actions and the risks involved in specific collective action situations characterized by or favouring a certain institutional setting. Guiding principles for individuals in specific action situations are rationality and opportunism. Rationality is not perfect but can be bounded, for instance, by limited information processing capability (van de Laar 1990: p.37)

The collective action situations common pool theory is concerned with arise primarily under a common property regime, one of the four basic property regimes now commonly distinguished in the literature (Bromley 1989; Feeny *et al.* 1990; Schlager and Ostrom 1992). These are (1) private property, based on exclusive and permanent individual ownership; (2) state property, based on government management of natural reserves (parks, forests); (3) common property, a system of group-ownership with bounded membership and internal allocative mechanisms for individual usufruct rights, while behaviour of all group members is subject to a set of generally accepted rules; both usufruct rights and management rules are embodied in various institutions; and (4) open access, with total absence of property rights over resources, resulting in no rules or restrictions regarding access and resource use. In practice, common pool theory is almost just as much concerned with open access regimes, as a recurrent question to be tackled is how to transform open access regimes, which have a high risk of overexploitation or misuse, into sustainable and efficient common property regimes. Common pool theory is indirectly concerned with the other two property regimes as well, firstly because another frequent question is to what extent common property management in a given situation is superior to management under the other two property regimes, and secondly because, on a secondary level, i.e. the management level, each property regime may incorporate features of the other regimes. Common property regimes, for instance, cannot be operational without rules that regulate individual access. Similarly, the usufruct of state owned resources often rests with individuals (leaseholders) or groups resulting in forms of joint management, while in private regimes resource use still needs to be coordinated. Finally, even in open access regimes, there may be dormant claims that may be brought to life when the appropriate technologies, means or markets become available.

The various contributions to common pool theory conceptualize resource management as patterns of interaction which are conditioned by the technical and physical attributes of the resource, the decision making arrangements between the resource users and/or between resource users and external parties which together constitute the institutional setting. This interaction produces a certain outcome in terms of costs and benefits for the resource users and in terms of efficiency of resource use and the integrity of the resource. The technical and physical attributes and the decision making arrangements are exogenous variables in the short run, but not in the long run (van de Laar 1990; p.11). Changes in the productive value of the resource would equally require institutional changes in order to produce an optimum outcome, whereas changes in the institutional and socio-economic settings would lead to different interactions, changing in their turn the final outcome and the productive value of the resource.

The physical or technologically induced characters of groundwater give it the economic attributes which render groundwater prone to be treated as a common pool resource. It is *subtractible*, whereby it is meant that each individual user is potentially capable of subtracting from the welfare of other users. This is an attribute common pool resources share with private resources (Goetze 1987). However, within limits all users can derive benefits *jointly* from the resource. Due to this jointness of use, groundwater and other common pool resources also resemble public goods[2]. Jointness of use follows partly from the fact that common pool resources, and groundwater in particular, tends to be *indivisible*: it cannot be partitioned among private owners. The land holding the groundwater stock can of course be demarcated and divided among private owners, but the groundwater held in the land is mobile and physically interconnected, a feature shared with other fugitive resources such as shoals of fish, wildlife or air in the atmosphere. Evidently, these conditions also make it difficult to regulate access to groundwater and to *exclude* others from its use. However, some ability to exclude others from the use of groundwater is a prerequisite for bringing its management from an open access regime under a common property regime. Generally, if it is difficult to exclude others from the resource and easy to coordinate its use, common property regimes constitute appropriate management regimes. If both conditions are difficult to meet, then open access areas are likely to evolve. If it is difficult for resource users to coordinate their actions, but easy to exclude other users, state or private ownership would give the best management fit.

Early common pool theory is very much predicated on so-called *Prisoner's dilemma* strategies (Runge 1986; Wade 1987) leading to pessimistic conclusions on the viability of common property management regimes. In this classic situation, two persons, A and B, are faced with the dilemma of choosing from two strategies. Since they cannot communicate, distrust one another, or both, person A expects person B to choose the strategy which is disadvantageous to A. Therefore, A finds himself compelled to choose this strategy as well, because if he did not, he would be even worse off. B reasons the same way and does indeed

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2 For pure public goods no single beneficiary of a good subtracts from the ability of others to derive benefits. Examples are a lighthouse as a beacon for any number of ships passing or knowledge available to anyone (van de Laar 1990; p.17).

select the strategy A had expected him to select. Eventually, each adopts the strategy that will harm the other, and consequently, will harm himself. Had they cooperated, the outcome would have been optimal for both of them. In the same vein, it is argued that an individual making use of an open access or common property resource has an incentive to pursue his own interest in isolation of the other users and exploit the resource in such a way that it would increase his benefits to the detriment of the benefits of the others, thereby subtracting from their welfare. Under a common property regime, the practice of exceeding one's share in the resource to obtain greater benefits is often called 'freeriding'. Even if everybody else is also defecting (cheating), the freerider avoids the worst alternative of being the only one following the rules and thereby benefiting least of all. A fictitious example may illustrate this (Table 1).

Table 1. Fictitious example of a common pool resource use situation with different behavioral patterns of resource users (units 'x' of resource 'Y')

	Behavioral patterns			
	Individual defects	All adhere to rules	All defect	Only individual adheres to rules
Amounts used				
individual (1 user)	20	10	20	10
others (9 users)	90	90	180	180
total	110	100	200	190
Direct gains from defecting				
individual (1 user)	+10	0	+10	0
others (9 users)	0	0	+90	+90
total	+10	0	+100	+90
Indirect total loss resulting from overexploitation due to defecting	-20	0	-200	-180
Balance of direct gains and indirect losses				
individual (1 user)	+8	0	-10	-18
others (9 users)	-18	0	-90	-72
others on average	-2	0	-10	-8

Adapted from Nibbering, 1997

Defecting is advantageous to the free rider in that he alone reaps the benefits from his defective behaviour, whereas the damage caused by this behaviour is borne by all. Consequently, the freerider only bears a small portion of this damage and the benefits he derives from freeriding exceed the portion of the damage borne by himself. Under such conditions every individual resource user has an incentive to over exploit the resource until it is completely destroyed. This is Hardin's *Tragedy of the Commons* (1968). Also Olson's *Logic of Collective Action* is a further extension of the prisoner's dilemma. According to this logic, once a public good is supplied nobody can be excluded from its use; hence nobody has an interest to contribute to the provision of the public good and the public good will not be provided. When the public good is already available, individuals will be inclined to free-ride (Olson 1965).

In reality many of the assumptions underlying the prisoners' dilemma and its various extensions may hold in part or may not hold at all. They presume isolation of users, single time decisions (no learning effects) and the absence of social control, which is unlikely when the group size is small, because noticeability of free riding will increase with decreasing group size (Wade 1987). The greatest weakness of these models, however, is that they take isolated self-interest as the main principle. They ignore the possibility that rational individuals can arrive at cooperation or will prefer to adhere to group norms rather than to pursue private gains at each and every instance. In these models solidarity among users is absent. In contrast, another game theoretical model, called the *Battle of the Sexes* (Luce and Raiffa 1957) is not one of conflict but one of cooperative strategy, which may serve to show the importance of maintaining solidarity as a possible incentive for cooperation. Aside from moral aspects, solidarity may in the long run be important as a means of achieving social and economic security. In this model the players (a man and a woman) will gain most if they cooperate by conducting together an activity preferred by only one of them, no matter which activity the other player prefers. Here the key to successful long-term cooperation is that the players, and for that matter, resource users, return favours. More generally, when land users are sufficiently sure that other resource users will stick to rules that have been mutually agreed upon, cooperation may be the least expensive solution to a resource management problem for the collectivity concerned. It has been pointed out that it is not even necessary that everybody sticks to the rules -although that would be ideal-. If a critical number of resource users adhere to the rules, it can already be beneficial for an individual resource user to adhere to the rules as well and still derive net benefits from the exploitation of the resource. A number of free riders can be tolerated without the risk that all are led to defect which would cause the disruption of the common property management regime (Runge 1981). Reliable institutions have to provide this *assurance* or sure expectation that most if not all fellow resource users will cooperate.

Policy alternatives for sustainable management of common property resources that rely on prisoner's dilemma approaches could only reach acceptable outcomes under strategies of complete privatization, or through enforcement by an external agent, such as the state. By contrast, *bargaining* approaches assuming that a certain level of assurance can be reached, much more envisage prospects for management strategies based on intermediary regimes of voluntary cooperation.

Especially in situations of mutual dependence and presence of both behavioral and environmental uncertainty, cooperative resource management resulting from negotiations could yield favourable results. These intermediary regimes can be tackled by way of a transaction economic framework introducing the concept of *transaction costs*. These are costs incurred by resource users when they mobilize resources through market exchange or when they coordinate their activities within their farms or with other users of a shared resource. These costs include costs of information, negotiation, monitoring and contract enforcement. They are all scale variables, not necessarily linear, which makes it possible to analyze at the margin, the impacts of external factors which influence the various costs. We will give two examples of how the concept of transaction costs can be used to tackle the problem of optimizing management regimes.

If we assume a common property resource management situation, we would like to ask the question how many people of the community should be involved in decision making to obtain maximum efficiency. A decision by only one individual about the entire resource maximizes the probability that the decision is at variance with the interests of other group members. As more group members are involved in decision making, compromises are made, and more people will find the collective decision acceptable, total deprivation costs will decline (Figure 1a). On the other hand, the process of collective decision making incurs costs[3], the means for which could have been used for other (profitable) purposes. As the number of persons required to agree on management issues increases, so do the time, money and effort cost that must be invested (Figure 1b). Aggregation of the two cost curves will show where the cost minimizing solution can be found from the perspective of the entire group (Figure 1c). It also indicates that the group can live with a certain number of free riders because the decision and enforcement costs of total vigilance may be excessively high (Ostrom and Ostrom 1977).

If we now assume a resource management situation whose management regime may vary between private property and common property, the relevant transaction costs to be considered would consist of coordination (decision making) costs and costs of excluding non-shareholders. Within the community a balance between the two types of costs will have to be found and the size of property units will be defined accordingly (Field 1989). As for state property regimes, depending on what role the state assumes, involvement of the state may reduce certain transaction costs for individuals or groups of resource users, increase other transaction costs or both. Thereby the state may incur or reduce transaction costs of its own.

A second type of transaction costs can be distinguished. In the literature these are called 'contracting costs' or 'transaction costs of the second order' (van Steenbergen 1997). They refer to the costs of institutional change. We will call these costs *transformation costs.* Examples are the costs involved in the definition and refinement of access rights, the formulation and reformulation of conventions on resource use and preservation, the creation of enforcing organizations and management training of resource users and other parties involved in resource management. They also include the collection and sharing of information, consensus building and the trade-off between different interests.

Bargaining positions and interests of resource group users may differ, however. They depend partly on the institutions regulating access, conditions of resource use and the relations among the various resource users, and partly on the positions of resource users and institutions in a wider socio-economic setting. These interests and positions will determine the stands of the various parties in the bargaining process and thereby the bargaining process itself. Apart from costs and benefits considerations of individual resource users, it is equally important to understand who will pay the transaction costs and who will initiate changes or modifications in resource management regimes and pay the transformation costs (van Steenbergen 1997; p.27).

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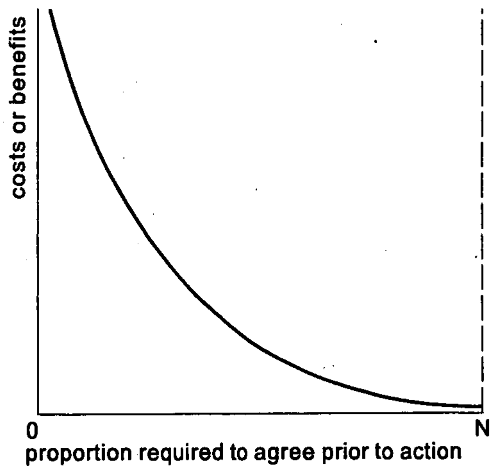
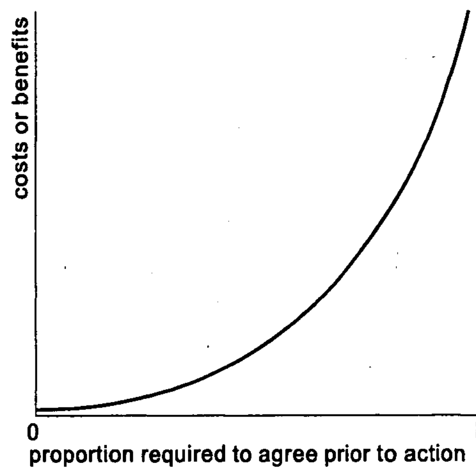
3 This is not to say that the use of open access resources would not involve transaction costs. Since access to such resources is not regulated, users must often make a large effort, requiring labour and capital, to forestall the actions of others or to defend one's interests against others.

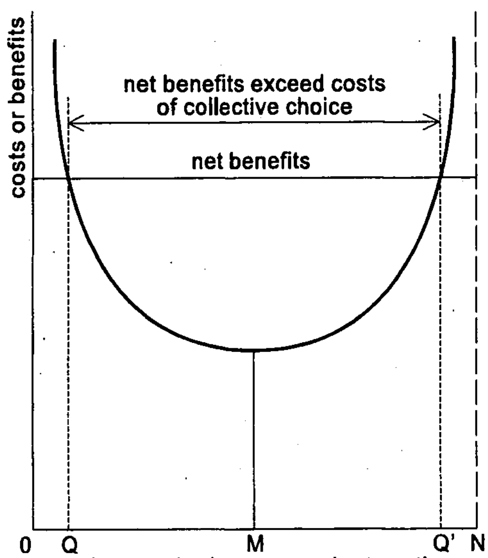
Figure 1. Potential decision making, potential depreviation costs and total (aggregate) costs of collective choice



1a potential deprivation costs



1b potential decision making costs



1c total costs of collective choice
M = point at which maximum net benefit is reached

Characterization of past and present groundwater management regimes from a common pool theoretical perspective

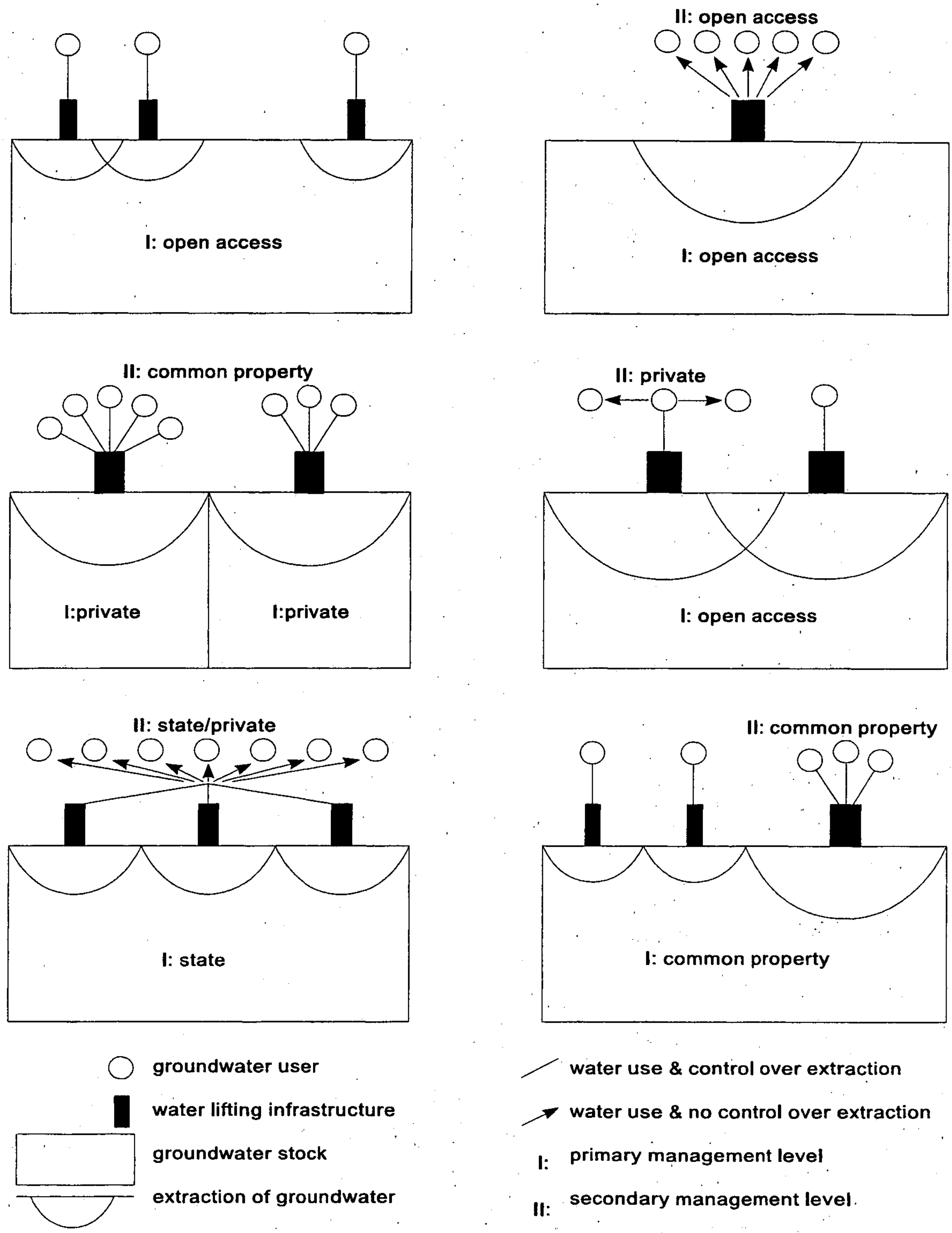
In this section we will try to characterize and analyze past and present groundwater management regimes in arid and semi-arid in South and South West Asia, using concepts and understandings from common pool theory. These characterizations are a useful starting point for exploring possibilities for the transformation of these regimes. Two management levels are distinguished: the *primary level* which deals with the interaction between individuals or collectivities that are involved directly in the extraction of groundwater, and the *secondary level* which is concerned with interaction between users sharing the same groundwater abstraction infrastructure or with interaction involving transfers of water from users owning groundwater abstraction infrastructure to users who do not. The two levels are concerned with different -though related- management objects. Management on the primary level focusses directly on the groundwater resource and looks at it at a greater spatial scale, whereas management on the secondary management level focusses on the infrastructure created and used to extract groundwater and the distribution of groundwater among its possible co-users and between infrastructure owning users and non infrastructure owning users. It thereby looks at groundwater at a more limited scale. Both management levels may involve the same resource users, but in a different way. Likewise, the nature of the management regimes at the two levels are not necessarily the same. Some typical examples of past, present and ideal water resource regimes are illustrated in Figure 2.

Historically, at the primary management level, groundwater has been exploited under open access regimes in which resource users may or may not have affected one another, depending on location, distance and scale of operation of the infrastructure they used (Figure 2a). These external effects of one user on the other must in most cases have been relatively small due to the small hydrological impact of the traditional technology used. Where everyone had its own extraction infrastructure, interaction, if any, was confined to the primary level. Where infrastructure was shared, there was a secondary management level as well. In such cases water was most likely taken without any particular regard for others, so an open access regime prevailed at the secondary management level (Figure 2b).

In arid and semi-arid areas in North Africa and South West Asia, however, more complex forms of groundwater management regimes came into being early on. On the secondary management level they can be characterized as common property regimes as they were centered around the infrastructure established for the abstraction of the resource and which was shared by a group of users (Figure 2c). It consisted of underground infiltration conduits or galleries to which a chain of dugwells were connected[4].

4 They are known in different countries by different names; they are called *ghanat* in Iran; *karez* in Azerbaijan, Syria, Afghanistan, Yemen and Pakistan; *sahzidj* in Yemen and Saudi Arabia; *falaj* in Oman; *fouggara, mayan, iffeli, ngoula, khettara* in the Maghrib countries and in Lybia (Caponera 1973; p.32).

Figure 2. Schematic representation of various types of groundwater management regimes



For their construction and maintenance great labour inputs were necessary requiring the labour force of a large group of people[5]. Here, joint efforts were needed not so much to safeguard the integrity of the resource, but to be able to extract it. Nevertheless, primary level management aimed at maintaining the integrity of the groundwater resource was also practised. Spacing rules were adopted prescribing a minimum distance between each gallery system. This distance was calculated in such a way that any new gallery would not affect the yields of existing ones, which, practically speaking, amounted to the privatization of small bodies of groundwater.

The resulting management regime at the primary level could therefore be considered *de facto* as a private resource management regime. Secondary level management was organized as follows: the owners of the infiltration galleries and associated wells had exclusive rights to use the water contained in them. Co-owners shared in its (fluctuating) water yield proportionately to their participation in construction and maintenance works. Rights were transferable by inheritance, renting and sale (Caponera 1973). It seems that, large though the construction, maintenance and coordination costs of these constructions may have been, the benefits must have outweighed them, considering the long periods for which these galleries were used. Also, coordination costs must have been lower than they would be today since communities were more closely-knit.

However, during the last three decades or so, favourable marketing opportunities for various crops and the easy and heavily subsidized availability of water lifting technology launched in the arid and semi-arid regions of the world have led to a real groundwater rush, tapping reserves which could not be reached with older technologies. Tubewell-based groundwater development for domestic use and irrigation has been enormous in these areas. One could quite well speak of a frontier situation in present-day groundwater exploitation, because, as is usually the case in such a situation, people have undertaken the exploitation of groundwater with little knowledge of the effects on the resource. The large scale adoption of tubewells and heavy pumping have led to enormous extraction rates taking place in a virtually complete absence of effective regulation. Extraction has exceeded recharge enormously. This overexploitation has led to a rapid depletion of groundwater resources which has been apparent from dramatically lowering water tables and the drying up of traditional surface bodies such as tanks[6] and springs. Or, in coastal areas they have caused the intrusion of saline water into the groundwater extraction zone.

Where traditional surface water supply systems or underground water extraction systems existed, they have often been disrupted by modern ones because of the lowering of the water table induced by the invasion of tubewells. The former could not cope with the increasing depth of the water table (Dhawan 1982). Similarly, traditional common property management regimes have been out-competed by private modes of extraction. Often the first to release their share in the communal systems were the larger farmers who had the resources to develop private wells. The heavy burden for maintaining the drying infiltration galleries then fell progressively upon the smaller farmers who could not afford the increased transaction costs (van Steenbergen 1997).

At the primary management level, these developments caused the traditionally privatized ground water stocks of the underground infiltration galleries to lapse back into open access regimes, and

5 The infiltration galleries were also constructed by big land owners and town communities which could afford the large costs of hiring the required labour force.

6 Artificial storage-ponds on the Indian Subcontinent.

where groundwater was exploited for the first time, open access regimes came to prevail right from the start, with all the risks accompanying such a regime. Groundwater users operate in almost perfect isolation from each other, on a 'first-come, first serve-basis'. Every land owner can, on the ground of riparian[7] rights, sink a tubewell and thereby enter the groundwater extraction scene without restrictions and can take water without restraints. Those that can reach deepest can get most water. A process of deepening and counterdeepening between tubewell owners has ensued. Eventually, a classic prisoners dilemma situation has arisen in which no one has an incentive to stint. Groundwater users often still believe that groundwater is inexhaustible, or that technological progress will always make it possible to exploit untapped reserves.

From the community point of view, however, the open access nature of groundwater is restricted because very often only the most fortunate landowners may have been able to generate the means to invest in the necessary infrastructure required for water abstraction. Even among land owners, access to groundwater may be restricted only to those who have a locational advantage. Small farmers and other weaker population categories often miss out on these developments. Therefore, one could speak of a 'restricted' or 'skewed' open access regime. This is not to deny that farmers having no infrastructure of their own can sometimes buy water from others, but they often have to pay prices which by far exceed exploitation costs. This shows that at the primary management level groundwater is dealt with as an open access resource, but once it has been extracted, the pump owner treats it as a private property resource and sells it to fellow villagers not owning tubewells, despite the fact that, if groundwater were to be a truly common pool resource, the latter should have the same rights to groundwater as the former (Figure 2d).

The buying and selling of groundwater implies the existence of groundwater markets[8]. Exploitative though these groundwater markets may appear, they probably lead to a more efficient and equitable situation than there would be if they were absent. Poor people are better off with the development of lift-irrigation systems, even if it is controlled by the rich. Besides, where landholdings are fragmented, most water sellers are also buyers because most farmers sink wells in one or two of their largest and best parcels and use purchased water for irrigating other parcels (Shah 1993b). However, whereas groundwater markets increase efficiency and equity, this cannot be said with respect to sustainability. The development of groundwater markets raises the rate of withdrawal of groundwater and therefore hastens the depletion of the resource (Shah 1994).

Secondary level management is not necessarily always private in nature. Where the ownership of tubewells is shared and operated jointly, common property management is practised (once more Figure 2b). Many managerial problems with the joint operation of tubewells have been reported, however. Conflicts arise due to the fragmentation of shares which are linked to land rights. In the end, weak shareholders often loose out (Janakarajan 1997). Yet collective tubewell ownership is often advocated as one of the ways in which groups of poor people or women's groups can benefit from groundwater exploitation (Kahnert and Levine 1993). Also public (state) tubewells

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7 Riparian rights are rights that are merely derived from the fact that the user lives adjacent to the resource, which means in the case of groundwater, that the user owns land situated above the resource.

8 Some argue that the so-called groundwater markets are in fact markets for renting water lifting equipment, because water as such is not priced (Saleth 1994).

have been installed (Figure 2e). But most studies of state tubewell performance, regardless of the locale, have blamed state tubewells for several or all of the following weaknesses: unreliability, poor maintenance, frequent breakdown and long waits for repair, powercuts, domination by local powerful persons, indifference on the part of the operators, right of way difficulties and inadequate provision and maintenance of the water conveyance systems. Consequently, private supply has made deep inroads into the public sector. The transaction costs involved in these private supplies appear to be lower. There are no bureaucratic procedures and payments can be deferred easily. Also agreements to provide water are made well in advance and invariably kept (Kahnert and Levine 1993; Shah 1993a).

As groundwater reserves have been dwindling, the economies which have been built on this resource have come increasingly under threat (Shah 1993a; van der Gun and Ahmed 1995; van Steenbergen 1997). Conflicts over the use of groundwater between urban and rural areas and even within rural areas have been increasing (Janakarajan 1997). The question is how to change the prevailing exploitation regime in such a way as to make the use of groundwater more sustainable, more efficient and more equitable.

Clearly, at the primary management level the open access nature of groundwater makes the establishment and enforcement of a common property regime for groundwater difficult. At the secondary management level the existence of mixed management regimes make things even more complicated. A change over to private ownership by a great number of users is not possible in view of the physical nature of the resource and the high transaction costs of establishing and policing effective external boundaries. Consequently, there has been a general call for more state involvement in groundwater management. However, the open access situation makes it difficult also for an external authority to enforce access, exploitation rules and administer penalty clauses to reinforce good behaviour without giving any management responsibilities to the local users. Therefore, as with all common pool resources, the question of what sort of management regime would match the resource best is part of the current policy debate. A move towards coordinated use and exclusive property of some sort seems desirable. Common property regimes (Figure 2f) in combination with elements of state participation and private ownership should probably give suitable solutions for "sharing responsibility for the open access resource" groundwater now is.

Considerations for effective common property resource management of groundwater

In this section we will discuss a number of conditions, constraints, advantages and disadvantages that need to be considered in order to judge if, and in which manner, groundwater can be managed successfully as a common property resource. Departing from the present management situation (previous section), we try to operationalize the conditions and mechanisms formulated in common pool theory (see under Common pool concepts and theories) for the field of groundwater management. In line with the conceptualizations presented in the section on theories and concepts the discussion will be organized around (1) the production benefits from groundwater exploitation, which provides the very basis for groundwater exploitation; (2) the institutional arrangements needed for a common property management regime and the associated transaction costs, and (3) the institutional changes required to put these institutional arrangements in place as well as the associated transformation costs.

Production benefits

Net benefits derived from groundwater exploitation provide the incentive for groundwater users to use the resource. Net benefits are the outcome of gross benefits and production (exploitation) costs. They are determined by the management regime, the associated institutions and organizations that govern the resource, technology and market forces. Although the emphasis on this paper is on institutional issues, technology, marketing, pricing and taxation policies should also be part of the strategies aimed at a more sustainable and equitable use of groundwater. They can either reinforce or disturb actions taken in the institutional realm. The state-supported cheap supply of water lifting technology and energy has been one of the factors that have stimulated overexploitation of groundwater and future policies on this matter will greatly influence groundwater exploitation.

Since net benefits or expected net benefits are the driving force behind the actions of the resource users, any modification in the management regime should be justified by an increase in net benefits. Here two problems arise: that of the uneven distribution of benefits among the members of groundwater using communities, and that of weighing present benefits against future benefits (or losses). To illustrate these points, three different -rather stylized- management situations have been construed. The distributions of net benefits minus transaction costs among groundwater users of these three management situations are compared with each other (Figure 3). The three situations comprise: (1) the actual situation (open access); (2) a worst scenario for the future in which the open access regime is allowed to continue unabated; and (3) an appropriate form of equitable common property management. When comparing the actual situation with the worst scenario (Figure 3a), the latter will turn out highly unfavourable for all. Most resource users will have been forced to quit using groundwater altogether; only few will remain. These are the economically strongest and otherwise most fortunate groundwater users, but they will have to pump water at very high costs. Therefore even they will lose compared to the actual situation. When the actual situation is compared with the common property management situation (Figure 3b), the latter may turn out unfavourably for many big users because of the fact that actual extraction rates are too high to be sustainable, and any change to a more modest use will result for them in reduced extraction rates and part of the destruction of their investments. However, common property resource management will allow other members of the community, who had so far no or little access to groundwater, to gain more access to the resource or will allow them to increase their use, thereby improving equity. Therefore, apart from many losers, there may nevertheless be some winners as well. When the common property management option is compared with the worst scenario (Figure 3c), it must be clear that everybody or nearly everybody will gain from common property management. The biggest groundwater users, however, will gain relatively least of all. Evidently, in this case it is the large mass of potential winners that should bring about the drive to change the management regime. The extent to which it can be shown that in the end also the biggest users may still be able to gain from common property management should render them more amenable to change as well.

Basic institutional requirements

There are a number of basic conditions that have to be met in order for groundwater management under a common property management to be successful. The first condition is a shared understanding of imminent damage to the integrity of the resource and its causes. In other words, following up on the previous discussion, the comparison of the actual situation with the worst scenario should be made and its message accepted by all concerned. With this, the ignorance about the state of the resource, one of the premisses of Hardin's thesis will be eliminated. Secondly, while degradation of the resource may be obvious, information must be collected and provided concerning the total available ground water storage reserve, effects of exploitation on the integrity of the resource and its resilience. In a common pool management regime this information should be available for all resource users in a form and level of detail relevant to their capacities and needs.

This information will show what there is to gain in the long run with improved management, and the size of these gains will determine how much effort groundwater users will be willing to make in terms of transaction costs to attain these benefits and thereby, to what extent they would need additional support from outside to pay for transaction costs. In principle, if transaction costs to be borne by groundwater users exceed net benefits, there is no viable basis for a common property management regime. Moreover, there is also a strong relationship between the way this information can be generated and provided and the institutional set-up of the management regime.

The most important condition to be met, however, which is specific to common property management, is that groundwater users have the assurance that co-users will adhere to the rules that have been mutually agreed upon. Only this will make them willing to stint for the sake of conserving the resource, to support the necessary institutional changes and to participate in the deliberations and negotiations to achieve these changes. Clearly, this will be a long and reiterative process, which will in general have to start from a scratch because there are few precedents for cooperation of this kind and in the beginning no one knows what to expect from each other. If they have not done so before, people will have to learn to trust one another.

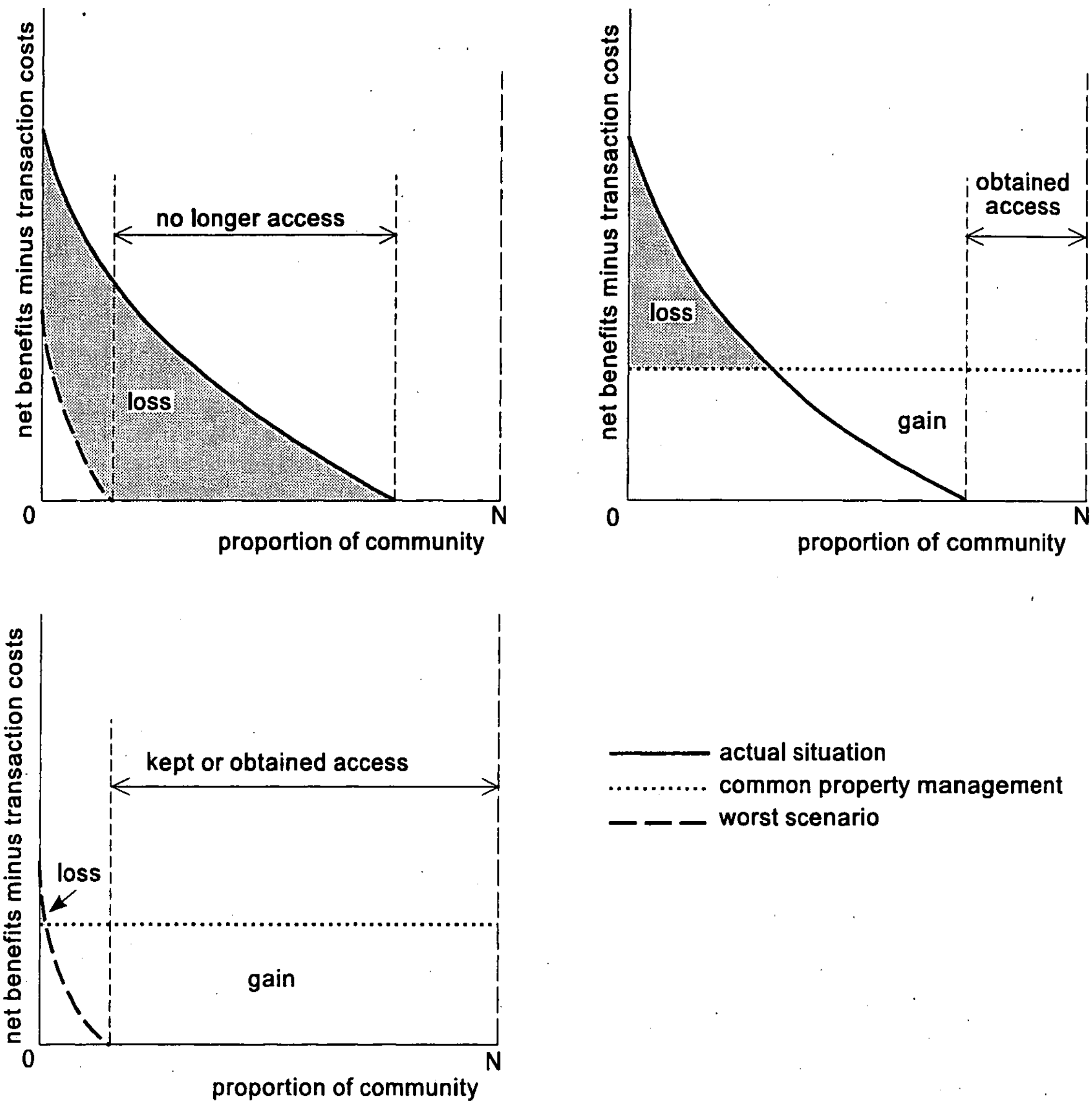
All these conditions have to do with the reduction of uncertainty. The institutional arrangements should give an effective solution in giving groundwater users more certainty about their resource and each other. Let us now discuss some of the aspects of the various institutional arrangements required for groundwater management under a common property regime. These arrangements and rules are concerned with access to groundwater, water rights, monitoring and rule enforcement and the organization of groundwater using communities.

Access to groundwater and water shares

The regulation of access to groundwater is one of the primordial institutional measures necessary before the management of a common property resource can be undertaken successfully. Various desirable if not utopian access situations can be thought of, such as those in which (1) all land holders have a share in the resource proportionate to their farm area (correlative system); (2) all members of the community have an equal share independent of land ownership; (3) all water rights are held by the poor to countervail the economic power of the big landowners; or, (4) all members have a share according to their needs.

In reality, when the integrity of the groundwater resource is at stake, there will be much pressure to curb the entrance of new claimants to the resource. Erstwhile users will try to secure their historical priority rights. The success with which they can do so depends on their size and strength vis-a-vis competing claimants, the degree to which they exploit the resource collectively, and the question whether the new claimants come from outside or not, causing strong local response if they do (van Steenbergen 1997). But also public policy-makers are likely -and actually have- to respond by restricting the development of new tubewells.

Figure 3. Distribution of net benefits among groundwater users under three different management situations: (1) actual situation (open access); (2) worst situation for the future (continued open access); (3) common property resource management



However, late entrants often tend to be resource poor farmers. Most early adopters of modern tubewell technology had been large and medium farmers, because of the large investment requirements and because of their obvious appeal to farmers with large holdings. Consequently, bans on additional tubewells risk to exclude small farmers from groundwater exploitation (Dhawan 1982; p.157; Saleth 1994; p.63).

The tendency for state authorities to apply measures such as spacing, siting and licensing of tubewells to counteract groundwater depletion is most likely due to the fact that these measures are very simple forms of groundwater regulation and have therefore low transaction costs. Yet these regulations, when imposed by state authorities, have hardly been able to restrict farmers' investments in tubewells (Shah 1993a; Ballabh and Singh 1997; p.33), which some ascribe to the rent seeking attitude of part of the enforcing authority (Shah 1993b). There are examples, however, of local communities which have applied these measures effectively (van Steenbergen 1997). At any rate, if restrictions on tubewells are imposed, measures should be taken on the secondary management level as well. Tubewell owners should be prevented from exploiting their monopoly or oligopoly position over groundwater by demanding exorbitantly high prices for the water they sell. To this end, water sale regulations should be put in place at the same time to ensure that non-tubewell owners have a reasonable access to groundwater. If groundwater is to be considered a common property resource, then only groundwater sales at cost price are justified and any tendency towards privatization of groundwater at the secondary management level should be checked.

Water shares should be established determining how much water individual groundwater users are allowed to use. At present, pump capacity and power supply largely determine the realized water rights of individuals. This has formed the basis for policies, such as horsepower restrictions, (electric) power rationing and power tariff manipulation. The efficacy of this regulatory approach at the primary management level is greatly circumscribed by the lack of quantitative restrictions on groundwater withdrawals, by the availability of diesel pumpsets and by the possibility of owning multiple wells or pumpsets (Saleth 1994; p.64). Government agencies have not been capable of monitoring the various devices to which the more fortunate groundwater users could resort to circumvent these regulations. The transaction costs of the type of monitoring this would require would undoubtedly be high.

To maintain the integrity of the groundwater resource, the aggregate volume of water shares to which users are entitled should be congruent with the total sustainable exploitation rate. This rate should be established after considering other interests, e.g. water needed for domestic use, for tank irrigation or for industrial purposes. If individual rights can be quantified within a water withdrawal limit set by the community (or a higher authority), the effects of water use by an individual on other users as well on the community as a whole can also be quantified, making it possible to determine possible compensation for the affected parties. Groundwater allocation rules should nevertheless be flexible. For instance, in years with much rainfall less water could be used to build up a reserve for years with little rainfall. Water rights may affect secondary level management as well. If groundwater users were only allowed to sell from their share, groundwater would reflect its true economic value (Saleth 1994). Also water fees could be introduced which would reflect social costs and they could be used to offset internal coordination costs. Both measures are likely to stimulate a more economical use of groundwater. Another advantage of defining water withdrawal rights would be the possibility of setting up rotation systems to avoid peak loads and to allow sufficient time for aquifer recharge (Saleth 1994; p.60). The costs of recording and keeping track of everyone's water withdrawal rights may be relatively cheap, as they would merely consist of the installation of water meters, but the costs of agreement, rule enforcement and checking meters may be very high.

At the secondary management level water rights and contributions to maintenance and other collective activities should be looked at simultaneously because they are often interdependent. Contributions to investments in pumpsets may determine water shares, whereas water rights may in their turn determine obligatory contributions to the development of water infiltration infrastructure.

Apart from regulating water rights, the pressure on groundwater can be relieved by promoting a more efficient use of water through regulating cropping patterns. The regulation of crop choice and timing, however, is tantamount to the de-privatization of land management. It would have to overcome all sorts of other barriers. These measures generally appear too difficult to handle for state bureaucracies, but may well be within the reach of communities. Water conveyance losses could be reduced through the application of more efficient technologies. Measures can also be taken to renew the groundwater stock more rapidly by increasing infiltration of rain water into the soil. Here, however, problems arise with the question of how much each individual groundwater user should contribute to these undertakings. Ideally, it should be proportionate to their water shares. As long as the amount of water used by individuals and the effect of water infiltration measures on the groundwater stock are not clear, this question will be difficult to answer and may be liable to another prisoner's dilemma type of problem. If these relations were clear, the need for labour for developing and maintaining water infiltration measures may give some scope for bargaining about water shares between big water users and small water users (see further below). However, even if these relations were clear users may not be willing to contribute if the measures do not directly affect the groundwater stock located under their own land (Bhagwat 1993; p.25).

Monitoring and rule enforcement

Following from the basic conditions for successful common property management of groundwater two types of monitoring are indispensable: monitoring the integrity of the groundwater resource itself and monitoring groundwater extraction rates by the co-users. Monitoring itself incurs transaction costs, but effective monitoring may reduce other transaction costs and exploitation costs, for instance by predicting water availability and by preventing disputes. The availability of simple and cheap methods to measure groundwater extraction may render monitoring easier and reduce its transaction costs. However, in the absence of scientific studies, limits of reservoir storage can only be discovered by trial and error. Although overdraft can be easily gauged by dropping water tables, total volumes will not be known and assessments will be complicated because groundwater tables fluctuate in time and in different parts of the basin.

Monitoring of the activities of individual resource users is difficult when it comes to actual extraction rates. Monitoring indicators should be derived from the collectively adopted rules on groundwater extraction. The withdrawn amount of water would be the best indicator, but in the absence of any devices or organization to measure water withdrawal, other, less direct, indicators would have to be used, such as pumping time, energy consumed for the water lifting operation, or, area irrigated. These other indicators are less attractive, because they may be easily circumvented, refer to variables which are not always under the users' complete control or are more cumbersome to measure. The draw-down interference of an individual tubewell could also be measured, at least in theory, because it is possible to connect the source with the individual, unlike the long term lowering of the water table which cannot be connected to any particular user (Kahnert and Levine 1993; p.9). Apart from the measuring problem *per se*, there is also a scale problem involved in monitoring, the monitoring and control of extraction of large numbers of individually owned wells is not considered feasible at all by some (Mosley and Arriëns 1995; p.38). It should be realized that if users have enough self-discipline and sufficiently trust each other, there is no need for extensive monitoring and its transaction costs will decline accordingly. On the other hand, the confidence an individual has in the entire common property management institution is undoubtedly partly based on the assurance that defecting behaviour of others will be detected, while at the same time one's own 'self'-discipline may derive from the same knowledge.

Effective rule enforcement and conflict management are crucial to the viability of any common pool management regime. Generally, fierce competition for scarce groundwater necessitates that any rule will have to cope with the tendency for rule breaking. Once group members are in a position to negotiate about rules of restraints they may also be able to negotiate enforcement and penalty rules for defectors. Hence no outside coercion will be necessary. The scope for rule enforcement very much depends on the degree to which defection can be monitored at a reasonable transaction cost. There is a clear danger that economically or socially powerful resource users can get away with certain misuses, in which case it should be possible to have recourse to higher authorities. Some rules, such as spacing rules, which pertain to matters that are clearly visible to all, do usually not require much monitoring or rule enforcement as they are likely to be soon internalized by those concerned. Local rules require legitimacy and should therefore be imbedded in national legislation. Water resource use legislation should, however, allow local rule making to retain enough flexibility in order to be adapted to local conditions and undergo necessary changes over time.

Organization of groundwater using communities

It would seem practical to make use of the existing social structures of sedentary communities to organize groundwater management. On the one hand, these sedentary communities usually have more or less accepted political institutions, while on the other hand groundwater users may not (yet) be prepared to invest in special groundwater organizations and personnel as long as the gains from improved groundwater management are unclear to them. However, the indivisible nature of groundwater which makes it difficult to partition the resource and to exclude other users at a level below the actual groundwater basin will interfere with effective management at this lower level, if it takes place in isolation. Groundwater basins are usually large and exceed the size of sedentary communities, a problem it shares with gravitational irrigation systems. As a result, groundwater users organized solely on the basis of sedentary communities may pay to reduce their own overexploitation only to be forced to bear the effects of depletion by neighbouring communities. Furthermore, there is also much evidence that traditional political and social organizations tend to desintegrate in the regions under discussion. They would be weak and transient foundations for present-day groundwater management. Therefore, existing social units cannot be appropriate vehicles for the organization of groundwater users, if they are not accompanied by other institutional measures.

On the other hand, the chances of classic common pool management with all other things being equal are greatest when the communities of users are small. Generally, as the size of the community increases the more difficult it becomes to achieve coordination among groundwater users and the higher transaction costs of coordination become. The best conditions for setting up small groundwater management groups can perhaps be found in relatively small mountain valleys. On large densely populated river plains with large groundwater basins it will be much more difficult to organize groundwater users along similar lines. Here the groundwater basin may be divided in various, preferably physically and/or socio-economically homogeneous zones. In each zone groundwater users could be organized in collectivities which have the right size to deal with certain management aspects, such as short term interference among wells (drawdown), but these collectivities will only deal effectively with medium and long term effects of groundwater exctraction if they are represented at the level of the groundwater basin and can coordinate management among each other.

However, even within small natural communities or small newly formed groundwater collectivities, the socio-economic and physical differentiation may still be substantial. Different social and physical settings may require different institutional solutions entailing different levels of coordination costs. In homogeneous communities with little asset and income differentiation, groundwater users are likely to have similar interests. Under such circumstances a few individuals (elders, leaders) may decide on groundwater issues the outcome of which would sufficiently satisfy most if not all groundwater users. The deprivation curve (Figure 1a) would be flat and the minimum cost solution could already be achieved with a relatively small proportion of the community engaged in decision making. In heterogeneous societies, however, with sharp economic and social cleavages, deprivation will be very high if decision making is left to village elders and decision making beyond the village elite will be very difficult. The decision making curve (Figure 1b) would be sharply exponential. Eventually, the elite may then not bother to attempt the undertaking of collective community action. Instead, they will use their superior economic power without restraint to their own benefit. However, if the elite is dependent upon inputs or other forms of support from the other members of the community, this might create a bargaining opportunity which can lead to restrained and more optimal collective action (Van de Laar 1990; p.45). Even rainwater infiltration measures may create such an opportunity. The implementation and subsequent maintenance of these measures may need substantial labour inputs. Big water users may not be able to provide enough labour themselves and may need the help of farmers with little or no access to groundwater. This may give the latter some leverage in bargaining with the former for a greater share in groundwater (cf. Ostrom and Gardner 1993).

