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A Strategy for Controlling Groundwater Depletion in the Sa'dah Plain, Yemen

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ABSTRACT *Over-exploitation of the groundwater resources is the major problem leading to groundwater depletion in the Sa'dah Plain, one of the major semi-arid highland basins of Yemen. Groundwater-irrigated agriculture is the chief economic activity in the Plain. Consequently, depletion places socioeconomic development in jeopardy. Owing to the lack of institutional arrangements and management instruments, government intervention is not likely to alleviate the crisis. One non-governmental approach that takes advantage of the existing local sociopolitical structure and customary law would be to adopt an annual abstraction quota. Approaching the crisis at a grass-roots level and relying on the conformity of the local citizens with customary law are the main characteristics of this strategy, the optimum objective of which is sustainable utilization of water resources.*

Introduction

The Sa'dah Plain is one of the intermontane plains of Yemen which illustrates all the different manifestations of groundwater problems in the country. It is a basin in seclusion as a closed water system. The Plain is situated in the Western Highlands of Yemen at a distance of about 250 km north of the Capital City of Sana'a in the centre of the Governorate of Sa'dah. The administrative centre of the Governorate is Sa'dah Town, which is located in the south-east. The area forms part of the catchment of Wadi Marwan, a tributary of Wadi Najran which drains into the Rub' Al-Khali Desert (The Empty Quarter) (Figure 1). With an elevation ranging from 1840 to 2050 metres above mean sea level (m + msl), the Plain slopes with a gentle gradient ranging between 0.2% and 0.5% towards the south-east where it collects in the stream channel of Wadi Marwan flowing in a northern direction into Wadi Najran. The Plain is surrounded by dissected, mostly steep and bare mountains up to an elevation of 2750 m + msl.

According to Koppen classification the area is mountainous semi-arid. Rainfall is sporadic and scanty and storms are usually short, intense and local. The average annual rainfall within the Plain for the period 1983–92 was about 135 mm with a standard deviation of 50 mm. There is no evidence of severe droughts in this period. In general there are two peaks of rainfall during the year: March–May and July–August. April is the month with the highest readings. Evaporation far exceeds precipitation during most of the year. Potential

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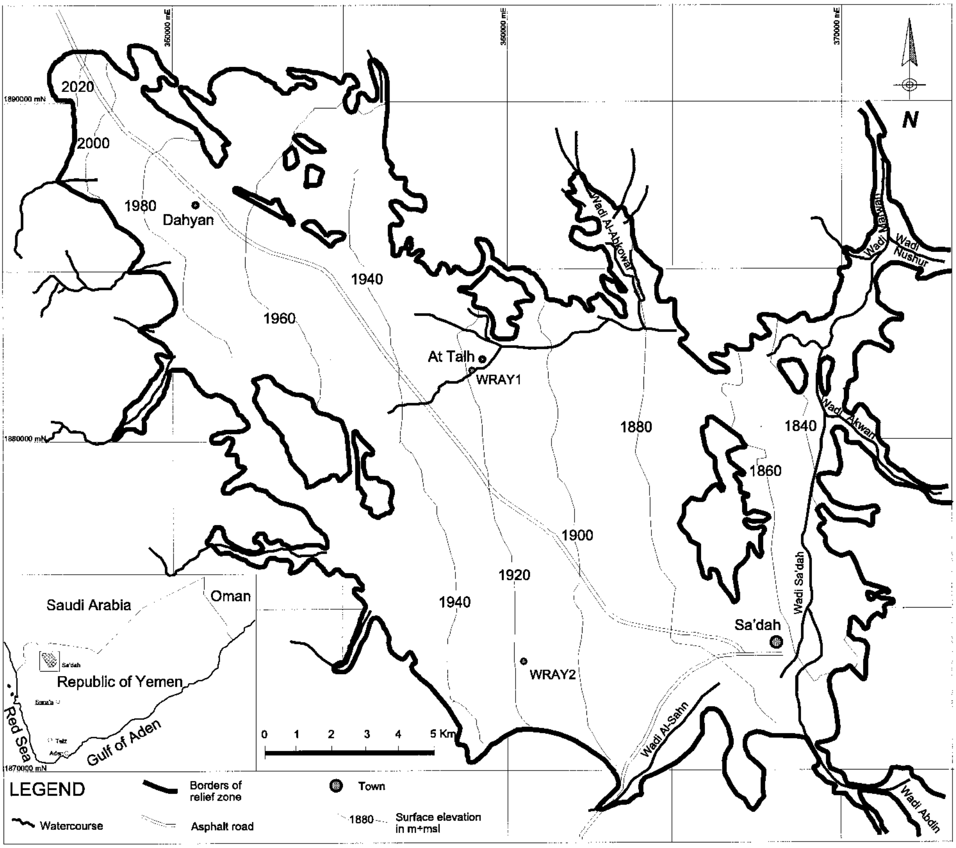

Figure 1. The Sa'dah Plain area.

evapotranspiration is very high in the area owing to its arid nature; the annual value is about 2280 mm.

The population of the area was estimated to be around 200 000 inhabitants in 1996. In the late 1970s, the directions of socioeconomic development in the country emphasized the development of irrigated agriculture. To boost the rural economy of the Plain, groundwater development was started to supply water for agriculture. Ever since, irrigated agriculture has replaced rainfed agriculture as the major economic activity in the area. Citrus crops and vegetables are the main agricultural products. Livestock rearing and agroforestry are marginal practices, although the potential for developing these activities is very high.

The major problem in the Plain is the over-exploitation of the groundwater resources, leading to groundwater depletion. As a result of scanty annual precipitation, flow in the wadis that drain into the Plain is rarely observed. Consequently, replenishment of groundwater is limited. In spite of that, more than 2500 wells tap the aquifer with an annual rate of abstraction that far exceeds the recharge rate (DHV, 1993a). Approximately 98% of the available water in the Plain is claimed by agriculture. Coupled with that is the inefficient use of groundwater in irrigation. The sandstone aquifer is the only reliable source of water in the Sa'dah Plain. Development of an alternative conventional source of fresh water is not possible and it is not viable to transport water from one basin to another in the Western Highlands of Yemen. Indeed, all basins in the Western Highlands of Yemen suffer from water scarcity and groundwater depletion. In the case of Yemen, the only feasible substitute for depleted groundwater is desalinated seawater. The major constraint is the tremendous economic cost of pumping the water to altitudes higher than 2000 m. This alternative may be suitable for coastal areas for supplying domestic and municipal water. As for the Highland Plains, this is not conceivable in the foreseeable future. Not only has geography ruled out the possible use of desalinated water for the Sa'dah Plain, but also the purpose of using the resource for irrigation is not viable. The gravity of the water crisis in the Sa'dah Plain is deepening. Groundwater is being depleted to such an extent that socioeconomic development is threatened by the cessation of irrigated agriculture. The signs of the severity of the crisis have manifested themselves in the total abandonment of a village in the area by its inhabitants. The wells went dry and the people had no other choice but to leave. The inhabitants were relocated in another part in the area (personal communication, MAWR officials).

Government intervention is not likely to solve the problem of over-exploitation, at least in the foreseeable future. The Government lacks the proper institutional arrangements and management instruments to control aquifer depletion. Thus, a non-governmental approach was investigated and is reported in this paper. The extent of groundwater depletion in the Sa'dah Plain was reviewed and a strategy to control it was proposed. A groundwater flow model was used to analyse some of the characteristics and consequences of depletion and the physical aspects of the control strategy.

Hydrogeology of the Sa'dah Plain

This section mainly draws on the two previous studies by YOMINCO/TNO (1983) and DHV (1992). The YOMINCO/TNO study investigated the water resources of the area. The major activities were a geophysical survey, a well inventory and aquifer tests. The DHV study in turn was based on the technical findings of that of YOMINCO/TNO with an update on the well inventory. However, DHV investigated other aspects related to water management issues, such as socioeconomic aspects.

In the Plain, regional uplift, block faulting and volcanic activity occurred during the Tertiary Period in association with the Red Sea rift system. These tectonic activities resulted in horsts, grabens, faults and fractures that are generally aligned north-north-west to south-south-east and north to south. The dominant structure in the area is the down-thrown graben of the Plain filled with sedimentary rocks; among them are the Paleozoic sandstones (Wajid sandstones) that are probably dissected by numerous faults of different orientations, forming rock blocks of different vertical displacement. In the Plain and the surrounding terrain, the Wajid sandstone is the oldest sedimentary rock (Figure 2). The formation consists of deltaic deposits and it is subdivided into two units: the Upper and Lower sandstone units. The age of deposition of the Wajid sandstone ranges from Cambrian to Permian and overlies the Precambrian basement rocks in an approximately horizontal bedding plane. The Lower Wajid sandstone is of Ordovician age and comprises yellow to brownish coloured, cross-bedded, medium-to-coarse grained quartz sandstones, locally interbedded with quartizic ironstones. At the contact with the basement a thin layer of basal

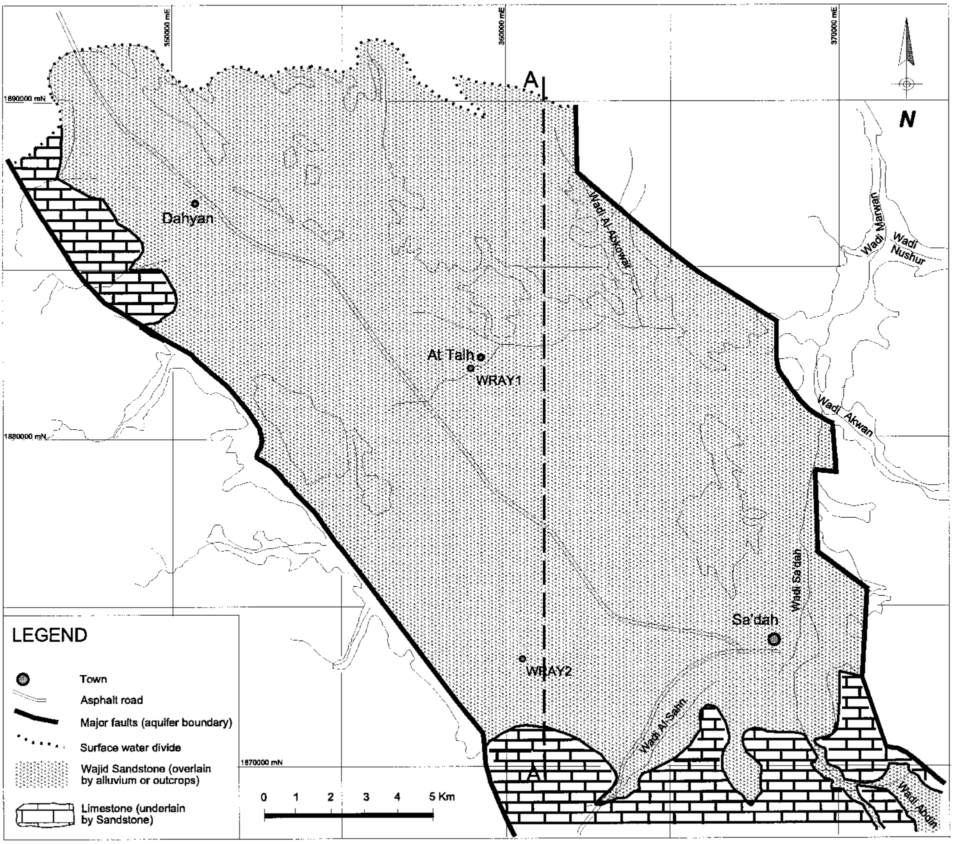

Figure 2. Hydrogeological map of the Sa'dah Plain.

conglomerates is exposed. The Upper Wajid sandstone of Carboniferous to Permian age also shows a massive depositional environment and consists of cross-bedded, light-coloured quartz sandstone and intercalations of clay, silt and mud balls. Outcrops of the Wajid sandstone are dominant north and east of the Plain. Elsewhere in the Plain, it is overlain by the alluvial unconsolidated sediments that vary in thickness from 10 m at the borders to 50 m at the centre. South of the Plain, the sandstone is covered by the Amran limestone (Figure 2). At the borders of the Plain, the mountain belts are mainly composed of impervious rocks intersected by alluvial wadi fills.