Strong differentiation in physical conditions at the level of groundwater management collectivities may also impinge on the chances of cooperation. People living in localities that are free from water problems, such as low-lying areas with higher natural water tables, or areas with access to sources of surface water, will not feel the necessity of contributing towards any management solution to solve the problems in another locality (Kumar 1994). Here too, if there exist any counterdependencies between those affected by groundwater problems and those who are not, there may be room for a bargaining solution.

Transaction costs

Bargaining, the definition of rules, monitoring and rule enforcement and any other activities that have to be carried out under a common property management regime will entail transaction costs. These transaction costs will have to be borne by someone. Where communities are homogeneous and groundwater users have similar interests, transaction costs can be expected to be shared equally among all co-users. Where both interests and capacities for paying transaction costs are diverse, one single group may be willing to pay the lion's share, if this group has a greater interest in maintaining the management regime than the rest of the community or if other groups compensate the former in a different way.

External developments may impinge on internal dependency relations between different interest groups within a groundwater using community. For instance, by providing cheap technology the state can make landlords independent on labour which used to be provided by other community members. This may provide the former with the opportunity to exploit groundwater for their own benefit without having to care any longer about the interests and needs of the latter. When landlords no longer bear their share, transaction costs may become too high for the other users and the management regime will disintegrate (van Steenbergen 1997).

However, the state can also reduce transaction costs for communities involved in common property resource management by giving support which may take various forms and, depending on the type of support, may prod management regimes into different directions. The state may reduce the cost of exclusion, for instance by legally banning new tubewells, thereby stimulating privatization of groundwater at the secondary management level, or, the state may reduce coordination costs, for instance by actively supporting local management groups, and thus stimulate the development of common property resource management. Generally, it may secure property rights, legalize the formation of organizations and preserve law and order. The state may also increase transaction costs for communities managing their groundwater resource under a common property regime by withdrawing one of the above forms of support or otherwise. At any rate, a major contribution of a national or regional government would be the protection of formulated access rights. In giving support, however, the state may reduce the communities' flexibility in decision making. Decision making arrangements must have some flexibility, to allow for adaptation to local conditions, to allow for a learning process for the community involved, and to deal with situations where there is uncertainty about the integrity and physical dynamics of the resource.

Institutional change and transformation costs

When institutional change is complicated, it will require intensive bargaining, and transformation costs will be high. This will be the case if one of the parties loses from the changes and the losses it incurs cannot be sufficiently compensated. If in water scarce areas the entire water 'ownership' regime were to be overhauled to further equity, this may, not unlike a land reform, run into fierce opposition even though groundwater ownership may not be as institutionalized as land ownership is. Lack of institutional change in resource management where one would expect change on economic and institutional grounds is often due to political factors with certain interests groups attempting to protect their vested interests (North 1990).

There are other reasons why institutional change may not come about. Although it may in itself be clear to all groundwater users that changes in management are sorely needed, the fact that groundwater can be used without management rules may perpetually postpone the moment when such rules are actually formulated and implemented. Since there are no clear rights and therefore no indisputable interests, it may well be possible that no one feels urged to take the initiative to change the situation. In such a case an external party will have to catalyze the process of change. Another reason why no action may be taken might be that the groundwater users judge the transformation costs too high in view of the expected gains from institutional change to warrant such an undertaking. This may be simply due to the fact that there is no knowledge or not enough knowledge on the resource or on the institutional management options, and it may be due to the fact that the group of claimants to the groundwater resource is often unrelated or do not have any structure yet to come to an understanding. However, in an open access situation with massive overexploitation, the longer institutional change is postponed, the smaller the chances of the groundwater users become to regulate groundwater management later on successfully. Groundwater users will be less and less inclined to take the necessary measures, because, with time, the net benefits of groundwater exploitation will decline. This will make the resource less valuable. At the same time transformation costs will increase because of the prospect of inevitable reduction of exploitation rates and the destruction of investments. Not withstanding equity considerations, the urgency of the matter would be a strong argument to slow down the proliferation of wells so as to have a better starting position for institutional change and to allow more time for starting a learning process in common property management (van Steenbergen 1997).

Transformation costs are likely to exceed the overall net benefits of institutional change in the short run. Under such circumstances it will be more difficult for resource users to invest in institutional change. The various institutions that need to be developed have to be accompanied by the organization of resource use in some form. Resource users have to share information, to make rules, to take management decisions, and to solve conflicts. Leadership is required, and certain people may be assigned special tasks. These require skills which will have to be developed. An external agency may take the initiative to guide this process and assist the community in acquiring the necessary skills. These and other forms of support help reform local resources management, which will reduce transformation costs for the resource users. Programmes of establishing user organizations or strengthening existing management arrangements fall in this category. The state may subsidize part of the transformation costs by encouraging organization and the collection of information, enabling more complex management levels, and the legal endorsement of local rules.

Also on the secondary management level, joint ownership and operation of tubewells and pumps usually involve substantial transformation costs, for instance to reduce social tensions in the group and to acquire skills to manage the group and the water lifting infrastructure. These costs are often difficult for the poor to bear. In the past private organizations or NGO's have typically absorbed a major part of these transformation costs, and have thus helped tubewell groups to overcome these thresholds. As is the case with transaction costs, transformation costs associated with group formation appears to rise disproportionately as group size increases (Kahnert and Levine 1993; p.10, 16). However, NGO-sponsored lift irrigation systems, though small, operate with a high level and quality of NGO involvement, which makes their replication on a large scale difficult (Shah 1993; p.146).

Although external support may be necessary to overcome initial obstacles in groundwater management under a common property regime, the type of management implies that some of the costs must be borne by the users themselves. The external parties concerned should therefore by all means avoid the danger of raising false expectations on the part of groundwater users as to future contributions by external agencies and their own role in the game. It should be made clear from the start that maybe a good deal of the transformation costs may be borne by external organizations, this may not be the case with future transaction costs. It should equally be avoided that groundwater users only take up groundwater management in order to get a 'reward' which is offered to them by the external organization as an incentive for their participation. When such incentives will cease and no genuine interest in sustainable groundwater management has been aroused, the newly established management regime is bound to fall apart.

The role of the state

The above tends to suggest that state intervention can be useful in resolving various conflicts in collective action. But state interventions can also make things worse. Transaction costs may become higher as a result of state interventions. Moreover, bureaucrats may have their own goals which can be different from the goals of the local groundwater users. The goals of government officers may only be to extract resources for themselves, to undermine the political or economic power of local elites or to assist the elite to obtain and consolidate the power of the state apparatus and/or to legitimize the political regime. A desire to optimize the welfare of the common pool dependent community may even have the lowest priority in state intervention.

Putting the responsibility for groundwater management entirely in the hands of the state may inhibit the emergence of better groundwater management. In water users communities characterized by strong differentiation the refusal of paying water fees by a group of users who feel disadvantaged by others may have little effect if the fees were collected by the state. In the worst case these non payers may just be persecuted for defaulting. If the fees were collected by a local groundwater management organization, non-payment is likely to hurt the community and thereby it would give the disadvantaged group a means for bargaining with the others for a better arrangement.

Inversely, the state can also be manipulated by one of the local interest groups embroiled in a common property resource conflict. Such a group may attempt to reduce its private transaction costs by shifting the incidence of its transaction costs, in part or in full, onto the government. Through this process these costs are diluted over the population at large and the successful party gains in the collective action situation (van de Laar 1990; p.37). The state may not only pay a part of the transaction and transformation costs, it may become a party itself in groundwater management. In this capacity it will have a direct interest in the bargaining process, for instance, if it is decided that public tubewells should be established side by side with existing private tubewells owned by large farmers, in order to provide small farmers with access to groundwater. It has already been indicated that the state can also very much influence production costs and benefits. It can enhance the productive value of a resource through development programmes or increase production costs by taxation and the like.

Concluding remarks

In the previous sections we have attempted to analyze the actual groundwater use systems with concepts from common pool theory. Groundwater can be characterized as a fugitive resource which in the arid and semi-arid regions of South and South West Asia have increasingly been exploited under an open access regime in which its users have been facing a genuine prisoners' dilemma. As a result, the integrity of the resource has come under threat. Also equity has been a problem as not all members of rural communities have been able to obtain access to the resource and their chances will deteriorate when the resource continues to dwindle. Subsequently, we have dealt with the various requirements, advantages and drawbacks of common property regimes. In this paper it has not been argued that common property resource management is the best solution for groundwater management in every situation, although we think that in some situations it is. The principal aim of the various discussions has been to show that, in principle, any groundwater management regime should be adapted to the physical, socio-economic, institutional and political situation at hand taking into account net benefits, differences in interests among the claimants to groundwater, transaction and transformation costs. Common property management, however, may be part of the solution in various degrees in combination with elements of state or private property regimes. Too often government regulation and local management are seen as opposites with nothing in between. This is regrettable because in a mixture of local and government rule the two components can reinforce each other. The previous discussions have indicated several times that groundwater management under a common property regime may have potential, particularly where communities are relatively small and little differentiated, or where they are differentiated, some scope for bargaining between various interests groups exist. In other situations may play of necessity a bigger role, but even in large groundwater basins with a large number of groundwater users there may still be possibilities for decentralized management. The state and other agencies can also give external support facilitating common property regimes, by appropriate and effective legislation, by creating favourable market conditions for groundwater and groundwater lifting technologies, by giving support for the development of local coordinative and managerial skills and by creating a political climate which favours transparency, accountability and justice. But steps are urgently needed. Or else, the rapid decrease of groundwater resources may cause water using communities to lose interest in investing in its management at all.

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Glossary

assurance	secure expectation as to someone else's future behaviour
common pool theory	the whole of concepts and theories that are relevant to the analysis of common property resource management
common property	system of group-ownership of resources with definite membership boundaries and usufruct rights assigned temporarily or permanently to individual members
efficiency	ratio between output and input of an activity
externalities	unintended positive or negative side-effects (spill-over) of economic activities of one agent that influence the production possibilities of other agents outside the market
free riding	behaviour by someone who benefits from the efforts of others, to which he himself does not contribute
institution	the set of rules actually used by a set of individuals to organize repetitive activities, thus facilitating coordination among them
integrity	quality of the resource base which is maintained if it does not deteriorate

joint management	management by a group of people of a resource shared by this group
open access regime	resource use regime with total absence of property rights over the resource resulting in no rules or restrictions regarding access and resource use
organization	group of individuals bound by some common purpose to achieve defined objectives
primary level management	groundwater management dealing with the interaction between individual or collective owners of water lifting infrastructure
secondary level management	groundwater management dealing with the interaction between users sharing the same abstraction infrastructure or between groundwater buyers and sellers
stint, to	to limit the amounts used of a certain resource
sustainability	resource use that guarantees the long-term maintenance of productivity without affecting the integrity of the resource base
transaction costs	costs of the mobilization of resources through market exchange and the costs of internal coordination
transformation costs	costs of institutional change

GROUNDWATER LAW AND ADMINISTRATION IN DEVELOPING COUNTRIES

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Introduction

Several groundwater experts have recently observed that groundwater in developing countries is by and large being left unmanaged (e.g. Katar Singh 1995; Van Steenbergen 1997). They have repeatedly deplored the absence of effective regulatory mechanisms. Nevertheless, a consensus now seems to be growing that groundwater is too valuable to be left unmanaged ; law and administration are needed to preserve the quantity and quality of groundwater. Moreover, the feeling is that the inequity resulting from existing legal doctrine calls for better law (Moench 1995: p.1; Prasad and Sarkar 1994: p.153). There are various suggestions as to what kind of law and what kind of management system should be entrusted with these new tasks.

Groundwater protection may or may not be a new issue, it is by no means the only subject that governments in developing countries try to administer and regulate properly, and then find themselves at a loss. In other words, many of the problems identified and the solutions suggested with regard to law and administration of groundwater in developing countries are not unique to that sector. They may occur in many other areas, from food distribution, building licences, to marriage law or land reform. The similarities of the administrative and legal aspects of those problems and solutions have even resulted in two fully-fledged fields of study: "development administration" and "law and development".

Since the 1950s, "development administration" has gradually become a subdiscipline of public administration to describe and prescribe practices of public administration in the Third World. The core subjects of this subdiscipline include policy analysis, implementation, decentralisation, intermediate organisations and participation, institution-building, administrative culture, and corruption. Certain concepts and theories from this field may bear relevance to the questions addressed in this workshop.

Even earlier than the 1950s, the role of law in Asia and Africa had become the subject of intense debate. Colonial scholarship had already acknowledged "customary law", "religious law", and many other "local normative systems" as "other conceptions of law". Yet, the colonial states and their successors - the states of the developing world - all established constitutions, laws and regulations, as well as ministries and local governments to enforce these laws and regulations, and courts for their interpretation in the settlement of conflicts. Since the 1960s, legal sciences have been enriched by what is known as "law and development" studies, in which the role of law and legal institutions in development processes have been critically assessed. Again, parts of this literature may be useful to the participants of this workshop.

The organisers of this workshop have provided us with a two-fold question: What are the principles of proper management of groundwater reserves, and how can proper management regimes be installed, given the conditions that prevail in many developing countries? I have been asked to comment on the legal and administrative conditions that prevail in developing countries, and to comment on various suggestions concerning groundwater law and administration.

In my comments, I shall first take you to the field of "development administration" to see what it has to offer. This is, in the first place, the search for an appropriate role of the state amidst competing claims that market forces or local groups should be the prime movers of development. Besides development administration has much to say about institutional strengthening. We shall then make a brief tour around the field of "law and development". Since groundwater is a natural resource which needs protection, it is a concern of environmental law and management. Therefore, I shall make some comments on our experiences with environmental law and administration in developing countries, with some examples from field research in Indonesia. Then, lastly, I shall turn to groundwater law and administration, listing problems to be solved and then commenting on the legal and organisational measures that have been suggested to solve them. I shall respond to this workshop's question by suggesting a set of basic rules for proper groundwater legislation and organisational frameworks for groundwater management.

The role of the state

Both law and public administration have always been closely associated with "states", and rightly so, I think . The problem, however, is that strong, effective, and law-abiding states are not the rule, as we have learned from practice and from studies. Literature on all sectors of development, including groundwater management, is filled with examples of laws and policies that have been badly implemented. This sad experience has actually affected the paradigms of development. In his book, Management Dimensions of Development, Milton Esman, one of the grand old men of development administration, described, how during the last decades, the naive, optimistic expectations of an almighty state that prevailed in the 1960s shifted to new creeds according to which the state fails almost everywhere and in all areas (Esman 1991: p. 1-19).

Three competing paradigms : towards a pragmatic consensus

Free-market ideologists, who believe in the "market", and workers at the grassroots, who believe in "local voluntary organisation", have united to this end. To my mind, there is a danger that the one naive belief - in the state - has been replaced by other naive beliefs. Esman has argued that these ideological stands - defending either state, market, or NGO as the prime mover of development - are rather one-sided. He has called for a pragmatic consensus to be reached in particular settings (Esman 1991). I fully agree with him on this point. Town planning, for example, should both learn from informal housing practices and build on market forces, but it should also remain an activity of government and regulation.

My brief excursion through the literature on groundwater management, though, shows that, with some authors, the three paradigmatic positions are still popular. In a recent book about groundwater law in developing countries, which focused on Indian states with comparative excursions to China and the USA, this is clearly expressed (Moench 1995). Others advocate pragmatic, flexible arrangements in which state, market, and grassroots associations can all play their roles (Van Steenbergen 1997: p. 81).

The case of India

The Indian case, which is described in the book by Moench (1995), is spectacular in that in 1970 the federal government had already prepared a draft bill on groundwater, and suggested to the states that it be enacted. The states, being politically dominated by big landowners, gave no follow-up. In 1992, the consequences of a groundwater crisis having become more visible in many states, the central government presented a new bill. So far, only one state, Maharastra, has more or less enacted this legislation, while Gujarat has also passed some legislation. Moench's book, which is the only recent book on groundwater law in a developing country that I could lay my hands on, reflects discussions by Indians, Chinese, and Americans about the bill and related issues. While all authors agree about the seriousness of the problem, they disagree about the strategies to be followed because they are generally tied up with one of the three paradigmatic positions.

The Secretary of the Central Groundwater Board in New Delhi, Mr S.C. Sharma, pleads for government intervention by legislation to establish new groundwater authorities in each state with the power to issue and cancel permits for groundwater extraction (Sharma 1995). This approach of "direct state control" is shared by many others in the state apparatus (Chandrasekhar 1995). They actually call for water rights to be vested in the state.

Marcus Moench, the book's editor, however, maintains that state regulation is probably not the optimum approach, because there is little hope of effective implementation. He considers the law-oriented "direct state control" approach too "insulated from local involvement" and suggests that it may well be obstructed by the wealthy, politically influential well-owners (Moench 1995(b): p. 39-41). In search of an alternative, he identifies an "overall tendency in current water resources management thinking" ..." towards greater participation", and he then calls for legislative structures to provide avenues for participation and local management (Moench 1995(b): p. 42). He meets with the approval of others, who suggest that indeed the problem can be solved by voluntary efforts by right-thinking persons (Srinivas 1995), with the help of a traditional culture of co-operation (Turnquist 1995), or through a new system of co-operative societies (Katar Singh 1995; cfr van Steenbergen and Oliemans 1997: p. 14). It occurs to me that some of these authors are confusing "local" with "non-governmental" which might actually blur the real issues at stake. Anyway, Moench himself concludes also that fully decentralised approaches based for example on private ownership or village level groups, will not be sufficiently effective either (Moench 1995(a):p. 3).

Later, Moench spots another "major trend in current water management thinking", which is "the potential use of economic levers and water markets". Markets would facilitate private transactions, shifting water to higher-value/lower-volume use (Moench 1995(b): p. 44). Only potential negative effects - the author calls them "social and environmental externalities" - could then be addressed by direct state control and regulation.

Looking then for what would, in the Indian case, constitute an optimum mix of legislation, voluntary initiatives, and market forces, some authors refer to American experience with law and administration, especially from semi-arid areas in the western states of the USA They suggest that this provides useful models and recipes (Katar Singh 1995: p. 73; Moench 1995(b): p. 47; Thomas 1995; Turnquist 1995: p. 90). Only one of them, Chhatrapati Singh (1995) explicitly raises the question "whether legislative approaches used overseas and by international conventions have any bearing upon the Indian situation, given the political, economic, and social set-up of India". I agree with this author that this question needs an answer based on research. In the meantime, I would suggest a cautious approach since this set-up in India and other developing countries is indeed quite different from that of the USA and other western countries.

Development administration

"Administration", according to Herbert Simon, "is getting things done". In developing countries, the "thing to get done" is called development. This consists of a broad list of policy objectives. So development is an umbrella concept comprising, say, a dozen constituent processes, each of which refers to progress in a certain field.

Development policy

The processes of development concern nation-building, security, economic growth, social justice, education, health, environmental protection, democracy, authenticity, and, I would like to add here, good governance and legal certainty. Those are the goals of development, which, in most countries, are elaborated in sectoral state policies. The great development debates mainly deal with the interrelationships between these processes and, when their goals conflict, with which is the preferable one: security or democratisation, security or legal certainty, economic growth or environmental protection, economic growth or social justice, social justice or cultural authenticity? Such conflicts between different goals of development are at the bottom of most dilemmas of law and administration. Any sensible policy must be based on a careful balancing of interests and a deliberate preference for certain objectives over others.

Groundwater management is no exception. The groundwater crisis, for example, raises issues of political stability and security, of economic growth, of environmental protection, of social justice, of public health, of good governance, and of legal certainty. They all contain wonderful development goals, but there are several conflicts and tensions between them. Strict environmental protection may, for example, decrease economic growth, antagonise big landowners, reduce legal certainty, thereby endangering stability and co-operation with good governance.

In the words of groundwater management expert Smith (1995: p. 139): "There is no real correct answer to the question what is good groundwater management". I quote, "The answer depends upon what values a system seeks to maximise. One might as well ask: whose values?" (Smith 1995: p. 140)

Institutions and policy implementation

To get the formation and implementation of state policy actually done, administrators and civil servants operate organisations - big, medium, and small. Most of these institutions are oriented towards improving the condition of people (i.e. they are people-oriented).Each developmental goal, elaborated into sub-goals and tasks, has been entrusted to one of more of such institutions: security to police, education to schools, health to primary health units, agricultural growth to agricultural co-operatives and rural banks, irrigation to water bureaux, and so on. New tasks have always led to the establishment of new institutions, which, in turn, have created the perennial and unavoidable problems of administrative co-ordination and competition.

Those who advocate a greater role for local management organisations may well know that there are all kinds of local organisations. They include deconcentrated state offices, decentralised local government councils, co-operative associations, beneficiaries' councils, community development committees, traditional authorities (cfr. Uphoff and Esman 1974).

They all act locally. Using the term "local management" in contrast to "state management" would therefore create confusion. Another terminological issue is the use of "institution" as a broad term that includes: arrangements, associations, rules, regulations, and behavioural patterns (Schrevel 1997: p. 7, citing Coward). Personally, I prefer to use "institution" as an equivalent to "organisation", as most people do in development administration, rather than helping to introduce such confusing expert jargon. Actually, the general principle of using clear terminology is always helpful, also in groundwater resource management.

Development requires effective organisations that can turn tasks into results. Which factors determine whether such an organisation is effective in the sense that it can implement its tasks? There is a theory of three-fold support to implementation processes which I have derived from one of the theories of development administration that has survived the 1960s: the Institution-Building Model. On the basis of that theory, I submit that a successful implementation of tasks requires three-fold support: from the institution itself, from the target group, and from the wider context. The institution itself needs three things: resources, internal structure, and leadership. Whether the target group complies with the organisation's policy depends upon their interest, their access, as well as the reach and the possible use of force by the organisation. Social contexts include the social and cultural context, the economic and financial context, and the political context of both institution and target group. Although this theory was developed in the 1960s for state institutions, it can also be applied to semi-public or private organisations aimed at people-oriented development.

Among the greatest threats to effective organisations are corruption and red tape - phenomena that one finds throughout society - in national governments, local governments, as well as in private associations. Each framework of policy, law, and organisation may sooner or later be confronted with the forces of corruption. It ought to be anticipated as much as possible. The fight against corruption should be an integrated part of any groundwater management effort as well as of its organisational design.

Most articles on groundwater management touch upon some of the factors involved in research preceding implementation, but only partially. What we need is a number of regional case studies that systematically uncover three things. First, what happens inside groundwater institutions; which equipment, leadership, personnel, and behavioural changes would be needed for effective implementation of policy and law? Secondly, how do different types of water-users actually perceive their own groundwater practices and the upcoming crisis; how do they interact, communicate, relate to various types of local institutions, so as to find out what could really be expected from state intervention, self-organisation, or a mixture of both? Thirdly, how would the implementation of alternative groundwater policies be affected by the wider contexts, notably by political power structures (both centrally and locally), economic forces, and socio-cultural value systems? It is quite a job, but far from impossible. When foreign experts get involved in making policy recommendations and suggesting arrangements, preceding field research becomes mandatory. A good example is given by van Steenbergen's Ph.D. research, in which he presents three case studies in Baluchistan. Marked differences between the three areas are demonstrated, in the roles played by government institutions and local groups, by legislation and customary rules, and by the different target groups in those three areas.

Decentralisation

Because groundwater management is a new task for the state, and no precise division of tasks has yet been made between the levels of central, regional, and local government, much of the recent debates on management of groundwater resources focus on the issue of decentralisation. According to Moench (1995(a): p.1) the primary tension in India's growing debate on groundwater law, is "between those advocating centralised regulatory structures and those who view decentralised approaches as being both more implementable and equitable. World-wide, many people think highly of decentralisation because of its connotation with democracy. Nevertheless, departing from a simple slogan such as "decentralisation good, centralisation bad" would be a gross mistake. For decentralisation can take on many forms (e.g. "democratic" devolution as well as "managerial" deconcentration). Some of these forms would clearly aggravate problems instead of solving them.

In several parts of Africa and Asia, devolution in the health sector has already proved a disaster (Gilson 1994; Dreesens 1997) . In China, as we can also learn from Moench's book, rapid decentralisation of water management has not yet brought about the hoped for benefits. Anyhow, key functions of groundwater management (e.g. hydrological research and data analysis) should definitely remain with the central government.

From studies in development administration, it has been learnt that no generalisations ought to be made on the relationship between decentralisation and development. It has rather been suggested that this relationship be deconstructed. First, it should be acknowledged that full decentralisation means the transfer of the four-fold set of tasks, resources, legal powers, and actual decision-making power. Quite often, only parts of this set are transferred. Besides, there are innumerable variations of decentralisation.

Reflection on an appropriate arrangement in a particular case (e.g. groundwater management in a given country) requires pondering the following questions: Which goals of development are actually sought? Which degree of decentralisation would then be desirable? Should there be many tasks, powers, resources, or just a few? And which form of decentralisation would be most appropriate? For example, is it the British model of devolution in which private citizens have taken the initiative to pool their resources and rule their locality, or the French model of deconcentration in which central government has penetrated all lower levels of governments with appointed officials who administer local affairs (Alderfer 1960)? Which particular type of decisions should be transferred to lower levels: major policy decisions, minor executive decisions?

To my great surprise, many authors overlook the fact that whether decentralisation is desirable or not depends on the capacities of the transferring level as compared with the capacities of the receiving level. The transfer of tasks from a well-run directorate of a national ministry to a provincial board, full of corrupt, unskilled officials without any resources, is doomed to fail.

The endemic weakness of intermediate organisations

It has often been assumed that "intermediate organisations" should emerge to link the values and structures of the state with those of the communities. Communities consist of strong informal networks of family members, friends, clans, caste associations, groups of believers , saving groups. They sometimes back parts of the state, parts of the markets, and even sometimes parts of NGOs. Many efforts have been made to organise those communities into some sort of local management organisation - from the famous Community Development in India since the 1950s to the co-operative movements. Most efforts have failed since intermediate organisations must lack a real power base. They fit neither into the local community structure nor into national states. In practice, either power holders from local communities took over, or the supervising government agency squashed the intermediate organisation to death. Yet many observers of groundwater problems support the need for some form of "intermediate level institutional framework" linking both national levels to local levels and state to society (see Moench(1995a): p. 2).

It is striking that, as late as in 1997, Indian authors again suggest that the co-operative model be followed. Katar Singh (1995: p. 76) suggests that "Landowners need to be organised into some sort of formal association under some law so that their activities are legitimised and their decisions legally backed up". He proposes that landowners be obliged to form co-operative water associations, which would make and enforce all necessary rules on pumpage, pricing, and the sale of water. He then wants to vest the landowners' water rights in the co-operative associations. The rights could be sold on lease to individuals for a certain period. The associations would pay a fee to the government. The farmers would buy shares in the association. All wells should be transferred to the association. The society should then auction to its members the right to use tubewells for irrigation or to sell water. "We know", writes Katar Singh, "that it is a novel idea beset with numerous legal, financial, operational, and managerial difficulties in its implementation. But the serious consequences of not doing anything warrant immediate action." (Katar Singh 1995).

Actually, the idea is not at all new, and we have learned from many instances that it did not work. Co-operatives are much too often hothouse plants in the cold - intermediate organisations with goals that are displaced by the goals of private or state actors.

All these failures do not wash away the need for governments and NGOs to communicate intensively with the target groups about policy and about the organisational forms to be chosen. In India's recent groundwater bill it is proposed that each state establishes groundwater boards. Representation of water users would be one way to establish a mechanism for consultation. People who may be affected by state intervention, ought to be consulted about their experiences, ideas and preferences. Representation in a regional board is not sufficient though. Hearings in rural areas should also be convened to listen to other voices as well as to explain the background of the state's groundwater management.

Law and development

Legal certainty

One of the dimensions of development is the increase in legal certainty This requires good legislation, lawful administration, and independent judicial decision-making. In most developing countries, much progress has yet to be made in these three areas. Legislation has frequently been inconsistent, unrealistic, and inaccessible. Administration has been plagued by unrealistic planning, lack of skills and resources, sloppy registration, bad communication, lowmorale, corruption, and a marked lack of attention to legal aspects. Judiciaries have been much less independent and also less professional than constitutions suggest.

Thus, in the average developing country, there is no properly functioning legal system; it is rather, as an Asian colleague once put it, a system in-the-making. So, on the one hand, nobody would deny that law is relevant and indispensable in managing a country; on the other hand, most insiders know that in practice the legal system does not work properly.

The need for inside knowledge of the law means that, when designing legal policy instruments, one should keep in mind that, although one should respect the law, in practice one cannot fully rely on its enforcement. Yet before adding new elements, one has to know the legal system. In the first place, this will guarantee that new legislation is consistent with the basic legislation already in place. In the second place, in a given country, some parts of the legal and administrative system may do better than others (e.g. tax administration may be much more efficient than land registration, courts may act more efficiently and independently in criminal law cases than in administrative law cases, or provincial governments may have better law-making skills than local governments). Such inside knowledge of legal systems is vital in drafting new regulations. More than once, however, drafters in developing countries adopt regulations from other legal systems or from international treaties.

Law families

When studying the use of legal transplants into a foreign legal system, jurists generally follow the path carved out by their colleagues of comparative law, like the famous René David from France or Konrad Zweigert from Germany. From them, we have learnt that the world has a few major legal systems that have more or less spread over the world: common law, continental law, socialist law, and a group of "other conceptions of law". The assumption is that the legal systems of most countries, including developing countries, are essentially based on, or are at least closely related to, these mother systems, which mainly originate from Great Britain and the United States, as far as common law is concerned, from France and Germany for the continental law, and from the Soviet Union for the socialist law. The "other conceptions of law" include major, well developed, religious normative systems, such as Islamic law and Hindu law, as well as customary law, which is essentially unwritten and local.

Common Law or the Anglo-American group of legal systems is widespread throughout former parts of the British Empire in Asia and Africa, North America, Australia, and, of course, Great Britain itself. This law is basically judge-made law rather than being laid down in comprehensive laws and codes. It requires a strong and independent judiciary, but leaves it to individual citizens to call upon a court, except in criminal cases. Much of the available groundwater management literature is written in English and refers to certain problems with the "common law". Indian experts complain that British Common Law has left them with a rights structure that allows no legal limits to groundwater extraction by individual landowners (Moench 1995(a): p. 1).

Continental Law or the Roman-German group is widespread throughout those parts of Asia, Africa, and Latin-America that once formed part of the other colonial powers such as France, Spain, Portugal, Germany, Italy, The Netherlands, and Belgium, and also in some countries that were not colonised such as Japan, China, Taiwan, Thailand, and Turkey. The law here is basically made by legislators. Major examples are the Napoleonic codes dating from approximately 1800, and, later, some German codes. Recently, the new Dutch civil code has served as a model in many parts of Eastern Europe and the former Soviet Union. So, the continental system requires strong, highly skilled legislators. While private property and freedom of contract belong to its core elements, it also embodies a strong bureaucratic tradition in which the administration actually allocates rights to citizens by granting or cancelling a permit or licence.

Socialist law also used to be a major family before the collapse of the communist empire in 1989. It originates from the continental law, but key elements such as private property and freedom of contract have been replaced by socialist notions. For natural resources, this doctrine would focus on their social function and on the sovereign rights of the people as embodied in public ownership of land, water, and forests.

There can be no doubt that, of old, customary and religious rules on groundwater have developed in those areas that experienced a practical need for it. From a historical perspective, religious rules, notably Islamic rules, can essentially be considered a continuation, or reform, of local custom in certain areas of the Middle East during the early Middle Ages. Such rules are therefore often too limited in scope to function as an autonomous basis for new groundwater management. On the other hand, insofar as they have an appeal with local populations because of their practical and or symbolic value, an effort should be made to incorporate such rules in emerging legal regimes. An authoritative book on water laws in Muslim countries was written in the 1950s by the Italian lawyer Dante Caponera, and it was recently revised. It shows that the Islam contains certain provisions regarding water, some of which regard restrictions on water use. One example is the bordering land of a well, the so-called *harim*, on which it is forbidden to dig a new well so as not to affect the quality or the quantity of existing wells. Another example is the Islamic rule that water should be the common entitlement of all Muslims and that it is forbidden to sell it (Caponera 1954: p. 17). Brief recapitulations of the water laws of Muslim countries can also be found in Chandrasekhar (1995: p. 20-21) , while Van Steenbergen (1997) demonstrates how the *harim* rules have successfully been applied in Baluchistan.

Legal pluralism

During the 1970s and 1980s western academic studies of laws in developing countries have been dominated by the paradigm of legal pluralism, as it was developed in legal anthropology. The monopoly of the state in law-making was rejected, and rules produced by any kind of ethnic, social, or functional group were labelled as "law". The theoretical and political underpinning of this trend can be traced back to colonial days, when local customs were called *adat* law (*adat* is the Bahasa Indonesia term for custom) , folk law, or customary law in order to justify the recognition and application of local, social rules of the people, not only by indigenous courts but also by colonial state courts. For some time after independence, many countries maintained the idea that their legal system, or considerable parts of it, could be founded on customary law or religious law. In most fields of law, this idea has faded with time. In some fields, however, notably in family law and a few parts of land law and criminal law, this idea has been pursued by incorporating religious and customary rules in the state's legal system.

After the rapid social and economic changes of the last decades, I think we should be hesitant to give general legal recognition to "folk-law" systems as such. I rather believe that legislators, judges, and legal scholars should consider, case by case, to what extent elements of local culture, such as customary rules, deserve recognition as law.

Law-making in developing countries

Against this comparative and historical background, we must realise that the making of effective law in developing countries is not an easy job. If a country belongs to the continental tradition (e.g. Indonesia or Brazil), it may face other legal problems than countries bound to the common law doctrine (e.g. Pakistan or Tanzania). Yet, in matters of land and water in Indonesia or Ghana, customary law may still play a more significant role than religious law, whereas in Pakistan, being an Islamic state, religious law is important. In both Tanzania and Indonesia, the socialist imprints on natural-resources law are still visible, but all countries have subscribed to international treaties that are often framed in the English language, smuggling in all kinds of concepts that have developed in common-law countries. So, from a purely technical viewpoint, coherent law-making is already quite a challenge.

At the same time, apart from technical considerations, the law-makers are caught up in several fields of tension. Firstly, should they follow trends set by international bodies or western countries, or should they come up with something clearly national and authentic, something visibly Pakistani, Indonesian, or Egyptian? Secondly, should they give in to ethnic pressure from fundamentalist parties by stressing and strengthening the old rules derived from Hinduism, Islam, or the culture of Zulus or Zapatics? Thirdly, in many law-making processes, there is still the tension between state-led socialism and market-led capitalism, the latter having lately been strongly promoted in the Third World by donor countries and institutions since Reagan and Thatcher decided in the 1980s that that was better for their own countries. Fourthly, there is the tension between authoritarian, centralist approaches and democratic, decentralised approaches, again the latter being happily promoted by donors, since we have found that decentralisation and democracy work rather well in the west. In the fifth and last place, there is severe tension between the rule of law as the supreme standard of all human action, and the actual normative standards - or the lack of them - in the daily processes of informal, and often illegal, fixing and wangling that play such dominant roles in the lives of the people in developing countries. In discussing useful laws and other policy instruments, we should beware of those fields of tension, and try to help in finding a proper, stable position in their midst.

How developing countries have coped with such complexities and tensions of law in development can be illustrated with many examples. Since our main concern is with the management of natural resources, in particular of groundwater, I shall now give some attention to the relevant fields of law and policy, being the environmental management and the environmental law of developing countries.

The development of environmental management and law

A new legal-institutional infrastructure

Over the last decades, most developing countries have established a body of policies and regulations to protect natural resources. Since the UN Conference on the Environment in 1972 in Stockholm, these countries have ratified many environmental treaties (Otto 1991). At present, most countries have their environmental management act, their ministry of public authority for environmental protection, their sectoral plans and regulations and licensing systems concerning nuisance, water pollution, industrial pollution, air pollution, as well as the protection of soils, forests and other nature reserves, and their flora and fauna. In many countries, efforts are underway to set up environmental management offices at regional and local levels.

Often, the present environmental legislation is already supposed to provide some broad protection to groundwater, but it seems that the time has now come to regulate groundwater protection more explicitly and more precisely. A few years ago, a UNESCO study group suggested that indeed groundwater protection law should be seen as a new branch of environmental law. What would that mean?

The objectives of creating a branch of the law are usually two-fold. Firstly, certain policy objectives are deemed desirable, and secondly, it is intended to create legal certainty in a particular area of human action. Legal certainty is one of the major goals of any legal system.

In any given area, the degree of legal certainty basically depends on three conditions: firstly, on the prevalence of legislation that is recognisable and consistent; secondly, on the prevalence of state institutions that themselves comply with those rules and induce private citizens to do the same; and last but not least, the prevalence of effective judicial remedies in cases of non-compliance. In short, all three parts of the trias politica need to be in good shape; otherwise legal certainty will suffer.

How is the condition with regard to environmental law (Otto 1996: p. 33)? Several studies on the environmental laws of Indonesia and India give us the following indications and hypotheses as points of departure (Otto 1991; Munneke and Otto 1990). For the following sections, I have drawn quite heavily on our research in Indonesia, but I have few reasons to assume that the condition of environmental law in other developing countries will be either much stronger or much weaker.

Environmental legislation

During the 1980s, considerable progress was made in environmental policy-making and legislation. International principles of environmental policy law, formulated by the Grundland Commission and by commissions of legal experts, have found expression in national policies, programmes, and laws. Environmental law became an important subject, also in developing countries: it was included in the curricula of law faculties, in the practice of business firms and legal consultants, in the extension programmes of NGOs, and in international development co-operation programmes.

Legislation often seems to be fairly coherent and more accessible than the laws in many other fields. Yet, three legislative bottlenecks must be mentioned. Firstly, many legislative provisions are still very broad and ambiguous, so they badly need implementing regulations, which have often been delayed. Secondly, eclectic absorption of legal concepts from different legal systems has sometimes led to confusion (e.g. the connection between new permit systems for, say, the control of water pollution, with existing nuisance permit systems; or the transplantation of the North American concept of environmental impact assessment, which seemed at one point not to fit in with the existing Continental-Dutch system based on laws and licensing). Such misfits have led to many calls for the co-ordination or harmonisation of environmental law. Thirdly, environmental law is in many instances connected to, and even dependent on, other fields of law. In order to have a polluter sentenced according to criminal law, courts will have to rely on the existing criminal law and criminal procedure law, especially the law of evidence. In order to accept claims from environmental pressure groups, the courts must conform to the law of civil procedure. If the law is not clear on these points, all depends on an administrative and judicial interpretation.

Environmental administration

In the administration of environmental protection, four major challenges have posed themselves: policy co-ordination, beefing up central organisation, decentralisation, and administrative culture. Most of these issues have already been dealt with in a general sense in section 2, "Development Administration".

Although the concept of sustainable development has found its way into five-year plans and other policy documents, the ministries that are primarily geared towards economic growth (e.g. agriculture, industry, public works, transport) simply outweigh a ministry of the environment, and dominate national policy-making. Yet, to fulfil its mission, this ministry must try to influence decision-making processes in these often hostile ministries. This requires a strong homebase and highly skilled officials and strong political backing from the top. In Indonesia there even is no full-fledged ministry for the environment since the government is of the opinion that a lighter co-ordination mechanism is better equipped to deal with the other ministries. On the other hand, a central agency was established after the model of the American Environmental Protection Agency.

But even with hard bureaucratic infighting and many resources, it has proved to be very difficult to build a strong central institution for environmental management in times when economic growth is limited or even absent and when governments are supposed to shrink rather than expand. Moreover, provincial and local governments are seldom strong partners in environmental management. Local entrepreneurs and other economic interest groups will often be able to put more pressure on them than NGOs can do. Don't forget that the role of the local press, the natural partner of environmental NGOs, is still often curtailed so that it cannot reveal environmental scandals to the public.

Changing administrative culture remains difficult but is a conditio sine qua non. Corrupt practices are part and parcel of environmental administration. All sorts of do's and don'ts are circumvented: licenses are bought, officials are bribed, and honest leadership to control the controllers is in short supply. These, briefly, are some basic problems of environmental administration, which may also apply to groundwater management.

Environment in the courts

It is before the courts that weaknesses in the legislation become fully exposed, but there are other problems as well. In environmental cases, courts in developing countries are confronted with the following challenges: access, innovation, unity, and dissemination (Otto 1996: p 51-58)

Access is a problem because victims of pollution, often poor people, seldom have the financial means, administrative skills, and mental state needed to start a court case against a company. They are therefore dependent on institutions that perform social litigation on their behalf. At least in Indonesia, recent case law on locus standi of such environmental NGOs has already improved access.

As regards innovation, impartiality, and judicial activism, some countries clearly have a better reputation than others: India, Egypt, and Ghana can be considered more developed than, say, Indonesia or China (Tiruchelvam 1983; Otto 1995; Pompe 1996). Indeed, available literature on South Asia suggests that court cases sometimes play a role. In Van Steenbergen's Baluchistan cases, though, it seemed a venue to protract old enmities rather than a way to resolve groundwater dispute. One of the dangers of adapting American legal models is that it is precisely the American systems that have powerful, independent and innovative judges, who make big landholders, and even governments, obey their indictments while conditions outside the western world are so different.

Unity in judicial decision-making is another problem in many developing countries, where Supreme Courts have backlogs that count into the thousands, so that it will take many years before firm case law can be established at the highest level.

In the meantime, in many countries, the dissemination of the decisions of lower courts remains troublesome so that they are not always exposed to public and academic scrutiny, or even to other courts. The registration and smooth communication of court decisions would, of course, be in the interest of parties - including NGOs, police, and prosecutors - to obtain points of reference in preparing new cases.

When we study the environmental law in developing countries, we find many such conditions. The situation may not be very encouraging for drafters of new groundwater legislation. Understandably, many observers have been attracted to management systems that are less oriented towards law and administration such as common property resources management. However, it is not self-evident that this can provide a way out. As Nibbering has demonstrated to this workshop, it can only work if it is easy for resource users to co-ordinate their actions. If they cannot, the state and the market are better alternatives. Probably, one has to be prepared for a reality in which none of the alternative systems can be very effective. But if the goal is making effective legislation one should be realistic and face the gloomy realities of legal process, unfair markets and quarrelling local groups rather than play to the gallery.

Groundwater law and administration

The problems

According to the literature, there are at least five main groundwater problems to be solved:
1. The danger of exhaustion of groundwater reserves, now or in the future;
2. Falling watertables causing harvest losses, rising costs of pumping, and land subsidence;
3. Tail-end deprivation;
4. Salinisation due to rising watertables;
5. Loss of usability due to pollution.

The first three problems call for a reduction in groundwater extraction; the fourth problem calls for a carefully balanced combination of pumping, irrigation, and drainage; the fifth problem calls for the control of water pollution. In this section, I shall focus on the three related problems and, at the end, shall briefly comment on the other two. It is important to note here that, in practice, these problems do not have to occur simultaneously or at the same place. This calls for a differentiated, adaptable management regime.

Basic rules and institutions for groundwater control

At the moment in many developing countries, land owners drill and pump as they like (Moench 1995: p. 50), and there is a growing consensus that this must be stopped. But how? After the above account of the conditions of law and administration in developing countries - especially in environmental management - the questions remain: what amount and what type of law are needed, what kind of institutional framework is needed, and which solutions are needed in case specific legal and administrative bottlenecks occur?

Let me first sketch some very rough outlines, which can be elaborated in greater detail later. On the basis of the literature that I have gone through, I suggest that there are a few basic rules and a few basic institutions that together constitute the heart of a groundwater management system, and about which a general consensus has grown (Chandrasekhar 1995:22-23).

1. There must be a legal limit to the freedom of landowners to drill and pump as they like;
2. There must be a Lower Groundwater Institution (LGI) at a regional or local level;
3. The LGI must register all wells and users in its area;
4. The LGI must regulate and re-allocate rights to drill and use groundwater, either through a licensing system or otherwise.
5. The LGI must conduct direct monitoring and supervision;
6. There must be a Higher (national or provincial) Groundwater Institution (HGI);
7. The HGI has the task and powers to collect and analyse hydrological data on groundwater;
8. The HGI also has the task and powers to make a classification of areas according to the urgency of groundwater problems and the specific management regime needed;
9. The HGI has the task and powers to co-ordinate its policy with other higher government institutions;
10. The HGI has the task and powers to oversee groundwater management at a higher level.

My impression is that these basic rules reflect a general consensus among most governments and experts. Yet, there are two serious problems surrounding these rules.
The first problem concerns the composition of the Lower Groundwater Institution that is needed, and the type of rules it will make and/or enforce. To arrive at an optimum arrangement, the factors mentioned in the previous sections should be thoroughly analysed.

The second problem is simply that there will be widespread resistance from landowners against limitations imposed on their freedom. Their opposition will, of course, focus on rules and institutions that regulate and reallocate the unlimited groundwater rights that have been so much in their interest. To achieve their political and economic goals, they will also use legal and administrative arguments, which we shall discuss below.

What kind of lower groundwater institution?

Generally speaking, there are three basic models for Lower Groundwater Institutions: a government office, a people's group, or a mixed government-people's institution. The first two correspond with two of the three paradigms that were discussed in the introduction of this paper: state and local groups.

Certainly, each model has its pros and cons, and different conditions in different countries call for different models. Two books, one by Van Steenbergen (1997) and the other by Moench (1995), give us helpful information: Van Steenbergen especially by his empirical case materials, and Moench because he gives us so many different approaches, some of them based on doubtful argumentation.

Let us take a look at the three case studies from Baluchistan by Van Steenbergen (1997). In Kuchlak, the people's group of *"kareze"* management collapsed; the people's group managing collective dug wells collapsed as well. Finally, on the basis of new legislation, a set of decisions by the Provincial Water Board settling water disputes brought some control, albeit rather limited.

In Mastung, a people's group of tribal elders made serious efforts to control all water users, but their influence on new dug-well developers was too limited and disputes continued until the government, the local administration, took the initiative to gather the group of elders and, together with them, to establish rules. A supervising organisation was created consisting of three elders to issue permits and safeguard the rules. The elders found little time to attend to their duties, however, so this people's group also collapsed. Gradually, responsibilities shifted to the government.

In Panjgur, a highly dispersed and informal people's group of *"kareze"* shareholders is in power. They control the area and intimidate potential dug-well developers to protect their *"kareze"*. If their intimidation has no effect, the government will usually back them and decide the case.