The Upper and Lower Wajid sandstone are considered as one hydrogeological unit. As a consequence of tectonic block-faulting, the depth of the underlying impermeable basement complex varies between 100–150 m in the northern part of the Plain and 600–700 m in the southern part. Groundwater flow is supposed to take place in the pores of the sandstone matrix; however, both geological evidence and the results of some tests point to a contribution of fractures and fissures to the overall hydraulic conductivity. It seems that the sandstone aquifer is characterized by a hydraulic conductivity of some 0.1–0.3 m/day, increased locally by secondary fissures. Transmissivities varied from 20–400 m^2/day. The average porosity of the total Wajid sandstone series is in the range of 5–10%, while effective porosity might be around 5%. It is possibly a little higher (5–10%)

in the friable, weathered upper horizons of the sandstone aquifer. Given such hydraulic properties, the Wajid Sandstone is classified as a moderate aquifer. In 1983 piezometric levels varied between 1970 m + msl, by the northern borders of the Plain, and 1820 m + msl at the discharge zone at the mouth of Wadi Marwan. By 1992, the levels had fallen to 1960 m + msl and 1800 m + msl. Groundwater flows from the north, west, east and south to Wadi Marwan, north-east of the Plain. Impermeable basement underlies the sandstone and is classified as an aquifuge.

The alluvium overlying the sandstone is unsaturated and serves as a rainfall collector whereafter the flow infiltrates into the sandstone aquifer. In the wadis debouching into the Plain, the alluvium is a system of significance since it receives recharge from runoff from the surrounding mountains. Characterized by favourable hydraulic properties, the system is composed of highly permeable wadi fills with some lenses with perched water. Parts of the sandstone aquifer outside the extent of the Plain are covered with the Amran limestone, which has some very poor hydrogeological characteristics as water flows through fissures, cracks and other secondary openings.

The annual recharge seems to be constant due to the buffering action of the thick alluvial deposits that cover the Wajid sandstone. Besides, infiltration through the soil profile takes place only when there is no soil moisture deficit. Hence, in cultivated areas where the soil generally has a low moisture deficit, a higher percentage of rainfall is likely to infiltrate. In other parts of the alluvium, substantial amounts of rainwater are lost by evapotranspiration. Most of the recharge water comes as runoff from the surrounding mountains west and north-west of the Plain and infiltrates through wadi fills. This assumption is supported by the increase in groundwater salinity from west to east, reaching its maximum at the natural discharge zone in the mouth of Wadi Marwan.

With 1100 wells operating, the total amount of abstraction from the sandstone aquifer was 57 MCM in 1983. The annual gross abstraction rate, mostly for irrigation purposes, increased from about 1 MCM around 1970 to about 80 MCM in 1992, when about 2330 wells were in use in the Plain. Figure 3 explains the history of annual groundwater abstraction in the Plain. Doubling the number of wells within that period, with improved well design and construction, caused about 30% increase in gross abstraction. The mean well yield measured during the 1992 well inventory was 3.3 l/s, about half the 6.7 l/s determined in the 1983 well inventory. Owing to the deteriorating productivity of the wells, the net annual abstraction was assumed to top out at 65 MCM beyond 1992. Between 1984 and 1986 the annual rate of well drilling in the Plain was at its peak when a total of about 813 wells were drilled. By 1986, the number of wells was almost twice the number that existed in 1983. Consequently, the rate of pumping must have escalated proportionally. Abstraction from the aquifer outside the border of the Plain, mainly due south, was insignificant as few wells tapped the aquifer in that vicinity.

To formulate a management strategy, a model was set up with the following objectives:

- to estimate annual natural recharge to the sandstone aquifer;
- to analyse groundwater depletion;
- to simulate the effects of proposed strategies.

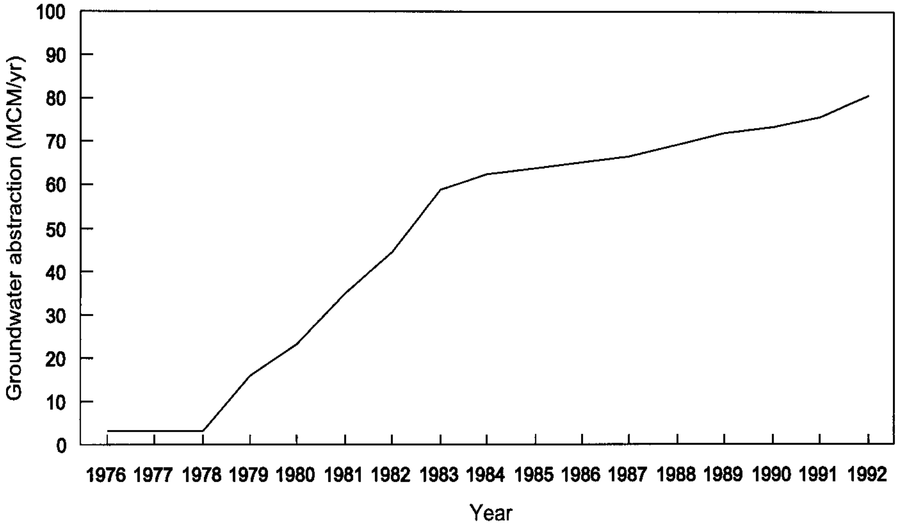

Figure 3. Growth in annual abstraction in the Sa'dah Plain.

The thickness of the Wajid sandstone, which was assumed to be one aquifer, varied between 200 m and 700 m, covered by a thick dry alluvium, varying in depth between 10 m and 50 m. The aquifer is mainly unconfined, except for small parts in the south and the north-west where the aquifer is confined by the Amran limestone. It is assumed that primary pores and secondary fractures and joints are very well developed in the sandstone so that the aquifer can be approximately simulated using a porous medium approach. Therefore, the widely applied groundwater model code MODFLOW (MacDonald & Harbaugh, 1988) was employed to simulate groundwater flow in the aquifer. The simulation of the heads was over an annual scale from 1978 to 1992 since a strategy would be designed for several years with overall regional objectives. The model was calibrated first by adjusting the values of the hydraulic conductivity to produce the groundwater head contour pattern of the year 1978 as the steady-state situation.

Using the simulated steady-state heads of 1978 as the initial condition, a transient model was calibrated by mainly adjusting the storage coefficient and the recharge rate such that the simulated heads fitted the measured groundwater heads of 1983 and 1992, and the historic records of six observation wells. An annual recharge rate of 6.5 MCM was an output by the calibrated model as part of the water-balance calculations. Recharge was estimated at 10 MCM by YOMINCO/TNO (1983) and 7.2 MCM by DHV (1992).

Extent of Groundwater Depletion

A decline of groundwater level that varied between 0.5 m and 4.5 m was recorded between 1983 and 1984 (Danikh & Van der Gun, 1985). Over the whole Plain the average was 1.5 m. In 1991–92 the average groundwater decline was reported to be 5.6 m over the whole Plain. An average of 40 m was estimated between 1983 and 1992 (DHV, 1993a). Figure 4 shows the hydrographs of two monitoring wells that were installed in 1984. Well WRAY1 is located in the middle of the Plain, while WRAY2 is located close to the edge of the Plain at the

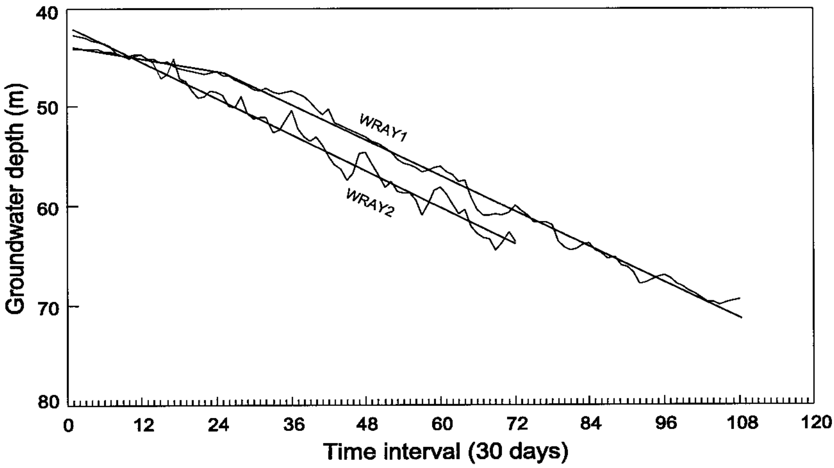

Figure 4. Hydrographs and fitted trends for WRAY1 and WRAY2.

recharge zone (see Figure 2). The last records were obtained in 1992 and 1990 for WRAY1 and WRAY2, respectively. By performing a time-series analysis on the monthly readings, a trend was fitted for each series at 95% confidence level (Figure 4). Nonetheless, the series of WRAY1, with 108 periods of one month each, was divided into two parts. The first part consisted of 24 periods. It implied that the response of the aquifer to the hydrological stresses, mainly pumping, experienced a steeper trend as the rate of pumping increased in 1986. The annual rate of well drilling was at its peak during that period.

Few seasonal variations were observed in the series of WRAY1 as compared with WRAY2, indicating that the effects of depletion are stronger at the middle than at the recharge zone. These results also provide additional support to the assumption that recharge mainly comes from the wadis at the edge of the Plain. In Figure 5 the fall of piezometric levels between 1978 and 1992 is shown for a north–south cross section in the Plain. Figure 6 shows a contour map of the spatial extent of depletion. Values varied depending on the abstraction intensities and the relative recharge locations. Declines were most pronounced around Sa'dah Town, where abstraction intensity was higher than other parts of the Plain. Further north, declines were noticeable around the population centres of Al-Talh and Dahyan.

One of the consequences of groundwater depletion is the reduction of the saturated thickness of the Sa'dah sandstone aquifer, leading to increased pumping costs and ultimately abandonment of wells. By using the results of the model simulations the diminishing volumes of the saturated sandstone were calculated for different years (Figure 7). In 1983 depth to groundwater was between 20 and 40 m below ground surface over most of the Plain (Van der Gun, 1985). A range of depths of 40 to 80 m was observed in most parts of the Plain in 1992 (DHV, 1994). However, depths exceeded 90 m in the same year in areas west of Sa'dah Town. In the area between Al-Talh and Dahyan, north of the Plain, groundwater depth was reported to be more than 80 m. Another consequence was the change in water quality. Change in water quality due to increased salinity was observed (average EC from 750 μS/cm in 1983 to 950 μS/cm in 1992) (Van der Gun, 1985; DHV, 1994).

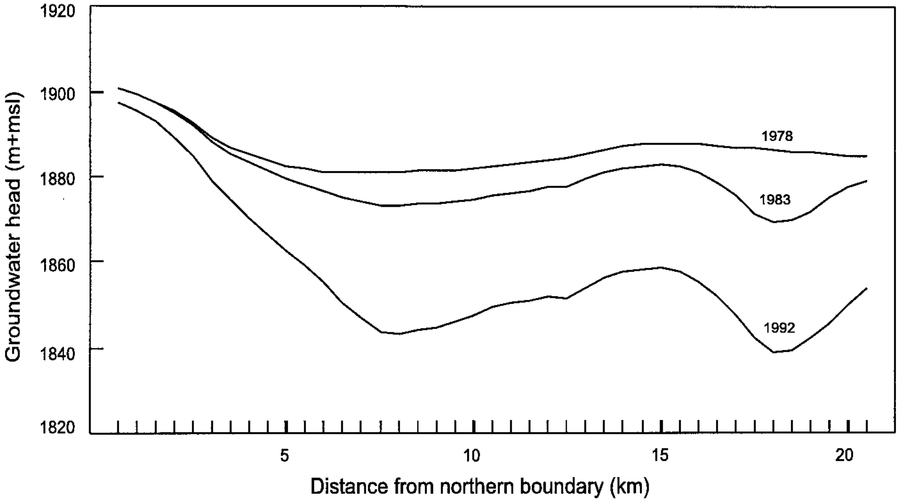

Figure 5. Fall of piezometric levels along section A-A of Figure 2.

Strategy for Controlling Groundwater Depletion

Current Situation

Since certain government policies and development directions often lead to depletion of water resources, changing these policies and directions is often the essential initial step toward sustainability. During the past few decades, the Government of Yemen has adopted a country-wide supply-orientated water resources management strategy to secure the needs for water for different purposes. Groundwater was viewed as the natural exploitable resource to induce socioeconomic development. The aridity of the region did not support other options. Groundwater resources development has the advantage of scale over surface-water development. It does not require large-scale projects such as dams, canals and other engineering structures. In comparison, surface-water utilization requires large diverting and regulating structures along with the technical expertise needed to design, construct and operate them. Another advantage was the widespread occurrence of groundwater in the different regions of the country giving the government a good opportunity to reach out to remote communities with 'tangible' development. In addition, the development of groundwater resources in any region of the country was accessible by many competing users with the simple technology of drilling a well. Coupled with the need for irrigation water to support agricultural development was the need to satisfy the growing domestic demand for water.