Summarising, people's groups often play a role, but they have a tendency to collapse. Government officers have an important role to play as conflict settlers and as partners in rule-making and rule-enforcement. No mixed institutions were created.

The USA provides some examples of highly sophisticated people's groups. As the scarcity of groundwater became acute and conflicts arose, farmers and other water appropriators - in response to court orders and after long deliberations - created water districts and established water users' associations to regulate pumping and impose other constraints (Katar Singh 1995: p. 75-76).

The participants pooled money, technical information, agreed to have voluntary cutbacks of 25-30%, and each year reported their withdrawals. The associations hired staff (i.e. water masters) for the monitoring and sanctioning.

According to Katar Singh, "India could learn many lessons from this experience and design a similar strategy (see section 3, on intermediate organisations). A plea for immediate action deserves our support, but is this the right direction? Surprisingly enough, the same author, Katar Singh, in the same article, describes an experimental project, supported by Norway from 1974 until 1987, with joint ownership of tubewells by small farmers, but which did not succeed because of intra-group conflicts, a weak position vis-a-vis competing tubewells (private and public), an inability of the group to frame appropriate rules, a lack of participation of members in decision-making, and an inadequate power supply.

Essentially similar reasons led to the collapse of agricultural co-operatives in many developing countries. Van Steenbergen's cases from Kuchlak and Mastung follow the same direction.

Katar Singh (1995: p. 97, footnote 18) also warns against pseudo-co-operative societies, and this warning should be taken seriously. In developing countries, it is highly probable that a co-operative society will develop either into a cover-organisation of the local strongmen or into a local extension of the central government. One can easily agree with Katar Singh's thesis that, for the success of any group endeavour in natural resources management, the rules for equitable sharing must be framed and enforced ruthlessly by the group (Katar Singh 1995: p. 77), but it must also be acknowledged that empirical evidence suggests that this seldom occurs.

Active government intervention seems indispensable. The next question then becomes: should such intervention be undertaken by a deconcentrated, sectoral office for water management or by the local administration? My suggestion would be to create regional water boards, chaired by the chief of a province or district, but technically supervised and supported by one of the water management ministries or the ministry of the environment.

Members of such water boards should include expert officials and regional leaders, representing the values and interests of the people. The representation of people in such boards helps to establish the principle of consultation. People whose fate will be affected by state intervention should be consulted to hear their experiences, ideas, and preferences. However, representation in a regional board is not enough. Regular meetings in rural areas should be convened to listen to other voices as well, and to explain the background of groundwater management.

Legal bottlenecks?

Basic Rule 1 suggests that there be legal limits to the freedom of landowners to use and sell the groundwater they extract from underneath their land. Much of the literature on India suggests that, in common-law countries like India, such limits would be against the law.

It is suggested that there are four legal doctrines in common law, none of which allows for state control. I do not agree with that suggestion. Indeed, the oldest common law doctrine is the riparian doctrine or absolute ownership doctrine, which scarcely limits the rights of landowners to extract groundwater; implicitly, their share is absolute (Katar Singh 1995: p. 75). This doctrine, however, has been supplemented by the doctrine of reasonable use. According to this, groundwater rights are limited to "reasonable use" on overlying land. A third doctrine goes one step further: the doctrine of correlative rights that has been developed in the United States. It says that, in times of scarcity, the court, if called upon, would permit the overlying owners, as correlative or co-equal owner, to have access to their proportionate share. So the court, if called upon, would limit the rights to "proportionate share with reasonable use". As these doctrines all attribute rights to landowners, one may ask what would be the rights of tenants and landless labour, especially when they have had access to groundwater in the past. Coming to their rescue, common law jurists have developed a fourth principle: the doctrine of prior appropriation. It states that first water rights are vested in those who were first in time, regardless of land ownership (Turnquist: p. 88 , footnote 26).

From this account, we can learn two things. In the first place, even in common law doctrine, limits have already been set according to reasonable use and proportionate share. But in the second place, the control according to common law rests in the hands of citizens who call upon courts to make decisions with new rules that are obeyed. The latter condition would seldom work in developing countries because of access problems and problems with efficiency and impartiality on the side of the courts (see section 5, "Environment in the courts").

One may then ask with what right can the government itself set up a control and licensing system to stop landowners from using groundwater, which they regard as their private property, and, in this respect, whether the legal conditions differ between common law countries and continental law countries.

The new Dutch Civil Code, which can be considered the most modern civil code in continental law countries, holds a pleasant surprise. It states in Book 5, Section 3, on "Property of Immovables", that the property of land includes, unless the law states otherwise, the groundwater that has come to the surface by a source, well, or pump. The legislator assumes that groundwater is res nullius (nobody's thing) until it has been brought to the surface (Stolker 1994: p. 311). In other words, until it is pumped up to the surface, it is no one's property. Whether a landowner is allowed to extract it, and how, and in which quantity, can certainly be decided by administrative law. Moreover, the groundwater will become the landowner's property "unless the law states otherwise". So, in this continental code, I can see no legal problem in groundwater control.

I have tried to find out what common law doctrine has to say about this matter. It is clear that under common law groundwater cab also become the landowner's property through accession. It is also evident that environmental law can put limits to an owner's use of his property. But I have no decisive information on whether groundwater is a res nullius, before it is pumped up. Anyway, I would not be surprised if this whole argument that has developed in India would be very weak from a legal point of view, and not more than a quasi-legal cover for strong economic and political interests. Further study, however, is needed to sound this out.

Since law in developing countries is often ineffective anyhow, some observers turn to religious or customary rules. It is easy to suggest that local water-use rights are equitable and should therefore be backed and legitimised by state law (Katar Singh 1995: p. 78). I do not believe that this can be a panacea, as I explained above when I referred to legal pluralism (section 4).
When problems become urgent, rules must be clear and, if necessary, enforceable in the end by state authorities. This calls for legislation, rather than mere reference to traditional rules. Having said this, I hasten to add that legislation can be national, regional, or local, that legislation should be simple, and, inasmuch as possible, should reflect the values and norms of the communities addressed. The rules framed by local administration, together with tribal elders in Baluchistan, could therefore have taken the shape of a regional regulation, enforceable before the courts, and thus adding to legal certainty in groundwater management.

Conclusion

It has often been proposed that local groups should be involved in groundwater management and that legislation should conform to local ideas. One must agree. that terms like participation, local management, local acceptance, legal pluralism and decentralisation have a pleasant ring. However, in some areas landowners must really be stopped from pumping as they like , against their will but for the sake of other people and future generations. Here the need arises for strict administration and law enforcement with strong backing of a central government. If there is no political will or administrative capacity to do so, escalation into an armed conflict should not come as a surprise.

This article suggests that state intervention for groundwater management is a must. Political agenda-building to make protection of groundwater resources a priority issue is badly needed. The question of decentralisation should be addressed systematically. Implementation problems are to be anticipated by focusing on institutions, target groups as well as social contexts. The internal structure of local groundwater institutions should minimise opportunities for corruption. In order to build strong institutions, mechanisms must be developed for consultation with targets groups of local users. In this respect self-organisation by local groups ought to be welcomed but not imposed.

Any groundwater law aims at an increase of legal certainty in its field. However, general conditions in most developing countries are such that one cannot rely on the effectiveness of a legal system. Yet one should make the best of it and therefore try to understand the roots and the structure of the national legal system concerned. New groundwater legislation needs to be brought in harmony with existing environmental law and other relevant legislation. Thus, legal models for groundwater control from other countries should not simply be transplanted. Whether indigenous rules of religious or traditional origin should be incorporated ought to be decided on a case to case basis. It is for sure, though, that , whether in common law, civil law or indigenous law, water rights based on landownership must be limited.

Before governments can control groundwater resources research should be carried out not only in hydrology but also in the socio-economics of groundwater users and use as well as in development administration and law. Such research should aim at finding pragmatic solutions enabling state, market and local groups to contribute to good groundwater management (Moench 1995(b): p. 47). The basic rules developed in this article can serve as a point of departure.

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EVOLUTION OF WATER RESOURCES MANAGEMENT IN YEMEN

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Introduction

Yemen has an old tradition of irrigation involving comprehensive hydraulic structures such as the ancient Dam in Marib at the fringes of the desert where the Queen of Sheba was residing, and rainwater harvesting on the mountain terraces in the Highlands where the Imams were reigning. For centuries the country managed to maintain a delicate environmental equilibrium making use of the available surface water and groundwater resources.

In the last three decades the country has fallen into a water crisis characterised by very rapid mining of the groundwater resources, which has created water supply shortages in major cities, has resulted in environmental deterioration and abandonment of agricultural grounds and has limited the access of the population to safe drinking water.

The main causes of the water crisis are familiar from other countries of the Middle East: rising demand as population and market-led agriculture develops; groundwater exploitation getting out of hand; and Government policy that has promoted expansion rather than efficient use and sustainability management (World Bank 1996).

The situation in Yemen stands out, however, amongst other arid countries: in no country in the world is the rate of exhaustion of aquifers proceeding so fast. Yemen also stands out because of the still weak capabilities of governance structures. It will not be possible to approach a realistic solution in short time whereby the Government will be in such a control that it will be able to avert further crisis development at every place in the country.

Still the challenge has to be met, if the Highlands are not to be deserted by the population in the coming decades. The results of action will only be partial and should be focussed on hot spots. The results of inaction would be catastrophic.

This paper summarizes the evolution of the water crisis in Yemen, bringing together three elements of water resources management: the natural resources, the triggers for depletion and the management institutions.

It describes the comprehensive water policy framework which has been designed by the National Water Resources Authority (NWRA) to cope with the situation. The central theme is that it is believed that NWRA, as a public body, has an important strategic role in managing the water resources of the country, but that it can only do that by developing an innovative process through which an instrument is developed which identifies and concerts actions with end-users. This instrument should be the regional water action plans which NWRA intends to develop with large partnership of the end-users in the region.

Scarce water resources

Information on the water resources of Yemen has been rather exhaustively compiled in a summary report with the title "The Water Resources of Yemen" (Van der Gun *et al.* 1995). The report was the last technical report produced by the Water Resources Assessment Yemen (WRAY) project, a series of bilateral projects financed by the Netherlands Government in the period 1982-1995 which contributed significantly in building capacities for groundwater management in Yemen (Negenman 1995). For the compilation of the summary report approximately 600 technical reports and publications related to Yemen's water resources were identified of which the most relevant were studied and summarized. In the following sections a synopsis of the topographic, climatic and groundwater conditions is given following the information in the summary report. The report underlines actually one of the first principles of installation of proper management system namely: availability of essential, uniform, consistent and reliable information about the (ground)water resources in a country. On basis of this information trends in the water resource system can be identified, enabling the verification of the integrity of the resource basis.

The unique location of Yemen on the Arabian peninsula, surrounded by the Red Sea and the Gulf of Aden in combination with the large contrast in elevation, influence strongly the climatic features. The mountain slopes in the west and south-west facing the Red Sea and the Indian Ocean respectively receive more rainfall than the highlands and the zones facing the deserts in the interior. Predominantly the climate of Yemen can be described as semi-arid to arid, with rainy seasons during spring and summer. Average annual rainfall in the most favourable situated locations in the highlands is from 500 to 700 mm, decreasing rapidly from 200 to less than 50 mm in the largest part of the country. Many different landscapes can be distinguished in Yemen: coastal plains, mountain massifs, plateau's and desserts.

The runoff generated by the rainfall creates intermittent surface water flows through otherwise dry streambeds, also called wadis. Water from these wadis constitute the most important source of groundwater recharge in Yemen. Four major groundwatersystems can be distinguished in Yemen (see Figure 1): Tihama Quaternary Aquifer bordering the Red Sea and consisting of alluvial material containing predominantly fresh groundwater. This aquifer system is recharged by the wadis descending from the mountains; Southern Coastal Plains bordering the Gulf of Aden with similar features as the Tihama Quarternary Aquifer, only with more limited thickness; Extended Mukalla Complex underlying the central part of Yemen reaching a thickness up to 1000m, with modest depths to the groundwater where Quarternary deposits are lying. This sandstone complex constitutes the largest groundwater system in Yemen; Highland Plains scattered over the mountain massifs constituting favourable areas for groundwater development.

Table 1 lists estimates of annual abstractions, average recharges and volumes of fresh groundwater stored in the four mentioned aquifer complexes. It is clear that a national scale groundwater abstraction is exceeding the rate of groundwater recharge and that the groundwater resources are being mined. The approximate annual abstraction from the aquifers systems is 2,110 Mm^3. Abstractions are on average approximately 1.4 times of their actual recharge. The most endangered aquifer systems are those of the Highland plains, where most of the population is living. The ratio of abstraction to average recharge is here 5. The Extended Mukalla Complex has a huge volume of water in storage, but is located far from socio-economical important areas. The rate of recharge is relatively low. Recharge in Table 1 is infiltration of surface water from wadis when these are flooding.

Declining water tables in the aquifer complexes confirm the mining situation. for instance in the Sana's basin the location of the capital of Yemen, groundwater levels have declined some 80 meters over a period of 20 years.

Table 1. Abstraction rates, recharge rates and groundwater storage for the main aquifer complexes in Yemen

Aquifer complex	Abstraction	Average recharge	Fresh groundwater stored	Remarks
	(Mm^3/year)	(Mm^3/ year)	(Mm^3)	
Tihama Quaternary aquifer	810	550	250 000	Quaternary aquifer
Southern Coastal plains	225	375	70 000	several Quaternary aquifer units
Extended Mukalla Complex	575	500	10 000 000	Cretaceous Sandstone with interconnected Quaternary desposits
Highland plains	500	100	50 000	various isolated units with variable lithology

Source: Van der Gun 1995

The quality of groundwater has not been studied in detail in Yemen. Electrical conductivity is the only parameter which has been measured at sites. In coastal areas groundwater has deteriorated as a result of abstractions because of connate or intruded salt water, such as is the case in the old well-fields of Aden. Groundwater pollution in the major cities as a result of increased water use is an actual problem. As central wastewater collectors do not exist in the major cities, and most of the houses have cess-pits, diffuse infiltration of contaminated water is occurring. High rate nitrate concentrations in the deeper groundwater under the city of Sana's confirm this pattern.

Triggers for rapid groundwater depletion

The medium- and long-term economic development of Yemen is very much dependent upon the appropriate management and sustainability of the scarce water resources in the country. Given the increasing water demand resulting from the combination of several inescapable factors: population growth, higher water supply requirements, increasing deterioration of the water resources both in terms of quantity and quality and the growing awareness of environmental conservation; the water resources potential is becoming alarmingly short to meet socio-economic development requirements.

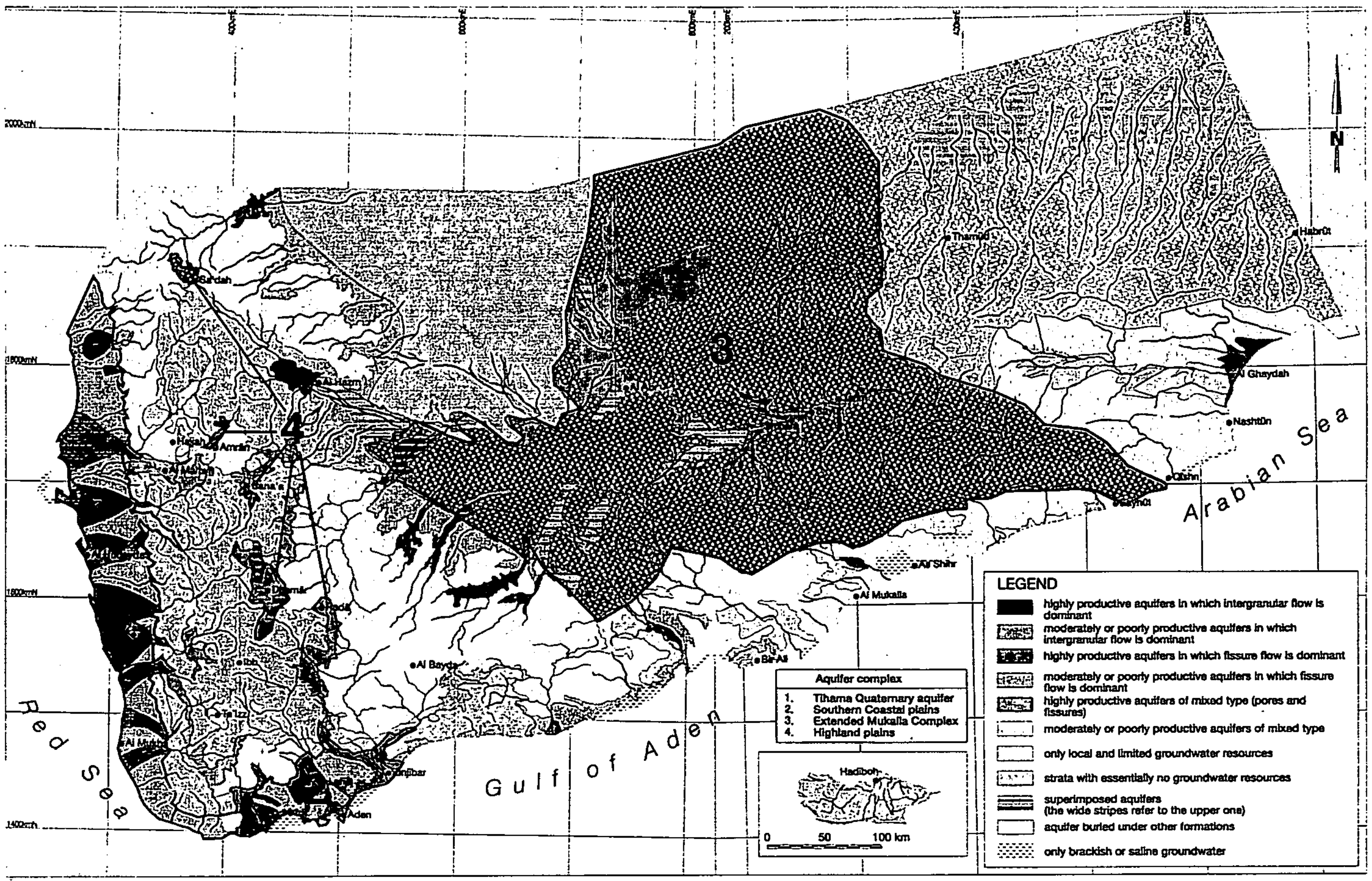

Figure 1: Schematic hydrogeological map of Yemen and the major aquifer complexes (after van der Gun et.al., 1996)

Table 2 provides some basic facts and figures with respect to the socio-economic situation of Yemen.

Table 2. Facts and Figures about Yemen

Title	Value
Population (million - 1995)	16.3
Population growth rate (% 1990-2000)	3.7
Urban population (% of total population)	23.4
Population doubling date at current growth rate	2013
Total labour force (% of total population in 1995)	41.0
Woman labour force (% of total labour force)	14.0
Labour force in agriculture (% of total labour force)	57.0
Labour force in industry (% of total labour force)	17.0
Labour force in services (% of total labour force)	24.0
Total Gross Domestic Product - GDP (BYR 1995)	249.2
Share of agriculture in GDP	21.0
Share of industry in GDP	24.0
Share of services in GDP	55.0
Gross domestic investments as % of GDP (1993)	20.0
Gross domestic saving as % of GDP (1993)	3.0
Tax revenues as % of GDP (1993)	17.0
Government expenditure as % of GDP (1993)	51.0
Export as % of GDP (1993)	5.4
Import as % of GDP (1993)	20.1
Land Area (million ha 1993)	52.8
Arable land as % of land area	2.6
Irrigated land as % of arable land	26.2
Internal renewable water resources per capita (1000 m^3 per year 1993)	0.2
Adult literacy rate (% 1993)	41.1
Life expectancy (year 1993)	50.4
Access to health (% 1993)	38.0
Access to safe water (% 1993)	47.0
Radios per thousand persons (1992)	28.0
TV's per thousand persons (1992)	28.0
Agricultural water demand (1997 Mm^3)	2,546
Industrial water demand (1997 Mm^3)	42
Municipal water demand (1997 Mm^3)	247

Sources: Various issues of UNDP Human Development Reports; National Five Year Development Plan (1996-2000); and Statistical Year Book, 1995.

The severity of the gloaming water crisis was, however, not felt until recently. Initially the available water resources were considered to be sufficient to meet demands. Net abstractions were not much higher than the natural recharge. However, population continued to increase at a high rate and water demands kept growing. The growing population caused rapid expansion in the irrigated agriculture to satisfy the need for food and fast developing lucrative crops such as *qat*, vegetables and fruits, resulting in high water consumption. It also gave rise to increase in drinking water demands, especially in urban areas where population increased faster as result of migration from rural to urban areas. The magnitude of the problem was not well understood until the aquifer water levels started to decline significantly.

The Government of Yemen is presently pursuing a growth oriented strategy to achieve its national economic development objectives. More food has to be produced to avoid heavy food imports and to improve the balance of trade position; the industrial base has to be expanded to modernize the secondary sector and to avoid dependence on foreign goods; and the urban and rural water supply have to be expanded to accommodate rapidly growing urban and rural population and to improve present health conditions. Such increase will require corresponding large increases at higher cost rate in the volumes of water to support the overall economic development process. There is a growing awareness that sustainable economic development requires efficient and effective management of the country's water resources. At the same time. it is widely recognised that it is a difficult task to accomplish, especially since water resources is traditionally considered as a free good; in many parts of the country, especially the more seriously affected by the water crisis, watermanagement decisions are made locally and are difficult to control.

In essence water has become the most limiting constraint in the development process. This problem is either the consequence of the water policies that have been pursued in the past, or due to the fact that necessary actions were not taken to correct the factors that have led to the present situation. It appears that a number of technological, social; institutional and economic factors have contributed to the present water crisis in Yemen.

The technological aspect is the introduction of modern drilling technology and pumps, which began on a large scale in about 1970. Previously most of the wells were for irrigation and municipal water were hand-dug and were self-limiting in terms of the amount of water abstracted. Now the total number of wells is reported to be more than 40,000, and this number is consistently growing while, on the other hand, water use efficiency in agriculture is extemely low due to poor water management practices.

The annual population growth is 3.7 percent per year. This translates into an increasing sectoral demand further increased by upgraded standards of living of the population, and the specific requirements to curb the deterioration of the water quality. The water demand estimates for the different water consuming sectors for the year 1997 are present in Table 2. The major water consuming sector in the country is agriculture. Since the available water resources are becoming increasingly scarce, it is extremely important to allocate them in a proper way.

From the water resources sustainability perspective, the major source of concern is the continuously increasing demand for water in agriculture. This situation is very critical in some of the regions (e.g. Sana's, Taiz, Sada'ah, Amran and Marib) where pumping depths have already exceeded the economic limits for most of the crops, except for qat and other cash crops. Inadequate government controls and farmers unawareness about the seriousness of the situation are the major reasons for over exploitation of groundwater resources for irrigation purposes. Low irrigation efficiencies and poor water management practices further contribute to rising irrigation water demands.

The number and scale of conflicts among competing water users in Yemen is increasing. The competition between the Taiz municipal watersupply and the groundwater irrigated agriculture in the same well field area resulted in May 1995 in a water crisis in the city. The already limited municipal water supply in city reduced from every two weeks to once every 40 days, with an atrocious waterquality of more than 2000 uS/cm. The water supply company and the farmers were blaming each other for the depleting the well field, which was located in a alluvial valley with only limited thickness of the aquifer. Another new resource in a sandstone aquifer further located from the city was already identified in 1991, but was not accessible for the municipal water supply because of conflicts with the local population over the benefaction and transfer rights of the groundwater.

According to the Moslem cultural tradition, water is considered to be a free natural resource, an open access resource or "*Mubah*", which means: permissible, free available for all. But the religious teachings have also repeatedly emphasized to make judicious use of it. In semi-arid zones, where water resources are, in any case limited, it is, however, very hard to convince people, that a natural good perceived as God's "gift" should be restricted. To change this perception, a large (and delicate) public awareness campaign is required. At the same time, the population, particularly the rural population, has to be more involved in water resources planning and management decisions through localized consultative processes.

Much of Yemen relies on groundwater for water supplies, over-pumping has led to rapid declines in many locations. No serious efforts were made in the past to augment existing supplies using non-conventional water sources (such as: waste water treatment and reuse, water imports and desalination). Reclaiming municipal waste water for agricultural reuse is an excellent and essential management strategy because it improves the environment by reducing the amount of waste discharged, and conserves water resources by lowering the demand for fresh water abstraction. One possible reason for not pursuing these options could be the need for huge capital investments - much beyond what the country's resources would permit. No consideration was given either to upstream and downstream water users, as well as basin management. Moreover, along the same line, water resources scarcity was never addressed as a part of the land use policy.

In water scarce situations, reallocation among water users is always considered to be an effective alternative for adjusting to water constraints, but no attention was paid to formulate policy on these lines. It is estimated that in the Sana's basin, one of the most water stressed regions in the country, only 20% transfer from agriculture is sufficient to meet the municipal water demand. On the nation-wide basis, only 10% transfer from agriculture is sufficient to meet the overall municipal water demand. Rainfall harvesting is another supply side option to augment existing supplies, but, in the absence of effective central planning, no evaluation of the feasibility of bench terraced lands and water harvesting using advanced technologies have been considered so far.

The demand management side portrays similar picture as has been commented above for the supply side. No comprehensive public awareness programs have been designed and implemented to influence user's behaviour towards water conservation. Similarly, water delivery efficiencies are still extremely low in both the urban and rural water supply and irrigation systems. water tariffs based on cost recovery principles may prove to be an effective policy instrument to enhance water use efficiencies, but, in practice, water is available free of charge (apart from the cost of abstraction) to anyone whose property permits the drilling of wells. No fees are levied on these private developments.

Evolution of the water institution

In October 1995 the National Water Resources authority (NWRA) was established by Presidential Decree. The establishment of NWRA meant the end of years of struggle and the formation of a consensus between different parties in the fragmented water sector of Yemen to achieve an independent authority for the management of the water resources. In the following sections a brief description is given of the institutional development process leading to the establishment of NWRA. Only at the end of the process some principles can be distinguished according to which the Yemeni Government guided the decision making about the organization of the water sector.

After the proclamation of the Yemen Arab Republic (YAR, the former North Yemen) in 1962, modern government was established and the country relinquished isolationism. In 1967, the People's Democratic Republic of Yemen (PDRY, the former South Yemen) was proclaimed, after it withdrew from the British Commonwealth.

The two young republics had diverging philosophies on their own social and economic systems. In the Yemen Arab Republic a rather open and market-oriented system was followed, while in the People's Democratic Republic of Yemen a Marxist central planning system was adopted. The two countries merged in 1990. In May 1991 a new constitution was approved in a referendum.

The events in water resources management and development in Yemen in the period 1960-1990 can be characterized chronologically as follows:

- Establishment of new governments in the separate Republics and re-orientation of the national economies;
- Unprecedented and uncontrolled increase of groundwater development in private and government sectors, as a result of the introduction of modern technology financed by the Government of the Yemen expatriate labour force in the Gulf countries;
- Establishment of the National Water Supply and Sewerage Authority, responsible for urban water supply;
- Execution of large water resource development studies to enhance urban water supply and irrigated agriculture with surface water and groundwater;
- Lack of coordination between the different water-related agencies and authorities;
- Water resources assessments studies confirm rapid depletion of the groundwater resources; first attempts to introduce water resource management and control (establishment of High Water Council in 1981);
- First signs of adverse effects of large-scale groundwater abstractions in the highlands become apparent (drying-up of springs and shallow wells, deepening boreholes);
- Continued uncontrolled increase in groundwater abstractions (Sada'ah, Sana's, Rada, Tihama);
- Comprehensive water resources assessment and management studies prove that groundwater abstractions exceed groundwater recharge in most areas; simulations predict critical depletion within 10-15 years;
- Donor coordination attempts to coordinate actions, plans and projects in the water sector.

The present decade (the nineties) can be characterized as follows:

- Continued uncontrolled groundwater abstractions and drilling;
- Deepened and dry wells in highland plains;
- Several new attempts to introduce water resource management and control (draft legislation submitted to Parliament)
- Growing awareness of the population and of water resources professionals about the gravity of the water resources management issues in Yemen;
- Identification of a large supra-regional groundwater resource in the eastern part of the country;
- Donor coordination;

- Start of the formulation of a National Water Policy: consensus achieved about the institutional reform;
- Increased coordination between water-related agencies and authorities;
- Establishment of the National Water Resources Authority in October 1995, responsible for water resources management and control, with far going authorities and powers.

After unification in May 1990 three attempts were made to introduce water resources management:

- The newly formed Ministry of Agriculture and Water Resources (MAWR) was made the responsible for the planning, development, management and control of the water resources. The assignment of all these responsibilities to one ministry met strong opposition, including the GHD, and split the water sector into two camps. Because the MAWR represents and serves the irrigated agriculture sector, which is the largest water user in the country, some were unhappy about making it responsible for the management of the water resources. However, MAWR was supported by the World Bank (Land and Water Conservation Project). In April 1991 a draft Water and Irrigation Law proposed by the MAWR was submitted. In December 1991, a decree was issued giving the MAWR the responsibility to regulate the drilling of wells until the enactment of that law. The law was, however, never enacted and the decree is not being observed. In the Amran area, where it should have been introduced first, no control is taking place.
- In 1990 the Technical Secretariat (TS) of the High Water Council (HWC), which since 1986 has been supported by a Technical Assistance project financed by UNDP, submitted draft National Water Legislation which included a proposal to reorganize the HWC and re-establish the Technical Secretariat. No action was taken. The effort of the TS was reinforced by a Rapid Water Sector Overview conducted in 1991, which set a timetable for moving ahead. Again, no action was taken by the Government.
- In 1992 the MAWR, with support of the FAO, initiated the development of an appropriate institutional and policy framework to enable the government to undertake an integrated, comprehensive and sustainable approach to water resources management. An interdisciplinary team of Yemeni specialists, including various GDH staff, was assigned to participate in the process. The exercise resulted in the presentation of a National Water Policy Document in December 1993. The National Water Policy Group advised that the planning and regulatory functions be organized separately from the water users. The MAWR openly discussed various options and acknowledged that it should not necessarily be vested with the planning and regulatory functions. The consensus created resulted in October 1995 in the establishment of the National Water Resources Authority (NWRA) with far going authorities and mandate for becoming operational but is still far from full control over the water sector.

In retrospective the today water crisis in Yemen can mainly be attributed to the absence of an effective Government role in coordinating sectoral activities in an integrated manner. Consequently, the donors concentrated their assistance in promoting sub-sectoral developments which were not consistent with the national development objectives. Due to lack of national ownership and commitment, much of the donor driven projects somehow proved to be unsustainable in the long-term, especially after the withdrawal of donor assistance. with the establishment of NWRA the Yemeni Government has realized the need for a more integrated and coordinated approach for sector management.

The basic principle followed during the last years of the institutional reform was to achieve a separation between the management of the water resources and the delivery of water to the end users. It was opted to establish an independent central water authority with far going powers directly linked to the Prime Minister.

Guidelines for water management in Yemen

Policy statements

With the establishment of NWRA, a potential powerful authority was formed to address the water crisis in Yemen which has been worsening over the last two decades. NWRA has been vested with a broad mandate and authority to carry out effectively water resources evaluation, planning, development, and management, and to formulate national water policy.

In essence, it is recognized that, under the present conditions, the renewable water resources in all regions of the country are insufficient to meet the current and future demand on a sustainable basis. On the other hand, the demand in water resources continues to grow as a result of population growth and economic development leading to an increased competition for water resources, among the different water sub-sectoral users (agriculture, industries, rural and urban water supply and sanitation, municipal and others).

It is realized that the present water crisis is largely the result of more than 30 years of ad-hoc water policy which focussed on water supply development projects for various users with little or no consideration of water resources demand management or sustainability of the water resources. This policy has proved to be counter-productive as it led to depletion of aquifers in many regions to an extent that jeopardizes agriculture investments and disrupts the daily life in several cities.

Eventually, the Government has recognized the need for efficient water resources management in its national development priorities outlined in the Five-Year Development Plan (1996-2000).

Policy requirements should reflect the specific context of the water sector in Yemen and the present conditions of water resources management and the draft water legislation should provide the framework for the enforcement of the water policy. Accordingly, the National Five-Year Development Plan has outlined the following guiding principles within which specific measures and policies could be designed to optimize the use of water in order to maximize benefits to the society:

- All water resources in the country shall be considered as state owned property and utilized in compliance with the national water legislation. Drinking water supply has a priority over any other use. Government authorization is required for all significant water withdrawals from common resources: surface water, groundwater, recycled water, and other;
- Groundwater mining shall be evaluated on the basis of sustainability and regulated in a manner that does not hamper the well-being of future generations.
- In view of stakeholders conflicts arising mainly from water scarcity, the process for water resources management and development shall be based on full participation of water users, communities, planners and policy makers in decision making. Raising public awareness about water related issues to mobilize public support for water management policy is a must.
- In view of the fact that Yemen is a country of many hydrological units, the resource management shall be exercised on well defined hydro-geographic units;
- The system of water rights should acknowledge traditional and existing rights, provide for clear rules governing appropriation, expropriation and reallocation of allocated rights, and allow for transferability. Consistent with the system of water rights, responsibility of all users should be defined to avoid damage to water quality and

quantity, as well as enforcement mechanisms for restitution in the event that allocated water rights are infringed;

- Water shall be recognized as an economic good; maximizing the value of water use may be a key element of the national water policy. This requires that water should be allocated to its competing uses based on its economic value. The allocation mechanism should ensure that water is transferred without conflict and with fairness from low value uses to the ones which society places the highest value;
- While making inter-sectoral allocation decisions, first priority in the allocation of the nation's water resources should be given to meeting the reasonable needs of the population for human and domestic consumption. Second priority should be given to industry, tourism and other service sectors. Third priority should be given to the agriculture sector. Sectoral allocation of water and its usage should be governed subject to the enforcement of effective management plans buy the public and private entities concerned, as well as proper assessment of social and environmental impacts of water usage.
- Since water usage leads to changes in the quality and quantity of water, issues related to water quantity and quality should be treated together within the context of water resources planning and management.
- Distinction between the management of the resource and the delivery of water services needs to be outrightly recognized. With respect to planning, management and allocation of water resources, the NWRA should retain full responsibility, adopting approaches to management and regulation that recognize the unitary nature of the resources, the pervasive existence of externalities and the close interaction of quantity and quality issues. In this context, institutional and technical capabilities of NWRA should be strengthened to enable it to play an effective role in managing Yemen's scarce water resources. On the other hand, responsibility with respect to provision of water services or for that matter execution of water related projects should stay with the existing entities;
- In situations when water management objectives are in conflict with each other, the water allocation or transfer decisions should be based on the notion of equity or fairness. The principle of compensation to those surrendering rights should be considered;
- Both in irrigation and municipal water supply projects, cost recovery policy can be varied to allow poorer people to pay less, and better of can pay proportionally more. Similarly, water charges for crops could be adjusted based on relative profitability of crop.

The ultimate goal is to attain sustainable socio-economic development trough management and development of the water resources of the country in an efficient, equitable and sustainable manner. Specifically, the following immediate objectives have been identified in the Five Year Development Plan:

- Protect water resources from over-exploitation, quality degradation and irreversible damage;
- Allocate water resources among different users to sustain economic growth with equitable distribution of benefits and balanced demographic distribution, and;
- Satisfy society's need for water, food and ecological stability by meeting drinking water requirements, by providing for safe disposal of wastewater and solid wastes, by increasing productivity per units of land and water, and by maintaining an ecological balance.

Sustainable groundwater strategy outline

On the basis of the policy statements in the Five Year Development Plan a national programme for sustainable water resources management has been defined. The national programme strategy takes into account the specific of the natural water resources system in Yemen, the institutional setting, the constraints inherent to prevailing socio-economic features, guiding principles resulting from local customs and experiences, and experiences gained elsewhere in similar conditions. A strategy is outlined which mainly focuses on halting the process of groundwater mining. In this context, the chief intent is: (i) to define a target date to reach an equilibrium between net water withdrawals and renewable water availability in the future, (ii) to define the amount of groundwater mining which is to be permitted between the present and the target date. The following general measures have been defined to constitute the programme strategy:

General measures:

- Strengthen the technical and institutional capabilities of NWRA;
- Approve and implement a new water law, together with the associated regulations, especially those for drilling and import of drilling equipment.
- Develop a water resources data base accompanied by institutional capabilities at national/regional levels to analyze water supply/demand relations at the basin level;
- Formulate and evaluate rational water management strategies for the regulation and control of water use;
- Integrate water resources management with the national economic development process in an interactive mode;
- Initiate a programme to monitor the performance of activities in terms of water withdrawals, waste discharges, efficiency of water use, and continuous monitoring of water table levels and of water quality;
- Create awareness among the general public and policy makers about the seriousness nature of the water resources problems facing the nation through educational and public information campaigns;
- Coordinate donor activities in the sector to avoid duplication of efforts and to ensure best utilization of resources available through external assistance.

The following specific measures are considered:

- Examine the structure of subsidies on production inputs and adjust it to reflect conditions conducive to water conservation;
- Introduce stiffer import duties on pumps ans other imported equipment used for groundwater abstraction. Provide economic incentives important for water conservation (e.g. subsidies, tariff concessions and tax incentives for investment in effluent treatment plants and recycling equipment installed by private sector);
- Promote a system of water pricing that should encourage water conservation. This includes introduction of crop-based charges in the agriculture sector; a structure of progressive tariff rates based on production cost of water int he urban water supply system; and pollution charges based on the volume of wastewater produced;
- Control groundwater exploitation by regulations for well registration, spacing, depth, horsepower and annual abstraction volume according to zones and uses; by permits and taxes for well operators; and by the institution of protection zones;
- Implement measures so that farmers achieve greater irrigation efficiency. Measures proposed in this context may include special credit facilities for farmers for the acquisition of the materials and equipment needed for efficient use of water;

- Implement research and extension services to teach and advice farmers on techniques to achieve higher productivity, especially as related to water conservation. Also implement measures to discourage expansion of irrigated area (especially under qat);
- Reuse treated water, charge for disposal of effluent so industries may consider recycling water;
- Provide technical information on water saving technologies to the water consumers in the industrial sector.

In summary, the main intent of the strategy for the sector is to provide necessary basis for sustainable economic and social development by implementing a comprehensive program of water resources management at national and regional levels. This involves , inter-alia, planning and implementation of efficient water resources management policies in relevant sectors, involving local communities in water resources management decisions, and integrating the management of several consuming subsectors at different levels. Measures outlined above will only yield until water legislation is forced in its entirety.

Legislation

Water legislation has been studied over the last decade without achieving a consensus of the parties concerned. Recently the government decision to create NWRA gave a new impetus to the formulation of appropriate water legislation and related regulations. The draft document was prepared in March 1996 and presented to the Cabinet. It is presently being scrutinised at different levels of the Government. The Draft Water Law consists of 98 articles under 9 sections.

In Section (I) - General Provision and Goals - the basis and goals of the law were declared. The most important issues in this section are three. The first is that all water resources which exist within the boundaries of the Republic were considered natural resources. Which means that they are owned as public property (as per Constitution). The State's role is to orient and organize their exploitation so as to serve public welfare. The second issue is that of the concept of organising the utilization development and management of water management as an integrated and indivisible sector of economic development. The third issue deals whit groundwater which, according to the law, were considered natural resources shared among their beneficiaries. This means that all benefactors shall share the duties and responsibilities to protect these resources against depletion and pollution so that the individuals will not harm the interest of the society. For this purpose, the State's intervenes to organize the utilization of these resources and prevent their exploitation except by prior permit.

Section (II) - Water Resources Management - deals with the basic principles of water resources management. As for the basic principles of water resources management, it was declared that water resources shall be managed and developed in such a way a to satisfy the intent of this law and in the light of the general policy proposed by NWRA ad issued through cabinet resolution. Then, for the purpose of water resources management the country is proposed to be divided into basins. The basins should have Basin Committees linked to the Branch of NWRA in this region.

Section (III) - Water Resources Planning - states the requirement that NWRA has to prepare a water plan for each basin. After ratification the plan becomes part of the National Water Plan (to be prepared every five years). This section also gives NWRA the authority to review water-related development projects and give opnion of these plans prior to their implementation.

Section (IV) deals with the various aspects of water use. It authorises NWRA staff to enter any private land or farms or any other establishment to make various water measurements or to undertake field studies. This section also requires NWRA to register water rights and water wells, and to issue permits for drilling when the water action plans allow. The section also requires NWRA to develop criteria and standards for various works relating to water wells, protection zones around water wells, well fields, springs and stream flows. This in addition to criteria and standards for drinking water, for water used in the food industry, irrigation water, treated municipal wastewater and industrial wastewater.

Section (V) - Water Resource Conservation and Protection - deals with two aspects; namely water resources conservation against depletion and protection against pollution. The law requires NWRA to adopt techniques and measures to conserve water uses. The issue of water transfer within and between various basins was also regulated; the law granting NWRA the power to recommend to the Cabinet the permission of water transfer between basins. Regarding water pollution of the water resources (including the sea). The law regulates in this section also the system of waste discharge permits.

Section (VI) - Flood Control - outlines the role of the State in protecting the population and property against flooding disasters through various measures, including the installation of early warning stations, land use zoning, prevention of housing construction in flood zones, periodic inspection of flood protection structures to ascertain their safety. The particular role of NWRA is to provide the necessary technical advise regarding the locations of the early-warming stations, to submit recommendations to concerned authorities so as to ensure the protection of flood prone regions against disaster and to carry out the periodic inspection of the flood protection structures.

Section (VII) - Means to Enhance the Development of Water Resources - started by creating or recognising a water sector as one of the sectors of development planning. The budgetary allocations for this sector shall be part of the State's investment budget so as to enable the development and management of water resources as an integrated and indivisible sector of economic development. In this Section a special fund "The Water resources Development Fund" was established. The financial resources of this fund consist of the allocations made by the Government to support water resources development, fees and charges approved by the Cabinet; such as:

- Water benefaction fee, on drinking and household consumption and on commercial and industrial use
- Water sale fee or charge on water sales whether directly from wells or via private networks or after bottling by individuals and private companies;
- A water resources quality-protection fee, for protection against pollution due to sanitary wastewater as well as commercial and industrial liquid wastes; etc.

In Section (VIII) - Enforcement Procedures and Penalties - authorised staff of NWRA who are charged with monitoring and inspection are granted the powers of enforcement officers through a resolution issued by the Attorney General upon nomination by NWRA. These enforcement officers or security officers are charged with the task of identifying infringements and offences against the provisions of the law and preparing reports describing the violation or offence.

In Section (IX) - General and Concluding Provisions - it is stated that NWRA is the State's sole institution responsible for the drafting of water resource policies and the strategies for their development as well as the study, planning and management of these at the national level.

Water resources management instruments

The tasks, responsibilities and duties which NWRA intends to preform following the outlined principles and strategy to actually get hold of the water crisis are enormous. They are also highly risky and little track record is available to anticipate if the strategy can be actually succesful.

Policy sense, strategic view and a focus on implementation will be very important to turn the tide, before damage is too great. An innovative tool or instrument must be developed the coming years in Yemen which can be used to introduce adequate water resource management. NWRA will develop the coming years regional water resources management plans. The regional water action plans, as a result from these planning studies, will have to form the basis on which NWRA has to implement and establish water resources management and control, and well may be the innovative instrument we are looking for.

Similar planning studies were carried out in Yemen during the past years and intended to contribute to a proper use and protection of the water resources, without an intended bias towards any of the possible uses and users of the water resources. These studies were very much pioneering in the field of water resources management and the approach was very much at the strategic level, without going into the detail of proposing actual measures to be implemented to get hold of he situation (Van der Gun and Wesseling 1990; and Saif, Gieske, Brouwer and Negenman 1993). The studies were also developed during a period when the water institution in Yemen was not yet available. Furthermore, they were approached "top-down" with little attention for stakeholder participation in the decision process.

Law and enforcement oriented measures will be very difficult to implement in Yemen because of the prevailing power structure in the country, limited public awareness, insufficient legislation and the absence of capability to monitor and control measures at the field level. Therefore "top-down" approaches in the water resources management planning may meet difficulties at the level of implementation whenever the proposed measures are of a restrictive nature.

Decentralized- and stakeholder self-management approaches which operate "bottom-up" may not be complete and sustainable as the "common pool resource" aspect is not addressed adequately. For Yemen a planning methodology for water resources management has to be tried out which combines the merits of the strategic "top-down" with the decentralized "bottom-up" approach.

The implementability of the plans will depend on the availability of a comprehensive legal framework of laws and by-laws, strong and competent institutional capabilities of NWRA at the central and regional levels, and acceptance of the plan by the stakeholders after the formal approval of the plan by the central and regional government.