In the Sa'dah Plain modern groundwater development was extensively started around 1978. It was mainly financed by Yemeni Nationals in the neighbouring countries. The objective was to induce 'immediate' socioeconomic development in the region by expanding irrigated agriculture. The aquifer cannot sustain the rate of abstraction. If the situation continues in the Plain with the present total abstraction rate, the groundwater flow model predicts that the aquifer will be exhausted by 2032. The fall in groundwater levels under the present unsustainable conditions was simulated by the model shown in Figure 8. Water scarcity in the region will then be augmented by aquifer depletion leading to the collapse

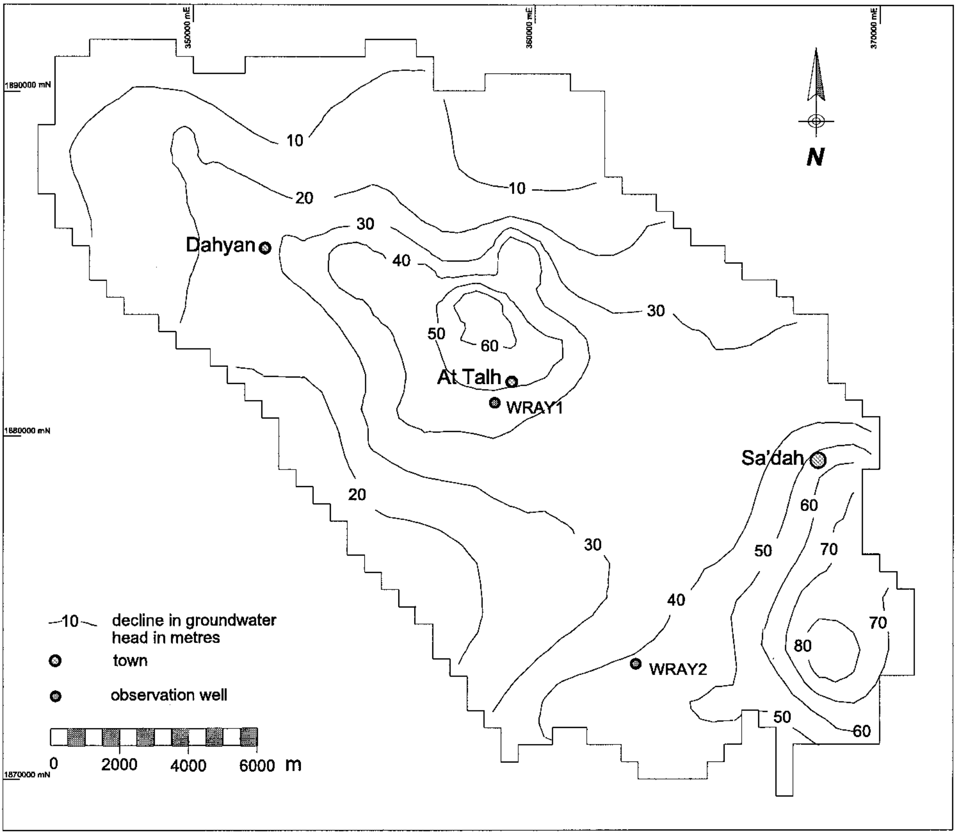

Figure 6. Decline in groundwater levels from 1978 to 1992 according to the calibrated groundwater model.

of the rural agricultural economy and the outmigration of inhabitants, probably to the other intermontane plains. Owing to high abstraction levels, aquifers in these areas are already under tremendous stress and cannot support additional demand. The situation in the Sa'dah Plain, and in many other intermontane groundwater basins in Yemen Highlands, gives rise to the question of the viability of groundwater-irrigated agricultural development in the region. The national environmental and social costs may surpass the benefits. Therefore, influencing demand becomes the most important measure in the transitional progression towards sustainability.

Current Institutional Arrangements

Currently, the major responsibility of administering groundwater resources in the Plain lies mainly with the Ministry of Agriculture and Water Resources (MAWR). Through its local agency, MAWR issues well-drilling licences and supervises activity in the field. Licensing is required by a Governmental Decree that has the power of a by-law. Water resources planning and management is not practised by MAWR according to the strict definition of the term. Water comes in as the main input in agricultural production. Expansion of agriculture is the goal of MAWR. With the advent of the National Water Resources

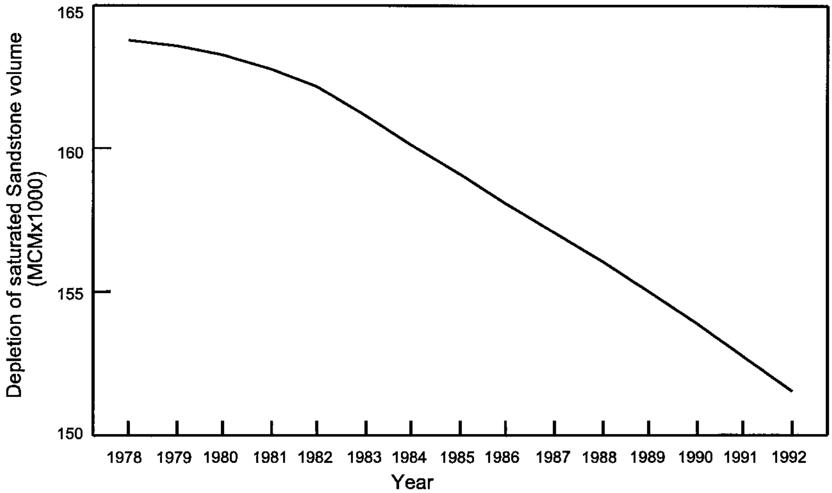

Figure 7. Diminishing volume of saturated sandstone as calculated by the calibrated groundwater model.

Authority (NWRA) in late 1995, the name of the Ministry may be changed in the future. According to the Presidential Decree that established the Authority, it is the sole governmental agency responsible for studying, planning and managing water resources and the formulation of water resources policies and development strategies at the national level. It is supposed to replace the previous High Water Council which did not have much success. In spite of that, it is still a stiff task to conceive, formulate and implement national strategies to control aquifer depletion, let alone local strategies for rural areas such as the Sa'dah Plain. Another organization involved is the Local Council for Cooperative Development (LCCD), which is in charge of domestic rural water supplies. Furthermore, parts of Sa'dah Town are supplied by the National Water and Sewerage Authority (NWSA). Finally, there is the General Authority for Rural Electricity and Water (GAREW), whose main responsibility is the design and construction of domestic water supply schemes for rural areas. Although all these organizations rely on groundwater to deliver their services, no coordination exists between them. In the future, NWRA is supposed to achieve such coordination as a result of its activities. The Water Law, the major management instrument, is still at the draft stage. Absence of the Water Law impedes the Government's ability to intervene at the local level. Allegiance of the local inhabitants to the tribal system is so strong that the Government relies on tribal leaders (sheikhs) for matters of political relevance to the area. Even if legislation exists, it will take a long time to overcome the adherence of the local inhabitants to the customary tribal law. It stands to reason that taking advantage of the existing sociopolitical forces to confront the water crisis can be an alternative to the minimal local official institutional arrangements for water resources management.

Water Demand Management

The case of the Sa'dah Plain is a specific example of all the other Yemen Highland plains where the situation requires investigation of the possibilities to

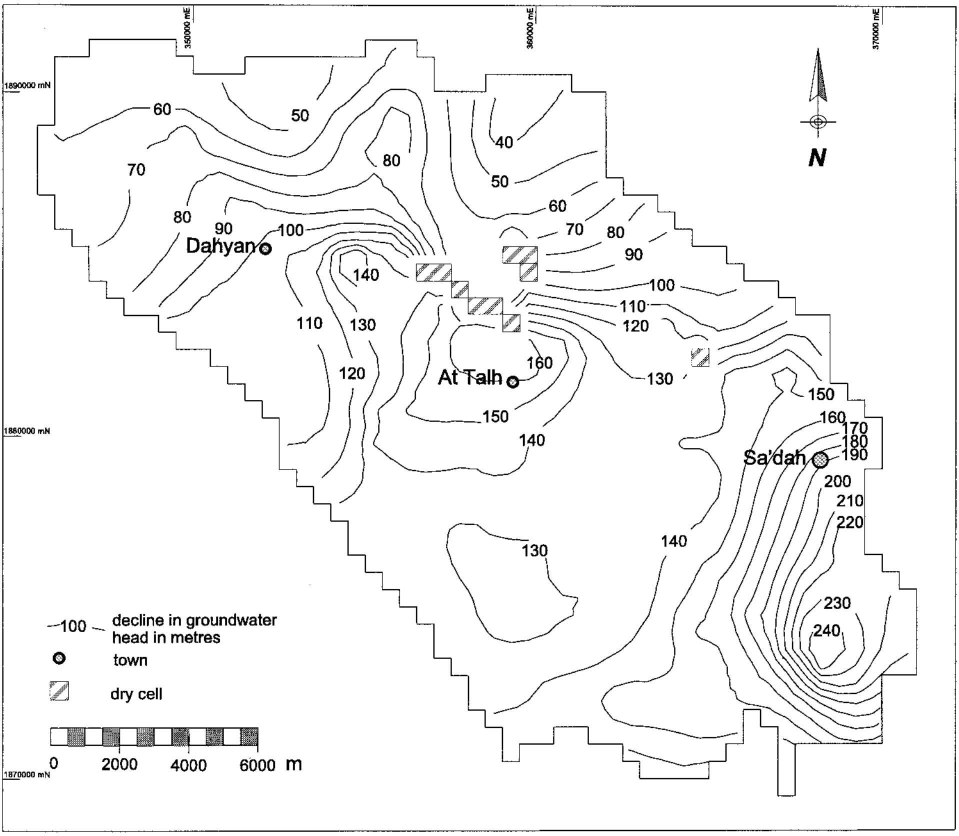

Figure 8. Decline in groundwater levels 1978–2020 under present conditions according to the calibrated groundwater model.

control demand. Demand control is the first stage in a strategy of sustainable utilization of water resources. In view of the identified adverse effects of groundwater resources development in the Plain, the following demand management objectives may be specified:

- improving the irrigation efficiency;
- improving allocation of groundwater resources for agricultural and domestic use;
- postponing new borehole construction by efficient use of available water;
- moving toward sustainable groundwater development.

The improvement of irrigation efficiency is the most important measure that will dramatically influence the demand for groundwater. Total irrigation efficiency was estimated to be about 41%. Conveyance efficiency was assumed to be 75% since more than 50% of irrigation water is conveyed by pipes. The rest is conveyed by unlined ditches. As for application efficiency, it was about 55% owing to the absence of irrigation scheduling and poor levelling of fields (DHV, 1994). Thus, at farm level a great margin of improvement is required. Because of the aridity of the Plain, evaporation losses must be very high. Therefore, all irrigation water should be conveyed by pipes.

Conjunctive use of groundwater and spate water should be implemented at all possible locations. Traditional spate-diversion structures should be improved and modernized. By making more spate water available for irrigation, farmers will reduce groundwater pumping. Furthermore, the yield of the rainfed agriculture, which is about 50% of total agricultural land (DHV, 1994), should be improved.

Historically, all over the country, variable water fees were levied only on surface water users (spate irrigation) depending on their location on the conveyance network. The objective was to recover both capital and operation and maintenance costs of the diversion structures. To ensure equity and sustainability of water resources management, farmers upstream paid more than downstream farmers (Bamatraf, 1991).

As for groundwater, in former times the sustainable use of the resource and the established water rights did not imply any social costs. Deep wells did not exist and groundwater mining was not practised. Shallow wells were the main source of groundwater. Groundwater abstraction was controlled by natural recharge mechanisms, achieving physical sustainability. The present situation is different and charging groundwater users becomes a necessary conservation measure. Externalities that result from lowering groundwater levels must be considered and assessed. Quantifying such externalities enables the managing institutions fairly and effectively to influence the user group causing the externalities. Drilling new wells and deepening existing wells must be prohibited. Diversifying away from irrigated agriculture must be planned for and priority must be given to domestic use. On the other hand, subsidization of water-saving irrigation equipment should be implemented and certain cropping patterns should be discouraged (especially qat![1]). Of course, implementing all these and other possible measures requires proper institutional arrangements.