Finally, this all is only possible if the people of Yemen, including leaders, politicians, scientists, engineers, farmers, civil servants and citizens accept their true destiny and also become aware of their duty towards management of their living environment for their own generation and the ones to come as it been described in the inspired old arabic verse: *Cultivate your world as if you would live forever; Prepare for the hereafter as if you would die tomorrow.*

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THE USE OF THE HYDROLOGICAL MODEL SIMGRO AS A SUPPORT TOOL FOR GROUNDWATER MANAGEMENT IN AN IRRIGATED AREA IN MENDOZA, ARGENTINA

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Introduction

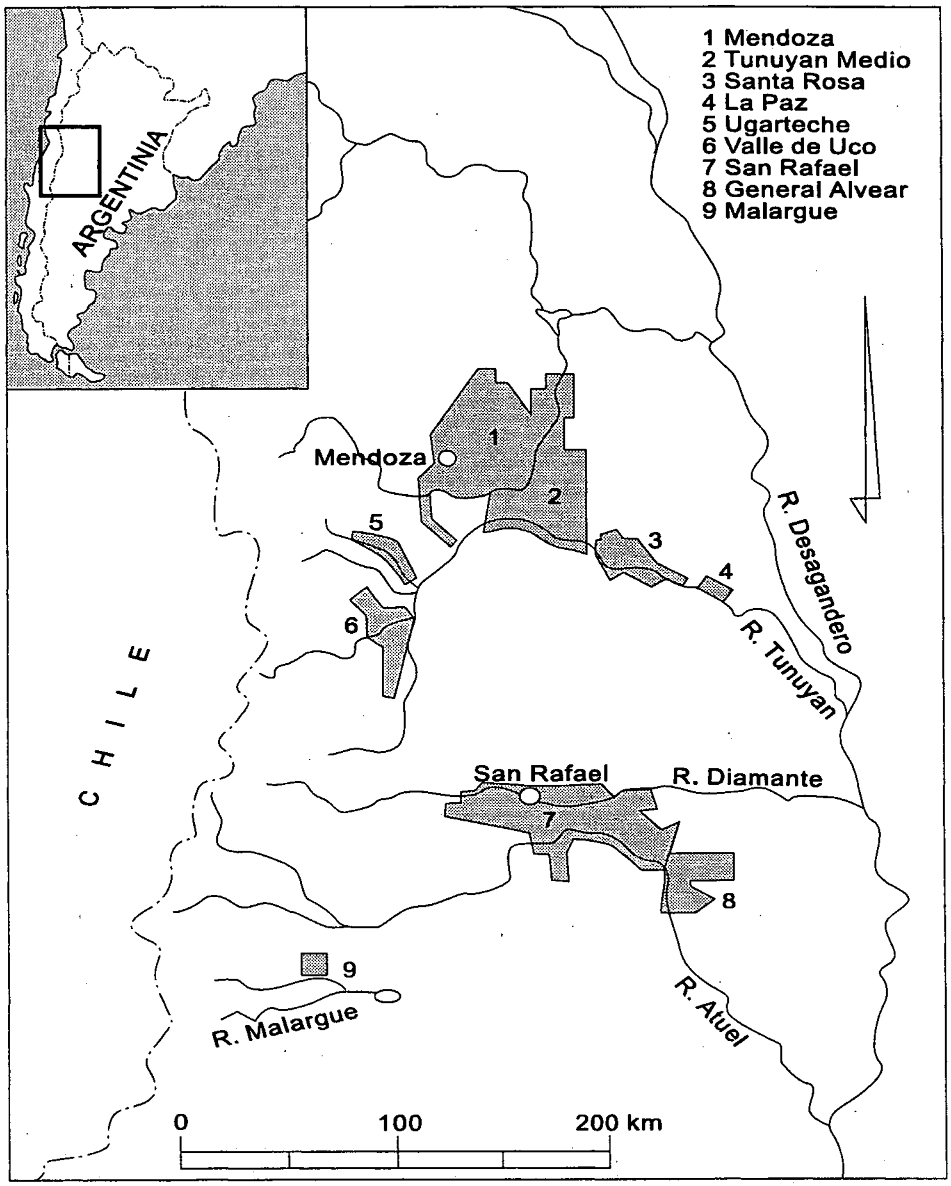
Irrigated areas all over the world are constantly being expanded. In Argentina, there are about 1 627 000 ha under irrigation (Morábito 1997). Between 1970 and 1994, the cultivated area increased by 53%, which is equivalent to a yearly increment of 1.8%. Mendoza, with 358 500 ha holding irrigation water rights, is the province with the largest irrigated area. In this part of the country, semi-desert conditions prevail, precipitation being approximately 200 mm/year and potential evapotranspiration 1300 mm/year. The people are therefore dependent on river water and groundwater. Mendoza's five main rivers used for irrigation are: the Mendoza, Tunuyán, Diamante, Atuel, and Malarghe (Figure 1). The other rivers are not used for irrigation.

About 3% of the province consists of irrigated areas. The major crops are: vineyard 53%, fruit farming 17%, vegetables 11%, fodder 8%, forest 6%, olives 3%, and others 2% (Estadisticas Agropecuarias de Mendoza 1988). The province has about 9 000 km of irrigation canals. Of these, 500 km of primary and secondary canals are concrete-lined; the others are earth-lined. In the lower parts of the irrigation systems, there is also an extensive network of drainage collectors, with a length of approximately 2 500 km.

In principle, only surface water is used for irrigation. Water is allocated on the basis of the area with irrigation water rights, but there are no precise figures of the actually cultivated area. In wet years, this practice has led to over-irrigation and, in certain areas, to a gradual rise in watertables. The result is often soil salinisation, which brings about a decline in productivity and a deterioration in the environment. On the other hand, during periods of drought, the inadequate distribution of scarce water reduces the production potential. The surface irrigation applications are then complemented with water pumped from subsurface aquifers. It has been estimated that, in the province of Mendoza, the area irrigated only with groundwater is 80 000 ha, whereas that irrigated with both surface and groundwater resources covers approximately 30 000 ha. In areas with surface water irrigation, there is in principle no need to use supplementary groundwater. Because of the misallocation of surface water, however, the need for groundwater exists, especially when vegetables are grown (Baars and van Logchem 1993).

The conjunctive management of surface water and groundwater is a complex situation, in which hydrological models can be useful tools. One such model is the regional hydrological model SIMGRO, which can simulate the water flow in the saturated and unsaturated zones, and the flow of the surface water. It can take into account the effects of irrigation, drainage, groundwater use, and their impact on the evapotranspiration of different crops (Querner *et al.* 1997). SIMGRO can analyze and evaluate specific operational measures and can quantify various strategies for their effect on agricultural production. Such strategies could include: the present situation; the maximum groundwater extractions without causing over-exploitation, and measures to control the quality of the groundwater.

Figure 1. Irrigated areas in the province of Mendoza, Argentina. District 2 is taken as the pilot area.



This paper will demonstrate the use of the model SIMGRO in the Tunuyán Inferior area as a support tool for decision-making in water management.

Water management

Water management in Mendoza is in the hands of the General Department of Irrigation (DGI), an autonomous governmental organization. The highest authority (the superintendent) is nominated by the Governor of the Province, with the agreement of the Provincial Senate. The superintendent holds his appointment for five years. In the area of influence of each river in the province, he delegates his authority to a sub-delegation, which is responsible for managing the water in its area. The sub-delegation is nominated by the superintendent and is assisted by technical and office personnel.

The DGI is responsible for water management in the entire province, down to the primary canals and the delivery of water to the Water Users' Associations (WUA). These associations are responsible for distributing the water to their various users. In 1995, Mendoza had 14 Water Users' Associations, with a membership of 40 000.

For operation and maintenance, irrigation tax has to be paid. The approximate annual fee for the use of surface water is about 45 U.S.$/ha/year, of which 59% goes to the DGI (a total of 10 mln U.S.$/year) and the rest is for the WUA's (8 mln U.S.$/year).

The use of groundwater

In Mendoza, groundwater can be exploited in an area of 530 000 ha. The depth to the watertable generally varies between 10 and 30 m, but in large areas depths are very shallow. The extensive exploitation of groundwater started in the 1950's with the appearance of the depth pump on the national market. The mean exploitation depth varies between 80 to 300 m. The optimal depth for groundwater extractions is 200-300 m, because the quality of the groundwater improves with depth.

The groundwater resources along the rivers Mendoza and Tunuyan Inferior have been estimated at around 45 000 mln m^3 (Plan CRAS 1968). Only 20% of these resources can be used, however, because of poor water quality. DGI (1994) registered about 18 200 wells in Mendoza, of which only 8 900 are in use. The mean discharge of a well is about 50 $l \cdot s^{-1}$ and its use depends on the water need of the crop according to the farmer's criteria. The costs of using groundwater are about 3 to 4 times higher than for surface water and depend on the costs of electricity and the efficiency of the pumping equipment.

DGI is granting concessions for the exploitation of groundwater. Users submit a request to DGI, giving details about the location, the amount of extraction, and the area to be irrigated. The Groundwater Department of DGI analyzes all requests, considering the present use of groundwater in the vicinity of the proposed well. No new wells may be constructed less than 80 m from other existing operating wells. The concession for the use of groundwater is, in principle, of indefinite duration, but DGI can cancel the concession because of a different use of the well than applied for, excessive lowering of groundwater levels, changes in the quality of the extracted water, and if the well is not used for two years.

In dry years with low river flows (1976-1977 and 1996-1997), less water is available for irrigation and more groundwater is extracted than is being recharged to the aquifers. The result is lower watertables. In periods with high river flows (1982/1983), more surface water is used and this results in over-irrigation and a groundwater recharge that is more than the extractions. Although groundwater is a reliable source, farmers believe the groundwater to be `poor' in comparison with surface water, because surface water carries fertile sediments (Baars and van Logchem 1993).

The Tunuyan River Irrigation Scheme

The Tunuyán River Irrigation Scheme delivers water to 74 300 ha (figure 1). Land use in the area is predominantly for grapes (55%), fruit trees (9%), vegetables (3%), fallow (29%), and urban (3%). The soil is of alluvial origin and the predominant texture is loamy sand. The irrigation water for this scheme is extracted from the Tunuyán River at the Gobernador Benegas diversion dam (max. capacity 60 m^3-s^{-1}). To meet water requirements, a storage dam El Carrizal has been constructed upstream. The original irrigation scheme was constructed about sixty years ago. Primary canals are partially concrete-lined and serve lower-order canals. Secondary and tertiary canals are unlined and require intensive maintenance in the form of weed and silt removal. The irrigation scheme functions with continuous flow in the primary and secondary canals and with rotational delivery at tertiary level. The average irrigated area served by a tertiary canal ranges from 60 to 180 ha. The common irrigation practice is surface irrigation with near zero slope (< 0.2% for furrow and border irrigation). Because of the rotation system, the quantity of irrigation water is not sufficient to irrigate the entire land of a farm within one rotation. The water is commonly applied to about one-third of the farm land, the total farm area being covered in one month.

Every year, a water delivery irrigation plan is drawn up, based on the volume of water expected to be available. This forecast volume considers the volume of snow accumulated in the mountains during winter and spring and the water stored in the reservoir El Carrizal. Water is rigidly allocated to areas with irrigation water rights, but there are no precise figures on the actually cultivated area or the cropping pattern. Changes in the cropping pattern and the abandonment of cultivated lands because of low profits have created differences between water requirements and water delivery (i.e. water misallocation). These two combined effects cause water shortages and water surpluses. As a result of irrigation excesses, some areas are affected by high phreatic tables and salinisation, thereby causing environmental degradation and yield decreases. If surface irrigation water is scarce, farmers need to pump groundwater, with the corresponding increment of costs and aquifer overexploitation. On the average, farmers use 25% of additional groundwater for their fields with water rights (Baars and van Logchem 1993).

Problems related to the use of groundwater

A consequence of using groundwater is the deterioration of the deeper aquifers. The extractions cause groundwater to flow from the upper aquifers to replenish the deeper aquifers. Further causes are bad sealing of bore holes when wells were being constructed and breaks in old piping, which is still being used, or not used, but is not adequately sealed. The problems of groundwater quality were first noticed at the end of the 1980's. The sources of groundwater pollution are nitrification due to the leaching of agricultural fertilizers. Urban centres and industries add to the problems. Another contributing factor is the oil exploitation taking place in the area.

For the area irrigated by the Tunuyan River, the groundwater quality measured is about 1.6 to 1.8 dSiemens/m but, in some parts in the last few years, values of 2.3 dSiemens/m have also been measured. The mean salinity of the surface irrigation water is 1.2 dSiemens/m. The shallow groundwater (upper aquifer) shows a mean salinity of 7 dSiemens/m, with extreme values from 4 to 12 dSiemens/m.

In August 1997, the authorities began to realise that they must exercise much more caution in granting new groundwater concessions and that water gauges need to be installed at the wells to quantify the amount of water extracted. These tentative measures have caused great concern among the farming community all over the province. But the authorities have become aware that they must take measures to protect the groundwater resources.

These measures will include:
- Making farmers conscious of the need for a rational use of groundwater (it being a finite and deteriorable resource);
- Quantifying the volume of groundwater that is being extracted for irrigation;
- Estimating the maximum extraction from groundwater that is possible without causing over-exploitation;
- Avoiding pollution and controlling the quality of the groundwater.

The regional hydrological model SIMGRO can help in implementing such measures.

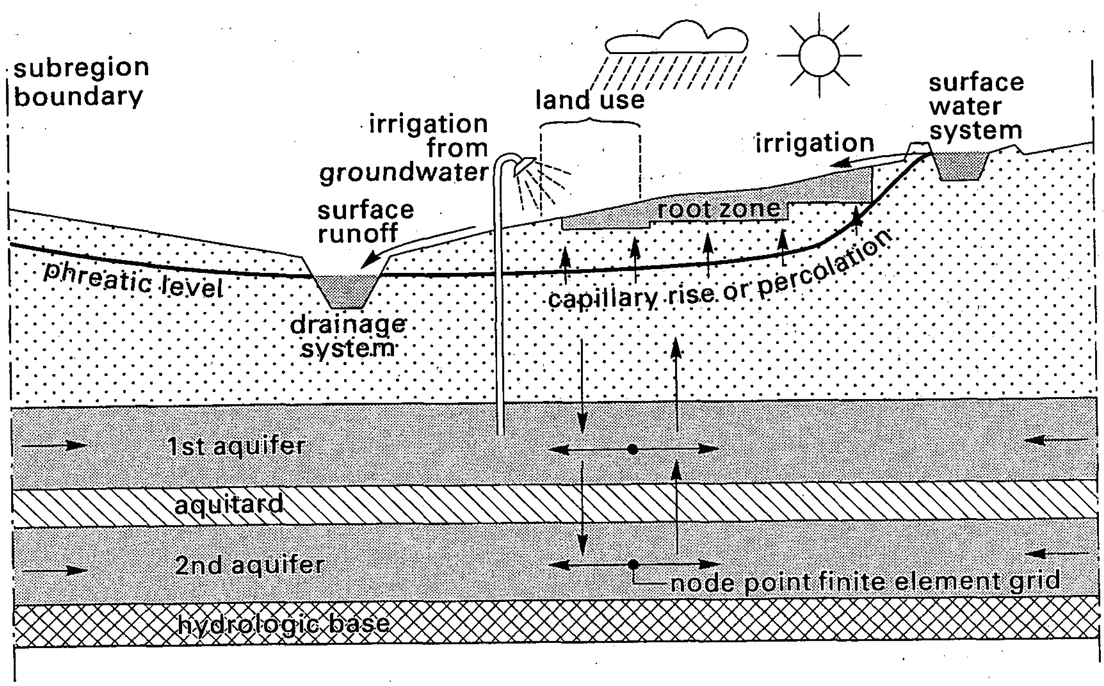
The model SIMGRO

The SIMGRO Model (Querner 1997) can simulates the water flow in the saturated and unsaturated zones, and in the surface water (figure 2). It takes into account the effects of irrigation and its impact on the water requirements of different crops. The model is physically-based and can therefore be used in situations with changing hydrological conditions. The model has been devised in such a way that it requires only a limited number of input data, making it computationally less intensive in simulating a given field situation.

Saturated groundwater flow is modelled by means of the finite element method. The region has been divided into a network of nodal points. Quasi three-dimensional flow is considered, which means horizontal flow in water-bearing layers and vertical flow in the less permeable ones. Groundwater levels and fluxes are calculated per nodal point. A number of nodes represent a sub-region, describing the water flow vertically in the unsaturated zone (Figure 2). Within a sub-region, the soil properties and hydrological conditions are assumed to be homogeneous. Land use is divided into agricultural areas (various crops) and urban areas. Agricultural areas are irrigated with surface water and/or groundwater.

The unsaturated zone is modelled per land use by means of two reservoirs, one for the root zone and one for the subsoil (Figure 2). The root zone is considered to have inflows and extractions, these being precipitation, evapotranspiration, irrigation, percolation, and capillary rise. Water is stored in the root zone until equilibrium is reached. The excess water percolates to the saturated zone. The actual evapotranspiration, derived from a potential level, depends on the moisture content in the root zone. The groundwater level is calculated from the water balance of the subsoil with the use of a storage coefficient, which is dependent on the depth of the watertable below the soil surface.

Figure 2. Schematisation of the hydrological system for a sub-region in the SIMGRO model (adapted from Querner 1997).



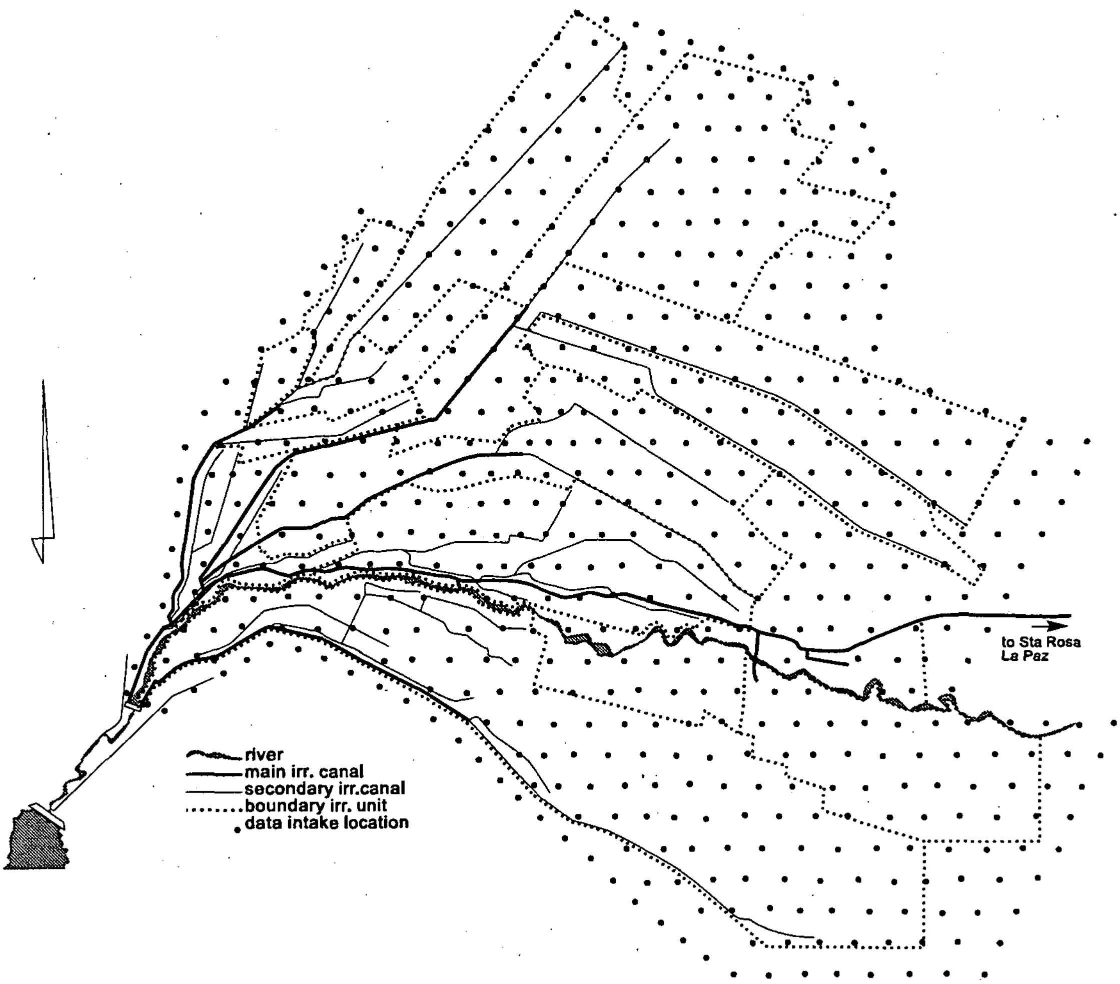
The surface water system is made up of the irrigation canals on the one hand and the drainage canals on the other. Among other things, the model takes into account water deliveries, surface water levels, losses from irrigation canals, and irrigation water extractions (Querner 1993).

The use of SIMGRO for the Tunuyan Inferior

Input data

The finite element network, comprising 632 nodes spaced about 1500 m apart, is shown in Figure 3. The nodal network of the irrigation area is sub-divided into 29 sub-regions. The sub-regions were identified by operational criteria (command areas) and different soil types. For the groundwater system, five layers were considered. The first, third, and fifth layers are aquifers with transmissivities ranging between 500 and 1000 $m^2 \cdot d^{-1}$. The second and fourth layers are aquitards with a vertical resistance of between 60 and 300 days.

Figure 3. Finite element network of Tunuyan Inferior irrigation disctrict (as shown in Figure 1) and division into subregions for SIMGRO (as shown in Figure 2)

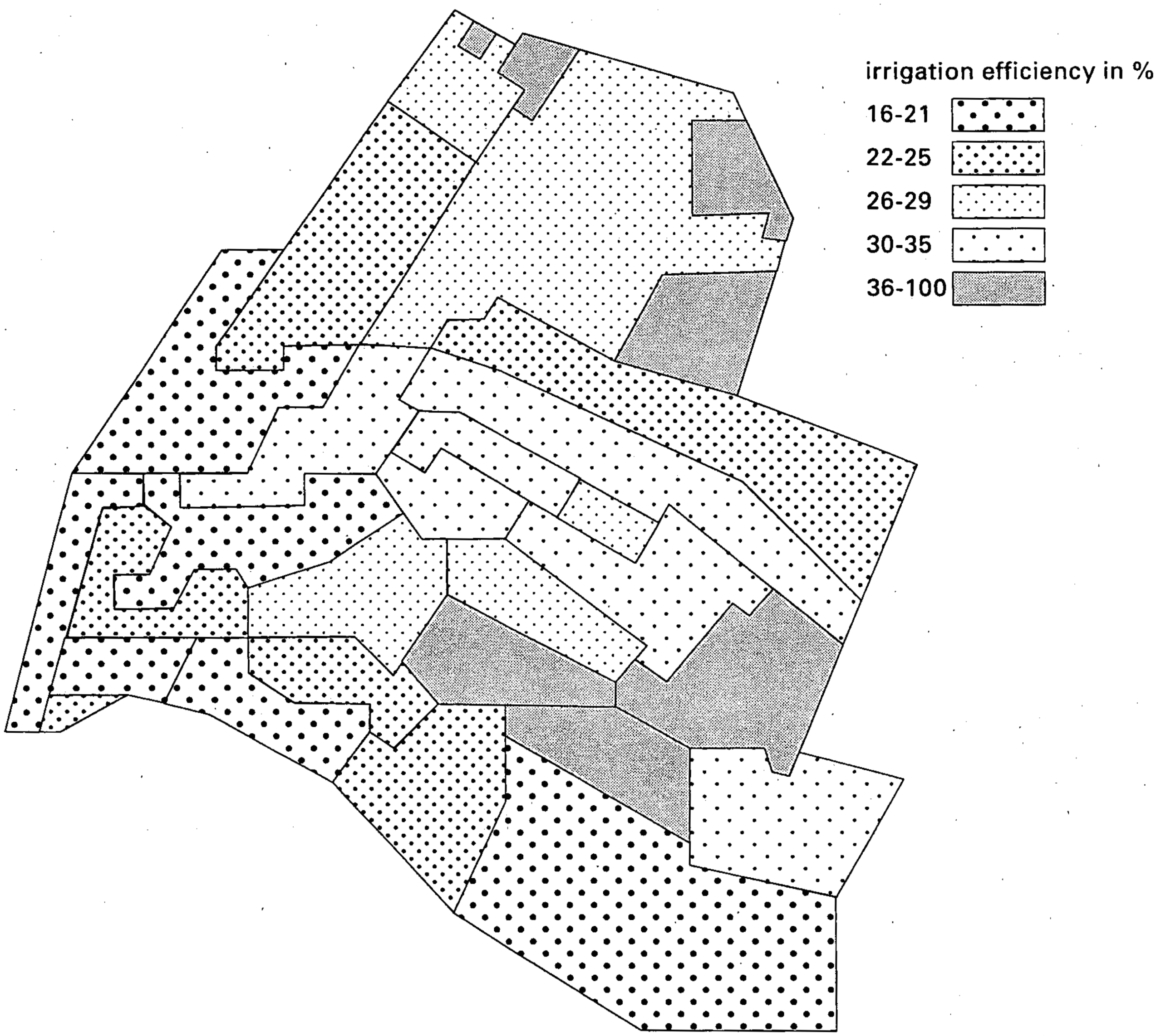


As input data, the SIMGRO model requires the potential evapotranspiration of a reference crop. The potential evapotranspiration of each crop was derived from crop factors. These values were calculated from local studies on water consumption by agricultural crops and from satellite data (Morábito and Querner 1993). The land use was obtained through field questionnaires conducted in 50 representative fields of each canal for further use to support satellite data analysis. For the model, eight different land uses were distinguished: grape (vineyard), grape (trellis), fruit trees, winter vegetables, alfalfa, olives, and uncultivated and urban areas.

From scenarios like the above, the SIMGRO model enables the water authorities to forecast how the hydrological system will react to different management strategies, and so help them to obtain a better water allocation.

To calibrate the model, one needs information on the water volumes entering the canal network. The volumes measured at the primary canal intake were multiplied by a conveyance efficiency for the network in the sub-region (Chambouleyron *et al.* 1982). To transform these volumes into irrigation depths, the actually cultivated areas were taken into account (Morábito et al. 1995). Groundwater extraction was calculated from data on the power consumption from four electricity companies. Wells with internal combustion engines were disregarded because of their small number. Power consumption and discharge rates were measured at a number of wells; this yielded a relationship that could be applied to the data provided by the companies to obtain groundwater extraction in each sub-region. It was estimated that up to 60 mm/month is extracted for irrigation (Morábito 1996).

Figure 4 Calculated project efficiency for the Tunuyan Inferior irrigation district (season 1987/88)



Model analysis

The SIMGRO model was calibrated for the 1987/88 irrigation season. Calculated and measured groundwater depths were compared. Differences were minimized by changing various input parameters. Also compared were the actual evapotranspiration, calculated and derived from field data, for different crops (Morábito and Querner 1993).

The model makes it possible to calculate the irrigation efficiency in the study area. Project efficiency (e_p) is defined as the ratio between the actual evapotranspiration and the total volume of water used for irrigation (surface water and groundwater). Figure 4 shows e_p variations over the Tunuyan Inferior irrigated area. The calculations yielded an average of 38%, which is very close to the measured value of 39% (Chambouleyron et al. 1982).

Scenarios

Based on the reference situation (season 1987/88), some example scenarios were defined to show the effect of possible future situations. These scenarios are:

- An increase of 10 000 ha in the irrigated area (former uncultivated land), cultivated with vegetables (50%) and fruit trees (50%);
- A reduction in the use of groundwater for irrigation (50% and 25% of the use in the reference situation).

In the scenarios, it was assumed that the same amount of irrigation water (surface water and groundwater) is available as was applied in the reference situation. An increase in the irrigated area results in an increase in e_p from 38% to 44%. A reduction in the use of groundwater also gives higher project efficiencies. For 50% and 25% of the groundwater extractions, the project efficiency becomes, respectively, 0.46 and 0.52.

The conjunctive management and protection of surface water and groundwater

The optimal use of water for irrigation should focus on an integrated exploitation of both surface water and groundwater. This can be achieved by regulating the surface water through damming and by using groundwater in equilibrium with its recharge.

For proper management, one must have accurate information on the resources and the exploitation of these resources. This means having data on:

- The quantity of surface water applied for irrigation;
- All extractions of groundwater;
- Isoline maps for different years;
- The evapotranspiration and water needs of different crops;
- Losses from irrigation canals;
- The areas of actually cultivated land;
- The hydrological situation in wet years;
- The hydrological situation in dry years.

A detailed monitoring programme should form the basis of the management of the water resources. This means that all the incoming and outgoing flows of water have to be assessed. An accurate estimate of the groundwater recharge is difficult because of its temporal and spatial variability, and the complex effect of human interventions such as irrigation. Computer models can support the monitoring programme and can give the authorities an insight into the different components. An overview can be presented for regions showing to what extent the groundwater resources are being used sustainably or whether over-exploitation is taking place. This water balance procedure should be followed for average hydrological conditions, but also for pronounced dry periods. This will reveal whether, and to what extent, the resources are being used on a temporal basis.

Conclusions and recommendations

In principle, in the province of Mendoza, Argentina, only surface water is used for irrigation, but groundwater is being used more and more. Because of the rigid allocation scheme, surface water is misallocated and farmers in the Tunuyan Inferior use an additional 25% of groundwater in compensation. A consequence is the over-exploitation of this resource. In general, the use of groundwater in Mendoza is not restricted, but DGI has no tools to estimate the impact of the existing and new extractions. Over the last ten years, concern has been growing about the severe environmental impact being caused by the use of groundwater. Groundwater is extracted from deeper aquifers, which contain water of very good quality. The groundwater recharge is of lesser quality, because it contains salts and nutrients. The groundwater system is a finite source of water of good quality, which is slowly diminishing. Farmers must be made aware that this resource is limited. What is needed is the conjunctive management and protection of surface water and groundwater. This means that detailed information must be available on the water input and all the uses and losses of water.

Regional hydrological models of surface water and groundwater have been applied in an irrigated area in Mendoza. The use of such models can support decision-making in water management. The benefit of a physically-based model is its use in situations with changing conditions that affect the hydrological system. The models can, for instance, help to forecast the effects of changes in allocations of surface water and groundwater. During periods of drought, the models can identify any inadequate distribution of scarce water and can reduce aquifer overexploitation. The models can also evaluate the effects of incrementing the irrigated area, the problems of salinisation, and the requirements for drainage. An important aspect is the need to simulate the hydrological processes as accurately as possible and to include operational irrigation practices. The drawback of a modelling approach is the great demand for reliable input data. This paper gives some general information about the use of the models. More details of the modelling approach and the results have been described by Querner et *al.* (1997).

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GROUNDWATER RESOURCE MANAGEMENT IN PAKISTAN

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Geography and hydrology

Pakistan is often described as a country of cross-roads. Geographically it is the place where Asia Minor, Central Asia, and the Indian subcontinent come together. Within the country, this translates into the geographical division between the vast Indus Plain in the East and the mountainous regions in the West and the North.

Pakistan consists of four provinces: the Punjab and Sindh in the Indus Plain, and the more mountainous North West Frontier Province and Balochistan. Each of the provinces has a large degree of administrative autonomy. In addition to the four provinces, there are several special border regions that are administered directly by the federal government. These are the high-altitude Northern Areas of Pakistan, the tribal areas along the border with Afghanistan, and the territory of Azad Kashmir, disputed by India.

At the last census in 1990, Pakistan's population numbered 112 million. With the population growth rate close to 3%, the population in the year 2000 is expected to be 147 million. Much of the population will continue to depend on agriculture as the main source of income. In 1990, agriculture constituted 26% of the gross domestic product, and it provided employment for approximately 50% of the population. Irrigated agriculture is of prime importance. It generates 90% of Pakistan's agicultural production. Thanks to the investments of the last 120 years, the Indus irrigation system, covering 86% of the national irrigated area, has become the largest contiguous irrigation system in the world. The area commanded by the Indus irrigation system is 14 million ha. Groundwater has become an increasingly important resource for irrigation, particularly in the Punjab, in the northern Indus Plain, where it contributes an estimated 40% of the on-farm water supplies. Outside the Indus Plain, groundwater is the mainstay of irrigation in large parts of Balochistan.

The dependence on irrigation is related to the arid conditions that prevail in most of the country. Only the northern Punjab and most of North West Frontier Province receive more than 250 mm of precipitation a year. In comparison, the annual evapotranspiration in the country as a whole ranges from 1250 to 1800 mm. Accordingly, in most of the country, irrigation, either with groundwater or with surface water, is a sine qua non for agriculture. Estimates of total surface water resources are 172 billion m^3. Estimates of total groundwater resources are 57 billion m^3. Of the groundwater supplies, however, 30 to 40% is considered unsuitable for agriculture.

The geographical division between the Indus Plain and the mountains has a parallel in the aquifer systems between the two regions (see map). The Indus Plain was formed by sediment deposits from the Indus River and its tributaries, and it is underlain by a highly transmissive, unconfined aquifer. In the Punjab, most groundwater supplies are fresh. The main exceptions are the areas of saline groundwater in the centre of the interfluviums ('*doab*'), particularly those between Multan and Faisalabad, around Sargodha, and in the south-eastern part of the province.

In the southern part of the Indus Plain, in Sindh, groundwater supplies are more problematic. With the exception of a small strip along the Indus River, groundwater supplies are highly saline. The discharge from the aquifers in Sindh is generally less than that in Punjab (Survey of Pakistan 1989). Supplies are even less in the eastern deserts and the western limestone ridges bordering the Indus Plain.

Balochistan and North West Frontier Province are geologically more complex. In Balochistan, land formations consist of limestone, sandstone, and shale formations alternating with sand, silt, and gravel deposits. The aquifers are confined and generally yield only limited quantities of water. The quality of groundwater is unsuitable for agriculture in parts of Balochistan, particularly in some of the coastal areas, in patches in the large, alluvial Kacchi plain in the east, and in several valleys in the uplands. Although the picture for North West Frontier Province resembles that for Balochistan, irrigation with groundwater in North West Frontier Province is more recent and, until recently, less extensive. This is owing to the less arid conditions and ample surface water resources. Another difference is in the areas around Bannu and Mardan, where there are thick and extensive aquifers. In Bannu, however, the fresh water is overlain by saline water.

Groundwater law and policy

The use of groundwater for irrigated agriculture in Pakistan has a long history. The existence of vertical well systems ('*karezes*') in Balochistan was documented by Greek travelers as long as 2500 years ago. Persian wheels formed an important element in the flood-recession agriculture in the Indus Plain prior to the development of surface irrigation. The present degree of groundwater exploitation in Pakistan is unprecedented

In 1960, groundwater still accounted for only 8% of the farm-gate water supplies in Pakistan's most populous Province, the Punjab. Twenty-five years later, in 1985, this amount had gone up to 40%. This figure is nowadays considered to be on the conservative side[1]. Fresh groundwater was exploited to be used conjunctively with surface water. This way, intense shallow tubewell development in the Indus Plain made up for many of the deficiencies of unreliable and insufficient water supplies in the Indus irrigation system. Outside the large-scale irrigation in the Indus Plain, groundwater development changed the face of many arid areas, in particular in Balochistan and North West Frontier Province, and in the unirrigated tracts of Sindh and the Punjab. According to official estimates, the development of shallow wells and deep tubewells has played the main role in the expansion of the area under cultivation in Pakistan, with 75% of the increase in water supplies from 1960 to 1985 being attributable to public and private groundwater exploitation. During the same period, the cropping cropping intensity increased by 39% (MINFA 1988).

With this dramatic increase in the intensity of groundwater exploitation, the policy landscape has changed. The main policy issues now relate to environmental sustainability and welfare, i.e. how to avoid declining groundwater tables and deteriorating groundwater quality in fresh groundwater areas, and how to ensure equal access to this increasingly important natural resource. Two different, and partially opposing, policy themes dominated the political agenda. The first theme was the control of high groundwater tables in the canal irrigated areas in the Indus Basin. The second theme was the active promotion of tubewell installation as a means to encourage agricultural development.

Controlling high groundwater tables in the Indus Plain

The first theme of rising water tables was related to the inadequate provision of drainage facilities during the development of the canal irrigation system in the Indus Plain. The extremely flat topography of the Plain, the poor natural drainage, and the semi-arid climate with high evaporation eventually resulted in waterlogging. The problem was first noted in the Rechna and Chaj Doabs in the twenties, and it has increased gradually ever since. It took on very serious proportions after the floods of the fifties increased the already high water tables.

Waterlogging occurred throughout the Indus Basin. A nation-wide survey, undertaken from 1976-1979, established that in 22% of the Indus Basin the water table was within 6 feet of the ground surface, and that in a further 30% the water table was within 10 feet of the surface. Associated with this waterlogging was the salinization of the soil from capillary rise and evaporation of the mineralized groundwater. This added to the existing salinity of the soil. Salinization was particularly prevalent in areas with fine-textured soils, inadequate irrigation supplies and marginal and saline groundwater. Salinity and waterlogging occurred in patches, concentrating in minor depressions in the generally flat area. Within these depressions, the slightly elevated areas usually suffered most from salinity (Choudhri 1977)[2].

The government's response to the alarming spread of areas with high water tables was a large-scale crash programme of land reclamation known as the Salinity and Control and Reclamation Projects (SCARP). In this programme, high water tables were combatted primarily by vertical drainage. Experimentation had been undertaken previously by the Irrigation Research Institute to reduce the groundwater recharge from irrigation channels. Partial lining and staggered irrigation supplies had been tried out. None of these experiments resulted in conclusive recommendations (Choudhuri 1977). In 1954, the first large tubewell drainage scheme started, and soon a second benefit of the drainage tubewells was realized: where the tubewells pumped fresh ground water, they not only lowered groundwater tables, but they also augmented surface irrigation supplies.

The government introduced the first legislation on groundwater at the same time as the vertical drainage projects started. In 1952 the Punjab Soil Reclamation Act was promulgated. This act created the basis for the Soil Reclamation Board to control waterlogging and salinity through the development and operation of drainage tubewells. The Board was in control of groundwater management in the designated land reclamation areas, and it could also instigate a licensing procedure to permit land owners to install private tubewells. The Board was later suspended, and its executive powers were eventually transferred to the Provincial Irrigation and Power Department. Although licensing rules were framed in 1965, this provision of the Act was never enforced.

Another act, announced in 1958, covers the same ground. This is the Pakistan Water and Power Development Authority Act. It is the legal basis for the establishment of the Water and Power Development Authority (WAPDA). WAPDA is a federal agency, responsible for the development of the major power and irrigation and drainage infrastructure. The operation of the irrigation and drainage infrastructure is usually transferred to the provincial irrigation departments. According to the act of 1958, WAPDA shall control Pakistan's groundwater resources, and it shall issue official area-specific rules in the exercise of this control. Nevertheless, such rules have never been announced. On paper, the WAPDA Act conflicts with the earlier Soil Reclamation Act, which gives the provincial irrigation the responsibility for, and the control over, groundwater management. The groundwater regulations specified in the two Acts have never been implemented.

In the years following the promulgation of the Acts, many SCARP Projects were undertaken. The SCARP projects typically involved the installation of batteries of high-capacity, electrically powered deep tubewells that pump water from depths of 40 to 120 m [3]. By 1995, there were more than 15,000 public deep tubewells in the Punjab and Sindh and - to a limited extent - in North West Frontier Province. Twelve thousand of these - particularly in the Punjab and North West Frontier Province - yielded fresh ground water. The deep tubewells were usually installed at the head of a tertiary channel (watercourse), and they facilitated crop intensification. In areas with saline groundwater, the deep tubewells either discharged in an open surface drain, or they mixed their saline effluent with fresh surface water in main channels and distributaries. Although most SCARP projects consisted of deep tubewells, some of them made use of open surface drains and subsurface pipe drains. The only systematic groundwater monitoring programme in Pakistan was initiated as part of the SCARP Programme. To assess the performance of the public deep tubewells, the SCARP Monitoring Organization measured groundwater level and deep groundwater quality in the designated SCARP areas. There were no measurements taken outside of the area.

Tubewell promotion for agricultural development

Besides the control of waterlogging and salinity, a second important policy in the 1960s, 1970s, and 1980s was the promotion of private tubewell development. In canal-irrigated areas, private tubewell development can help alleviate drainage problems. This was probably one reason why the licensing procedures of the Soil Reclamation Act and the WAPDA Act were never enforced. Outside the canal irrigated areas private tubewells can foster economic development. In the unirrigated parts of the Indus Plain, in Balochistan, and in North West Frontier Province, private tubewells make it possible to bring large tracts of land under cultivation.

Private groundwater exploitation was stimulated in several ways. Foremost among these was to provide subsidized power supplies to tubewell owners. Electric charges for tubewell owners in the Punjab and Sindh were 40% less than the normal rate. In Balochistan and North West Frontier Province, the subsidy was 60%. Several government programs promoted tubewell development by providing free pumpsets and wells, and by making soft loans (Johnson 1989).

Private tubewell development soon took off, even without public subsidies. Private tubewell ownership in the Indus Plain exceeded 400,000 in the early 1990s. By this time, Balochistan and North West Frontier Province each had more than 10,000 tubewells. By the late 1980s, the Report of the National Commission on Agriculture concluded that groundwater development could now be left entirely to the private sector. Almost all government support to private tubewell installation came to an end. The most important exception was the continuation of the low electricity tariffs for agricultural tubewells.

Current groundwater issues

Groundwater policy of the last 40 years in Pakistan can be summarized by a number of characteristics:

> The focus of groundwater policy was on the control of waterlogging and the stimulation of private tubewell development. Government interventions were supply-

driven. There was little concern about overexploitation of aquifers or deteriorating groundwater quality.

- Groundwater policy relied on public investment and subsidies rather than on regulation. Legislation was not enforced. It was not clear whether the federal government or the provincial governments should regulate groundwater exploitation.
- All policies were initiated and implemented at provincial and federal level. The involvement of local government was minor. There was no involvement of local farmers' organizations. Local government and farmers' organizations are weak in Pakistan.

During the last 40 years, the spectacular increase in the number of private tubewells has changed the setting entirely and invalidated the old policies. In several fresh groundwater areas in the Indus Plain, there has been a complete volte-face. Where 30 years ago high groundwater tables were the major threat, groundwater levels have now declined due to private tubewell development. Salinization through capillary rise is no longer a threat, but the intense pumping poses other threats to soil and water quality.

Outside the canal-irrigated areas of the Indus Plain, the promotion of private tubewell development is outdated. Groundwater is no longer the limitless resource it once was. In the absence of effective regulation, the large numbers of tubewells have resulted in groundwater mining. In addition, the social issue of distribution of access to groundwater has come to the fore. Because most of the tubewells are privately owned, the question is: How can people without a private tubewell use the groundwater? The next section begins with a discussion of the current groundwater issues in the Indus Plain and the mountain provinces. It concludes with a brief look at another emerging groundwater issue, i.e. the declining urban water tables.

Groundwater issues in the Indus Basin

Punjab

Owing to public and private groundwater development, waterlogging has disappeared from most fresh groundwater areas of the Punjab. It persists, however, in isolated natural depressions and in areas with saline shallow groundwater, in particular in the centres of the interfluviums and in the south-east. As a result, the Punjab suffers from the paradox of having areas with high water tables and areas where tubewell development has been so intense that water tables are declining. A study undertaken in 1990 suggests that in the Punjab the volume of groundwater extracted significantly exceeds the volume of water recharged. The study estimates the difference to be as much as 27% on a provincial basis (NESPAK/SGI 1991), but this overextraction is concentrated in a number of fresh groundwater areas.

Localized overexploitation in fresh groundwater areas has already lowered groundwater tables 2 to 4 m in some places. There are also fears that the intense use of groundwater will lead to a deterioration of groundwater quality. The first reason for such a decline in groundwater quality is the intrusion of water from saline groundwater zones into the overpumped fresh groundwater zones (Ahmad and Kutcher 1992). The second reason is associated with the heavy reliance on groundwater vis-à-vis surface water, particularly towards those tail-ends of the distributaries and watercourses where surface water supplies are scarce and erratic. (Recent research by IIMI Pakistan indicates that unreliable tail supplies are related more to the type of outlet than the distance from the distributary head.) Because groundwater is generally far more saline and sodic than canal water, the increased reliance on it in certain areas is bringing more salts to the soils and causing deterioration of soil and groundwater quality. VanderVelde and Kijne (1992) established this scenario for the tail-ends of two distributaries in the Punjab, but in other distributaries fresh groundwater recharge is better at the tail-ends. The extent of groundwater-induced secondary salinization still needs to be established. In their study of the SCARP-1 project area, Beg and Lone (1992) looked at changing groundwater quality parameters in 1900 tubewells over a time span of 25 years. They established that overall groundwater quality had deteriorated, particularly in residual sodium-content levels. Many of the wells in which groundwater quality had improved were next to an even larger number of wells where quality had deteriorated. In another study, undertaken by IWASRI (1995), soil quality was monitored in SCARP areas. The IWASRI study established that only 7% of the sample plots had turned saline and/or sodic from the long-term use of tubewell irrigation. These plots were mainly irrigated from tubewells with marginal water qualities. The study also found that in 41% of the plots, soil salinity and/or sodicity had disappeared. In summary, the data on the extent of the changes in soil and groundwater quality due to secondary salinization is inconclusive and contradictory.

The spectacular increase in private tubewells in the Punjab began in the 1960s, with the installation of 'black engines.' These are low-speed prime movers that operate on crude oil. The rural electricity grid expanded in the 1970s, and electricity became the preferred source of energy for the tubewells. Gradually the electricity tariffs - although still subsidized - went up[9]. Between 1989 and 1993 flat rates increased by 126%, and electricity lost its popularity as the main source of energy. The big boom in private tubewell development in the 1980s was generated by the availability of locally manufactured high-speed diesel engines *('peters')*[5]. These diesel engines, with a typical capacity of 12 to 15 hp, operated centrifugal pumps, lifting between 20 and 30 l per s. The relatively low investment costs (usually below US $ 1200) opened up the sector to small farmers. Moreover, there were no fixed energy charges for the diesel engines, as there were for electric pumpsets. This was particularly useful for conjunctive water use, for which the hours of utilization of the pumpsets were relatively low. In the irrigated areas of Dera Ghazi Khan and Layyah districts, in the cotton belt of the eastern Punjab, the number of tubewells doubled between 1981 and 1987, and then doubled again between 1988 and 1991. By 1993, tubewell density in Dera Ghazi Khan had increased to 4.4 per 100 acres from 0.7 in 1981. In Layyah, in the same period, tubewell density increased to 2.7 per 100 acres from 0.5 in 1981. Operation factors (the proportion of hours of utilization) were 5.3% in Dera Ghazi Khan and 3.9% in Layyah (van Steenbergen 1993). In the rice-and-wheat belt in the south-western Punjab, the growth in tubewell numbers was exponential. With the data they collected data from the Lagar Distributary of the Lower Chenab channel in Sheikhupura district, VanderVelde and Johnson (1992) established that the number of tubewells had increased four-fold between 1980 and 1989. In 1989, tubewell density in the area also served by public SCARP tubewells was 2.2 per 100 acres. In another canal command in the same area, the Mananwala distributary, Malik and Strosser (1993) found that tubewell proliferation and density were comparable. The average operation factor was 9.4%, higher than in either of the two cotton belt areas.

Within the separate canal command areas, there is no clear-cut pattern in tubewell densities. Intuitively, one would expect the dependence on groundwater to be higher at the tail of the systems, where surface supplies are generally low. And indeed, tubewell densities in the canal commands of Dera Ghazi Khan increased steadily towards the tail of the distributaries, whereas tubewell operation factors were more or less constant throughout the command area. This indicates that in the tail areas of Dera Ghazi Khan there are short peaks when water is in high demand and all of the tubewells are used intensively. In Layyah, on the other hand, groundwater utilization is relatively uniform throughout the canal command area. The explanation is that rotational surface water supply makes the distribution of surface water scarcity relatively equitable in Layyah. As a result, the demand for groundwater in Layyah is uniform in the different parts of the command area. In Mananwala, tubewell densities were comparatively high in the head reach and in the tail reach of the distributary. The intense use of groundwater in the head reach is explained by the prevalence of rice. In the tail reach, groundwater is used as a substitute for the surface water supplies, which are sometimes lacking altogether (Malik and Strosser 1993).

A remarkable finding in all four case study areas is that tubewell densities in areas with marginal groundwater quality do not substantially differ from those in areas with fresh groundwater. Yet particularly in many tail reaches, little good quality surface water is available to mix with the marginal quality groundwater. This is the reason why some have warned against the danger of groundwater-irrigation-induced soil salinity in the tail reaches (Murray-Rust and vander Velde 1992). It is only in areas with very saline groundwater, such as the Fordwah Sadiqia area in the extreme south-west of the province, that tubewell densities are lower. The tubewells that are in use are usually skimming wells, which skim off the thin layer of fresh water that floats on the saline water.

An issue related to the distribution of tubewells over the command area is the theme of equity in access to groundwater. Several authors in the early 1980s argued that access to groundwater was being monopolized by a few 'water lords,' who could afford to install a tubewell[6]. In reaction, others pointed out that the inequity in ownership was mitigated to some extent, as less fortunate farmers could hire the tubewells (Meinzen-Dick and Sullins 1992, Strosser and Kuper 1993). There were debates on several ways to make the water markets more effective in reaching non-owners. Nevertheless, the question of access to groundwater has to be placed in a dynamic perspective. There are indications that tubewell numbers have increased as tubewell operation factors have decreased. A number of surveys took place in Dera Ghazi Khan and Layyah. In 1983, operation factors were 5.3% in Dera Ghazi Khan and 6.0% in Layyah. A second survey in 1986 recorded higher operation factors: 9.5% in Dera Ghazi Khan and 8.0% in Layyah. In 1992, however, tubewell operation factors were significantly lower: 5.3% for Dera Ghazi Khan and 3.9% for Layyah. In the six years from 1986 to 1992, the number of tubewells in Dera Ghazi Khan had increased by 174%. In Layyah, the increase was 131%. What appeared to have happened is that the demand for groundwater was slowly saturated in this period. Even so, the number of tubewells increased. Small farmers, especially, purchased their own tubewell, sometimes pooling resources with others. This decreased their dependence on tubewell-water purchases from other farmers. For those who could still not afford their own tubewell, the situation improved nevertheless, as there were more providers. Water prices did not go up in this period, despite an increase in the water-lifting costs. This further suggests that groundwater market changed from a sellers' market to a buyers' market.

The tremendous growth in the number of private tubewells caused the government of the Punjab to reconsider its role in groundwater management. As shallow wells were providing vertical drainage, the government decided to phase out the public tubewells in the fresh groundwater areas. Over the years, operation and maintenance costs of the deep tubewells had become prohibitive. Moreover, the condition of the SCARP deep tubewells had deteriorated to the point where 67% of the tubewells were operating at less than 50% of their original capacity. The policy of phasing out public tubewells took shape in the SCARP-1 area, where farmers were provided with a subsidy to develop a private tubewell to compensate for the reduction in the discharge from the SCARP tubewell[7]. The intention is to close down all of the SCARP tubewells in fresh groundwater areas before the year 2002. The government's direct involvement in groundwater management will come almost to an end. Public deep tubewells will continue to be operated only in areas with saline groundwater, to prevent saline groundwater intrusion in fresh groundwater zones. It has to be said that in many saline groundwater areas the farmers have already made efforts to close down the tubewells, to prevent the saline effluent, which was often inadequately drained, from spoiling their land.

Sindh

Private tubewell development in Sindh has not been as intensive as in the Punjab. Two main reasons explain this difference. The first is that the surface irrigation supplies in Sindh are relatively generous, thus reducing the need for additional groundwater supplies (Ahmad and Kutcher 1993). The second is that groundwater is very saline in large parts of Sindh, although Ahmad (1993) has argued that, even so, in many areas, especially in the north, a substantial layer of fresh water floats on the more saline layers. More shallow tubewell development is possible, in principle, through the use of skimming wells. In several parts of Sindh, hand tubewells are already exploiting the thin upper layer for drinking water by using the fresh recharge from canals and distributaries.

At present, however, private tubewell densities in Sindh are far below those in the Punjab. For instance, in Moro and Sakrand districts, where shallow groundwater is fresh, there are only 0.8 private tubewells per 100 acres, even though fresh groundwater is available. As in the early stage of private tubewell development in the Punjab, most wells are owned by large landlords. There is relatively little selling of water from these tubewells. In Moro and Sakrand, only 2% of the tubewell owners reported selling water. The very skewed distribution of land is an important factor in how much water is sold. Large landlords in Sindh typically own very large tracts of land. Most of the tubewell water is used on their own holdings, and they have little interest in exploiting the well commercially. Smith and Pathan (1996) have observed for the fresh groundwater area of Moro and Sakrand that private tubewells are concentrated at the tail reaches, which receive very limited surface supplies. Rather than being used conjunctively, groundwater is used as a substitute for failing surface water supplies. Recent measurements under the SCARP Transition Project show no indication of groundwater-induced secondary salinization in Moro and Sakrand, but instead suggest that in recent years groundwater quality and soil salinity have improved owing to increased tubewell development and the leaching this has made possible (SSTNRPP 1997).

Because of the limited development of private tubewells, salinity and waterlogging persist in most parts of Sindh, even in some fresh groundwater areas. The problems are particularly severe in the areas with 'non-perennial' canals. These canals receive very copious supplies in the *kharif* season, causing the water table to rise significantly, only to fall again in the winter season, when the canals are not functioning. This annual cycle of rise and fall of the water table has brought the salts to the upper soil strata (Mukarram 1994). The problems in the perennial channels are different from those of the non-perennial channels. In the perennial channels, the water duties are generally lower. Salinity concentrates in areas with deficient surface water supplies because there is not enough water to leach the accumulated salts. This happens often in the tail reaches of the channels.

The provincial government is investing substantially in efforts to address the drainage problems. It is also starting the closure of the SCARP deep tubewells in fresh groundwater areas, as the Punjab government is doing. The most important project, however, is the construction of the Left Bank Outfall Drain, which provides surface and subsurface drainage to an area of 1,426,000 acres in Nawabshah, Sanghar, and Mirpurkhas districts. The project is constructing a spinal surface drain, which is supplied by a network of tributary surface drains. Subsurface drainage systems pump up saline groundwater and dispose of it in the surface drainage system, from where it ultimately finds its way to the Arabian sea. In areas where the Left Bank Outfall Drain has become operational, water tables have declined, although this may be owing in part to the absence of rainstorms in the years since the Drain's completion. Nevertheless, the Drain is still beset by serious operational problems, of which the two most pressing are the generating of the required operation and maintenance funds, and the twin use as a stormwater drain, for which the capacity is not sufficient.

Groundwater issues in the mountain provinces

Balochistan

Groundwater development in Balochistan has been very different from groundwater development in the Indus Plain, but equally dramatic in its environmental and social impact. In many parts of this scarcely-populated, semi-desert, western province, groundwater is the only source of irrigation. Indus canal supplies are available only in Nasirabad and its districts. In the remaining part of the province, spate flows and small surface streams irrigate a small portion of the land, but large tracts of land remain uncultivated.

For a long time the aquifers were exploited only by animal-driven persian wheels (which lift water from shallow wells) and *karezes* (which consist of tunnels that interconnect manholes, and which usually convey and collect groundwater over a length of 500 to 3000 m). The slope of the *karezes* is less than the land gradient, and they surface close to the command areas. The cost of establishing a *kareze* is high[8] and in most cases it is prohibitive for individuals, so construction is usually collective. A typical *kareze* in Balochistan will yield up to 200 l per s, and it will serve a maximum of 200 shareholding families. As the maintenance cost is high, the cooperative strength of the *kareze* shareholders is being constantly tested.
In the second half of the 1960s, dug wells became a popular alternative to *karezes*. This development was stimulated by a range of government programmes that provided subsidized dug wells to farmers. Groundwater supplies were considered limitless. Moreover, the thinking in the 1960s and 1970s was that *karezes* wasted water, as they flowed throughout the year, whereas commercial peak water requirements occurred during three months in the summer, when high-value fruit and vegetable crops needed to be irrigated[9]. The government promoted well development further by providing cheap electricity. To make it easy to collect dues, the government applied a system of flat rates to most electrified tubewells. This move encouraged overpumping, as the electricity charges bore no relation to consumption[10]. The most serious distortion of market mechanisms was the low recovery of electricity charges. For the period 1988-1992, the recovery rate was 47%. The average outstanding bill for each well was Rs 80,150 (U.S. $ 3000).

In the same period, improvements in the transport network facilitated an upsurge in the cultivation of high-value fruits and vegetables. The expansion of groundwater irrigated agriculture was unstoppable. According to official figures, 21.8% of the perennially irrigated land in the province was supplied by groundwater in 1989 (Agricultural Statistics 1989-1990). In 1993 there were officially 9639 electrified agricultural wells in Balochistan. To this number should be added the many electric tubewells without a legal connection, and the diesel-driven wells in the valleys that were not yet connected to the electricity grid. Diesel pump sets became popular in the command areas of the small and scattered surface irrigation systems, where they helped to safeguard adequate supplies in the summer irrigation season. In many valleys of Balochistan, groundwater exploitation soon exceeded sustainable yields of the confined aquifers. Groundwater levels declined at a rate of 0.25 to 1.10 m a year (WAPDA 1992).

There were winners and losers in the groundwater rush. Soon after the large-scale introduction of dug wells in the 1960s, the flow of many nearby *karezes* was affected. This process had a hydrological and a social component. During the early proliferation of dug wells, many parts of Balochistan were going through a dry climatic cycle, which lowered groundwater tables. Increased withdrawal from the new dug wells accelerated the lowering of the groundwater tables. *Karezes* became less viable, and the first people to release their share in the communal systems were often the larger farmers, who had the resources to develop a private well. The heavy burden of maintaining the drying *karezes* then fell increasingly upon the smaller farmers. The final outcome was often the collapse of the traditional system (Syukurallah *et al.* 1990) and a polarization of the access to groundwater. On the opposite side of the tally-sheet were the land owners who traditionally had no share, or a only small share, in the *kareze* supplies, and who now began investing in the development of dug wells. Water from the dug wells was sold to farmers who had no well of their own. Another common arrangement was water tenancy. Under this arrangement, a dug-well owner provided all of the water to the land of a fellow-farmer, receiving usually one-fourth or one-fifth of the crop as compensation.

In many areas, however, the decline of groundwater tables continued, and even the dug wells dried up. The only recourse was to develop deep tubewells. This could be done only at a high investment cost. The cost of a deep tubewell was close to U.S. $ 25,000, a price that only some farmers could afford. In areas where the decline of the groundwater tables was very great, access to groundwater was ultimately concentrated among a limited number of farmers.

Neither under customary law nor under government jurisdiction were there rules to control the decline in groundwater tables. No government organization had a mandate to handle the crisis. In a very few valleys in Balochistan, namely Panjgur, Kech, and Mastung, *kareze* shareholders took the initiative to frame efforts to control groundwater exploitation and prevent overdraft (van Steenbergen 1995). Generally, however, the only response to the crisis was to reactivate the traditional '*harim*' rule. The *harim* has its origins in Islamic water law. It specifies a prohibited zone in the vicinity of *karezes* and wells, in which no other well or *kareze* can be made. In Balochistan, the minimum distances of the *harim* were 250 m in silty soils and 500 m in gravelly conditions. Depending on the locality, the *harim* was interpreted either as the customary distance from the first well of the *kareze* (called the 'mother well'), or it was applied all along the length of the *kareze*. The *harim*, however, originated in the era of *karezes* and persian wheels, and it was in no way effective in regulating mechanized groundwater exploitation.

In the late 1970s, the provincial government took several initiatives to address the destruction of Balochistan's groundwater reserves. The response was mixed. The public subsidies to dug well and tubewell development and operation continued while new funds were made available for artificial groundwater recharge. Throughout the province 'delay-action dams' were constructed. These collected water after the sporadic rain storms so that it could infiltrate and contribute to the groundwater stocks. The effectiveness of these dams has been questioned, because the reservoirs tend to silt up, thus impeding recharge and reducing storage capacity.

Balochistan had the first - and so far the only - provincial government to issue legislation to control groundwater mining. In 1978 the Groundwater Rights Administration Ordinance was announced[11]. The objective of the Ordinance was 'to regulate the use of groundwater and to administer the rights of the various persons therein.'

Under the legislation, groundwater users were considered individuals with a direct relation to the law-implementing agencies. The 'rights of the various persons' were not quantifiable entitlements as such, but rather they were permits to develop and operate a groundwater abstracting infrastructure. The Ordinance established the procedures and framework within the district civil administration to issue permits for the development of new *karezes*, dug wells and tubewells. The relevant authorities were the District Water Committees, composed of government officials and two appointed local 'notables.' Before granting a permit, the committees heard objections from the surrounding landowners. Appeals could be made to the divisional commissioner (representing the next highest administrative level) and the Provincial Water Board. The permits were indefinite, as a well owner could always sink a new well to replace a dry one.

The Provincial Water Board resembled the District Water Committees, in that it consisted of appointed local notables and provincial government bureaucrats. The Provincial Water Board was charged with the task of formulating policies on groundwater withdrawal. The Ordinance specifically mentions making estimates of safe yields and existing levels of withdrawal, and administering all water points. With this information it was possible to specify the minimum *harim* distances in each region. The distances could serve as guidelines for the issuing of new water permits, thus introducing a system of modified, overlying water rights to manage the collective resource. On paper, the legislation offered a framework for local resource management that would involve the local administration and the tribal elders and allow flexibility in determining rules for using the communal groundwater resources. In principle, the strategy of promoting common property management regimes made sense in the valleys of tribal Balochistan, but unfortunately the announcement of the legislation was not complemented by an effort to establish such local rules. It was unrealistic to expect that community initiatives to frame local groundwater management rules would evolve spontaneously, and so the legislation failed.

The only local rule issued under the Ordinance was a total ban on new wells in Quetta Valley. This was announced in December 1990 with the intention of safeguarding the drinking water supply of the more than 600,000 people living in the provincial capital of Quetta. No other area-specific guidelines were issued. Instead, the ineffective *harim* rule was uniformly applied, which was not appropriate if the objective was to avoid overdraft. The use of the *harim* distances by the District Water Committees derived from these distances being quoted in the Ordinance as a mere example of a local rule. For lack of any other guideline, the District Water Committees applied these mandatory distances, conferring on them a semi-formal status. When farmers in one area disputed the refusal of a water permit on the grounds that in their area the local minimum distance was 200 feet instead of 750 feet, the chief minister reacted, and by decree he endorsed the *harim* all over Balochistan in October 1990. In practice, however, even these *harim* distances were applied in a few cases only. In most valleys a 'help yourself' attitude prevailed, and the Ordinance and its provisions were ignored.

North West Frontier Province

Due to the relative abundance of surface water resources, the higher rainfall, and the fragmented nature of the landscape, reliance on groundwater in North West Frontier Province has generally been lower than in Balochistan. Groundwater currently accounts for an estimated 11% of agricultural water supplies only. Nevertheless, in recent years, private initiatives and development projects have led to an intensive exploitation of groundwater resources, particularly in the intermontane basins in the northern and central part of North West Frontier Province (e.g. in Swat, Buner, Dir, Peshawar, and Mardan). Groundwater quality here is good to excellent. Valleys that were considered unproductive in the past have been put into production. At the same time, the risk of overexploitation has risen. Until not long ago, the only area in North West Frontier Province to record overexploitation of the aquifer was Parachinar, in the Federally Administered Tribal Area, close to Peshawar. The Shamozai and Kotlai valleys in Swat, and the Jandool and Adinzai valleys in Dir, however, are recent examples of looming overwithdrawal. They have numerous tubewells, equipped with turbine pumps and often powered by tractors or former diesel truck engines. Many of the tubewells are funded by remittances from family members working in the Middle East. In these areas, landholdings are often small and fragmented. Selling of water from the wells is quite common. Often it is the only way to exploit the well economically. Water prices are still quite high, symptomatic of the as-yet-unfulfilled demand for groundwater. As in Balochistan, lease and tenancy arrangements are common in exchange for ensured irrigation supplies, particularly in areas where groundwater is the only source of water. In some intermontane valleys, in particular the main Swat valley, tubewells are installed in the commands of the traditional irrigation systems both to be used conjunctively and as security against the sometimes faltering supplies in the traditional systems.

In other parts of the province, groundwater development is less intense. In the southern districts of Kohat, Karak, Bannu, and D.I. Khan, groundwater quality is mixed. There are patches of good, moderate, and poor quality groundwater with salinity and sodicity hazards.

So far, the provincial government has taken a passive attitude towards groundwater management, and in this regard North West Frontier province resembles the other provinces. No monitoring of groundwater levels or groundwater quality is done outside the few SCARP areas. From 1979 to 1986, a study was undertaken of the hydrogeology of North West Frontier province. As part of the study, a network of piezometers was set up. The piezometes remained unused after the completion of the study. Nominally, the Provincial Planning, Environment and Development Department and the Provincial Irrigation Department would be responsible for groundwater monitoring, but neither has taken initiative to do so. Similarly essential legislation and regulation are lacking. In Parachinar, the one area with a long history of groundwater mining, legislation would not suffice either, as tribal law and authority still prevail there.

Urban groundwater issues

Most of Pakistan's major cities rely on private pumping for domestic water supply. The piped supply from the Water and Sanitation Agencies is generally far too limited and unreliable. Shallow private wells are sunk in large numbers to augment supplies - even where restrictions are in force, such as in the city of Quetta (Balochistan). The large-scale exploitation of the aquifer underneath the cities has led to falling water tables and to contamination of water supplies by leaking sewerage systems and septic tanks, as Rahman (1996) has documented for Karachi. In Quetta, the overexploitation of the confined aquifer by agricultural users in the surrounding area has already led to doomsday projections, predicting that in the foreseeable future even the supply from deep groundwater to the capital of Balochistan will dry up. Another problem is the excavation of the river beds near the big cities, to provide building material. In the Malir River near Karachi, for instance, the disturbance of the river bed has already resulted in a limited recharge of water flows and reduced water levels in wells in the adjacent area.

So far these urban groundwater problems have gone unaddressed. The same is true of industrial groundwater contamination. There are indications that the uncontrolled disposal of industrial waste water and the sludge from petrol pumps has contaminated groundwater supplies, but there is hardly any monitoring of the problem, and even less control.

Implications

It is difficult not to be pessimistic about groundwater management in Pakistan. As the study on the Indus basin by Masood and Kutcher (1992:92) concludes, '...in all probability, the quality of groundwater, on which Pakistan depends for about one-third of its irrigation supplies, is deteriorating. Within a few years, most of it may be unusable, or out of reach of existing pumps. Given that tubewell farmers have been the singular bright spot in the sector for the last two decades, this prospect is most discomforting.' At the same time, waterlogging persists in the areas of saline groundwater in the Indus Plain. In the mountain provinces, in Balochistan, and in a number of areas of North West Frontier province, the intensity of groundwater mining is already far beyond sustainable limits. The decline in groundwater tables, it appears, can be stopped only by a drastic reduction in tubewell numbers. The trend is, however, the opposite, and it seems that only the shore will stop the ship. Finally, urban drinking water supplies from private wells in several large cities are in jeopardy as well.

The development of groundwater exploitation has brought bout major social changes too. The falling groundwater tables in Balochistan have led to the decline of *karezes* throughout the province, denying many farmers access to the vital resource. On the other hand, former have- nots have gained access to groundwater by developing dug wells. In areas where groundwater has fallen below the level that can be exploited by a dug well, deep tubewells appeared on the scene. Because the investment costs for a a tubewell are high, access to groundwater was monopolized by those who could afford to pay them.

To some extent, selling of water from private tubewells mitigates the inequity. Relatively brisk water sales are reported in all provinces. It is obvious, however, that non-owners are last in the cue, making groundwater supplies to them less reliable and, in times of scarcity, the object of a favour. These problem are compounded by rights-of-way issues and conveyance losses. This explains why in many areas shallow tubewell installation - which is relatively expensive - continued, even where there are active groundwater markets. Ultimately, with the number of groundwater providers increasing, the market was saturated. Water lease prices decreased, and non-tubewell owners had a larger choice of tubewells from which they could take water. While this increase in installed capacity improved equity in access, the downside was that it contribute even further to overdrafts.

Recommendations

It has been argued that groundwater management should be part of a larger effort to integrate water resource management in Pakistan (Bhatti and Kijne 1992). Ahmad and Kutcher (1992) argue that a reallocation of surface water supplies between fresh groundwater areas with relatively low surface irrigation duties and fresh groundwater areas with high irrigation duties and saline groundwater areas, would go a long way to reduce groundwater mining in the former areas and to waterlogging in the latter areas. Vander Velde and Kijne (1992) looked at various possibilities of redistributing surface water supplies along one distributary channel so as to improve groundwater quality in the middle and tail sections, and they concluded that insufficient surface water was available for the canal to achieve such an objective. Reallocation between and within canal distributaries is, moreover, politically unacceptable at present. Yet, given the need for integrating surface and groundwater management, one would hope that this will change, and that there will be more flexibility in redirecting surface supplies.

Ahmad and Kutcher (1992) argue further that channel and watercourse lining should be undertaken in saline groundwater areas to reduce seepage from the surface irrigation systems. At the same time, more investment in subsurface drainage is required. The costs of such investments, however, are substantial, and while they will probably prevent the problem from worsening, they can not remove it.

Yet even more is needed. For fresh groundwater areas, both in the Indus Basin and the mountain provinces, effective regulation is required. There is, however, a lot of ground to cover in this field. To start with, the data available on groundwater is patchy and often outdated or irretrievable. Systematic monitoring is limited to the SCARP areas, where it is done by the Federal Water and Power Development Authority. Outside the SCARP areas, very little monitoring is undertaken. There is an urgent need to improve monitoring of groundwater levels and groundwater quality. With respect to groundwater quality, there is also a need to start investigating the contamination of groundwater by pesticides, particularly in the cotton- growing areas, that account for the lion's share of pesticide consumption in Pakistan (World Bank 1996)

This raises a second issue, i.e. the responsibility for groundwater management. For a long time there was confusion as to which organization had the mandate in this regard. As explained, for a long time there was even confusion on basic issues, such as whether it is the province or the federal government that is responsible for groundwater management. The conflicting stands of the WAPDA Act and the Soil Conservation Act were noted, with the first confirming federal responsibility and the second confirming provincial responsibility. Even more confusion was added by an ordinance from 1979 (the Local Government Ordinance), which suggests that all groundwater falling within the local area of an urban council shall come under the control of this local government body. Fortunately, the new and overriding acts that have come into force in 1997, for the Provincial Irrigation and Drainage Authorities in all four provinces, makes an end to the confusion and puts the responsibility for groundwater management, irrigation and drainage operations, and cost recovery clearly with the newly established Provincial Irrigation and Drainage Authorities. These new authorities are to ensure that groundwater monitoring is undertaken, and they have a mandate to initiate policies to address groundwater management problems.

Moreover, the Environmental Protection Agency Act of 1996 offers the beginnings of a legal basis for groundwater-quality management. This Act calls for the establishment of Environmental Protection Councils at federal and provincial level that will set standards on groundwater quality. Most likely the provisions of the Environmental Protection Agency Act will be applicable to industrial effluent standards rather than to rural groundwater quality.

Because these Acts have been issued recently, little has happened in operational terms so far. The Provincial Irrigation and Drainage Authorities were notified of their promulgation only in the second half of 1997. Realistically, one can expect the Authorities to be occupied with establishing themselves as revenue-generating and self-accounting bodies for some time to come, before they will be able to address the challenges of groundwater management.

A third issue is the role of local organizations. On paper, the Balochistan Groundwater Rights Ordinance created the scope for the development of local rules and the involvement of local groundwater users. Unfortunately the Ordinance was badly implemented, and in one valley it even demoralized groundwater users who had developed their own pooled-resource management regime. An important lesson from Balochistan is that ordinances, acts, and laws are meaningless without enforcement and the involvement of groundwater users. The question remains, Who will take the effort of organizing the users of the new groundwater resource? In Balochistan and parts of North West Frontier province, organization appears to be the only way forward. In other areas (e.g. the Punjab and Sind), the sheer number of groundwater users is too large to even think of a local resource management regime. Yet regulation is not less important. It will simply have to depend more on public organizations, licensing, and cooperation with the agri-service sector. The formulation of such a regulatory framework is now being considered for the Punjab. This will have to be supported by a public awareness campaign, as awareness of the changed groundwater issues among farmers and political decision-makers is very limited, and much of the thinking is dominated by the period when waterlogging was still the main issue. Without such awareness, enforcement of any regulation will be difficult.

Finally, the price of groundwater needs to be mentioned. In the discussion on water management, it is often proposed that water prices should reflect water scarcity, so as to encourage more prudent water use. The question in Pakistan is, how to implement such a pricing system? Most tubewells run on diesel, making it hard to increase the price of diesel without hurting other non-agricultural diesel consumers. On the other hand, the subsidies of electrical supplies to tubewells continue. This is an anomaly that should be corrected. The tragedy of Pakistan is that groundwater is a very precious resource, yet, at the same time, it is a resource that can be exploited at very low cost.

Endnotes

1 Van der Velde and Kijne (1992) state that groundwater from public and private sources constitutes 70 % or more of the total water use in many distributaries in the Indus system.

2. The patchy nature of waterlogging and salinity meant that the impact of the problems was somehow mitigated, as farmers were cultivating several plots at a time and they generally had land that was affected and land that not affected.

3 The preference for deep tubewells rather than shallow tubewells has been a matter of controversy, because in general groundwater at greater depths is more saline than shallow groundwater. Experts such as Ahmad (1993) argue that it increased pumping costs and resulted in bringing very saline water to the surface, which in the absence of a well maintained surface drainage systems inevitably accelerated soil salinity.

4 Where the tubewells are used in conjunction with surface water supplies, the hours of utilization (the 'operation factor') are low. This makes flat-rate connections unattractive. But even the metered connections have a fixed component, independent of the actual consumption, which makes electricity relatively expensive. Calculations made in 1993 established that electricity starts to become competitive with diesel at operation factors of 24 % and higher. As a result, nowadays electrified tubewells are common only outside the canal command area in the Punjab and Sindh. For the same reason, electricity is popular in Balochistan.

5 Second in importance to the diesel engines are tractors driving the centrifugal pump, the 'power take-off points' (vander Velde and Johnson 1992).

6 Group-owned tubewells are unusual. Malik and Strosser (1993) found that 65 % of tubewells are individually owned. Most of the remaining 35% are owned by a limited group of family members. The main exception to this pattern is the community tubewells that have been established under the Second SCARP Transition Project since 1995. Groups of 15 to 25 usually small farmers are given a lump sum so that they can contribute to the financing of the development of a group tubewell. In May 1996, 1100 of these community tubewells were in operation in the former SCARP-1 area.

7 The closure of the SCARP tubewells has created inequities in water supplies in the watercourses. After the SCARP tubewells were installed, the watercourses were adjusted to carry the combined discharge of the canal supply and the SCARP tubewell. With the closure of the public tubewells, the watercourse is in many cases over-dimensioned, and the remaining surface water supplies can no longer reach the tail ends of the watercourses.

8 Nowadays *kareze* building is very much a thing of the past in most parts of Balochistan. Nevertheless, a *kareze* was constructed in Chagai District from 1986 - 1991 at a cost of Rs 2,700,000 (US $ 120,000).

9 In the remaining part of the year, flows, if any, were utilized on low-value wheat and melons, crops that for most farmers did not justify the economic opportunity cost of water. A report from 1977 (WAPDA 1977) looked seriously into the possibility of replacing a series of functioning *karezes* in Mastung Valley with a large number of tubewells, on the grounds that this would allow all water to be used for summer crops. Another report from the same period (Kemper *et al.* 1979) suggests investigating the possibilities of stopping the winter outflow of the *kareze* and storing the water underground.

10 Vested interests continue the system of flat rates. By suggesting the sale of all electricity now being booked under the flat rates, linemen are able to sell illegal connections.

11 Previously, groundwater disputes that were presented to the government were treated as land cases, and they were dealt with by the Board of Revenue. Sometimes the district administration gave them to a tribal council to decide.

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GROUNDWATER MANAGEMENT IN KENYA; THE NEED FOR IMPROVED LEGISLATION, DELEGATION OF AUTHORITY, AND INDEPENDENT DECISION-MAKING

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Introduction

Since the early eighties, the Dutch Ministry of Development Cooperation (DGIS) has been supporting a water resources management project in Kenya. Today, the project is known under the name of WRAP (Water Resources Assessment and Planning Project). This project has yielded a wealth of information about actual groundwater management in Kenya.

WRAP's aim is to strengthen the institutional capacity of the Kenyan Ministry of Land Reclamation, Regional and Water Development in:

- Preparing regional water resources assessment studies that consider both surface water and groundwater;
- Formulating District Water Development Plans that are based on those water resources assessment studies:
- Establishing national and regional water resources databases; and in
- Developing water resources management models.

The project is based at Ministry Headquarters in Nairobi; the study and planning areas are located outside Nairobi, and consist mainly of arid and semi-arid lands.

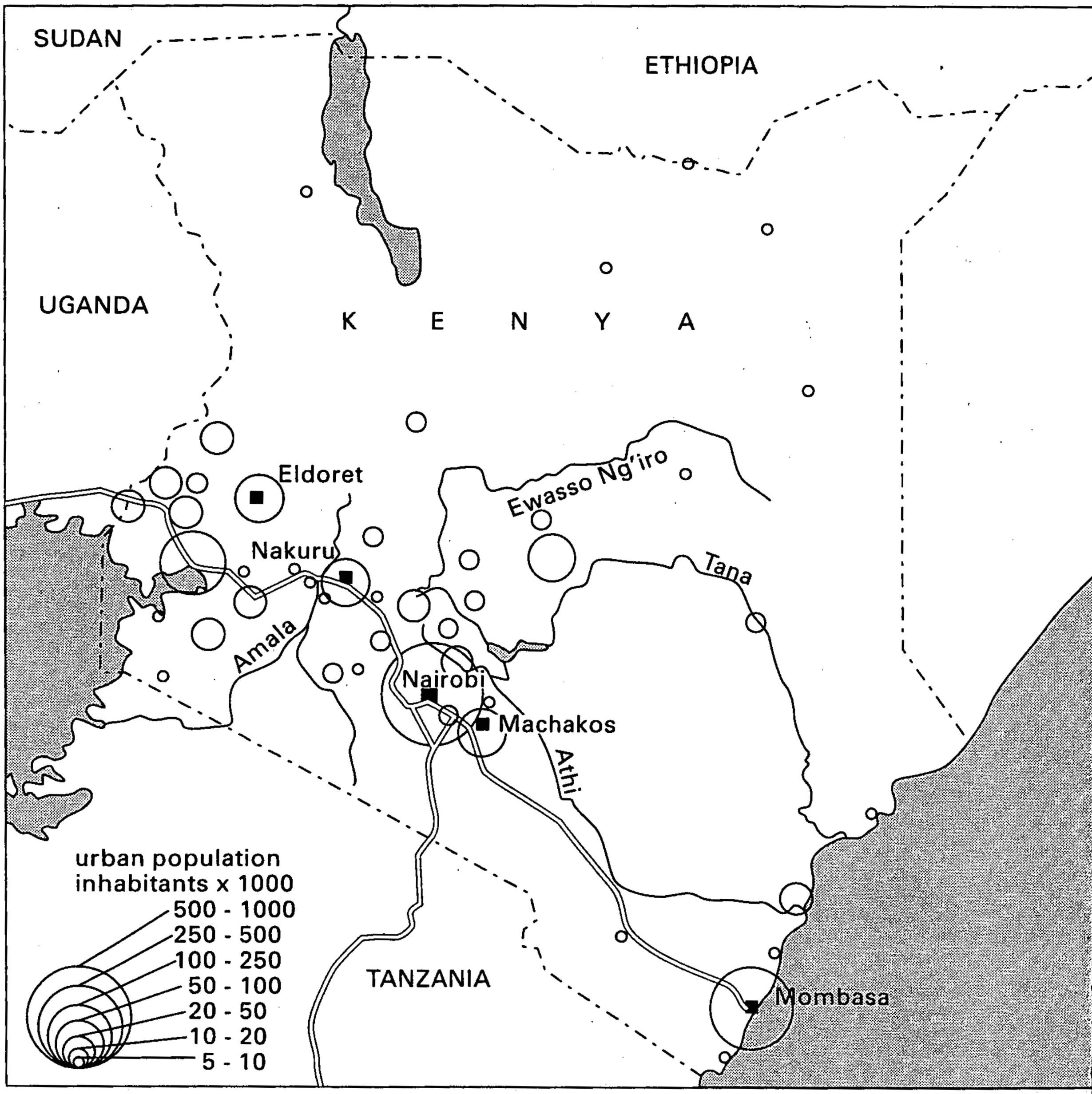
The project has a limited scope and mandate, in the sense that it operates in specific districts and within the existing organizational set-up and structure of the ministry. In operating within this framework, the project has experienced the limitations of the present set-up and structure of water resources management.

This paper is based on experiences obtained within the WRAP project. It describes and analyses how groundwater in Kenya is managed and the role played by WRAP in influencing groundwater management practices. The paper describes first Kenya's groundwater resources. It continues with a discussion on the formal rules and regulations for groundwater management. The next sections focus on groundwater management in practice and on the direct and indirect effects of prevailing practices. Subsequently the successes and failures of WRAP and the impact that WRAP could have are discussed. In the last section of the paper a number of recommendations on how groundwater management in Kenya could be improved are formulated.

Groundwater resources in Kenya

Kenya is a large country (about 17 times larger than the Netherlands). Some 80% of the estimated population of 30 million, however, live in a narrow zone running from west to east, from Kisumu and Eldoret along the borders with Uganda towards Mombassa along the Indian Ocean (see Figure 1).

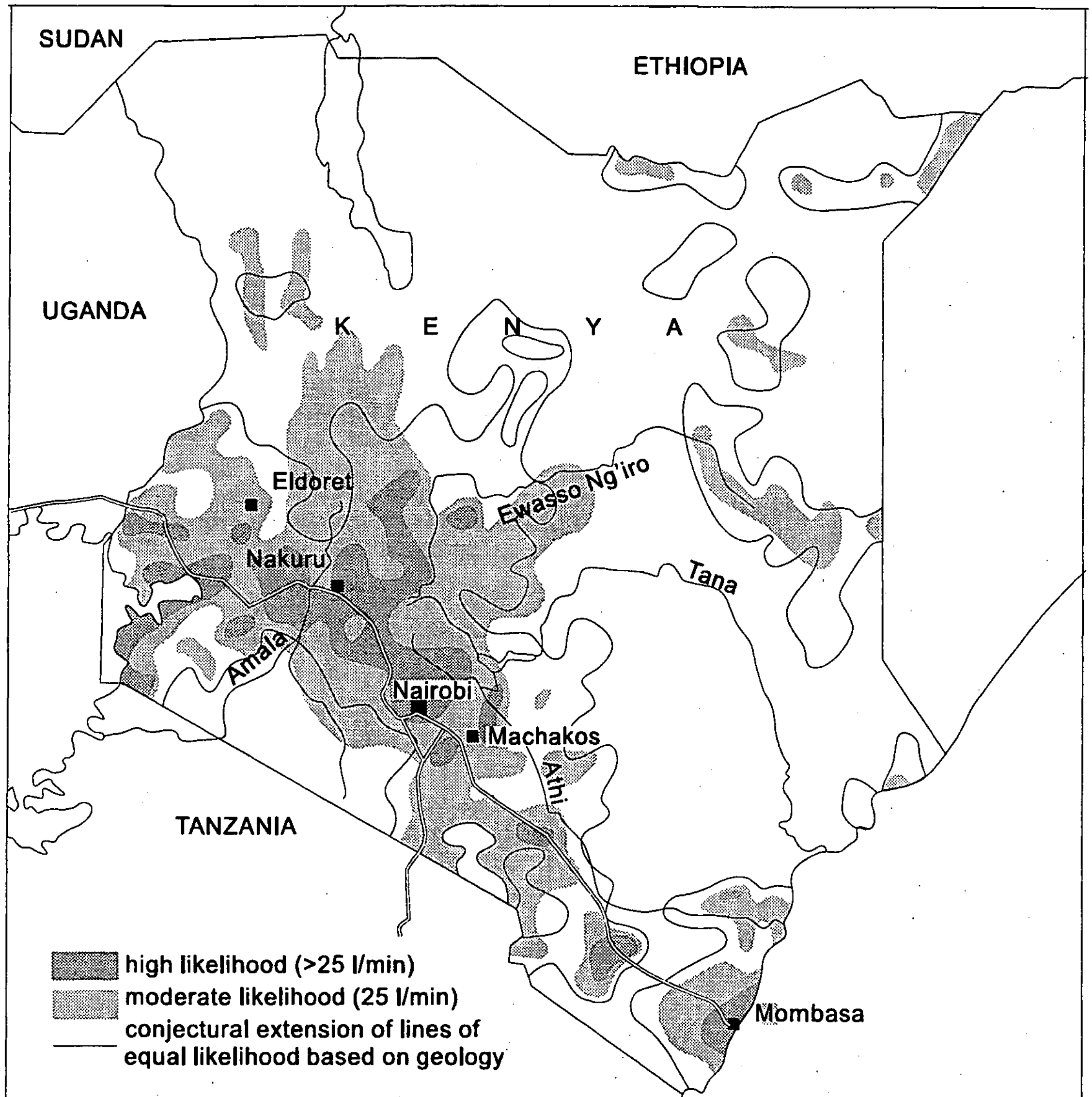
Figure 1. Population distribution in Kenya



This zone is very fertile and there is sufficient water to sustain agricultural development. In this zone, particularly along the downstream sections of the rivers where a lot of water is used for irrigation, there is huge competition for water. In some areas, this has caused rivers to dry up for part of the year. Most of the available surface water is turbid, heavily polluted with biodegradable substances, and contaminated. Erosion, agriculture-based industries (e.g. coffee factories), and a fast-growing population with inadequate sanitary facilities have created a situation in which complex water-treatment systems are needed to make the abstracted surface water suitable for domestic or industrial use. Water-quality standards have become stricter; there is a rising demand for "high quality" clear water which can, for instance, be used for horticultural purposes (e.g. for drip irrigation). Most of the piped water supply systems in the country are unreliable. This applies particularly to piped supplies with extensive distribution systems and to pumped water supplies.

Another phenomenon, which can be observed around the major towns, is the inability of the water supply company to cope with the expansion of the towns; areas located further away from the main water supply lines do not get enough water. The demand for reliable and independent point-source water-supply systems is rising

Figure 2. Groundwater production areas in Kenya



Under these circumstances, it is very attractive to sink a private bore-hole. Its owner will be assured of a reliable source of water (not drying up), a proper source (not contaminated; limited need for water treatment), and an independent source (not shared with other users).

Despite the great demand for the development of groundwater resources, there is only a small group of consumers capable of sinking a bore-hole. Moreover, surveying and drilling activities are controlled by a very small group.

Shallow groundwater, which could be developed through hand-dug or hand-drilled wells, is only found along some rivers and in areas with major sedimentary deposits. In most areas, the bore-holes needed to abstract groundwater would require a depth of as much as 260 m. The cost of sinking such a bore-hole is high; a rotary drilling rig is needed to sink the hole. Moreover, extensive surveys are needed to identify a site where a bore-hole can be sunk with a reasonable chance of success. And even then, there are no guarantees that the bore-hole will be able to supply the required yield; the bore-hole could even be dry. This has resulted in a situation in which only a small group of financially powerful individuals and private organizations are able to pay for a bore-hole. The survey work is done by a small group of Ministerial experts and the bore-hole is sunk by one of the few capable contractors.

Groundwater management in Kenya

The Water Act and the Water Board

Water resources management in Kenya is vested in the Water Act. The Water Act, Cap 372 of Laws of Kenya, is "An Act of Parliament to make better provisions for the conservation, control, apportionment, and use of the water resources of Kenya, and for purposes incidental thereto and connected therewith". The present act, which repealed The Water Ordinance of 1929, commenced on 7 May 1952, after which minor amendments have been made.

Under section 4 and 5 of the act, the control of every body of water shall be exercised by the minister in accordance with the act. ("The minister" is the Minister of Land Reclamation, Regional and Water Development). The act also confers various powers to the minister.

Under the act, various authorities, boards, and committees are prescribed with various duties, powers, and functions. Responsible at the national level is the Water Apportionment Board, which has a supervisory and decision-making task. The Water Apportionment Board is advised at catchment level by six Catchment Boards (one for each drainage area). Apart from the Catchment Boards, the minister has used his authority to install District Water Boards (one in each of the 80 districts of the country). The responsibilities of the Catchment and District Water Boards are rather limited and are basically restricted to advising the Water Apportionment Board on water resources matters.

According to the act, all applications for a water permit, transfer, cancellation, or renewal of a permit must be considered by the Catchment Board before being considered by the Water Apportionment Board. Whereas the Water Apportionment Board usually accepts recommendations by the Catchment Board, it is not bound to accept every recommendation made by a Catchment Board; it may accept, reject, or modify any recommendation. Like the Catchment Boards, the District Water Boards have an advisory task.

The Water (Apportionment) Board is an old institute, which was already established in 1935. At that time, it was a totally independent agency. The Ministry of Water Development was still a division within the Ministry of Agriculture. The Catchment Boards also date back from the colonial period. The District Water Boards are a new phenomenon. They were established in 1992.

According to the provisions of the act, any of the powers, duties, or obligations vested in the Water Apportionment Board by resolution of the Water Apportionment Board, may be delegated by it to any authority, board, committee, or person, subject to limitations which the act may provide. Consequently, the board, under various resolutions, has delegated some of its powers, duties, or obligations to various officers of the ministry.

The main water resources management tool is the water permit. A water permit is required in all cases of proposed diversion, abstraction, obstruction, storage, or use of water from any body of water unless declared not to be a watercourse or as exempted. An application for a water permit must be made in the manner prescribed by the act and in compliance with standing requirements of the Water Apportionment Board.

Permits are issued by the Water Apportionment Board, which should base its decision on advice given by the relevant Catchment Board. In a similar way, the Catchment Board should be advised by the relevant District Water Board.

None of the institutions responsible for water resources management (neither the Water Apportionment Board, nor the Catchment Boards, nor the District Water Boards) has the capacity to independently implement basic activities of water resources management (e.g. water resources monitoring, water resources data analysis, and planning of the available water resources). These activities are all done by staff of the district water engineer's office, the provincial water engineer's office, and the Water Resources Divisions of the Ministry Headquarters. The district water engineer is Secretary to the District Water Board. The provincial water engineer "advises" the Catchment Board. The heads of the Divisions of Surface Water, Groundwater, and Water Quality, and Pollution Control of the Ministry Headquarters form the secretariat to the Water Apportionment Board.

Groundwater management in practice

The Water Apportionment Board has delegated most of its powers of issuing groundwater permits to the Groundwater Division of the Water Resources Department of the Ministry of Land Reclamation, Regional and Water Development. In this way, the Groundwater Division, which was already responsible for groundwater surveys and groundwater monitoring, became responsible for all matters related to groundwater management. The head of the Groundwater Division is a geologist.

In the following cases (i.e. in most of them), no permit is needed to abstract groundwater:

- "If such abstraction is made without the employment of works, that is non-mechanical means such as direct watering a permit is not required." This means that for most shallow wells with buckets, there is no need for a permit;
- "When the works for the development of groundwater are not situated within one hundred yards of any body of surface water, provided the well (or bore-hole) is not within half a mile of another well or within a conservation area. However, a notice on Form WAB 26 must be submitted to the Water Apportionment Board." This means that in most cases there is no need for a permit, while the notice on Form WAB 26 is frequently not submitted.

The Groundwater Division has staff at both provincial and district levels. The district and provincial geologists are responsible for all issues related to groundwater management, including groundwater monitoring, bore-hole site location, supervision of drilling works, and advice on requests to sink a bore-hole. This means that all groundwater matters, both water resources development and management-related, are done by one and the same officer.

The staff posted to the province and district headquarters report to both the provincial and district representatives of the ministry (the District Water Engineer and the Provincial Water Engineer), as well as to the had of the Groundwater Division.

Acting on behalf of the district and provincial water engineers, the district and provincial geologists are the main advisors to the District Water Board and the Catchment Board. Having staff at district and provincial levels advising the District Water Board and Catchment Boards on groundwater matters, the head of the Groundwater Division has a dominant role in groundwater management.

The established procedure for getting approval to sink a bore-hole is as follows :

- A request to sink a bore-hole is forwarded, in writing, to the head of the Groundwater Division;
- Headquarters-based staff of the Groundwater Division first of all check whether the planned bore-hole site is not located within 100 yards of a river, nor within 800 m of an existing well or bore-hole, nor within a conservation area; only in those cases is a permit needed;
- The staff of the Groundwater Division (based at Ministry Headquarters, at the Provincial office, or at the District Office) will then implement a groundwater survey to assess whether groundwater is available at the indicated site, how deep the groundwater will be, and how much the expected yield will be;
- The results of the groundwater survey are indicated in a survey report, prepared by staff of the Groundwater Division;
- Once more, the applicant has to forward his request to sink a bore-hole, together with the survey report, to the head of the Groundwater Division, who, on behalf of the Water Apportionment Board, decides whether the bore-hole can be sunk.

Approved bore-hole site locations, together with the bore-hole completion numbers, are recorded on topographical map sheets (Section "Maps and Records"). Other data (e.g. the depth of the aquifer) are stored in data sheets, which can only be retrieved via the bore-hole completion number. There is no direct linkage between the survey report (survey report number) and the bore-hole completion number.

Approval is only required to sink a bore-hole. There is no need for approval to build a septic tank or to sink a shallow well.