Proposed Institutional Arrangements

Historically, the Yemenis have devised various water management instruments. Structures for spate-water diversion for irrigation were constructed on many wadis. In the framework of the customary law rules were set to distribute tasks and costs of management. Traditionally, development of spate irrigation was essentially a cooperative venture which was closely related to the existing social structure in the wadi area. A set of rules for charging beneficiaries was established. Since fields upstream obtained more water than those downstream, upstream fields paid more than the fields located downstream. Farmers used to hire 'water masters' (*wakil*) for each wadi to resolve disputes related to water rights and to supervise the maintenance of water works. Disputes on (spate) water were settled within the traditional system of tribal customary law, administered by the water master or a committee of village sheikhs or dignitaries who belong to the tribes of the litigators. Guided by customary law as a powerful management instrument, people have managed for generations to solve the problems of spate irrigation. This system can be improved by the introduction of modern methods and technology. Since groundwater-irrigated agriculture is a somewhat modern practice in the country, little traditional experience has accumulated.

The absence of a water law in Yemen is becoming a priority issue that makes discussions about groundwater management merely theoretical. Drilling a well without a licence is not punishable by law. Neither NWRA nor MAWR can take a farmer to court for doing so since, according to the law, no wrongdoing has been committed. If the Government decided, say, to prohibit deepening wells, the decision could be contested by any private citizen. Any judge at the lowest level in the judicial system would rule out such a decision as being a violation of the constitutional rights of the citizens, i.e. their property rights.

According to the Sharia't (Islamic Law), water in its natural state is common property and proportionment of the resource must be equitable. This principal was incorporated in the Draft Water Law of Yemen (NWRA, 1996). Nevertheless, according to customary law, a well and the water in it are the private property of the person who dug the well (Frederick, 1993). The owner of the well cannot prevent users from satisfying their human needs. In view of the aquifer concept this traditional rule may not be applicable any more. Co-dependence of wells tapping an aquifer is an established fact. In addition the rule was introduced when depletion was not a serious threat to society. This aspect of customary law therefore mitigates against the sustainable development of an aquifer. Another principle of the Sharia't stipulates that preventing damage takes precedence over accruing benefits. Thus, the concept of user right rather than property right may be closer to reflecting the co-dependence of wells tapping an aquifer.

In the late 1960s, the cooperative approach was adopted to deal with development issues throughout the country. To institutionalize this approach, Local Councils for Cooperative Development (LCCDs) were initiated. The LCCDs are semi-official organizations whose members are elected by the inhabitants. The basic idea, which originated in the rural districts, was to encourage people in the local communities to cooperate to solve their development problems. Later on, specifically in the 1970s, a law was enacted to regulate and support the LCCDs. For every 500 inhabitants in every district a representative is elected for five years. An executive body of five, seven or nine members is then elected by the representatives. In addition, a chairman, a secretary-general and treasurer are elected (DHV, 1994). The members of the Councils are the local leaders, dignitaries and sheikhs. Thus, the structure provides for the social forces and minimizes, or probably eliminates, unnecessary conflicts within the tribal system. As regards financial affairs, they can collect different fees as stipulated and regulated by the law. The responsibilities of the Councils encompass rural development services such as roads, schools, health centres, tree nurseries, planting of forest trees and domestic water supply. The LCCDs hire professionals in the different disciplines related to the tasks to be achieved. Some of them are permanent employees, such as engineers and accountants. The LCCDs no longer play a significant role in agricultural development or water management. The farmers wish them to become involved again in solving problems. The projects of GAREW are executed in collaboration with the LCCDs, who undertake operation and maintenance later. Under certain circumstances, the Councils collect funds for construction of new water-supply projects. They constitute the most favourable institutional framework for involving the main stakeholders in groundwater resources management, since the goal of the LCCDs is to induce socioeconomic development in rural areas. In the Sa'dah Plain, the limiting factor to development is water. Therefore, LCCD activities should be centred around water resources management.

Towards a Sustainable Strategy

Sustainable water resources management is a multidisciplinary activity. Nonetheless, since the main constraint in the case of the Sa'dah Plain is groundwater availability, the main theme of the strategy must concentrate around this topic. Thus, the trigger for water resources management in the Sa'dah Plain is the adverse effects of mining the only aquifer in the Plain. However, first, the strategy must be socially acceptable, and deal closely with the social structure and prevalent societal norms. Total involvement of stakeholders is necessary. Second, the strategy should be physically sustainable. The annual recharge to the aquifer is the total possible abstracted volume under physical sustainability. Third, it is not possible to keep up the sustainable conditions without proper institutions. Institutional sustainability implies the capacity of the involved entities to continue to run the management process after establishment. The extent to which stakeholders are involved in managing the resource determines the institutional sustainability of the strategy. Institutional arrangements should be considered in the context of the indigenous sociopolitical structure. Fourth, the strategy should aim at financial sustainability of the management activities. If the stakeholders accept the proposed management arrangements, they will be willing to share in financing. Recent experiences in the rural areas of Yemen have shown that people contributed to building rural roads. Later on, they continue to contribute to road maintenance. Sanctions for non-compliance and penalties for misuse must be translated into monetary values. Therefore, a strategy achieves institutional sustainability by the degree of stakeholder involvement, i.e. direct participation in decision making in all management issues. Finally, as noted before, customary law and traditional social forces are the chief management instruments to assure conformity with and implementation of the strategy. Since depletion is the main issue in the water management strategy, groundwater levels were adopted as the principal criterion in judging physical sustainability.

The proposed strategy was developed by taking into account the constraints of the problem domain. These constraints are:

- socioeconomic development and opportunities for future generation;
- limited possibility for developing additional supplies;
- decline of groundwater levels.

Thus, the decision variables are mainly controlled by the problem of depletion. Therefore, four important characteristics of any considered strategy are linked to the management objectives:

- control of abstraction;
- change in cropping pattern;
- water demand management (irrigation efficiency);
- institutional arrangements.

The assumed time horizon of 25 years, starting in 1996 and extending to 2020, for the formulated strategy was assumed for two reasons:

(1) The recent socioeconomic development started in the early 1970s. The situation of over-exploitation of groundwater is related to that. Reversing the negative effects may take at least the same time.
(2) The population of the Sa'dah Plain will, roughly, double by the year 2020.