Groundwater exploitation

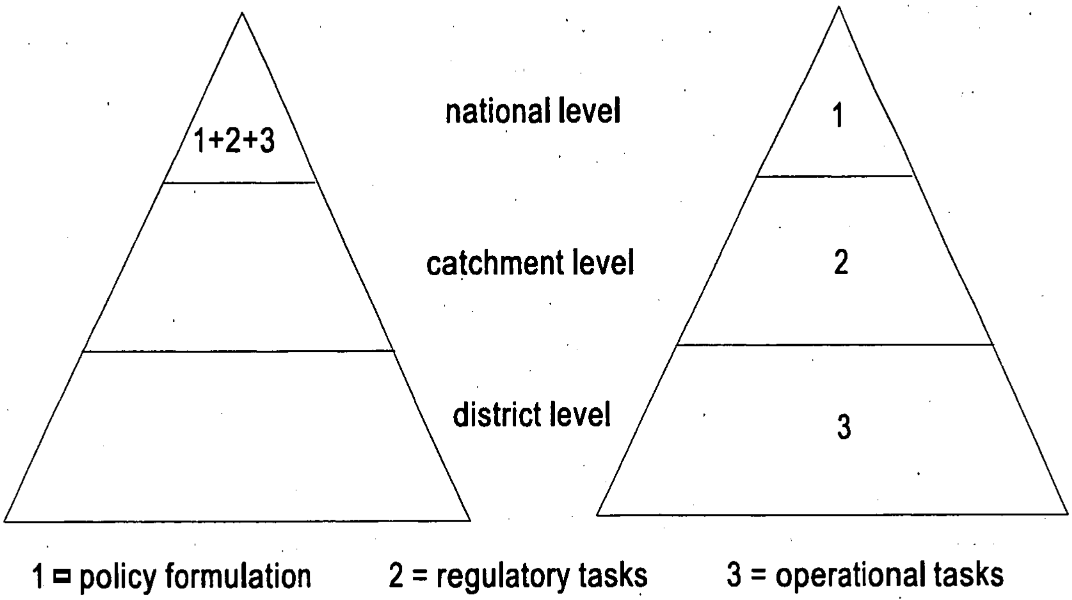
Groundwater management in Kenya means groundwater exploitation. The amount of money spent on groundwater monitoring, groundwater data analysis, and groundwater development planning is very limited; almost all funds are spent on groundwater exploitation. The only restrictions on a massive development of groundwater resources are the difficulty in finding sufficient groundwater and the cost of sinking a bore-hole. Otherwise, there are hardly any restrictions. So, even though there is a huge demand for the development of groundwater resources:

- Legal requirements are fairly limited (in most cases there is no need for a permit, while a simple request to the Groundwater Division is sufficient to get the required approval documents;
- Applications are submitted by powerful/influential individuals;
- Negative impacts of abstracting too much groundwater are (still) limited and are of a localized nature.

The perception that the amount of water which can be abstracted is limited and is determined by the groundwater recharge is accepted but not translated into management tools. This is clearly reflected in the criteria that are used to decide upon the need to apply for a groundwater permit. A bore-hole can be sunk as long as there is no negative impact on an already existing groundwater abstraction (i.e. not within 800 m of an existing bore-hole). Sustainability criteria (i.e. how much groundwater is already being abstracted from a certain aquifer) are not taken into consideration.

Another indication of the dominant role that groundwater exploitation plays is the way water resources management activities are organized. Water resources surveys, water resources monitoring, analyses of water resources data, and advice on water resources matters are not done by the District Water Board, the Catchment Board, or staff of the Water Apportionment Board, but by staff of the district water engineer, the provincial water engineer, and the Water Resources Department of the Ministry, who all fall under the Director of Water Development of the Ministry of Land Reclamation, Regional and Water Development.

Figure 3. Water resources management - Top-down or bottom-up?



Top-down management

In water resources management, there is a need for policy formulation, regulatory tasks, and operational tasks. In Kenya, all these matters are controlled from ministry headquarters. Groundwater management in Kenya is very much a "top-down" activity, with policy formulation and regulatory tasks done at the national level and operational tasks controlled from the National level. In particular, the donor community and non-governmental organizations have pleaded for a far more community-based and bottom-up organization of the water resources management system.

Operational tasks can be done at the community/district level; regulatory tasks should be done by the Catchment Boards, while the national level should only be involved in policy formulation. This will require a delegation of responsibilities to lower administrative levels, which will be very hard to realize. As much as possible, things are done from Nairobi. The arguments for this are:

- Funds and equipment are scarce and should be used in the most efficient way, which means from a central level;
- Only at the central level does one have the required data to make decisions on water resources management matters;
- Only at the central level is the required expertise available to analyse and interpret the survey data.

These arguments are only partly valid. Probably one of the most important "background" reasons is to control (and benefit from) the development of groundwater resources.

Separated management of surface water and groundwater

According to the Water Act, the Water Apportionment Board is responsible for issuing permits for both surface water and groundwater. The Water Apportionment Board, however, has delegated its authority on groundwater matters to the Groundwater Division of the Ministry. In a similar way, the Surface Water Division deals with requests for abstracting surface water. (Unlike groundwater, the District Water Boards and Catchment Boards are still involved in advising the Water Apportionment Board on surface water matters.) There is no exchange of information or consultation on water resources matters between the Groundwater Division and the Surface Water Division; each Division has its own mandate. It is very difficult, however, to separate groundwater and surface water. In particular, in the arid and semi-arid areas in which WRAP operates, surface water becomes groundwater and groundwater becomes surface water. Surface water infiltrates and becomes groundwater while groundwater constitutes the base flows of the rivers.

It appears to be very difficult to integrate the activities of the Surface Water and Groundwater Divisions. WRAP has put a lot of effort into integrating the two disciplines in its integrated water resources assessment studies. But:

- Right from the educational training stage, surface and groundwater are considered to be two "independent" entities. The Department of Geography of the University of Nairobi is responsible for the training of hydrologists; a hydrologist only deals with surface water. The Department of Geology is responsible for the training of geologists, who, among other things, deal with groundwater matters. Hydro-geologists or geo-hydrologists belong to a very scarce species;
- There is a clear tendency to "build kingdoms". An exchange of water resources information is often considered not useful because of the strategic role information plays in sustaining these kingdoms;
- In most areas, there are no regional aquifers that would enable a certain borehole to be categorized as belonging to a certain hydrological system; multilayered systems and faults and fractures complicate modelling. As a result, it is difficult to relate surface water and groundwater to each other.

Lack of planning

Kenya has a National Water Master Plan, which was prepared with the support of JICA (Japanese International Cooperation Agency) and approved in 1992. This National Water Master Plan focuses closely on water resources development issues. There is no National Water Resources Management Master Plan. The National Water Master Plan is not used for purposes of water resources management.

Within the framework of WRAP, District-Scale Water Resources Assessment Studies have been prepared and, based on these studies, District Water Development Plans (DWDP's) have been compiled. These DWDP's are based on the sustainable management of the available water resources.

Despite being approved by the Ministry and the District Development Committee, the planning as indicated in the DWDP's is not being implemented. Most groundwater development activities are taking place autonomously and unplanned.

Conclusion: In most cases, any medium-term or long-term planning for the development and management of groundwater resources is missing. Even if such a plan exists, it often lacks the general support needed for it to be used as a guiding document.

Administrative units as planning units

Most of the staff of the Water Resources Department have been posted to the district and provincial offices. Each district has a district geologist and a district hydrologist; each province has a provincial geologist and a provincial hydrologist. This set-up has been chosen in order to be able to advise the district and provincial water engineers on water resources development matters. The district- and province-based geologists and hydrologists, however, should also advise on water resources management issues. The areas of jurisdiction are confined within the province/district boundaries. In some cases, these province/district boundaries coincide rather well with the catchment boundaries; in most cases, they do not. Only at central Nairobi level has the Surface Water Division assigned coordinators for certain drainage/catchment areas.

Sector development policies

Most of Kenya's ministries have a sector-development task. Apart from having a Ministry of Land Reclamation, Regional and Water Development, there is a Ministry of Planning and National Development, a Ministry of Marketing, Agriculture, and Livestock Development, and Ministries of Tourism and Industry, which also focus on sector development. There is a Ministry of Environment and Natural Resources, but this ministry is very young and weak.

Neither the Ministry of Environment, nor the Ministry of Land Reclamation, Regional and Water Development, nor the Ministry of Planning and National Development have the tools to set boundary conditions to these sector development plans. There is, for instance, no feed-back between, say, the Ministry of Industry proposing industrial development in a certain area - development that will make heavy demands on water resources availability - and the Water Resources Department of the Ministry; the consequences of such a development are not discussed. Discussions do take place at district level on the preparation of the District Development Plans, but not at central level, where decisions on sanctioning and the allocation of money are made.

No funds - no monitoring - no data - no management

Governmental funds are limited. Funds are allocated based on the revenues generated by a ministry for a certain activity. As a result, more money will be allocated to the operation of governmental water supplies (which generate income via the water fees) than to water resources management, which generates hardly any income. The treasury's budget allocation for water resources management is therefore very limited.

Funds allocated for water resources monitoring are centrally controlled by the heads of the Surface and Groundwater Divisions and allocated through the offices of the District Water Engineer (DWE). Apart from controlling the operational funds, the DWE also controls the means of transport to be used. Most of the limited funds that are available for water resources management are therefore used at central level or at district level for other purposes.

Water resources management is a costly exercise. A poor infrastructure and limited availability of equipment means that even a simple flow measurement will cost a considerable amount of money. A flow current metre needs to be brought to the site (requiring a 4WD car with a driver). Measurements need to be taken by a hydrologist or assistant hydrologists with some assistants. All need field allowances because they probably have to camp/sleep outside their duty station.

The final result of this trend has been that, from 1992 onwards, water resources monitoring has almost come to a standstill. In most cases, District-based staff are idle because there are no funds to allow them to go to the field. Without updated information, it becomes impossible to plan and manage the water resources development.

Instead of "sharing responsibility for an open access resource", groundwater management in Kenya can rather be characterized by: "a small group of experts controlling the access to a resource which is difficult and costly to develop, a resource which is in principle considered to be "unlimited"".

The direct and indirect effects of poor groundwater management

Before describing the effects of poor groundwater management, two introductory remarks need to be made. Firstly, only some of the effects of uncontrolled groundwater development are visible. Groundwater levels are hardly monitored; indications are that groundwater levels are dropping because of over-pumping, but supportive data are scarcely available. And secondly, at this moment, the effects of poor surface water management are considered to be much worse (being much more visible) than the problems due to poor groundwater management. In particular, the massive abstractions of surface water for irrigation are such a "hot issue" that the smaller, "better distributed", and less visible abstractions of groundwater are considered to be of less importance.

To describe the effects of poor groundwater management, a sub-division can be made between direct and indirect effects. Direct effects are: over-pumping, drops in groundwater levels, salt water intrusion, and groundwater pollution. Indirect effects are: no representation or involvement of other beneficiaries of groundwater management, no planned development of groundwater resources, corruption, and a huge gap between the stored information on water resources and the real field data.

Direct effects

Over-pumping

A pumping test is done immediately after the bore-hole has been drilled. Based on the results of this test, a permissible yield is indicated. In a lot of cases, this permissible yield appears to be less than that needed by the applicant. A larger pump is then installed with a large draw-down and a larger chance of the bore-hole filter being clogged. Design changes (e.g. omitting an overhead storage tank because of no money) lead to reduced pumping heads and as a consequence to larger abstractions. The total absence of adequate monitoring of groundwater abstractions leads to a short lifetime of bore-holes and pumps.

Drops in groundwater levels?

In some areas, shallow groundwater levels have dropped. This has led to a situation in which low-cost, groundwater-based, water-supply systems (e.g. shallow wells, springs, and water holes) can no longer be used. The locations of most of these low-cost shallow groundwater resources have not been documented. Nobody knows whether a planned bore-hole will be in the immediate vicinity of an existing spring, well, or even bore-hole (if not documented or sunk without a permit).

But, in many areas, there are substantial seasonal fluctuations of groundwater levels. Question: "Have the groundwater levels dropped because of the dry season or because of groundwater abstractions from high capacity bore-holes?" In most cases, no conclusive answer can be given.

Saltwater intrusion

Apart from falling groundwater levels, over-pumping, particularly along the coastal strip, has led to saltwater intrusion. Small fresh water pockets floating on brackish or salty sea water can easily be depleted. Along the coastal strip, many bore-holes, but also shallow wells, have had to be abandoned for this reason.

Groundwater pollution

Groundwater is considered to be a safe and reliable source; groundwater is hardly ever treated with chlorine, aerated to reduce the iron content, or treated to reduce the F content. But bore-holes are sunk almost everywhere (as long as water can be found), also in areas that are not protected and which lack basic sanitary/waste disposal facilities. It is even attractive to sink a bore-hole as close as possible to the distribution areas (limited cost of transmission). As a result, even groundwater abstracted from a bore-hole is no longer an absolutely safe water resource.

Indirect effects

No public debate on groundwater matters

At regional level, there are sufficient opportunities to discuss groundwater matters: via the District Water Board, the District Executive Committee, the District Development Committee, Non-Governmental Organizations, other ministries and politicians.
Also at catchment level, there is public representation to discuss groundwater matters. There are representatives of each district present at the Catchment Board meetings.

At the central level, however (where decisions are made), public debate is hardly possible. Representatives of other ministries participate in the Water Apportionment Board. Their influence, however, is very limited. This applies in particular to groundwater matters, which have been delegated to the "experts" of the Groundwater Division.

No planning

A planned development of the available water resources requires a multi-sector approach, with adequate input from the different water users. The main water users in most areas are agriculture (irrigation) and livestock development. The development of the agricultural and livestock potential is planned by the Ministry of Agriculture and Livestock Development, which is not involved in water resources management. As indicated above, "other" water users are not involved in decision-making on groundwater abstractions. Under these circumstances, it appears to be almost impossible to develop and implement a planned groundwater development.

No public control

As a result of centralized decision-making and the limited number of qualified and capable drilling contractors, a situation has arisen in which a very small group of people decide on a request to sink a bore-hole. Such a situation is prone to mis-use.
Apart from the fact that objective decision-making is no longer taking place, it also has a very frustrating effect on the "other" institutions involved in groundwater management. The District Water Boards and the Catchment Boards have stopped discussing groundwater abstractions, and staff involved in water resources monitoring are frustrated.

Virtual reality

Groundwater management decisions are made in Nairobi and are based on data available at the groundwater database (maps and records). As indicated earlier, only some of the groundwater abstractions are registered. Moreover, Kenya has a poor communication system. Information exchange is done via data forms, which are filled in by hand and posted to Nairobi. At regional level, there are no organized data storage systems or computers. Field monitoring data are sent directly to Nairobi, without proper processing or analysis. Internet, although available and possible, is not allowed. There is therefore a huge difference between data available at central level and the real situation in the field. Inaccurate bore-hole completion records are only one of the results of completely centralized decision-making and data storage.

Wrap: successes and failures

WRAP has had a certain impact on water resources management, including groundwater management. WRAP, however, was not initiated to improve groundwater management. WRAP was established to train staff of the Ministry of Land Reclamation, Regional and Water Development;

- In the implementation of integrated water resources assessment studies;
- In the implementation of District Water Development Plans; and
- In the dissemination of Water Resources Information for purposes of water resources development.

Moreover, the project operates in specific areas and does not have a nation-wide mandate for the implementation of Water Resources Assessment Studies and District-Scale Water

Development Planning. Even within the WRAP framework, however, there have been opportunities to make some changes in the system.

A multi-sectoral approach

Much effort has been put into establishing - at national level - a Multi-Sectoral Steering Committee composed of representatives of the different ministries involved in water-related matters. Through the project, this committee would give guidance in setting policy for the water resources assessment studies and for the district water development plans to be prepared in the areas of project operation.

The joint Kenya-Netherlands Formulation Mission for the Water Resources Assessment and Planning Project, Phase IV (WRAP IV), included in its recommendations, under point 10, as follows:

> "It is recommended that, at the national level, an Inter-Ministerial Steering Committee be established to review the activities and preliminary findings of the project on a quarterly basis. This Inter-Ministerial Steering Committee will consist of the Ministries of Water Development (Chairman), Culture and Social Services, Environment and Natural Resources, Health, Livestock Development, Planning and National Development, and Reclamation and Development of Arid Areas and Wastelands."

Between February 1992 and September 1993, the WRAP IV Inter-Ministerial Steering Committee met three times and made one field visit to West Pokot District.
The tasks of the committee were formulated as follows:

- The WRAP IV Steering Committee advises the Ministry of Water Resources (later changed into Ministry of Land Reclamation, Regional and Water Development), with respect to policy matters regarding water resources assessment and district water development planning;
- The WRAP IV Steering Committee has to co-ordinate the Water Resources Assessment Studies and District Water Development Plans to related plans of the other Ministries involved in the development of water resources;
- The WRAP IV Steering Committee can be used as a forum to discuss the involvement of other Ministries in the implementation of the studies and plans.

It appeared to be very difficult to get Ministerial representatives with sufficient clout to make decisions. Moreover, even within six months, there were many changes in representation from each ministry. After the 1993 mid-term evaluation, it was decided to revive the Steering Committee, but to limit the composition only to representatives of the donor and the Ministry of Land Reclamation, Regional and Water Development.

Integrated water management

One of the project's aims was to institutionalize, at national level, a Water Resources Assessment Section. This section would be responsible for Integrated Water Resources Assessment Studies, implemented by teams of hydrologists, geologists, and chemists. The section was indeed established and existed for a few years. During the last institutional reform, however, it was abolished. The section had never received the support it needed; it was clearly "tolerated" because of the project input into the section. Cooperation from the Groundwater Division was always at a minimum. On the one hand, the Water Resources Assessment Section was seen as a threat to the existence of the other sections/divisions. On the other hand, the need for integrated water resources assessment studies was never really felt. At district level, the integration of surface water with groundwater and water quality aspects has not created many problems.

The project has also been fairly successful in establishing a National Water Resources Database, which gives the opportunity of combining surface and groundwater data.

Strengthening the district level

Most of the project activities, particularly those related to the preparation of District Water Development Plans, are done at district level (District Water Office). Institutional strengthening at district level is possible and is badly needed. On the one hand, WRAP has succeeded in establishing a Water Resources Section to build Regional Water Resources Databases and, together with the district staff, to prepare District Water Development Plans. On the other hand, the project had to make a very substantial effort in getting this done. But in fact, the district level is too low, has insufficient capacity, and, perhaps even more important, depends too much on the central level to sustain this task. Another limitation, of course, is the district approach and the inability to go beyond the district boundaries in planning.

Strengthening the catchment approach

The project has attempted to get direct support to the Catchment Boards, but this was not accepted by the Ministry. Under the present phase V, however, the project is preparing water resources management models for two catchment areas where the demand for surface and groundwater had reached such a level that conflicts have arisen. The models will be used for scenario analysis, the results of which will be presented to the Catchment Boards to give them better tools for decision-making.

Water resources monitoring (system and finding)

Within its areas of operation, the project has revived surface and groundwater monitoring. More recently, the project started the operation of a national monitoring network. Establishing a regular monitoring system, however, appears to be a difficult exercise. Monitoring is costly; as long as project funds are available, there will be no problem. Handing over the monitoring network to the government at this stage will almost certainly lead to the collapse of the monitoring. Budget allocations for water resources monitoring purposes are too low by far.

The project has tried to solve this problem by developing a system of direct funding. Organizations or individuals who want to get water resources information from the WRAP-supported National Water Resources Database of the ministry have to pay for this information. The funds generated in this way are then used for water resources monitoring.

This approach was both a success and a failure. There is sufficient interest in obtaining reliable water resources information. Funds generated are at least such that, along with external support, a limited water resources monitoring network could be sustained. However, the control of funds is almost impossible; it appears to be very difficult to use the funds generated by selling water resources information for the purposes of water resources management. Another negative effect is that the fees set by the ministry are too high; having very limited funds, the ministry raised the fees for supplying bore-hole completion records to extraordinarily high levels. Formalizing the process of issuing water resources information has, on the one hand, led to improved data security. On the other hand, the project has received a lot of complaints from the field that it had become impossible to use the established informal ways of getting the required data - data for which, moreover, people had to pay.

Conclusion: suggestions to improve water resource management

It is very difficult to prescribe, as an outsider, how water resources management in Kenya should be organized. The African context is quite different from European or American conditions. Delegation of power and authority, for instance, is very hard to realize. Nevertheless, it is possible to indicate in which direction water management should develop. It is also possible to indicate which steps might be feasible and which are not.

There is a need for improved legislation, delegation of authority, and independent decision-making.

Improved legislation

The Water Act should be modified. All activities related to the mechanical abstraction of groundwater, as well as to the disposal of waste water to the underground, should be subject to approval by the issuing of a permit.

Delegation of authority

The centralized system of water management, in which all decisions are made at one central level, should be changed. Policy issues should be dealt with by an independent Water Apportionment Board.

Operational issues should be dealt with at "catchment level", or even "sub-catchment level". The number of "trans-boundary" aquifers in Kenya is limited; it is therefore proposed to use surface water catchment boundaries to delineate the areas of authority for groundwater management.

The present number of six Catchment Boards should be increased. The area of jurisdiction of the Rift Valley Catchment Board should be subdivided into a number of smaller units.

There is hardly any scope for the "District Water Boards". These boards are completely "development-oriented"; they will not be able to deal with catchment-based water resources management.

Changing the water resources management system can best be done by strengthening the Catchment Boards. Strengthening the Water Apportionment Board, with the aim of changing it into an independent water resources management policy-setting institution is, under the present political situation, considered to be not "feasible".

Public decision-making

Strengthening the Catchment Boards should be done by giving them the tools for proper decision-making. Within this context, WRAP aims to develop water resources management models, which can be used for scenario analysis. One of the main features of these models will be a "powerful" presentation of the effects of increased surface and groundwater abstractions on water resources availability - a presentation that can be understood by "non-experts".

The mobilization of influential "non-experts", such as local politicians, is considered to be the best approach in reaching a more balanced decision-making process. At present, the scarce know-how is only available at the central level. Very few people have access to the decision-makers at this level.

The Catchment Boards already have public representatives. The potential power of these representatives should be mobilized. The Catchment Boards should become more independent from within. Board members should be given more know-how and better tools to work with. Only then will they be able to make the sound decisions that are required to safeguard the precious water resources of Kenya.

MONITORING OF GROUNDWATER QUALITY: EXPERIENCES FROM THE NETHERLANDS AND EGYPT

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The views expressed in this paper are the personal views of T.E. Hoencamp. The text of this paper was written by A. Schrevel on the basis of the recorded presentation by T. E. Hoencamp.

Introduction

Groundwater management and groundwater monitoring are two activities, which are not only closely related, but in fact are inseparable. Without proper groundwater monitoring, effective groundwater management is not possible. This chapter discusses groundwater monitoring within the context of groundwater management. It will do so by looking at the cases of the Netherlands and Egypt.

The examples and experiences discussed in this chapter are derived from years of direct involvement of IWACO in groundwater monitoring and management. Involvement in the case of the Netherlands includes advising provincial and central governments, drinking water companies, and industries with an interest in groundwater. At the request of these parties, groundwater monitoring systems are designed and set up, assistance is provided to interpret data, and existing monitoring systems are optimised. The experiences in Egypt are mainly derived from the 15-year co-operation between the Research Institute for Groundwater (RIGW) and IWACO within the framework of the Dutch-Egyptian co-operation program. The joint activities during this period included the preparation of hydro-geological maps, the inventory of aquifers and their potentials, and since four years now, the design and implementation of a groundwater quality monitoring network.

This chapter has four sections. In section one, the question is discussed why monitoring is necessary, which role monitoring plays in groundwater management, and which data have to be collected in groundwater monitoring. The following deals with experiences from the Netherlands. Two examples of groundwater monitoring, and how monitoring data contribute to the formulation of groundwater management policies, are presented. The subsequent section deals with the establishment of a groundwater monitoring network in Egypt. The focus is on critical decisions in the design of a national monitoring network. The concluding section presents a set of principles for effective groundwater monitoring. These principles are based on Dutch experiences in operating a network and the more recent experiences of establishing a network in an arid country like Egypt.

Monitoring

Groundwater resources are not static; they change under influence of natural processes, the actions of groundwater users, and management decisions. Changes can be either planned or uncontrolled. As long as active management does not take place, all changes are uncontrolled by definition. Changes occur with respect to both volume and quality of water bodies. Trends in groundwater resources can be either unfavourable or favourable.

As groundwater is the invisible part of the hydrological cycle, monitoring is a prerequisite to detect and understand changes in quality and quantity of groundwater bodies. Groundwater monitoring involves data collection. Unlike collecting data for the sake of some academic research purpose, data collecting for groundwater monitoring is focused on providing necessary information for management decisions. At all times it should be avoided to collect data for the sake of collecting only, as this results in excessive amounts of data that will never be used. The danger of 'data grave yards' should be avoided.

Data are meant to be fed into the management process. They should be interpreted and used to support management decisions. Management decisions in turn have an impact on a groundwater resource. Monitoring will pick up the changes in the resource that result from these decisions. This new information is brought to the attention of decision makers again, who may be prompted to take new decisions. In other words, groundwater management is cyclic and groundwater monitoring is an essential stage in this process.

It could also be said in other words. Groundwater monitoring means having your eyes in the ground. Its purpose is to understand groundwater resources, and to detect changes and trends in groundwater resources.

Figure 1. The cyclic nature of groundwater monitoring

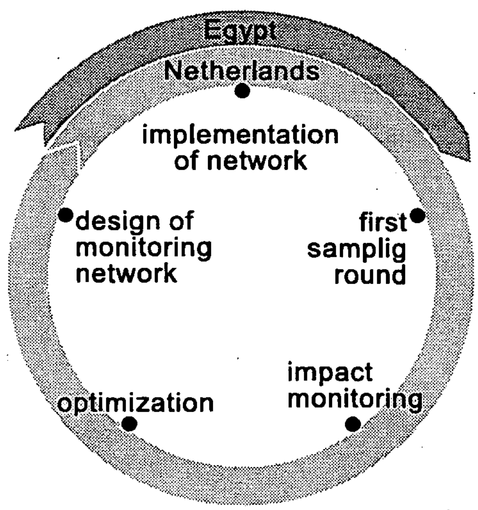


Figure 1 depicts the cyclic nature of groundwater management and the role of monitoring. In the Netherlands groundwater quality has been managed since decades, the various steps of the cycle have been taken several times. In Egypt, groundwater quality management is relatively new; only the first steps of the cycle have been taken. In Egypt groundwater quality monitoring started some three years ago. The first step was to design a national monitoring network. Subsequently, monitoring wells were installed; the physical network was completed only recently. Collection of water samples will start at the beginning of 1998. The experiences gained in the Netherlands with setting up groundwater quality monitoring systems were a useful input in the design phase of the Egyptian network.

Water quality monitoring in the Netherlands

Data on water quality in the Netherlands are collected and analysed on national level at four years intervals. The data are collected by the National Institute of Public Health and Environmental Protection (*Rijks Instituut voor Volkshygiëne en Milieu*, RIVM), which for this purpose operates a network of some 340 wells. These wells have screens at about 10 and 25 metres below ground level. The RIVM is also responsible for data interpretation and assimilation. The data serve practical purposes: they are released to the general public and to specialised organisations, such as RIZA and KIWA.

The design of the data collection network, thereby the system of wells, is based on two criteria: soil type and land use. Three soil types are used in the design process for water quality monitoring in the Netherlands: sandy soils, clay soils and peat soils. Four different land uses are distinguished: agriculture, nature, industry and urban. On the basis of these criteria, homogeneous areas with respect to soil type and land use are identified. An example would be an industrial area on sandy soils near town A. Town A, on the same sandy soils complex, would be a separate homogenous area (same soil type, but different land use). The result is a large number of homogenous areas. The wells are distributed at random in these areas. The location of the wells were determined mainly according to statistical principles

Groundwater quality monitoring implies in general the monitoring of four processes. These are (i) nitrification of groundwater, (ii) acidification, (iii) migration of contaminants, and (iv) salinisation. Nitrification of groundwater is caused by contamination with manure and fertiliser (nitrate problem). Acidification occurs as a result of pollution by industries and transport. Information on the migration of contaminants is particularly relevant in the case of large industrial zones, such as the Rotterdam harbour. Salinization is due to intrusion and upsurge of salt and brackish water; it is a potential risk in the western part of the Netherlands along the North Sea coast.

Initially, the Dutch monitoring network did not provide sufficient information on changes in water quality. This was partly because the network was designed purely on the basis of statistical criteria. An extension of the network was required. Over and above the 340 wells used for water quality monitoring, another set of wells of roughly the same number have been installed by the provinces. Doubling of the number of wells was required in order to gain sufficient information to support groundwater management at a more regional scale (provincial level). In the Netherlands groundwater management is the responsibility of the provinces: ultimately the provinces decide where groundwater can be used or should be protected, how much can be extracted, etc. (see also the contributions by Pellenbarg, Arnold, and Romijn, this volume.)

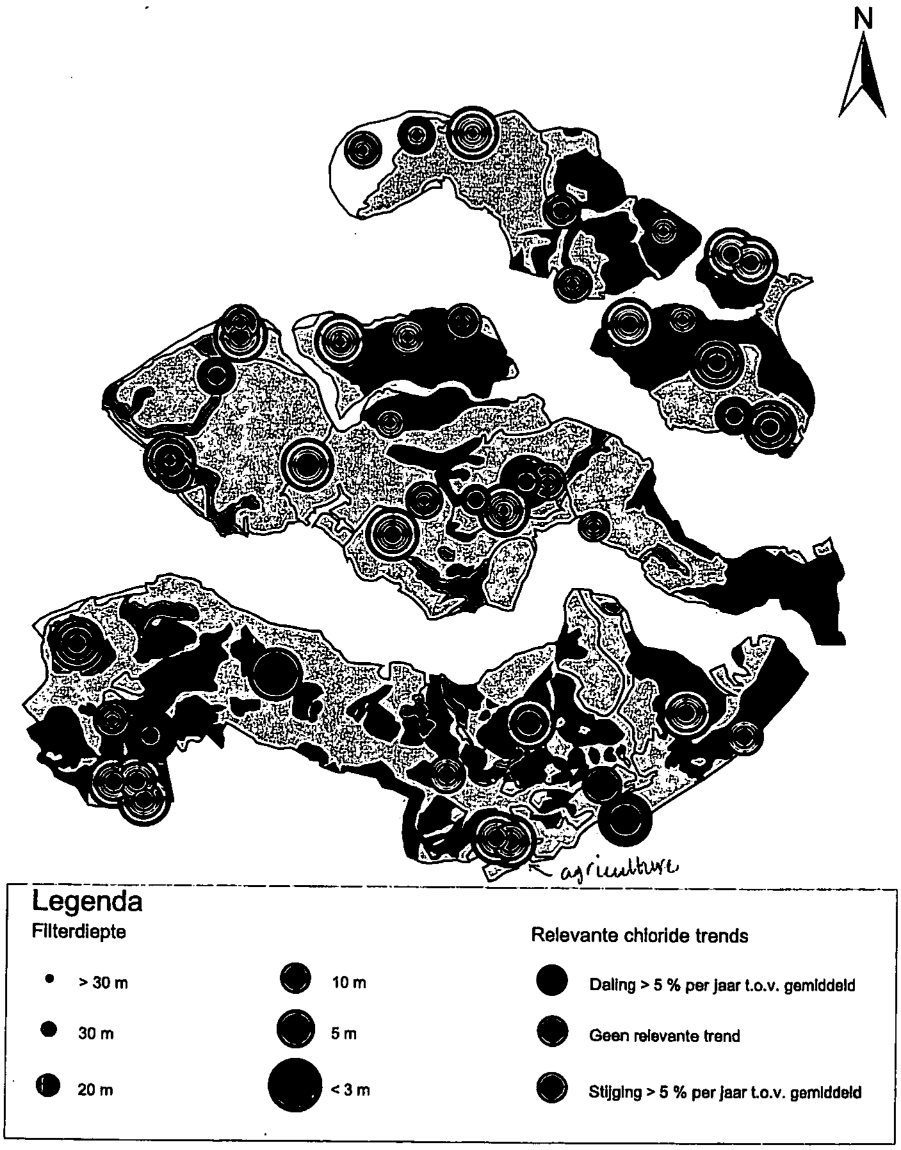
An example will explain the water quality monitoring system in the Netherlands. The example also shows how monitoring data have directly influenced groundwater management decisions.

Walcheren

Figure 2 shows the region of Walcheren. Walcheren is one of the former islands of the province of Zeeland, which is the Dutch province with the longest coast line. The figure is a typical example of an output map for visualisation of groundwater quality conditions. The map looks simple, but the amount of data needed to prepare such a map is substantial. The dots (consisting of several coloured rings each) on the map represent monitoring wells. Each well has three filters, which are situated at different depths. The rings on the map represent these filters; smaller rings stand for deeper filters. The colours of the rings indicate trends in relative changes of chloride values. A negative trend in chloride means that water is becoming more brackish. This is indicated by the colour of red. A positive trend, that is a decrease in the value of chloride, is indicated by the colour of green. The condition that chloride values remain unchanged (neutral) is indicated by the colour of blue.

drained their land by using a very effective subsurface drainage system. In fact, the drainage system was so effective that too much fresh water was drained off. Salt water replaced fresh water; the At location B on Figure 2, farmers blue ring became red. The monitoring system provided the data to observe this trend. Data analyses and interpretation led to the explanation.

Figure 2. Groundwater monitoring Zeeland, The Netherlands



A water management decision, involving both provincial authorities and farmers, was taken. It was mutually agreed to avoid excessive drainage. This would probably stop and even reverse the intrusion of brackish water. The understanding of what exactly was going on underground was correct. As a result of the management decision the brackish water near the surface turned fresh again after a few years.

Both of the above mentioned examples illustrate the relation between groundwater quality monitoring on the one hand and active groundwater management on the other.

Groundwater quality management in Egypt

The national Research Institute for Groundwater (RIGW) was established in the 1950's. One of the first activities of the institute was the establishment of a monitoring network with wells all over the country. Until recently the wells were used almost exclusively for the measurement of water levels. The quantitative aspects and not the quality aspects where the aspects that policy makers were interested in. Water levels were measured regularly, at monthly intervals. Altogether some 800 wells were installed.

Water quality management became an issue only in the early nineties. The RIGW published three studies that assessed contamination of groundwater by waste products from the agricultural and industrial sectors and from households. The assessments were based on a preliminary monitoring campaign (RIGW/IWACO 1990). The study of the RIGW showed that agricultural pollution occurs at least locally. Farmers all over the country, but in particular in the irrigated Nile basin (Nile valley and delta), apply high levels of fertiliser. Contamination of groundwater with nitrates is most serious along the fringes of the Nile basin. Here, soils are more sandy, highly permeable and thus more vulnerable to pollution. Immediately adjacent to the Nile and in the Nile basin itself, the aquifer is less vulnerable to pollution. A thick layer of clay (upto12 metres) protects the underlying groundwater, which is of relatively good quality.

Industrial waste is another source of contamination. Groundwater quality monitoring in the industrial areas around Caïro and new industrial cities, like Sadat City and Tenth of Ramadan, aims at detecting if groundwater is polluted with industrial waste products (heavy metals, industrial solvents, dying agents, etc.). Pollution is expected due to a general lack of adequate treatment and environmental care systems. In some cases industrial waste water is transported to oxidation ponds and discharged afterwards into infiltration areas. During this process contaminated water could infiltrate directly into the subsoil and mix with good quality groundwater.

A third source of contamination of groundwater in Egypt are open drains that are used as sewers. Water from these open drains is often contaminated with bacteria from domestic sources. It infiltrates into the subsoil and reaches groundwater bearing layers down to a depth of 15 m below surface. This contamination is a direct threat to public health, especially in areas where shallow hand pumps are used.

Groundwater is becoming a more important source for water supply (domestic, industrial and agricultural purposes) and groundwater quality problems require actions at the central level. To accommodate these requirements, a national groundwater quality monitoring network was established. Based on Dutch experiences, a network was designed applying a process-based approach. This implies a relatively long design period of about three years. The process-based approach includes a thorough inventory and interpretation of the various geological, hydro-geological and hydro-chemical data and processes.

Special care is warranted during the early stages of designing a monitoring network. The problem is that each monitoring system produces its own set of data. Once a system is in place, it is difficult, and often impossible, to produce other data than the system was designed to produce. In the case of Egypt, designers started at the end of the process and moved backwards. They first made an overview of the immediate and mid-term data requirements among clients (Ministry of Public Works, drinking water companies). Subsequently, a monitoring system was designed which would produce these data. This in turn determined the location of the wells, well depths and screen depths.

The objectives of the national groundwater quality monitoring network are:

- to quantify changes in groundwater quality, either caused by pollution or by salinisation;
- to describe the overall current groundwater quality status on a national or regional scale.

The process-based design procedure is summarised in Table 1.

Table 1. Process-based procedure for setting up the national groundwater quality monitoring network, Egypt

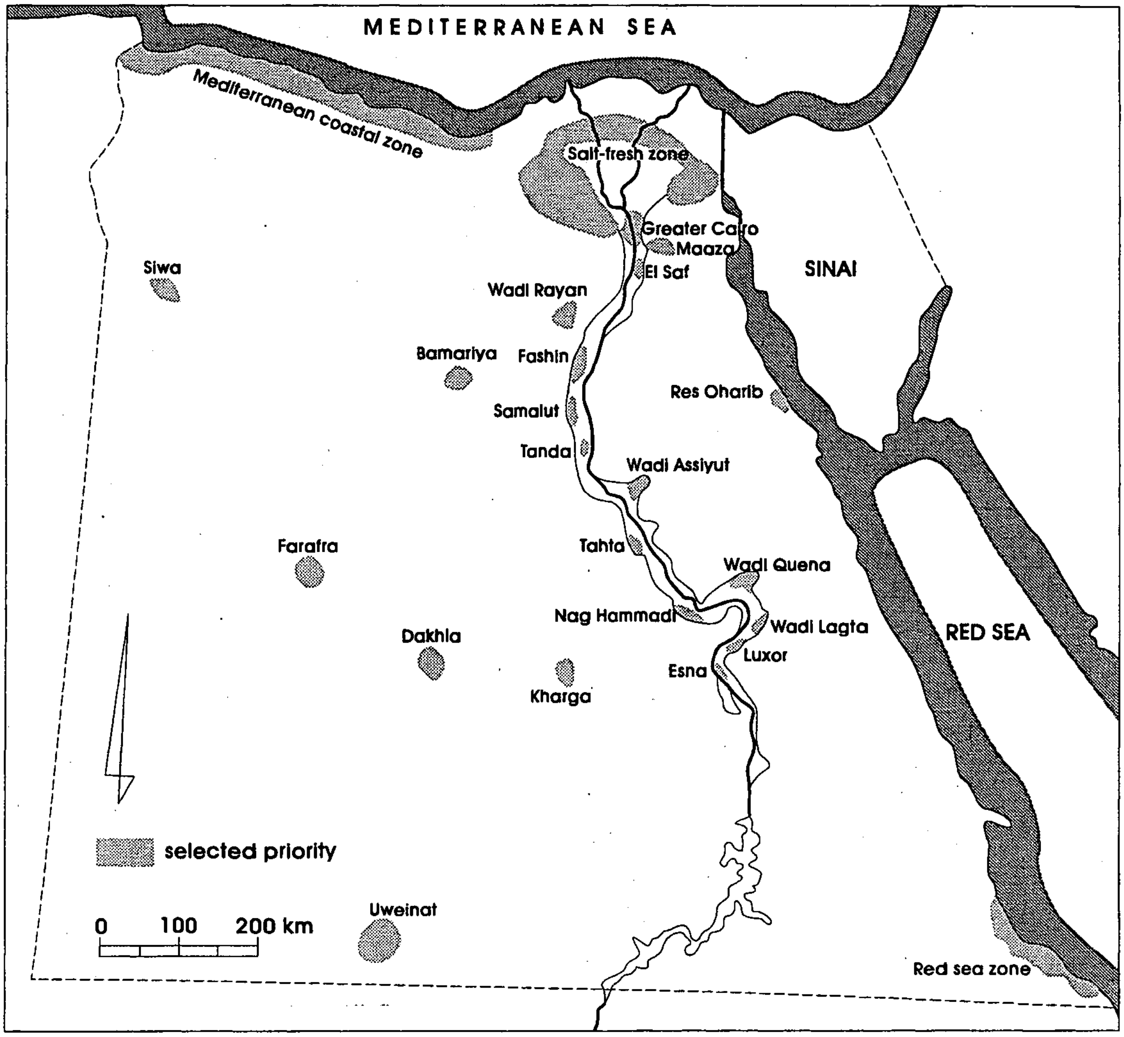
Step	Activity
1	Identification of regions and aquifers
2	Identification of hydro-chemical units
3	Identification of priority sub-areas
4	Selection of areas for monitoring salinisation
5	Identification of homogeneous pollution units
6	Selection of monitoring areas and final distribution of wells
7	Detailed design
8	Construction of wells
9	Sampling, analyses and data reporting
10	Evaluation of data, reporting and optimization

source: RIGW/IWACO 1994

Data collection and inventory is carried out in step 1 to 5. In step 6 priority areas are identified. These are areas where relative are rapid changes in water quality are expected. The total number of wells that could be installed is estimated on the basis of available budgets and other resources The distribution of wells over the priority areas is based on the size and potential threats (salinisation, pollution). Detailed design (step 7) starts with a general determination of well locations and well depths. In order to decide exact locations, conceptual hydro-geological models are produced for each priority area. In such models the information produced in step 1 to 5 is included. This includes data on main aquifers, groundwater flow directions, possible sources of pollution, and areas of salt water intrusion. On the basis of these models, the detailed network of monitoring wells is determined.

Figure 3 shows the priority areas for groundwater quality monitoring in Egypt. The main aquifer in Egypt is the Nile aquifer. This aquifer underlies the Nile valley and the Nile delta. Other aquifers are more local in nature, like the aquifers near the Mediterranean and Red Sea coast, which exist in wadi deposits, fractured rock or limestone. The proposed priority areas are all examples of aquifers in which rapid changes in either volume (because of large scale groundwater abstraction) or quality are expected. In these areas a relative larger numbers of wells will be installed. In areas where changes in groundwater quality are not expected to be acute, a less dense network is designed (remaining part of the Nile basin). The emphasis in the latter areas is on reference wells. Sampling, that is, data collection, will take place with a frequency of once a year in the priority areas, where rapid changes are expected, and once every five years in areas where changes will not occur as rapidly.

Figure 3. Priority areas for monitoring



Concluding remarks and recommendations

This chapter is concluded with a number of comments and recommendations on groundwater management and the design and establishment of monitoring systems. Some of these recommendations have a more general character and have been suggested also by other contributors to this book.

Integration of groundwater and surface water in day to day management

Groundwater and surface water bodies are physically interlinked; and need to be managed in an integrated way. Egypt is in the favourable situation that both surface and groundwater are under the responsibility of the Ministry of Public Works and Water Resources (MPWWR). The institutional integration of surface and groundwater management in Egypt is therefore not an issue.

Initially, groundwater and surface water management/monitoring in the Netherlands was carried out by different institutions. During the last decade the concept of integrated water management has been introduced.

Participation of (ground)water users in the management of their resource
The MPWWR has made a start with involving various users (industries, tourist companies, drinking water companies, and of course, farmers) in decision making. As an example can be mentioned an integrated water management project involving users, which will soon start in the Aswan region.

Both quality and quantity aspects need to be considered in water management
Practically this means that research institutes, like the RIGW, but also the Drainage Research Institute and the Nile Research Institute, will be actively involved in water management. This results in, for example, exchange of information and comparison of data sets. This will help in getting a consistent overall picture of the (ground)water resources in Egypt.

Also in the Netherlands further integration of the monitoring agencies is required.

Data needs of clients determine the design of monitoring networks.
The data needs of clients, the actual users of data, determine the design of a monitoring network. A first step is the formulation of relevant questions. Relevant hydro-geological processes and expected trends in groundwater quality should be investigated prior to network construction. A process-based design procedure, which takes into account available data and existing hydro-geological knowledge, will provide fit-for-purpose networks.

Related is the need to be consistent in the operation of the groundwater quality network. Sampling approaches, analytical techniques in laboratory, etc. should not be changed (without warning) during the monitoring process, as this results in data and conclusions that can not be explained.

Improvement of data collection systems is required from time to time. Monitoring systems provide specific data, namely the data that the systems are designed to produce. Information needs may change over time. Changed information needs in turn necessitate adjustments in the data collection system.

In the Netherlands optimisation resulted in an extension of the monitoring network. Experience made clear that a statistical design approach has its limitations and that a process-based design procedure results in a more fit-for-purpose network.

Water users need to be made aware of the potentials and the limitations of the resource they are using.
Water users and water managers, including decision making authorities, need more adequate information. Decisions to allow users to extract groundwater are sometimes based on limited information. In Egypt tailor-made maps are used that show both quantity and quality aspects of groundwater resources. These maps are easy to use by the responsible authorities and include sufficient information. The maps provide the basis for various (ground)water management plans. The existing licensing system could be optimised so as to serve as an effective management tool.

(Ground)water management will benefit from decentralisation.
In Egypt, decentralisation of (ground)water management has a special meaning, as water is considered a strategic resource. The country is almost entirely dependent on the Nile for its water. Without the Nile, there would not be Egypt. Notwithstanding this importance of water to the national economy and stability, decentralisation of groundwater management is still believed to be required. The main reason is that the distance from the central government to users is unpractically long. Lower level governments have a better view of conditions that affect water use and can react more rapidly to undesirable developments.

In the Netherlands authority to make water management decisions has also gradually shifted from national to regional level.

This paper is concluded with a final observation.
In all countries groundwater monitoring can be further improved. Ultimately a more complete picture is possible, showing in detail both quantitative and qualitative aspects of groundwater. However, a groundwater resource is a very variable medium (in space, time and composition). In particular the quality of groundwater is difficult to predict, as it changes constantly under influence of all kind of hydro-chemical processes. Processes that we may never be able to fully understand, or even measure.

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GROUNDWATER MANAGEMENT IN THE NETHERLANDS : BACKGROUND AND LEGISLATION

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Introduction

Until recently in history, groundwater in the Netherlands was never a problem. There was always plenty of good groundwater in the thick diluvial sediments, fed by precipitation and by rivers like the Rhine, Meuse, and Scheldt and their side-streams. The Dutch lowlands - the coastal zone at about sea-level - floated on groundwater, as they still do; and in the hills in the central, eastern, and southern parts of the country, there was no big shortage of groundwater either. The groundwater quality was quite good too. Only in some parts of the coastal area was the groundwater brackish or even salty, and at some places it still is.

Today, the groundwater situation is different. For economic agriculture, the drainage level was lowered to obtain a higher production; large areas were drained to build houses; and groundwater extractions for drinking water and industry increased. This is locally causing shortages of groundwater. Even groundwater quality is deteriorating, threatened as it is by industrial pollution, nitrates and phosphates (fertilisers, manuring), pesticides, and acid rain.

In the Netherlands, the groundwater level varies from 0.5 to 1.0 m below surface in the western parts of the land; in the higher areas from 1.0 to 20.0 m. By its hidden nature, the impact of groundwater extractions and pollutions upon groundwater quantity and quality is not easy to see, and only little by little have people become aware of the problems with groundwater. Now that groundwater monitoring networks have been established, they are revealing the effects that groundwater lowering is having upon nature and agriculture, and also the effects that polluted groundwater is having on surface water quality. Especially in a densely populated country like the Netherlands, people feel a strong need for regulation and legislation.

The authorities recognised the changing groundwater situation, studied it, and managed to relate it to other matters such as rain, surface water, drainage, and groundwater extractions. In 1984, this led to the Second National Policy Document on Water Management. In 1989, measures to combat the problem of man-made drought (damage to nature caused by lowering the groundwater level through drainage and groundwater extractions) were laid down in the Third National Policy Document on Water Management. Water management was adjusted to the new situation and so was the legislation: on 1 March 1984, a new Groundwater Act was passed. This act is mainly concerned with groundwater quantities; for groundwater quality, there is other legislation (e.g. the Soil Protection Act). Since 1987, there is also a Water Management Act that covers the management of surface water, surface water levels, water discharge and recharge, drainage, and the relationship between surface water and groundwater. The Groundwater Act covers groundwater management in relation to groundwater extractions by pumping. This paper will focus upon the Groundwater Act.

Groundwater in the Netherlands

When a hole is dug or drilled into the earth, the groundwater table is found at a certain depth. Beneath this level, all soil pores are filled with water and there is a positive water pressure; this is the saturated zone. Just above the groundwater level, pores can also be filled with water, but there is a negative water pressure. Closer to the surface is the unsaturated zone, which is important for all kinds of vegetation.
Beneath the groundwater table the water flows (very slowly, only a few metres or decimetres per year) according to Darcy's Law:

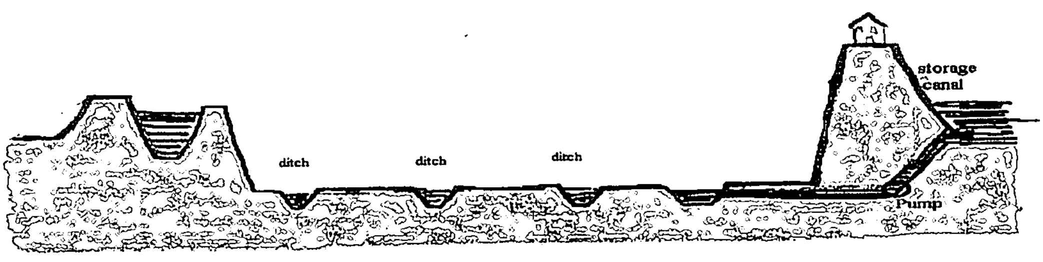
$$q = kD \cdot dh/dx$$

in which q = flow per unit length, kD = transmissivity, x = distance, and h = pressure head. In practice, it is not always as simple as that.

The western and northern coastal areas: the lowlands

In the western parts of the Netherlands, along the coast, land is just above or just below sea level. Large areas are 4 to 5 m below sea level. The deepest polders (east of the city of Rotterdam) are 7 m below sea level. In this zone, there is a complicated system of managing the surface waters with pumps, sluices, and many canals. Especially in peaty areas, the land surface is just a few decimetres above the level of the surrounding canal waters. In that situation, the groundwater table is directly influenced by the level of that surface water. Drawing down the surface water level by pumping (in earlier days, with windmills) means increasing the drainage of the land and a lowering of the groundwater table; this is the way the Dutch have always kept their land dry. On the other hand, drawing down the groundwater level too far is dangerous: the soil, losing its water pressure, will subside, especially in peaty areas. In some polders, the land surface has sunk 2 to 4 m because of continued drainage and over-pumping throughout the centuries. For a cross section of a Dutch *polder*, see Figure 1.

Figure 1. Cross section of a Dutch *polder*

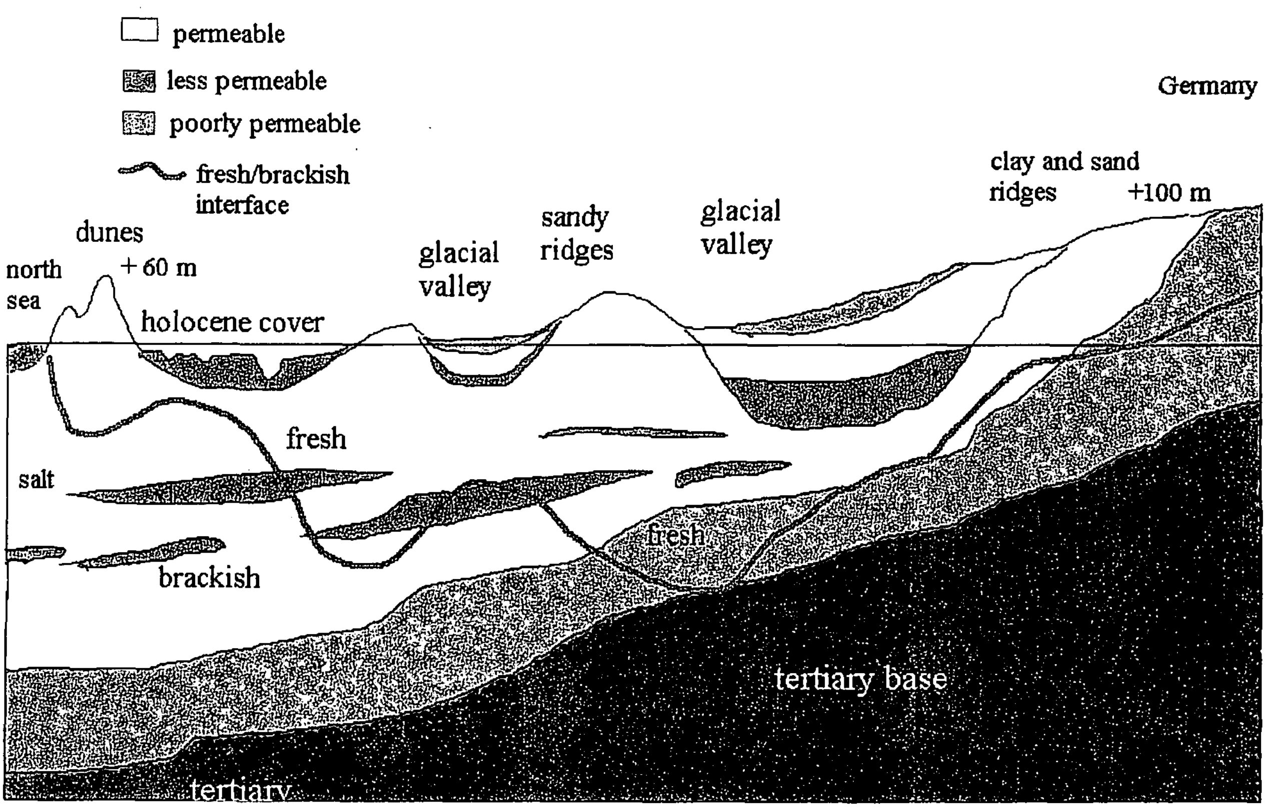


Scheme of a Dutch polder

The subsoil of these western and northern parts of the Netherlands consists of semi-permeable clay and peat layers of holocene age, ranging in thickness from 0 m inland to 25 m at the coast. Along the shoreline are dunes - sandy hills up to 40 m high - which protect the land from being flooded by the sea.

Below the holocene layers, there is a pleistocene system of permeable sand and gravel layers, also with some semi-permeable clay layers. The sandy layers act as aquifers and contain fresh groundwater. But, with increasing depth, brackish or even salt water is to be found. At a depth of 200 to 250 m, there is an impermeable base, the bottom of the Dutch hydro-geological system. Figure 2 gives a cross section of the Netherlands.

Figure 2. West to east hydro-geological cross section of the Netherlands



In these coastal lowlands, there seems to be enough groundwater and surface water, although it is not possible to extract groundwater everywhere. It depends on water levels and groundwater quality (fresh, brackish, salt, polluted). Locally, there can be a groundwater deficit or, rather, a shortage of fresh water.

Some aspects of groundwater extraction in the lower coastal areas are:

- Groundwater in the top holocene layers is not very useful for drinking water. It is polluted by industry, fertilizers, and pesticides. The poor quality of the surrounding surface water can also badly influence the groundwater quality in the holocene clay and peat layers;
- Lowering the groundwater table in the weak peat layers by extractions makes the land surface subside; the layers compress, and can cause damage to buildings;
- Extracting too much groundwater carries the risk of brackish or even salt water rising from the deeper pleistocene;
- The pleistocene layers form a better reservoir for drinking water, but here too, there are limitations to extractions. Pumping or over-pumping from these layers can bring up brackish or saline water. Lowering the water pressure in the pleistocene aquifer can cause a lowering of the groundwater table in the holocene top layers, causing subsidence and damage to buildings.

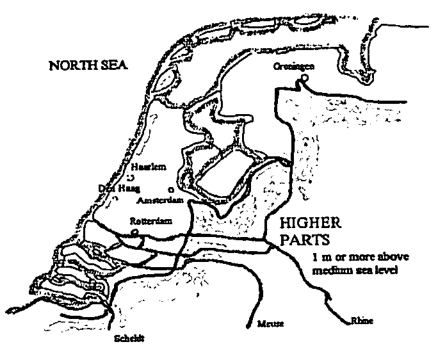
Better sites to extract groundwater are to be found in the higher parts of the Netherlands: the central, eastern, and southern areas.

The higher central, eastern, and southern parts of the Netherlands

It should be noted that "high" in the Netherlands only means "up to 300 m". The highest point is Mount Vaals, 321 m, in the south of the country, near the city of Maastricht on the Belgium/German border.

Most of the higher parts of the country range from 10 to 50 m above sea level (see Figure 3); some hills are 100 to 200 m high. The groundwater situation in these higher parts is more like that in most other European countries. There may be a rather thin layer of clay or peat at the surface, but down to the impermeable hydrogeological base, the whole system can be regarded as one big pleistocene package with some clay lenses. Those clay lenses are not always present. The Province of Drenthe, for instance, consists of pure sand. Also the sandy hills and ridges of the Veluwe area, in the Province of Gelderland, are only sand, created by the Scandinavian ice masses in the third glacial era. The highest hills here are about 110 m (Mount Imbosch). In the Veluwe, there are some local sands that look like small deserts, which, on a warm summer day, can have temperatures of up to 60°C (micro-climate).

Figure 3. Higher and lower parts of the Netherlands



Dividing the Netherlands in a "low" and a "high" part

Groundwater extractions in these higher parts directly influence the groundwater table and can damage the vegetation, as far as that vegetation depends directly on that groundwater. Most agriculture needs relatively wet conditions and so does much of nature. For agriculture, damage by lowering the groundwater table means decreased production; in the worst cases, crops wither and there is no drinking water for cattle. For nature that thrives in wet conditions (moors, brooklands, streamlets, etc.; very often protected wetland areas), it also means withering of vegetation and finally results in the disappearance of rare species.

So, although much more fresh water is stored in the higher parts of the country than in its lowlands, here too the amounts of groundwater that can be extracted are limited.

Some figures about groundwater and the use of groundwater

In an average year, there is a total inflow of water into the Netherlands of up to 110 500 million m^3; most of this is transported to the country by the River Rhine: 69 000 million m^3. Precipitation makes a significant contribution, with 30 100 million m^3; this is about 30% of the total amount of water, typical for a humid area. There are no large variations over the years, the average precipitation being about 760 mm/year. In the past six years summers have been relatively dry.

Table 1. Water balance of the Netherlands in an average year [10^6 m^3]

In		Out	
Precipitation	30 100	Evapotranspiration	19 500
Rhine (at the border)	69 000	Different uses	5 000
Meuse (at the border)	8 400	River outflow	86 000
Other river inflows	3 000		
	--------- +		--------- +
	110 500		110 500

In this hydrological situation, groundwater is extracted as is shown in Table 2.

Table 2. Groundwater extractions in the Netherlands

Groundwater extraction in the year 1988 (in mln m^3)	
Public water supplies	800
Industrial extractions	375
Sprinkling (agriculture)	175
Other extractions	100 +
TOTAL	1450

Given the problems with man-made drought in the Dutch countryside, it is not likely that much more groundwater is going to be extracted than it is today. Some groundwater is used by agriculture for sprinkling. Much more water, however, is "used", or "lost by pumping out", so for drainage of agricultural land to obtain suitable economic conditions for optimal production.

Table 3 gives information about land use.

Table 3. Land use in the Netherlands in 1983 (Central Bureau of Statistics)

	Land area (sq km)	%
Cultivated land	24 042	70.9
Woodland	2 969	8.7
Nature areas (heath, dunes, etc.)	1 557	4.6
Built-up areas (incl. roads)	5 356	15.8
Total land area	33 924	100

Total number of inhabitants in the Netherlands: 15.5 million

Groundwater management, the Groundwater Act

Introduction

The groundwater level can be influenced by varying the level of the surrounding surface waters, by building weirs, and by installing drains. This is more or less covered by the Water Management Act, which places much authority in the hands of the Water Boards. Because of the sometimes direct relationship between surface water and groundwater, especially in the lowlands, groundwater management very often means surface water management.

A Water Board is a typically Dutch institution, historically the oldest institution in the Netherlands. Some of them were founded in the 12th century. A Water Board manages the water system or systems of a unit-area, consisting of one or more polders. The unit-area is a hydrological unit, often a catchment area or part of a catchment area. Each province has several Water Boards within its borders; they are responsible to that provincial authority. In some cases, a hydrological unit or catchment area extends beyond the provincial border; then, the Water Board has to deal with two provinces. Nowadays, for efficiency, there is a tendency towards larger Water Boards.

The groundwater level is also affected by groundwater extraction; this is subject to the Groundwater Act. In the following pages, we shall take a look at some details of the Groundwater Act.

Historical review

Even in olden times, people in the Netherlands had fresh-water wells, most of them very shallow and dug by hand. It was not always easy to find fresh water in the Dutch lowlands, especially before the dikes were built. We know of the well in Iglo Tadema's saga (AD 100). Iglo was a Frisian chieftain who owned a well in the neighbourhood of Stavoren, Friesland.

Unfortunately, his men took too much water from that well. A dreadful dragon appeared and the well turned salty. It is not known which groundwater law the men had broken.

Another example is the well of Saint Willibrord (AD 700) near Castricum, North Holland. Saint Willibrord knew something about groundwater and showed the people where they should dig. This well, which contributed much to his popularity, still exists.

Again, little is known about water legislation in those times. There are, of course, the Old Frisian Laws, written in the years 1100-1300. It could be useful to study that legislation to look for aspects of water and groundwater management.

In the years 1700-1800, special fresh-water transport was needed to supply a big city like Amsterdam with drinking water. So about AD 1800, special "water vessels" transported fresh water from the lakes of Central Holland and Utrecht to Amsterdam. Only small quantities of water could be transported in this way, so this was only a short-term solution. Amsterdam, but also other large cities, needed large-scale water supplies. When surface water of good quality was no longer available, the city was constantly in search of good groundwater. Of course, groundwater was available in the dunes, but people were also aware of the presence of good groundwater at other sites, especially sandy areas in the central, eastern, and southern parts of the country. In the beginning of this century, about 1910, Amsterdam studied the possibilities of extracting groundwater near Barneveld, in the central part of the Netherlands. For the linguists: Barneveld, in English, means "spring field", which indicates the presence of water.

Around 1900, people were already using techniques of making groundwater wells, installing filters and pumps, and extracting the groundwater. But there still wasn't any groundwater legislation; there was no Groundwater Act as there is now. Those who wanted to extract groundwater merely had to apply for a license under the *Hinderwet* (the Nuisance Act). Nuisance was most characteristic for cases of groundwater extractions: if the extraction was considered a nuisance, no license was granted and no groundwater could be extracted.

In those days, of course, little was known about the consequences of groundwater extraction. Nobody knew much about the effects of lowering the watertable, which could be land subsidence, damage to buildings, or the withering of vegetation. A special "Commission of Experts" was therefore installed to study the possible consequences of groundwater extraction in Barneveld. As a result, the Barneveld plan was rejected and, for its groundwater exploitation, Amsterdam had to go to the dunes south of Haarlem. From that time onwards, Commissions of Experts were occasionally installed to investigate the consequences of groundwater abstractions.

In 1934, this led to a permanent Commission of Experts, known as the COWABO: the Commission extracting Water from the soil (Dutch: *bodem*). This COWABO Commission only dealt with groundwater extractions for industrial purposes and for the drainage of building sites. The COWABO could advise the National Government, the provinces, and the municipalities.

In 1954, the Groundwater Act Drinking Water Companies was passed by the Dutch Parliament. A special Commission of Experts on groundwater extractions was installed to advise the Minister of Public Health. This commission was called COGROWA (Comission Groundwater Act Drinking Water Companies).

From that time onwards, "nuisance" was no longer the most important item, but rather "tolerance" and "damage". Typical of this Groundwater Act was that, because of public interest and public health, licenses for groundwater extractions could be granted (if the expected damage was not too severe) and that people were to tolerate these extractions and their consequences; but those who suffered damage could get paid or compensated for the damage done. Today, this act has been replaced by the Groundwater Act.

The new Groundwater Act has been in force since 1984. It covers all groundwater extractions - and infiltrations - for all purposes: drinking water, industry, sprinkling for agriculture, and draining building sites. Here, too, there is a system of tolerating groundwater extractions, granting licenses, and paying/compensation for damage involved. A Commission of Experts (the Technical Commission Groundwater Management) was again in operation, but, in the early 90's, the Commission was dismissed. The technical advice on groundwater extractions is now given by provincial experts who have built up the necessary know-how.

Headlines of the Groundwater Act 1984

There is no ownership of groundwater in the Netherlands. Even the land owner does not possess the groundwater under his territory; that is to say, according to the Civil Law, he only owns the water at the moment it has been brought to the surface. To extract groundwater on your own land, you need a license (or permit). The conditions are laid down in the Groundwater Act (1984). This Groundwater Act deals with groundwater extractions by means of an installation: a pump or a pumping station. Influencing the groundwater table by draining with ditches and canals is not subject to the Groundwater Act, but to the Water Management Act (1987).

The implementation of the various regulations of the Groundwater Act is in the hands of the provinces. In this way, the provincial authority is the groundwater manager.

An important instrument in managing groundwater is granting (or refusing) licenses for groundwater extractions. Another instrument is the registration of extractions.

But what is the groundwater managers's philosophy about the granting of licenses? In what cases will a license be granted? How much groundwater can we use? For what purposes?

In the Netherlands, a densely populated area with intensive groundwater use, possibilities are not unlimited. Up till 1980, it was assumed there should be about 1850 million m^3 groundwater ready for use. This "exploitable amount of groundwater", divided over the twelve Dutch provinces, formed the basis of groundwater management.

Today, with about 1500 million m^3 being used nation-wide, groundwater extractions will not increase much. Locally, where the groundwater table has dropped too far - with damage to nature and to agriculture - no more groundwater can be extracted. At other places, where surface water is plentiful, some more groundwater can possibly be extracted. For every region there is a "most suitable groundwater situation", a situation where the groundwater table corresponds best with local functions like agriculture, housing, and nature. In Dutch groundwater management practice, this "most suitable groundwater situation" is going to be defined, and will serve as the basis for the licensing policy. Of course, much research and a lot of discussions are going on about what is the "most suitable groundwater situation".

Another aspect is the kind of groundwater use. For what purposes? In the Netherlands, the limited groundwater resources are mostly reserved for special "high-class" purposes, purposes that absolutely need high- quality water: for drinking water, preparing food, drinks, etc. In some cases, a license can be refused, or water of a lower classification can be used (e.g. cleaning water for industries, cooling water, sprinkling, etc.).

Licenses are granted for ever: there is no limit in time. In the Dutch groundwater management system, the license is not transferable to other persons, neither can it be sold.

Summarising, the important keywords are "personal licenses", the "most suitable groundwater situation", and "high-class purposes" for groundwater use.

In the Netherlands, so densely populated, the influence of a groundwater extraction, especially a large one, is nearly always noticeable. There may even be damage to agriculture, to housing, or to nature. Nevertheless, a broad public interest (e.g. drinking water) can be the reason for granting the license and starting the extraction. In such a case, people have to tolerate the extraction, but they can be awarded compensation. So other keywords are_tolerance (you have to tolerate an extraction once a license has been granted) and compensation for damage.

But most important is a good groundwater policy, laid down in provincial water-policy documents that include sections on groundwater.

Provincial water management policy: groundwater section

By virtue of the Groundwater Act, the groundwater managers (i.e. the provinces) have to draw up groundwater plans, which should include:

- A description of the planning area;
- The aims and purposes of the groundwater policy;
- Measures to be taken, latest date of gaining the object, deadlines;
- An estimate of the costs of research needed for good groundwater management.

The groundwater section plans should be accompanied by the following information:

- Research details on relevant aspects;
- Investigation of all interested parties concerned;
- Relationship with surface water;
- Relationship with other plans and policies of the authorities involved.

Finally, there should also be some technical information:

- A description of the hydrogeological situation, particularly the "desirable groundwater situation, regarding all interests of nature and groundwater users involved";
- Registration of all groundwater extractions and infiltrations (their quantities);
- The influence of existing extractions and infiltrations;
- The future need for groundwater; the way it will be used;
- How to provide the future demands for groundwater? Are there any alternatives (like using surface water)?
- List of all research done and any other authorities involved.

Licenses for groundwater extraction

The Groundwater Act, in one way, is very special: once a license has been granted by the province, every citizen has to tolerate a groundwater extraction (or infiltration) whether he likes it or not. Very often there is a major interest of public water recreation or public health. This can be a reason for granting a license, even though there may be objections to it in the region.

The affected party can react in two ways:

- By asking the province for financial compensation for damage;
- By going to the High State Council to get the license cancelled before it comes into force.

Once the license has been granted and damage has been suffered (by farmers, for instance: decreased production, withering of crops, no drinking water left for cattle; also damage to buildings in housing areas), the affected party cannot lodge an appeal against that license. But, in such cases, he can claim compensation for the damage and can ask for an investigation into the damage. A Damage Commission of Experts will then study the damage and will propose the financial compensation to be paid to the affected party by the license-holder. The Damage Commission is a group of independent experts, paid by the provinces.

Before the provincial authority grants a license, it needs a technical report on all aspects of the planned groundwater extraction. This report is made by hydrological engineers of the provincial office, and is open to public inspection.

Very important in the license-granting procedure is the advice of the Provincial Water Management Commission, in which all parties concerned are represented.

Only the larger groundwater extractions are subject to the licensing procedure. It is not efficient to adopt this time-consuming procedure for lots of smaller extractions. For the relatively small groundwater extractions, special conditions are laid down in the Groundwater Act, and these extractions, of course, have to be registered; this can be regarded as a system of "common license". The smallest groundwater extractions only need to be registered; no special conditions apply.

Procedure of granting a license to extract groundwater, Dutch Groundwater Act

The steps that need to be taken before a license to extract groundwater is granted are the following:

To the province:

1. A written application is submitted to the provincial authority;
2. The province confirms the receipt of the application;
3. The province studies the application; makes a technical study of geo-hydrological, agricultural, and environmental aspects, and compiles this information in a technical report.

From province to municipality:

4 The date of hearing is agreed upon;
5 The application is posted at the town hall, visible to all citizens;
6 The hearing is organised by the Provincial Water Management Commission;
7 The municipality's judgement is pronounced;
8 The application + the municipality's judgement is sent back to the provincial authority.

Back at the province:

9 The application is discussed by the provincial water commission (managing commission: representatives of public organisations and all other parties concerned);
10 Back to the provincial authority, which decides whether to grant license;
11 The provincial decision is posted in the town hall, visible to the public;
12 Period of giving notice of appeal (by people who will be affected by the extraction);
13 License is granted and comes into force.

The procedure from Stage 1 (application submitted to province) to Stage 10 (decision made by province) may not take longer than 12 months. Stage 5 (application posted in town hall) to Stage 8 (application + comments and objections sent back to province) may take a maximum of 2 months, according to Article 19 of the Groundwater Act. The discussion by the provincial water commission (Stage 9) may take a maximum of 2 months.

Every year, about 15 to 20 licenses for larger groundwater extractions (more than 1 million m^3/year) are granted in the Netherlands. About 5 to 10 appeals are sent to the High State Council. There are, of course, numerous smaller extractions for many purposes; information about them is available from the provincial authorities.

Fees, levying

Every license-holder has to pay a levy to the province by virtue of the Groundwater Act. Article 48 of the act states the purposes for which the province can use this money:

- Research on groundwater problems, study of the provincial groundwater situation, and maintenance of the groundwater monitoring network (there are thousands of measuring points in the Netherlands);
- Compensation for damage:
    * If damage is caused by research activities ordered by the province (e.g. the effects of lowering the groundwater table by drilling tests);
    * If it is not quite clear which of the many groundwater extractions causes the damage.

  To avoid long waiting times because of very long and complicated investigations by the Damage Commission, the province can pay compensation.

The provinces decide which levy has to be paid; this differs from province to province. Most provinces have a levy of about 1 or 2 Dutch cents per m^3 extracted groundwater. This only has to be paid for the larger groundwater extractions, which have to be licensed. No levy is needed for the smaller extractions, but they do have to be registered.

Last year, the Dutch Parliament discussed an addition to Article 48 of the Groundwater Act, which will make it possible to use the levies to combat the problem of man-made drought. This will provide funds to pay for measures to restore damaged nature as far as this damage is related to groundwater extractions (20% of the drought problem is related to groundwater extractions; 60% is caused by drainage for agriculture). With this addition, levies will probably rise to perhaps 4 or 5 Dutch cents per m^3 extracted groundwater. This addition came into force on 1st January 1997.

Apart from the Groundwater Act, there is an Environmental Tax Act. The aim of this act is to make people aware of the environment and to prevent them from an endless use of groundwater, from polluting surface water, and so on. For these activities, people have to pay taxes to the National Government via the Ministry of Finance.

Using groundwater will cost the license holder:
- 34 Dutch cents per m^3 groundwater extraction for drinking water purposes;
- 17 Dutch cents per m^3 groundwater extraction for industrial purposes.

The yield of this tax flows directly to the state's finances and will not necessarily be used to solve groundwater problems.

The Groundwater Act; some articles concerning licenses for groundwater extractions

Finally, some of the articles in the Groundwater Act are presented as these are informative about the management system introduced by the Act.

Article 14
1. It is prohibited to extract groundwater or to infiltrate water, unless the provincial authority has granted a license for it;
2. Conditions can be added to that license to protect interests involved in groundwater management;
3. Stated in the license is how much groundwater should be extracted and the purpose of the extraction.

Article 16
1. A written application for a license to extract groundwater has to be submitted to the provincial authority;
2. The province declares by provincial regulation what information applicant should add to his application.

Article 18
The provincial authority sends a copy of the application and all other relevant information, including technical remarks, to:
a. Municipalities, water boards, and drinking water companies in whose region the planned groundwater extraction will take place, and also to the farmers' representatives;
b. The provincial water management commission.

Article 19
1. The burgomasters of the municipalities mentioned in Article 18 post the application for public scrutiny in the town hall, <u>one month</u> before the hearing mentioned in Article 19. The burgomasters announce this posting for the public in the official Dutch State Newspaper and also in regional newspapers;

2 During the period of posting for the public, anyone can raise objections against the planned groundwater extractions;
3 Within one month after the end of the period of posting for the public, the burgomasters send all objections to the provincial authorities.

Article 20
1 A hearing is to be organized in all municipalities involved; every person has the right to explain his objections;
2 A representative of the provincial authority leads the hearing; technical experts are present at the hearing;
3 A record is made of the hearing.

Conclusions

The Dutch groundwater policy and legislation have developed over a long period of experience. Now it is a complicated system of granting licenses based on the region's best suitable groundwater system, high-class purposes for groundwater use, tolerance, and compensation. It is very specific for the Dutch geographical system: a densely populated area with deep sediments and a humid climate.

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GROUNDWATER MANAGEMENT IN THE NETHERLANDS : A SECTORAL APPROACH TO INTEGRATED WATER MANAGEMENT

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Introduction

Even in a wet country like the Netherlands - or even particularly in a wet country like the Netherlands - problems with the quantity and quality of groundwater exist. Pellenbarg, in his paper "Groundwater Management in the Netherlands : Background and Legislation" gives a brief overview of the geo-hydrology of the Netherlands (this volume). Because of its typical geo-hydrology, the Netherlands, like most deltaic areas, has thick unconsolidated sediments and shallow groundwater tables. A strong interaction thus exists between the systems of surface water and groundwater. The quantity and quality of groundwater are closely related. In such a situation, where groundwater has an important function for different, mostly conflicting interests, groundwater management is very complex.

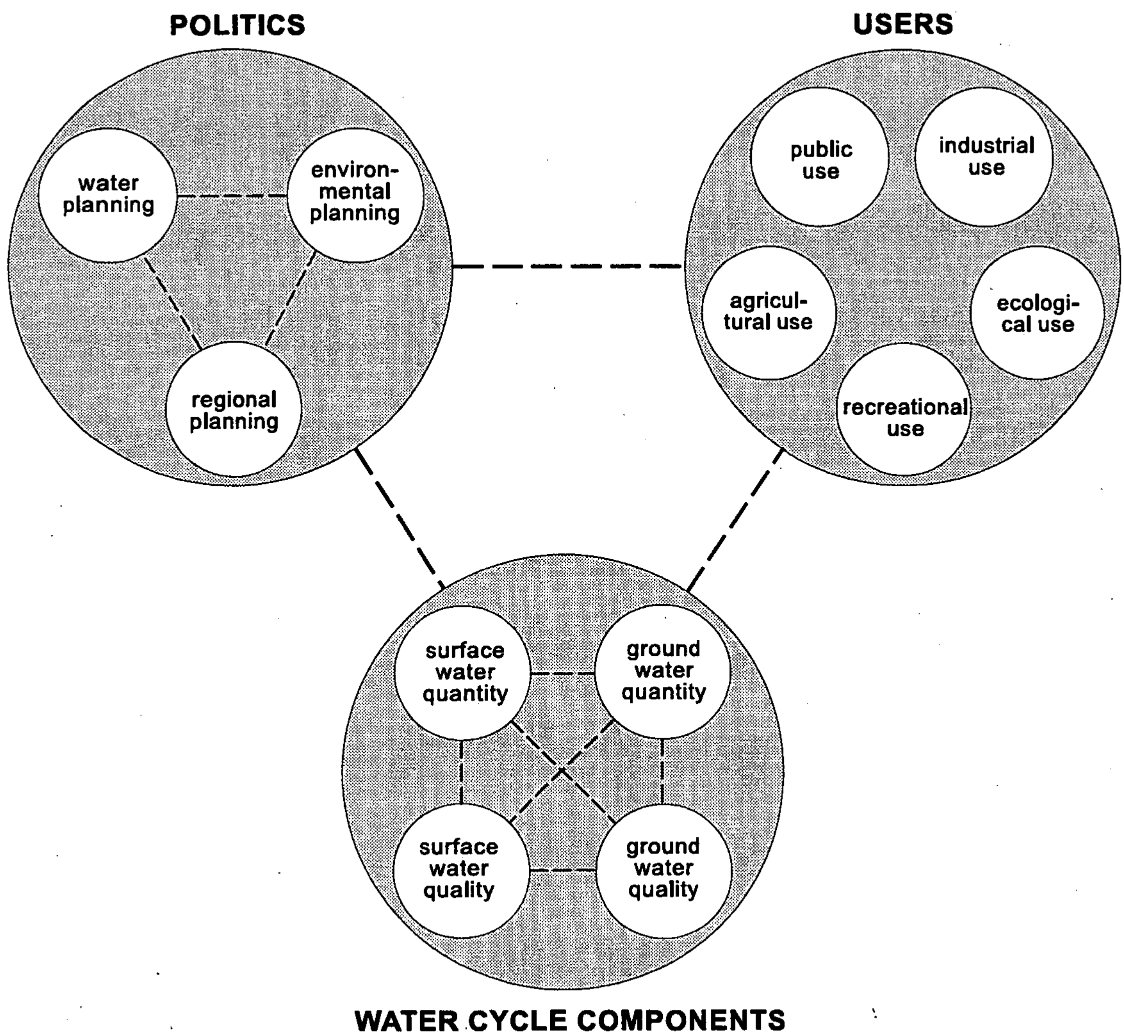
This paper will start with a review of the different users of groundwater, and will then go on to describe the developments in water management in the Netherlands. This will be illustrated by a new approach in using water resources management as a tool to solve the problems of desiccation[1], one of the environmental problems we in the Netherlands are facing.

Problem identification

Until the end of the seventies, groundwater management was mainly focussed on the interests of safety (keeping one's feet dry), and on supplies for drinking water, for industrial use, and for agriculture. Water management was characterised by a sectoral approach (i.e. each sector focused on its own developments, scarcely taking into account the interests and developments of the other sectors). The different sectors often have conflicting interests as to the quantity and quality of water. The policies developed for water, environmental, and regional planning were not attuned to one another. Surface water and groundwater were treated independently, as were aspects of quantity and quality. This stage in development is presented schematically in figure 1 (Engelen and Kloosterman 1996).

[1] Desiccation, dehydration and drought damage are all inadequate translations of the Dutch *"Verdroging"*. *"Verdroging"* is one of the themes for the Netherlands' environmental policy used to indicate a group of related environmental problems resulted from water shortages due to groundwater extraction and enhanced drainage (see further elsewhere in this paper)

Figure 1. Sectoral analysis, planning, and use.



Source: Engelen and Kloosterman 1996

In the Netherlands, safety is - and always has been - the most important factor. But, in a large part of the country, with peat and clay soils, high groundwater levels must be maintained to minimise the risk of land subsidence and the seepage of brackish water.

Since the fifties, water management has undergone a complete change. Water management measures for agriculture (e.g. the improvement of drainage systems) have been implemented on a large scale to intensify crop production and to prevent yield depressions by waterlogging. Agriculture used to suffer from high watertables in spring. But, with better drainage systems, the risk of drought damage in summertime increases. Integration is limited or lacking. Even so, drought damage was considered less harmful and sprinkler irrigation could always be applied.

Since the dry summer of 1976, sprinkling, with both surface water and groundwater, has been frequently applied. In the past few decades, groundwater abstractions for drinking water have increased, mainly because of the increase in population. Table 1 shows the increase in groundwater abstractions for agriculture and for supplies for drinking water and industry.

Table 1. Development in groundwater use for agriculture and for drinking and industrial water supplies in mln.m3/year.

	Groundwater abstraction in mln. m^3 per year				
	1962	1976	1986	1994	2015 (approx.)
Sprinkling	-	85	150	130	
Drinking water*	370	740	785	825	900
Industry	435	290	320	240	165

*) Roughly 2/3 of the total demand for drinking water comes from groundwater, and 1/3 from surface water

All these developments have contributed to a structural lowering of the watertable, not only in the areas where groundwater is pumped, but also in the adjacent nature reserves, which is leading to a degradation in the natural value of those areas.

The changes in water management can also result in a diminished intensity of upward seepage and in an increase in the distribution of poor-quality surface water to counteract drought damage in agriculture. The intensification of agriculture can also have a negative effect on the quality of groundwater, due to an intensive use of nutrients and pesticides. In general, with the greater use of groundwater, fresh groundwater has become scarce.

All these negative effects, especially for groundwater-related natural vegetation, is called 'desiccation'. It has become common in the Dutch geo-hydrological situation.

Summarising, it can be said that desiccation is caused by:

a Intensification of drainage for agriculture and urban areas;
b Increased groundwater abstraction for drinking water, industry, and agriculture;
c Increased evapotranspiration by crops due to higher crop production;
d Increased foreign[2] water supplies.

It has been estimated that the three causes, a, c, and d, contribute 60% to desiccation, b about 30%, and other causes 10%.

In 1984, two reports were issued: The Second Dutch Policy Document on National Water Management and The Indicative Multi-Year Programme on Environmental Management. Both reports were signed by the three ministers responsible for water management: the Minister of Housing, Physical Planning, and the Environment; the Minister of Agriculture, Nature Management, and Fisheries; and the Minister of Transport, Public Works, and Water Management. In these documents, the structural lowering of the watertable as a result of

[2] Foreign water means that due to a lower surface water level in this desiccated area water from another watersystem (area) with another water quality has been transported to this area. This different water quality has a negative effect at the ecosystem.

intensified groundwater abstractions and other measures in groundwater management was first noticed as a serious problem that could have a negative effect on nature.

After an initial investigation in 1987, the three responsible ministries ordered a second, more detailed, study to quantify and analyse the problem of desiccation. At the same time, the watertable was monitored in a large number of measuring points. This study showed a structural watertable lowering of 20 to 75 cm. Apart from the influence of water abstractions, the watertable had fallen by an average of 20 cm in areas where land consolidation programmes have been implemented, and by an average of 35 cm in areas where this had not yet been done. The difference is explained by the fact that, in the consolidated areas, improved drainage works have been implemented. Both studies, completed in 1989, contributed to the recognition of the problem of desiccation. Desiccation is a local but common problem and, along with 'eutrophication' and 'acidification', is considered a national environmental problem.

The solution : integrated water management

These problems were considered too complex to be looked at separately from their relevant surroundings and could only be solved by integrated water management. Integrated water management is based on an integrated water system approach. This action was set in motion in 1985 with the Dutch Water Management Memorandum, Living with Water.

> "A water system approach gives priority to the water system (including groundwater). The approach aims at the optimal co-ordination of the wishes of society with regard to the functions and the functioning of the water systems (sectors and facets) by means of an integrated consideration of them with the potential of the systems, using a technical infrastructure and a set of legal instruments".

In this philosophy, groundwater and surface water - and their quantities and qualities - should be considered together.

With this new concept, it was decided that, after the introduction of the Water Management Act (1987), there would be only one report drawn up for the presentation of the national policy on water management. Previously, two reports had been issued: Water Management of the Netherlands, which dealt with the quantities of groundwater and surface water, and the Indicative Multi-Year Programme for the Quality of Surface Water.

This new concept also had organisational effects. Within the Directorate-General for Public Works and Water Management, the separate divisions for the quantity and quality of surface water were brought together. Groundwater quality is covered in the Soil Protection Act, which falls under the jurisdiction of the Ministry of Housing, Physical Planning, and the Environment.

The Third National Policy Document on Water Management (1989) is the first report in which the national policy on water management was formulated. It covers the quantities of both surface water and groundwater and the quality of surface water. Based on the results of the earlier-mentioned studies of groundwater, an interim target and a final target were defined to control desiccation.
In this policy document, the final target was defined as:

"A groundwater situation (quantity as well as quality) managed in such a way that a sustained use of groundwater by interested sectors is guaranteed, as well as the sustainable development of nature, forest, and landscape".

To reach these objectives, lines of policy have been plotted. Some of these are presented below:

- The most suitable groundwater situation per area should be laid down in the provincial water management plans;
- Drainage measures, permanent groundwater extraction, and sprinkling using groundwater should be planned and attuned to one another in such a way that no (further) adverse effects on desiccation-sensitive areas occur;
- A start has been made with the regeneration of water management in desiccated forests and nature areas by restructuring measures and the adaptation of drinking-water extraction;
- The amount of fresh groundwater to be permanently extracted should be destined for domestic use and for those productive processes that require a high water quality.

To stimulate integrated water management, the government set up a system of subsidies to improve water management in the period 1992-1994. Under this system, the government financed 50% of regional pilot projects. The control of desiccation was one of the themes governed by this system. An example of a regional pilot project to combat desiccation is that of the Dwingelder Field.

The Dwingelder Field

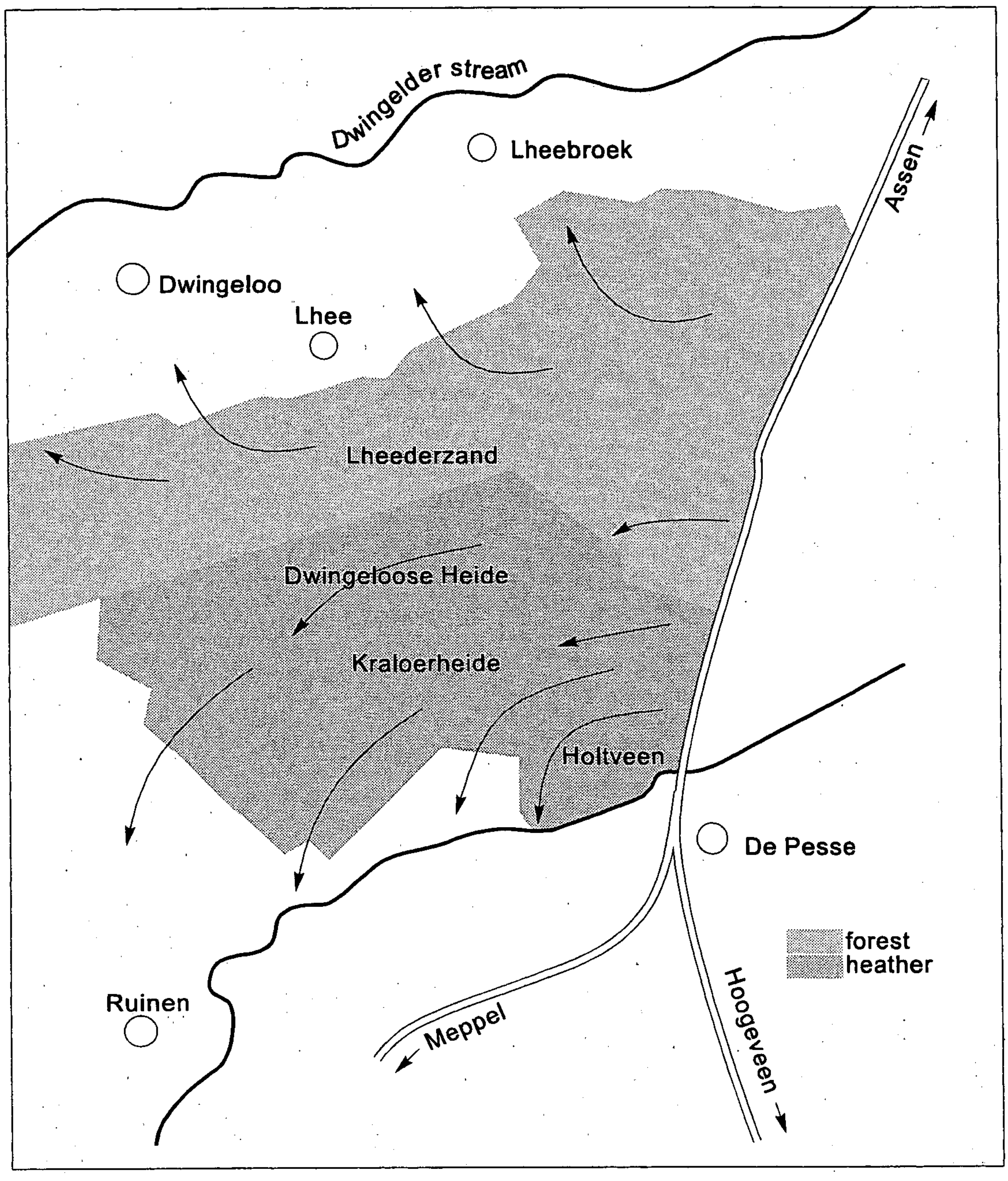
The Dwingelder Field is a moor in the south-west of the province of Drenthe (Figure 2). It is recognised as a National Park. The Dwingelder Field, however, suffers from man-made drought (desiccation). Since 1990, measures have been taken to recover the natural value of the area.

The Dwingelder Field is about 3500 ha of peat-moor and bushes, lying between two brooklets, the Dwingelder Stream to the north and the Ruiner Stream to the south. Drainage of the surrounding cultivated areas had resulted in a drop in groundwater levels of about 1.5 m. This had caused serious damage to the natural vegetation. Many species had almost disappeared. Until 1960, peat had been dug for fuel purposes. To allow this, drainage ditches were dug, which also caused a further lowering of the groundwater table.

A package of measures to combat the desiccation and to restore natural values has now been implemented. First, the level of the brooklet on the south side was raised by building an automatically-controlled system of weirs. The system is connected to a groundwater monitoring system, adjusted in such a way that the higher levels do not cause too much wet damage to the surrounding farms. Some pieces of farmland that nevertheless became too wet

could be bought and added to the National Park. This ingeniously controlled system is expensive: one million Dutch guilders (or approximately 300 guilders per ha)!

Figure 2. Location of the Dwingelder Field



Secondly, the peat-moor part with sphagnum vegetation in the south-east of the nature area became polluted by nutrients in the drainage water that passed the moor from cultivated areas.

A by-pass for this polluted drainage water has now been created. The peat moor has been hydrologically isolated, withholding the original water. Groundwater levels have risen 1.5 m over the last few years. This is giving a new chance for sphagnum vegetation. These measures have been combined with the removal of the top soil layer, which had become polluted with nutrients, and even with lead and cadmium (by rainfall). After this had been done, conditions were good enough to ensure the return of the original natural vegetation.

Monitoring is going on, but we can already say that this pilot project is a great success.

The institutional framework

The present policy for the control of desiccation has been established in the 3rd Policy Document on Water Management, and also in the National Environmental Policy Plan, the Policy Plan for Nature, and the Policy Plan for Drinking and Industrial Water Supplies. The three Ministries responsible (Housing, Physical Planning, and the Environment; Agriculture, Nature Management, and Fisheries; and Transport, Public Works, and Water Management) are all involved with the problem of groundwater and desiccation.

The responsibility of the National Government can be summarised as follows:
- Outlining the policy;
- Adjusting the legal framework (if necessary);
- Evaluating the policy and reporting to the Government and to Parliament (Evaluation Document on Water Management, Environmental Balance).

The National Governmental targets are elaborated in provincial water management plans and in the schedule of measures to be taken. Executing those plans is the task of the provinces, the water boards, and the municipalities, with the provinces playing a co-ordinating role. Their separate responsibilities are summarised below.

Provinces:
- Formulating the policy in water management plans;
- Granting licences for groundwater abstractions;
- Regulating sprinkling by means of provincial regulations;
- Regulating the management of water levels by means of provincial regulations;
- Supervising the policy of water boards.

Water Boards:
- Elaborating surface water management in management plans;
- Managing surface water.

Municipalities:
- Constructing and maintaining the sewerage system.

Desiccation

The National Environmental Policy Plan defines various measures for the control of desiccation. Under this Plan, three projects have become the responsibility of the provinces:
- The control of desiccation;
- Legal instruments to control desiccation;
- Reduction in water use.

After parliament had discussed desiccation, and with new information about the present situation, a resolution was passed that targeted a cut-back of 25% in the desiccated area by 2000, as compared with 1985.

In the framework of the evaluation of the 3rd Policy Document on Water Management, an inventory was made of the desiccated areas that had a function in nature. This inventory was a joint undertaking by the Institute for Inland Water Management and Waste Water Treatment (RIZA) and the provinces. It resulted in an 'indicative' map showing the desiccated natural areas. This inventory indicated that the desiccated area was much larger than had previously been thought. It was decided that this map needed to be regularly updated, because a lot of information was not yet available and because of the differences in approach applied by the provinces.

This map has been used as the starting point of a joint modelling study between RIZA and the National Institute of Public Health and Environmental Protection (RIVM). The model is being used to estimate which measures - both those of water management and the reduction in abstractions - have to be taken to achieve the desired reduction of 25% in the desiccated area and to calculate the costs of achieving this goal. Table 2 shows the results of this study.