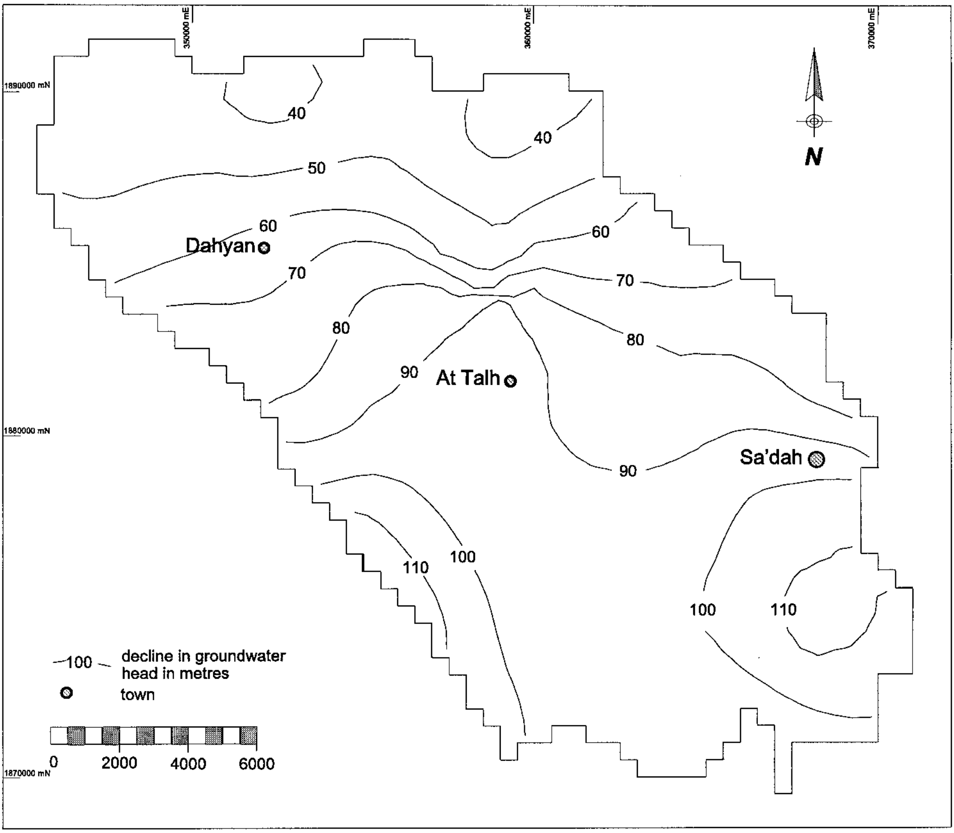

Figure 9. Decline in groundwater levels 1978–2020 under sustainable strategy.

Under this strategy, water demand management will be the major tool to influence water use, irrigation efficiency improvement to 75% being the main measure. The net abstraction will have to be reduced by about 11% per annum starting in the year 2000. In other words, an 'abstraction quota' has to be adopted. By the year 2020, total net annual abstraction will balance the annual natural recharge. In addition, diversifying away from irrigated agriculture will have a marked effect on reducing groundwater abstraction. Based on that assumption, a change in cropping pattern will take place in response to the diminishing rate of abstraction. Under the conditions of this strategy, the piezometric levels in the aquifer were simulated as shown in Figure 9.

The most important characteristic of this strategy is the institutional arrangements. The responsibilities of MAWR on groundwater should be transferred to LCCDs. At present the councils operate under the supervision of the Ministry of Local Administration. For the purpose of water resources management, they may be supervised by NWRA. The influence should be in a manner that incorporates their activities in the national water resources strategy. Management of groundwater resources by the LCCDs is especially suited to the Sa'dah Plain since the aquifer is secluded, and no inter-regional conflicts are possible. Hence, the powers of the Government are not required to resolve any inter-regional conflicts. Another reason is the homogenous social structure (tribal system) of the inhabitants (the stakeholders). In addition, democratic control is provided for by the beneficiaries as the main stakeholders (the electorate). The approach is based on cooperative action at grass-roots level. They can adapt, and already are adapting, to the traditional local leadership arrangements, which simply reflect the local sociopolitical structure. Another advantage is building on an existing institution which is more feasible at a lower political and economic cost (World Bank, 1993). The concept of the lowest appropriate level of decision making is realized. Furthermore, customary law would play an important role in organizing groundwater use.

The scope of their role needs careful design and may be delineated as follows, but not necessarily limited to these activities:

- decisions on annual abstraction quotas;
- implementing and monitoring abstraction levels in the different districts in the Plain;
- groundwater-level monitoring;
- supervision of drilling activities;
- dispute resolutions;
- local awareness campaigns;
- collection of water fees;
- promoting water-demand measures;
- incorporating groundwater irrigation and spate-water irrigation practices;
- introducing sustainable groundwater management principles into the customary law;
- helping create a sense of collective ownership and consciousness about the resource;
- coordinating domestic water supply schemes with GAREW and NWSA;
- coordinating rainfed agriculture research and extension with MAWR;
- coordinating the national water strategy with NWRA.

Concluding Remarks

Government intervention is not likely to solve the problem of over-exploitation in the Sa'dah Plain, at least in the foreseeable future, owing to the lack of proper institutional arrangements and management instruments. Thus, a non-governmental approach must be sought at a grass-roots level to confront the crisis, especially in rural areas where irrigated agriculture is the major economic activity. Besides, it is the local communities that would bear the burden of transformation to a sustainable solution. To redeem the situation, groundwater utilization must be brought back to sustainable levels by following a strategy that would reverse the current trend of over-exploitation. Under this strategy water-demand management would be the major tool to influence water use. An abstraction quota has to be adopted to reduce net abstraction by about 11% per annum starting in the year 2000 to balance the annual natural recharge by the year 2020. In addition, diversifying away from irrigated agriculture would have a marked effect on reducing groundwater abstraction. Based on that assumption, a change in cropping pattern would take place in response to the diminishing rate of abstraction. Institutional arrangements are a prerequisite for a sustainable strategy to be translated to actions on the ground. Customary law would play a big role in implementation and enforcement. According to this strategy, the responsibilities of the Ministry of Agriculture and Water Resources on groundwater would be transferred to the Local Councils for Cooperative Development (LCCDs) as possible candidates for a grass-roots-level organization.

Note

1. A plant whose leaves are chewed to induce a stimulating effect.

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