Table 2. Costs of measures for water management and drinking water supplies (mln. Dutch gld.)

	1994-2000	2001-2010
Measures for water management	518	p.m.
Extra costs for drinking water supplies	85 + p.m.	850
	------------------+	--------------+
Total	603 + p.m.	850 + p.m.

In 1993, the policy set out in the 3rd Policy Document on Water Management was evaluated. The results were presented in the Evaluation Document on Water 1994. Supplementary policy measures and financing were also incorporated in this Document. In the evaluation study, it was concluded that, to reach the target of reducing the desiccated areas by 25%, additional measures were essential.

Additional policy measures covering the following matters were proposed:

- Further concretising the targets;
- Adjusting the policy on groundwater, which means:
    * Drinking water will be supplied not only from groundwater but also from surface water;
    * Groundwater management is not only for the benefit of agriculture but also of nature;
    * Water boards are responsible for the water management of a specific area, in line with the function assigned to that area by the province;
- Responsibilities and role of the provinces:
    * Scheduling activities to counter desiccation before the year 2000;
    * Establishing the most suitable groundwater situation for different users in specific regions or areas;
- Area-specific policy;
- Administrative and legal aspects:
    * Adjusting legal instruments and finances;

- Financial aspects:
  - Agreements on plans for the allocation of costs for measures to be taken.

This paper will now present a few more details of the above-mentioned Evaluation Document.

Desiccation in the evaluation document on water 1994

A new, sophisticated, definition of desiccation

In practice, there appear to be several interpretations of the definition of desiccation. Discussions about these definitions not only delayed the execution of plans, but also resulted in differences in approach. The Evaluation Document gives a specific definition:

> An area is desiccated when that area has been allocated a natural function and the groundwater level in that area is not high enough and/or the seepage is insufficient to guarantee the protection of the characteristic groundwater-dependent ecological values on which the allocation of the function is based. An area with a natural function is also marked as desiccated when water of insufficient quality has to be provided to compensate for a low groundwater level.

Maps of desiccated areas 1996

The study also concluded that desiccation maps need to be regularly updated.
In 1996, the first indicative map (1994) had already been updated (Figure 3). The inventory of desiccated areas was principally based on the new definition of desiccation.
To get a more uniform map it was decided that:
The provincial map should be established at managerial level;

- The starting point is the function map of the provincial water management plan;
- Desiccated areas will only be included if there is a water management function focused on the conservation and restoration of natural values;
- An area will be considered desiccated if the actual water management situation differs from the desirable situation;
- The size of the nature areas is determined by the borders of the areas within which desiccated natural values are situated;
- Each province defines the difference between areas with a natural value only and areas with both agricultural and natural values.

This map includes information on on-going projects to control desiccation.
It has been decided that the map will be updated every two years. At this moment, preparations are being made to start the new map in 1998. The new map will also be used as to monitor progress in the control of desiccation.

Figure 3. Map of desiccated areas (1996)

The most suitable groundwater situation

The concept of 'the most suitable groundwater situation' replaces the old concept of 'the maximum recoverable quantity of groundwater', which was formerly used by the drinking water sector without taking other interests into account. Establishing the most suitable groundwater situation still appears to be a difficult matter, because a correct method for doing so is not yet available. The most suitable groundwater situation will form the basis of the water management policy, enabling, for example, decisions to be made on whether to grant permits for abstractions of groundwater.

Research is being conducted into various ways of establishing the most suitable groundwater situation. Under the National Research Programme on Desiccation, for example, the most suitable groundwater situation is being researched by differentiating between holocene and pleistocene Holland. One of the provinces has been requested to develop a suitable method that includes all sectors in that province. It is expected that the results of these studies will be available early in 1998.

The national research programme on desiccation

One of the activities in the control of dessication has been to set up a National Research Programme on Desiccation. The aim of this programme is twofold. Firstly, the programme was to disseminate the currently available operational expertise and instruments to execute the policy. Secondly, the programme has undertaken and stimulated more strategic research, which, in the long term, should lead to improvements in this expertise and a better motivation for the policy. Under the programme, eighteen research themes have been defined.

At this moment, the National Research Programme on Desiccation is nearing completion. A follow-up programme was recently formulated, under which the transfer of knowledge acquired during the research programme will be regulated. The follow-up programme includes several PR-activities such as a newsletter, folders, and workshops.

The Dutch Aquatic Outlook : surveying water systems

"The Water System Surveys" ("Dutch Aquatic Outlook" {DAO}) was announced in the 3rd National Policy Document on Water Management. It is a technical and scientific survey of Dutch water systems, encompassing an evaluation of current water management policies and an analysis of possible further lines of development. The analysis of current policy is based on measures that have already been formally adopted and are certain to be implemented. The situation expected to result from these measures has been compared with the current policy objectives. The results show that although the state of the water systems is improving, it is not yet good enough to ensure the widespread achievement of the various objectives.

To assist in the formulation of new policies, the DAO report Future for Water (November 1996) identifies problem areas and formulates alternative measures for the future in the form of three additional variants: 'Use Policy', 'System Policy', and 'Change'.

The DAO report and the accompanying background paper do not suggest specific choices, but provide the necessary information to enable those choices to be made during progress towards the Fourth Policy Document on Water Management.

The 'Current Policy' variant includes those measures that have already been implemented or are certain to be implemented (Viewing Years 2000 and 2015). In 'Use Policy', water and the water systems play a major role in human use functions such as agriculture and navigation. This variant centres on user satisfaction or user wishes (Viewing Year 2015). The 'System Policy' variant presents all technically practicable measures that could improve the quality of water systems (Viewing Year 2015). Changes in society could ensure that the target situations are achieved. This 'Change' variant would involve gradual physical and psychological changes in society, which would eventually produce a situation that appears to be considerably more attractive than the present one (Viewing Year 2045).

Groundwater and desiccation formed one of the themes within the Water System Surveys (DAO). On this theme, the WSV aimed at testing national policy targets against expected developments in society. The theme groundwater and desiccation has connections with other themes such as agriculture, drinking water supplies, and ecosystem development. These themes have been integrated in the analyses. Besides the present (reference) situation, simulations have been set up for the variants: 'Current Policy' by 2000 (aim: 10% reduction in desiccated area), and by 2015 (30% reduction); 'System Policy' (50% reduction by 2015) and 'Change' (100% reduction by 2045). Subsequently, packages of measures were analysed for these variants.

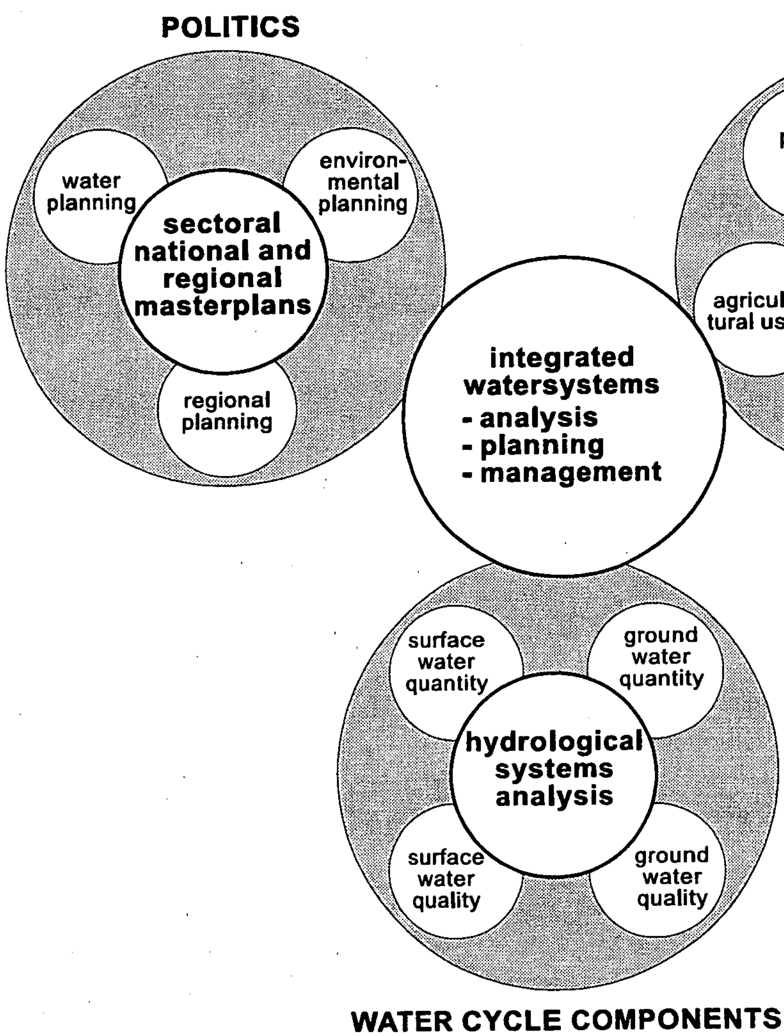
The following groups of measures have been singled out:
- Water management measures;
- Measures for drinking water supplies;
- Measures for industrial water supplies;
- Agricultural measures;
- Measures in urban areas.

The measures belonging to the different variants have been calculated with the hydrological models NAGROM and MOZART. The National Groundwater Model NAGROM is a saturated groundwater model, which communicates with MOZART through an interface facility, MONA. MOZART describes the flow in the unsaturated zone and the distribution of water from the main distribution network in the region. Both MOZART and NAGROM consist of a calculation centre and a database. These databases are made up of geographical databases covering the whole country, such as the Regional Geo-hydrological Information System (REGIS), the Surface Water Information System, Information about Land-Use, meteorological data, and deducted databases. All these data are stored in a Geographical Information System. With the help of the eco-hydrological model DEMNAT-2.1, the results of the hydrological calculations have been translated into ecological effects. The cost model AGRICOM has been used to translate the calculated changes in groundwater levels into agricultural costs. The developments within the water supply sector under various water management scenarios is simulated by the drinking water model ATLANTIS. This model calculates, amongst other things, the costs of producing drinking water and its energy consumption.

The results of the Dutch Aquatic Outlook contributed to the formulation of the "Governmental Intention" in the Fourth Policy Document on Water Management, recently published (September 1997). This Document plots the following lines of policy:
- The support for the approach to desiccated areas can be strengthened by involving the various actors (e.g. water boards, provinces, municipalities, nature-protection

organisations, farmers, water supply companies, and industries) in the remedial projects at an early stage;
- In their water management plans, the provinces, which play a key role, have been asked to establish the most suitable groundwater level for the medium term (2025) no later than 2002;
- Water management measures have the highest priority, considering that these have the most effect. Furthermore, water conservation could contribute to the control of desiccation. It is suggested:
  * Not to let the extraction from groundwater for drinking water supplies increase any further and to utilise sharper criteria for the use of groundwater (high and low value use, possibility of replacement, and efficiency);
  * To reduce the use of groundwater for industry and to change to surface water, particularly for low value uses.

Figure 4. Integrated approach in the analysis, planning, and management of water systems



Source: Engelen and Kloosterman 1994.

Further suggestions are:
- To adapt water management in rural areas in and around desiccated areas;
- To cut back on low value industrial water use from groundwater;
- To stabilise drinking water from groundwater, to increase supplies from other sources (surface water), and to reallocate abstractions from vulnerable areas;
- To place limitations on irrigation in agriculture;
- To de-connect rain water from sewerage in urban areas;
- To attune urban development better to water management;
- To evaluate provincial schedules.

Over the last ten years, integrated water management has, in general, been practised in the Netherlands. The awareness has grown that the integration per sector is not sufficient and that an even higher level of integration is required to cope with the water problems. What is needed is the integration of analysis, planning, and management of policies, user demands, and hydrological systems. This, in turn, will require the restructuring of legal rules and administrative and management territories and organisations.

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THE PROVINCIAL WATER POLICY PLAN FOR GELDERLAND : DOES IT LEAD TO PROPER GROUNDWATER MANAGEMENT?

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The author is grateful for information received from Mr A.G.G. Heeren, Project Manager of the Department of Water and Flood Protection, Province of Gelderland. The author, however, is solely responsible for this article.

Introduction

Integrated water management started in the Netherlands when the *"Wet op de waterhuishouding"* (Law on Water Management) was passed in 1988. Integrated water management received its shape with the publication of the national Third Document on Water Management (1989) and the first generation of Provincial Water Policy Plans, the one for *Gelderland* appearing in 1991. Studies on integrated water management, however, had already started in 1970.

The present situation in groundwater management can only be understood within its historical context. Four periods can be distinguished:

- 1900-1920: The establishment of regional water supply companies; groundwater is preferred as a resource because of its good quality;
- 1920-1940: Problems of public water supplies are steadily increasing in the western part of the Netherlands due to the scarcity of suitable groundwater and surface water resources; the first proposals for water legislation are rejected, mainly for economic reasons;
- 1945-1970: The prognosis of the demand for water in the year 2000 leads to extensive surveys to reserve "the last drops" of groundwater for water supplies; the Water Undertakings Groundwater Act (1954) and the Law on Physical (Town and Country) Planning (1962) are used for water planning; extensive programmes of drainage and land improvement are implemented to develop modern agriculture;
- 1970-1995: Completion of legislation on water and the environment; creation of a system of national master plans (*structuurschema's, nota's*); ecological and environmental assessment studies on groundwater abstraction and pollution.

During the first period (1900-1920), the Central and Provincial Governments stimulated the establishment of regional undertakings for public water supplies, the shareholders of which would be the local communities. The use of groundwater was preferred because of its good and safe quality. In the lower western part of the Netherlands, however, problems arose because fresh groundwater resources are mainly restricted to the dune areas, the polder areas generally having brackish water. Soon the dune water resources were exhausted, while urbanisation deteriorated other surface- and groundwater resources. Proposals for legislation on groundwater abstraction (1923), sewerage systems (1925), and the protection of potential water resources against pollution (1940) were rejected as being not (yet) feasible. During the second period (1920-1940), when problems in the western part of the Netherlands grew, studies were conducted by the Central Committee for Drinking Water Supplies, an advisory committee to the State. The studies (1940) included resource evaluations and forecasts of population growth and per capita water demand in the year 2000. Both were underestimated by 40-50%. Interesting is that State Public Works, State Forestry, and a consultant for Nature Conservation participated in this Committee, whereas agriculture was not represented.

In the third period (1945-1970), agriculture underwent a rapid development. From 1960 onwards, some very rainy years showed that, if agriculture were to be modernised and mechanised, extensive land drainage and improvement works were needed, especially in the higher sandy parts of the Netherlands. These works were duly implemented. Meanwhile, the Drinking Water Sector warned that these works could result in water scarcities because future additional groundwater abstractions would lead to a further lowering of the watertable. These conflicts led to the installation of the Study Committee for the Water Management of Gelderland in 1970. The resulting study is regarded as one of the first steps in developing integrated water management; it included water quality and ecological problems as well. Meanwhile, groundwater legislation, originally used to enforce groundwater abstraction for water supplies, was now used to restrict groundwater abstraction.

After 1970, environmental problems came to the attention of the decision-makers. Nitrate pollution of groundwater became well known. Legislation on surface water pollution (1970) and soil protection (1986) followed. Environmental Impact Reports were enforced from 1987 onwards. The very dry year 1976 (frequency 0.3%) caused an explosive development of sprinkler irrigation, although it became clear that, in the long run, sprinkling of grassland is not economically sound. Again groundwater abstractions increased. In 1987, a general "dehydration" of wet nature reserves was recognised as a major problem.

Since the appearance of the first Water Policy Plan (*Waterhuishoudingsplan*/WHP 1990) in 1991, five years of experience had been condensed in the second Water Policy Plan for Gelderland (WHP 1996). Meanwhile, the Water Boards had published their integrated plans for the three parts of Gelderland:

- The "Veluwe", situated north of the Lower-Rhine and west of the IJssel rivers;
- "Eastern Gelderland" situated east of the Rhine and IJssel rivers;
- The "River Region", between the Lower-Rhine and Meuse rivers.

This gives us the opportunity to evaluate:

- The development and integration of the separate plans for groundwater and surface water into one "overall" plan and policy;
- The integration of physical (town and country), environmental, and water planning and policy (*omgevingsbeleid*);
- The co-operation with local communities and Water Boards and the involvement of various interested parties;
- The realisation of objectives and standards;
- The implementation of water management by Water Boards and water supply companies;
- Costs and benefits of the water policy and its implementation;
- Monitoring of the water system.

Brief description of the First Water Policy Plan for Gelderland (WHP 1990)

Integrated water management

The Water Policy Plan (WHP) is an integrated policy plan for water management in the Province. It deals with directives for the development and protection of the water systems, including "natural" and "technical" structures for both groundwater and surface water. (National rivers and canals are excluded.) "Integrated" means that it includes earlier plans for the improvement of surface water quality and for groundwater abstractions.

The WHP has to be "attuned" vertically to the water policy of the Central Government, at the same time giving directives to the Regional Water Boards (*waterschappen*) and the local communities. It also has to be attuned to the Provincial Physical (Town and Country) Plan, and the Provincial Environmental Plan (which includes soil protection and the sanitation of polluted soils).

In 1989, about NLG 208 million were spent on water management in Gelderland:
- 150 million for the improvement of surface water quality, 90% of which was financed through "the polluter pays" principle;
- 56 million for the control of surface water levels, mainly paid for by the owners of land and buildings;
- 2 million for the control of groundwater abstraction, of which one-third was covered by the water supply companies (to maintain a monitoring network for groundwater levels) and about two-thirds by the Provincial Government, which used to be the groundwater manager.

Calculated over a provincial population of 1.8 million, the total water management costs of NLG 208 million mean NLG 115.- per inhabitant. For 1995, the yearly water costs were calculated for a "standard" household using 135 m^3 drinking water per year. These costs included those for dyke maintenance, for the sewerage system, and for the drinking water supply, and amounted to NLG 790.- per household. Today, as the household water use is 135 litres per head per day, this means that the standard household consists of 2.75 persons.

The WHP 1990 pointed out the following main problems:
- Water nuisance (groundwater levels too high) in various western and northern parts of Gelderland and in several cities;
- Drought damage (groundwater level too low) mainly in the eastern part of Gelderland and around the Veluwe; agriculture and nature reserves both suffered;
- Eutrophication of surface water and the need for research on micro-pollutants;
- The need for research on sometimes heavily polluted aquatic sediments;
- General pollution of groundwater by agriculture, acid rain, urban areas, etc.;
- The inadequacy of the surface water system to serve nature protection or recreation.

The WHP distinguishes long-term goals (25 years) and short-term policies and actions (4 years) to reach these goals step by step. The long-term policy receives its form by assigning to each region a specific "water function". A water function indicates for which purpose this part of the water system might be used (e.g. for agriculture, drinking water, or nature reserves). The water functions indicate the water level and the water quality by specifying the requirements for the proposed use within the constraints of the water system. The water system cannot produce more water than is available unless it is "over-exploited". In fact, the Province of Gelderland declares as its main goal:

> "To develop and maintain a healthy water system which guarantees a sustainable (continuous) use of water for humanity and nature."

This fits very well within the idea of sustainable development.

As the water systems have been deteriorating during the last decades and have sometimes been over-exploited as well, the long-term policy means cleaning up the water systems and restoring their natural values. This will mainly be achieved by realising quantity and quality standards that apply for the entire province, the so-called "base level", which serves as a minimum requirement. Special attention is being given to the protection and rehabilitation of the water-related nature areas (e.g. along brooks and rivers). As all drinking water in Gelderland is produced from groundwater, protecting groundwater against pollution is of the utmost importance.

The base level

The quality standards are called "general environmental quality standards" and are prescribed by the Central Government in its Third Document on Water Management (1989) as "Quality Objective 2000". For surface water, for example, standards for total phosphate are 0.15 mg P/l and for total nitrogen 2.2 mg N/l. There are standards for heavy metals and for micro-pollutants, not only for surface water but also for the sediments on the bottom of rivers and canals.

As base level for groundwater quality, the drinking water standards of the European Community apply. For example, for nitrate 25 mg NO_3/l (= 5,7 mg NO_3-N/l) and as maximum permissible 50 mg NO_3/l (= 11.3 mg NO_3-N/l).

As to the groundwater flow, the regional flow systems should be conserved and surface water levels should be kept as high as acceptable in order to reserve water for dry periods. Flooding, however, should be prevented.

The water functions

Besides the "base level", the following water functions are distinguished:

I	Water for agriculture;
II, III, IV	Complex of water for agriculture and nature reserves. The importance of nature reserves increases from II towards IV;
V	Water for nature reserves which have the highest ranking;
VI	Groundwater for drinking water supplies;
VII	Groundwater for industry and services;
VIII	Water in urban areas;
IX	Water for landscape and historic sites;
X	Water for boating recreation;
XI	Water for fishing recreation;
XII	Water for swimming;
XIII	Water for navigation.

All functions have their proper requirements as to water levels. For example, wetlands (wet nature reserves) require higher groundwater levels than agricultural land.

Groundwater is primarily reserved for drinking water because of its good natural quality. Groundwater abstraction for drinking water is guaranteed to a maximum of $170*10^6$ m^3/year. In 1988, these abstractions amounted to $136*10^6$ m^3 and in 1994 to $157*10^6$ m^3/year. The budget for private groundwater abstractions (industry and services) is $85*10^6$ m^3/year, the abstractions in 1994 being $77*10^6$ m^3.

In nature reserves (Function V), negative human influences should be negligible.

In urban areas, land subsidence caused by a lowering of the watertable should not take place. Nevertheless, watertables should be deep enough to prevent problems of "water in the basement". Storm water overflow from the combined sewerage systems into surface waters should be reduced as much as possible by building retarding devices (e.g. detention basins) in order to achieve the "general environmental quality standards" in the brooks and rivers.

Short-term groundwater objectives

In this paper, only the groundwater items of the short-term programme (1991-1995) will be considered. A distinction should be made between "active" groundwater control by way of surface water level control (control of the drainage-base level) - as practised by the Water Boards - and "passive" groundwater control - as practised by the Provincial Authority with its licence system for abstractions. The following objectives apply:

- A general constraint is a stand-still principle of drought damage in nature reserves (Functions II-V) caused by drainage works and groundwater abstractions, with 1985 as a reference year;
- In Functions I (agricultural areas) and VIII (urban areas), groundwater levels shall be suitable for the normal use of the land (task of the Water Boards);
- In several nature reserves, drought damage shall be diminished (task of the Water Boards and the Provincial Authority, with subventions from the Central Government);
- Demand management shall stabilise groundwater use for households, services, and industry (Functions VI and VII). Groundwater of good quality shall not be used for low-quality purposes (e.g. for cooling water). For a further development of drinking water supplies, induced recharge or artificial recharge shall be taken into consideration (task of the water undertakings);
- Natural recharge of groundwater shall be increased (e.g. by reducing evapotranspiration through the replacement of conifers with deciduous trees, by the infiltration of rainwater in urban areas, etc.)

Budget WHP 1990, period 1991-1995

The budget for the WHP 1990 activities amounted to NLG 27.5 million, to be paid by the Central Government (9 million), the Province (8.5 million), the Water Boards (10 million), local communities, and water supply companies. About NLG 6 million was to be spent for groundwater management (active as well as passive control).

Evaluation of the WHP 1990

During the period 1991-1995, emphasis was mainly given to:

- The creation of Regional Water Management Plans by the Water Boards (completed in 1995);
- The re-organisation of the Water Boards into larger "all-in" (quantity + quality control)

Water Boards;
- Putting pressure on regional projects for integrated water management.

At the end of 1995, only half of the foreseen activities had been implemented and only half of the Provincial budget (NLG 8.5 million) had been spent. Bottlenecks, especially for the rehabilitation of wetland reserves, were: obtaining the land area and compensating farmers for wetness damage due to the watertable rise needed for the nature reserves.

The quality management of surface water is outside the scope of this paper.

The WHP 1996

New developments

The long-term policy as to water functions is still in line with WHP 1990, although differing essentially on the abatement of drought damage to nature reserves ("dehydration"). A national analysis of groundwater levels over the period 1950-1986 showed that:
- In the higher sandy parts of the Netherlands, an average regional drop in levels of 0.2 m had taken place;
- In land consolidation areas, the average drop was 0.35 m;
- Locally, groundwater abstraction had led to a drop of 1 m or more.

Parliament, after discussing the "dehydration" as described in the Third Document on Water Management (1989) (through the Motion Lansink/Van Rijn-Vellekoop) decided on a reduction in the area of "dehydration" by 25% in the year 2000, as against the situation in 1985. This 25% reduction policy had to be included in the new WHP 1996. The Province, however, decided to aim at a reduction of 10-15% for 2000 instead of 25%.

In the WHP 1996 (period 1996-2000), emphasis is being placed on:
- Optimal surface water control for all interests involved;
- Protection and rehabilitation of wet nature reserves;
- Sustainable groundwater supply to households and special industries that need high-quality water;
- Urban water control.

All the above-mentioned items have implications for groundwater management. Priority is being given to what are known as "action zones", which are areas abundant in nature, mainly situated around the Veluwe, in eastern Gelderland, and the Gelderse Poort.

Special attention is being given to a better implementation of the foreseen activities.

Groundwater

The financial consequences of the WHP 1996 (period 1996-2000) amount to NLG 655 million, of which about NLG 150 million is related to groundwater management, as follows:
- Shifting 25% of groundwater abstractions for drinking water, services, and industry from the Veluwe to less-drought-sensitive areas: NLG 64 million;
- 25% reduction of other abstractions (de-watering building sites, sprinkler irrigation): NLG 35 million;
- Replacing 2500 ha of conifers with deciduous forest on the Veluwe: NLG 10 million;
- Regional integrated projects for "dehydration" abatement: NLG 28 million;

- Wetness abatement in urban areas: NLG 13 million.

In Gelderland, the groundwater abstractions registered in 1994 were:
- Water supplies: $157*10^6$ m^3;
- Industry and services: $77*10^6$ m^3;
- De-watering of building sites: $32*10^6$ m^3; and
- Sprinkler irrigation $27*10^6$ m^3.

So a total of 293 million m^3.

A total of NLG 148 million has been calculated as the cost of decreasing "dehydration".

As a consequence of the actions listed in the WHP 1996, the "standard" household will be charged NLG 950 in the year 2000 (in 1995: NLG 790).

Evaluation of the provincial groundwater management

The various subjects listed for evaluation at the end of the Introduction will be briefly considered here.

Integrated water management

The WHP 1990 and the WHP 1996 both showed great progress in integrating policies for surface and groundwater, both their quantity and their quality. The "active" and "passive" groundwater control is still in different hands (the Water Boards and the Province, respectively). The need for strong co-operation between authorities and organised groundwater users (water supply companies, industries, agricultural organisations such as the *landbouwschap*) is a main theme and strategy in the WHP 1996.

Integration of town and country planning, and environmental and water planning

The different plans within the Provincial Government are currently in the stage of being integrated by the simultaneous development of these plans.
Maps and key issues are attuned, as are the enforcement of legislation and the monitoring of the efforts of different participating authorities and private parties. Examples of key issues are:
- Sustainable (environmentally-friendly) urban and industrial development;
- Sustainable (nature-friendly) agriculture;
- Efficient traffic and transport.

Cooperation with water boards, local authorities, local communities, and water users in implementing the water policy

According to the WHP 1996, all "water actors" are now involved in the planning process, which took about three years. In this way, the Province expects to achieve better acceptance of its water policy and therefore a better implementation of the WHP 1996. The Province expects that, by allocating tasks and responsibilities, a "bottom-up" process will be started, which will lead to the realisation of the assigned water-functions.

Costs and benefits

The costs, especially those of "dehydration" abatement, were mentioned earlier. The drinking water costs, which are directly related to groundwater management, would rise by 10% or about NLG 0.20 per m^3. This, at least, is less than the general tax of NLG 0.35 per m^3 imposed on groundwater by the Central Government. This tax is not specifically used for water purposes, but is aimed at discouraging groundwater abstraction. The benefits will be better groundwater management, mainly for nature reserves and also for urban areas.

Monitoring

During recent years, a monitoring network for the quantity and quality of surface water and groundwater has been set up. It is maintained by the Water Boards and the water supply companies.

Concluding remark

The question asked in the title - whether the WHP's lead to proper groundwater management - can be answered in the affirmative for the instruments developed for planning, control, and monitoring. However, whether the policy objectives - which have been stated by the Central and Provincial Governments - are proper and realistic (especially those for "dehydration"), only time will tell.

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CONCLUSIONS OF THE WORKSHOP

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Introduction

The afternoons of days 1 and 2 of the workshop were spent in working-group sessions and in plenary discussions. Each participant was asked to join two working groups. Eight working groups were formed, each with one subject to discuss. Examples of subjects were "Appropriate Economic Policy Instruments", and "Required Levels of Decision-Making". The conclusions of the working groups were reported to all participants during reporting sessions. The reporting sessions were followed by plenary discussions.

To structure discussions, each working group was asked to concentrate on three questions and to formulate answers to these questions in relation to the subject of the working group. The questions were identical for each working group. These were the questions to be answered:

- is it relevant to distinguish between different situations or conditions?
- what should be considered the optimum situation?
- how can the optimum situation be achieved, given the prevailing conditions?

Thus, the working group discussing "Appropriate Economic Policy Instruments" would first determine whether different economic policy instruments are required under different conditions. It would then proceed with determining the optimum mix of economic policy instruments. Finally, it would discuss appropriate action to achieve the optimum situation that had just been formulated. The working group on "Required Levels of Decision-Making" would go through the same sequence, but would of course focus on its own subject.

Not all working groups could complete the discussions in the relatively short time that was available to them. Other working groups allowed discussions to proceed in a less structured way, thereby not necessarily focussing on the core questions. As a consequence, the three core questions were not covered completely in all cases. So instead of presenting the answers to the core questions in this report of the workshop, we present the main conclusions as reported by the working groups, and the reactions to these by other workshop participants.

In some cases, inconsistencies were found in what was concluded for one subject in relation to another. This will not surprise anyone, when it is realised that the topic of groundwater management is not only relatively new, but also highly complex. No attempt has been made to hide these inconsistencies in this report. Nor, for that matter, has any attempt been made to present discussions and conclusions more favourably than they actually were.

All working group reports and plenary discussions were recorded on tape and were typed out after the workshop. The conclusions of the workshop were also obtained from this material.

The management themes

Objectives of groundwater management

An absolute objective of groundwater management does not exist. It is not possible to say that groundwater management should always achieve one particular goal or set of goals. It all depends on the agreement between those involved in decision-making on what is to be achieved. This is the main conclusion of the discussions on the objectives of groundwater management.

Extreme solutions are possible. To give an example, a society could agree on extracting more water from a groundwater resource than could possibly be recharged, thereby agreeing to mining, and eventually to depleting the resource. This could be justified by arguing that the benefits obtained through this policy are used to restructure the economy. Other forms of capital could thus be created - forms of capital that can be put to work once the groundwater resource is depleted. Such a policy would be fully justified, workshop participants argued, provided it is embedded in well-argumented and consistent development plans. One could choose not to agree with this approach, but universally-valid arguments against it do not exist.
It all depends on the choices made. Or in Otto's words (quoting Smith), "There is no real answer to the question of what is good groundwater management. The answer depends upon what values a system seeks to maximise. Or, one might well ask, whose values?" (Otto, this volume, page 48).

The example shows another point on which workshop participants agreed: the priority of groundwater management need not necessarily be to safeguard the physical integrity of groundwater resources. Economic objectives can override environmental objectives.

A further conclusion was that proper groundwater management should not look at groundwater resources in isolation from surface water resources, but should look at all water resources in relation to each other. This is only logical because the hydrological relationships between groundwater and surface resources are many, and dynamics of groundwater resources cannot be understood unless seen in relation to those of surface water resources. An approach integrating groundwater with surface water is always required, regardless of the development stage of a society or country.

Groundwater management objectives depend on the conditions in a country. For example, a country embracing groundwater management for the first time may decide to start with mapping hydro-geological features in an effort to gain an insight into the potential of groundwater resources. As the papers on Yemen, Egypt, and Kenya show, this is indeed a choice that is frequently made. Another society may consider it necessary to prioritise access to groundwater by all, including the poor, thus putting emphasis on a priority of socio-economic development. Another example put forward in the discussions is a society that prioritises the use of groundwater for distinct uses (e.g. drinking water).

Notwithstanding what has been said above, the optimum situation was considered a situation in which environmental conditions are sustainable (i.e. they are not deteriorating), and priorities for the use of groundwater are consciously set.

Workshop participants argued that a distinction needs to be made between fossil groundwater reserves and renewable reserves. The former can be exploited, if it is accepted that eventually the resource will be depleted. The latter can be used as well, but a preference existed among workshop participants in favour of avoiding over-exploitation. It was concluded that a maximum of only half, or a third, of the net annual recharge should be abstracted each year.

A related point came up later in the discussions. It is interesting enough to be mentioned here, even though it may confuse matters. Eventually, all groundwater resources tend to some state of equilibrium, even reserves that are at present being over-exploited. Under conditions of over-exploitation, groundwater tables will fall and abstracting water will consequently become more costly. As a result, fewer users will be able to lift water and total abstractions will decrease, until the point is reached that annual abstractions are equal to annual recharges, at which moment a new, lower-level equilibrium has set in. This argument was brought forward in reaction to the statement that a balance needs to be maintained between abstractions and recharges. The question is: a balance at what level of equilibrium?

Required levels of decision-making

Two principles of natural resource management surfaced during the discussion on the most appropriate levels of decision-making. The principles were:

1. The institution with a mandate to manage a natural resource should have jurisprudence in an area larger than the area covered by that resource;
2. Management decisions should always be taken at the lowest appropriate level.

The second management principle was first formulated in a World Bank report, and refers to managing natural resources in general (see paper by Schrevel, this volume). Note that it says "the lowest appropriate management level", not "the lowest possible management level", which is something entirely different. It is these two forces, which can work in opposite directions, that determine decision-making levels.

More concretely, central governments should set priorities, but should refrain from getting involved in detailed matters. Provincial levels should integrate all water sources in their management activities and decisions, as well as economic and other factors. Local levels, including water users, should be involved in decision-making.

Transparency in institutional mandates and decision-making was mentioned as being important in achieving good groundwater management. Excellent data bases on which to make decisions, and sound legal frameworks within which to make decisions, were further considered important. On this occasion, as well as on many others, the need for awareness among decision-makers and users about the properties of "their" groundwater resource was stressed (see further below).

Good governance, law, and administration

Law and administration systems in many countries facing intensified groundwater exploitation are as yet inadequate to cope with quickly changing situations. Even in those cases where laws do exist, these often date from times when groundwater was not used as intensively as at present and when pollution was not the threat that it often is today. New laws are being written, but do not always provide the solutions to problems that groundwater users are facing. In the case of Baluchistan in Pakistan, sensible local initiatives were even frustrated by the introduction of a new law (Steenbergen, this volume). A core problem is undoubtedly law enforcement. Administrative systems are not equipped for the successful enforcement of existing rules and regulations.

The cases of Yemen, Pakistan, and Kenya are all examples of the lack of adequate legislation and groundwater administration. Much energy is being invested in these countries today in efforts to formulate adequate legislation.

The discussion on good governance, law, and administration concentrated on the ten rules for groundwater control as formulated by Otto (see page 58). Because of the lack of time, only the first of these rules was subjected to discussion.

Otto's first rule for groundwater control says that a legal limit must be put on the quantity of groundwater that a landowner can bring to the surface.
The discussion that followed focused on minimum conditions that must be fulfilled before such a rule can be effective. The rule itself was not challenged. The geographical focus was again on conditions in a semi-arid country.

For Otto's rule to be successful, the following conditions were listed:
- Groundwater users must first experience problems before regulations to limit water abstractions can be successful. Examples of problems are dry wells and the reduced success of neighbouring landowners in lifting water;
- Hydro-geological conditions must be known before the maximum abstractable quantities of water can be determined; a land classification system that reflects hydro-geological conditions must be put in place;
- The general public, and groundwater users in particular, need to be aware, or be made aware, of the acute nature of the threat to their groundwater resources. In fact, it was broadly felt that awareness creation is an absolute condition for successfully limiting groundwater abstractions by individuals.

An optimum situation is only possible if insight exists into the hydro-geological conditions in a country, and into the dynamics of groundwater use. The latter aspect includes an insight into how much water is being used, by whom, where, and for what purposes. An insight into groundwater use has not received much attention as yet, not even in countries that have benefited from foreign aid projects.

An optimum situation further entails an effective system of law and administration. Here, "effective" means not only adequate laws, but also includes proper procedures to effectuate laws and organisations to enforce them. Participants further felt that groundwater management is preferably entrusted to strong, existing organisations, rather than to a new organisation created for this purpose.

In achieving optimum conditions, existing land and administration systems first need to be analysed. An answer must be formulated to the question of whether, and to what extent, these are adequate. In a parallel effort, hydro-geological conditions must be mapped and groundwater use must be analysed.

Economic and other policy instruments

The discussion on economic policy instruments was an exceptionally lively one. This may be a reason why not all matters raised could be brought to a conclusion.

A general feeling prevailed that water pricing (i.e. putting a price on a unit of groundwater and making groundwater users pay that price), although a recommendable policy, is difficult to implement . Practical problems in using this instrument were the main reasons for hesitation, and sometimes for downright disapproval. Two main objections were raised. The first was the impossibility of the task of determining a price for groundwater. How much would it have to cost? Which price level could be said to be a fair reflection of its scarcity, or of its importance as a life-supporting component in ecosystems? The second problem concerned the many practical problems involved in collecting the amounts due. In some area, literally thousands of small farmers are using pumps and are abstracting groundwater.

Practical economists among the participants had answers to at least some of the objections raised. Thus, it was stated that indirect pricing was possible. The cost price of groundwater to users is equal to the costs of lifting water to the surface and applying it for its intended use. These costs include depreciation costs of the pump, and the costs of energy to operate the pump. A levy could be put on either the purchase price of the pump or on energy, which is usually diesel or electricity. This, however, is less straightforward than it seems, because these inputs are applied to other processes as well. It was argued that, particularly under conditions of scarcity, a levy on pump operation costs would be effective, because it would help to reduce abstractions.

It was further suggested that operating costs should be increased by a kind of tax. From this tax, research on groundwater resources and groundwater use could be financed. Increasing the cost of lifting groundwater by means of a levy or tax would work to the disadvantage of poorer groundwater users. This was seen as a problem and was discussed in terms of a choice between efficiency and equity. It was felt that governments have to strike a balance between efficiency and equity.

Overall agreement existed on at least one point. Where subsidies still exist on diesel or electricity, as is the case in India and Pakistan, these should be abolished. In one case, an exception would be permitted: this is when a government decides to support poorer sections of rural populations. A subsidy on their energy costs would effectively increase their spending power.

In addition to these direct and indirect ways of water pricing, a different category of economic policy instruments was discussed. These are the macro-economic policy instruments. Governments could do much to promote certain crops and discourage the cultivation of others. To reduce groundwater abstractions, high water-demanding crops could be discouraged (e.g. by taxing them). This would effectively reduce the demand for those crops. In Yemen, for example, the government should ban the import of low water-demanding food crops, thus stimulating the cultivation of these crops in Yemen itself. In these cases, farmers would be less inclined to grow high water-demanding crops.

The objection was raised that these measures work well in a relatively small country like Yemen, where climatological conditions are homogenous and agro-ecological zones few. In countries like Pakistan and India, however, where climate and crop-growing conditions are highly different from one part to another, such measures would not work. They would have positive or neutral income effects in one part of the country, and negative effects in another part. (The element of scale is all too often neglected in discussions on proper groundwater management.)

Roles of users, politicians, and groundwater experts

A distinction needs to be made between conditions of an abundance of groundwater and conditions of its scarcity. Where groundwater is abundant, users can pump as they please, but governments are well-advised to start mapping groundwater reserves and to monitor them. Under conditions of abundance, communication between the parties involved need not be intensive.

The situation is different under conditions of scarcity and intensive use. More important than anything else is good communication between politicians, users, and groundwater experts. Institutions that can facilitate communication should be set up (see below).

In the discussions, the diverse categories of politicians were divided into politicians at the level of central government, politicians at lower levels, and government officials. At the central-government level, politicians were said to have the task of setting rules and developing legal frameworks. They are also responsible for developing long-term strategies. Lower-level politicians work these out for their respective regions. In this way, the overall framework within which decisions on groundwater use and control are made, are formulated at central-government level. Decisions on actual groundwater use should be the mandate of the lowest appropriate levels (see also under "Required Levels of Decision-Making", above). The role of government officials is to control adherence to agreed rules and regulations. Groundwater users should be involved in management decisions.

The role of groundwater experts (i.e. hydro-geologists) was not spelled out in detail. All that was said was that groundwater experts were to feed decision-makers with information on groundwater resources and how these change with time. Note that groundwater experts are not expected to take control decisions themselves.

Good communication was considered extremely important. Different interest groups were recognised, including different groups of groundwater users (e.g. farmers and drinking-water companies), but also groundwater experts and even politicians. Each interest group has its own sources of information, its own understanding of the situation under the ground and on the ground, and its own interests to defend. Through communication, groundwater use and abuse could be controlled.

The suggestion was made that users and groundwater experts ought to sit down together and work out sensible solutions. These would then be communicated to the politicians responsible for decision-making. Defenders of this approach pointed out that users and groundwater experts have their own interests, and politicians have to defend the common interest. The way to achieve this situation is first of all to set up the institutions that facilitate communication, as outlined above.

Finally, a note of warning was heard. Although, in some cases, organising users is possible, in other cases it is hardly possible at all because of the numbers of farmers involved. Organising farmers in the Punjab, Pakistan, means that literally millions of individuals need to be organised. The often-neglected factor of scale is again in play here.

Data collection and monitoring

For proper groundwater management, two sets of data are required:
- data on water resources - both surface water and groundwater;
- data on water use and water users.

For water users, data are required on the different categories of users. Profiles of user categories should be made (large landowners, small landowners, drinking-water companies, different groundwater-abstracting industries). This would allow an understanding of the behaviour of different groups of users. Data should not only cover present uses, but should also make predictions on future use. It is also important to identify any constraints that different categories of groundwater users are experiencing.

In different situations, different sets of data are required. In general, the more constrained a situation is, the more detailed information is required. This is true, because more detailed decisions need to be taken. In contrast, when groundwater is readily available and used only by a few users who depend on the resource only to a limited degree, data on groundwater and groundwater use can be more general. In between these two extremes, many other situations exist.

Optimum data collection and processing are not achieved from one moment to another, but need to be developed over time. They mature with time, in response to demands for more data of some kind. The monitoring of groundwater resources and groundwater use and users should be an on-going process. The data that become available through the monitoring process need to be analysed. The analyses should show actual constraints or future constraints. This will call for corrective measures.

Finally, it was remarked that, under certain conditions, data may have to be protected. An example was mentioned of a donor-funded project that could produce a map showing in detail the groundwater potential in an area. Such a map would be of great interest to farmers planning to sink a well. They could use the map to determine where to drill, thereby avoiding sinking a well that would turn out to be dry. Under conditions of unrestricted groundwater abstraction, this kind of information could lead to accelerated groundwater exploitation, which would not be in anyone's long-term interest.

Preferable management regimes

The question of preferable management regimes was approached by first identifying the criteria required to distinguish between different groundwater situations and management regimes. Because of lack of time, the issue could not be taken further.

Criteria to distinguish between different groundwater situations were mentioned to be the relative scarcity of groundwater, the extent to which diversity of interests occur, and the degree of conflicts. For example, a groundwater management situation can be characterised by scarcity, highly diverse interests, and a high degree of conflicts. At the other extreme is the case of abundant groundwater reserves and few people interested in it. Other combinations are possible. It was assumed that each of the different groundwater situations requires its own management regime. Note that in this view, it is not the hydro-geological conditions that determine the kind of management regime that is required, but economic and social-political conditions.

For comparison, the reader is referred to the paper by Nibbering. Nibbering works out the consequences of three different management regimes in terms of long-term benefits to groundwater users. The first regime is the open-access regime. The second is the situation of continued open access. And the third is the situation where groundwater is used under a common-pool arrangement. Under the common-pool management regime, all groundwater users benefit most in the long run (Nibbering, this volume, page 25).

Training and dissemination of information

Training is felt to be badly needed. A lack of insight is widespread among those involved in groundwater management. The lack of insight is certainly not restricted to users. Also politicians, and even groundwater experts, can profit from training. These are also the target groups that were defined by the workshop participants: politicians, groundwater experts, and users.

Training should be directed not only to specific target groups, however, but also to the general public. National public campaigns should be organised to make people aware of the danger of over-exploiting groundwater resources and of polluting them. India's successful national public campaign to explain the properties of another natural resource (i.e. forests) was mentioned as an example.

Discussing the subjects that need to receive attention in training, the participants stressed the point that these should reflect local conditions. Results from on-going monitoring of local groundwater resources should be ploughed into the training material. Prevailing institutional arrangements and procedures should be explained as well.

A frequently-encountered problem was mentioned to be that data often exist, but are not shared with others. Or if they are reported, that they are often not used. In addition to training, the transfer of information between parties was considered to need improvement. Not only should reports be sent to decision-makers, a dialogue on the meaning and consequences of their contents should take place as well.

A few remarks were made regarding the costs involved in training and the dissemination of information. It was said that these should be borne by the government and by the users. But bilateral or multilateral organisations could be helpful in setting up appropriate facilities and routines. Training should be conducted by - foreign or domestic - research institutions. These institutions have data available. They are also best placed to organise training (although groundwater institutes as yet do not systematically collect and disseminate information on groundwater use and users!).

Epilogue

The discussions produced conclusions that were not presented under one of the above headings, or that have general relevance. Thus, it was said that underlying the discussions of the workshop was the assumption that societies in developing countries would allow the democratic approach favoured by the workshop participants. This would not always be the case in reality. One is therefore advised to accept that the recommendations of the workshop require adjustment to prevailing political conditions.

Four conclusions were heard again and again throughout the two days of the workshop. They deserve to be repeated here. They are:

- not only should hydro-geological data be collected, but also data on groundwater use and users; this is not yet taking place routinely, as is clear from the case studies;
- groundwater should not be looked at in isolation, but in relation to surface water; groundwater management should be part of integrated water management efforts;
- groundwater users need to be made aware of the condition of the resource on which they depend; and finally,
- groundwater managers - politicians, experts, and users - need training to make them better aware of groundwater conditions in their environment and to teach them appropriate management policies.

The workshop on "Groundwater Management: sharing responsibility for an open access resource" looked at a broad selection of relevant management issues. It may not have produced conclusive answers to all issues raised. Yet, it is hoped and expected that the workshop has at least improved our understanding of some of the problems involved.

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