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GROUNDWATER RESOURCES DEVELOPMENT AND THE MARIB DAM

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ABSTRACT The waterresources system of Marib has been investigated. The surface water resources and groundwater resources are strongly interrelated. In "Sabaean" times (2000 to 3000 years ago) a very efficient surface water development system (irrigation system connected to the "Great Dam") was applied. However the findings of the investigations reveal lirnited surface water resources. The impact of the new Marib Dam on the water resources system has been discussed for different scenarios. A possibility to make efficient use of the groundwater resources is presented.

INTRODUCTION

The water resources available to the Marib area, which is located at the edge of the Yemeni-Arabian desert the Ramlat Sabatayn, which forms the southwestern extension of the great Arabian desert, the Rub Al Khali *(The Great Empty Quarter)* have been investigated during the period 1986 to 1989. The investigations have been executed in the framework of a bilateral prograrnme for technical cooperation between the Yemen Arab Republic and the Netherlands. The executing agencies of the concerning WRAY-programme were the General Department of Water Resources Studies of the Ministry of Oil and Minerals (Yemen Arab Republic) and the TNO Institute of Applied Geoscience (The Netherlands).

[Since May 1990, the Yemen Arab Republic and the Peoples Democrah'c Republic of Yemen conshhute one country: The Republic of Yemen].

The position of the investigated area is shown in Figure 1. The area forms part of the Wadi Jawf-Marib Basin, which lies at the foot of the mountainous catchrnent areas of the Eastern Escarpment to the west. Before the construction of the new Marib Dam in 1986, the intermittant streamflow (storrnfloods) of the Wadi Adhanah could pass unhindered into the Marib plain area, where the flows became gradually less downstream because of diversion for spate irrigation and infiltration into the subsoil of the wadi beds and subsequent percolation (groundwater recharge) to the groundwater.

However since the construction of the Marib Dam in 1986 the stormfloods of the Wadi Adhanah are first stored in the Marib Dam Reservoir.

(The Marib Dam and Irrigation Project includes the construction of the dam and primary canals to irrigate a surface of 6890 ha by means of integrated development of surface water and groundwater. The dam and canals have been designed by Electrowatt Engineering Services Ltd, Switzerland. The construction of the dam and the primary canals have been completed respectively in 1986 and 1987. However, completion of the secondal y canals has become uncertain because of severe conflicts in the area. Only the secondary distribution system connected to diversion A, supplying only about 350 ha has been constructed).

Released water from the dam follows the old wadi streambed as far as the diversion structures of the prirnary canals, respectively 10 and 14,5 km downstrearn of the dam. Consequently the groundwater reservoir will be recharged only by infiltration and percolation through the wadi bed of released water from the dam. (Recharge from local runoff can be neglected).

Consequently recharge of groundwater, previously a matter of nature, became more or less an artificial matter, to be determined by adequate water resources management.

The results of the investigations, which have revealed the first continuous (geo)-hydrological records in the area, have pointed out that groundwater development could play a vital role in the integrated development of groundwater and surface water. During years with small amounts of surface runoff from the catchment, the irrigation Will depend on groundwater. However to make an efficient use of the groundwater resources a thorough study of the integrated water resources system and especially of the groundwatercomponent is necessary.

This paper will especially highlight the groundwatercomponent of the system and hopefully will bring forward some worthwile alternatives of development of the scarce waterresources of the area. It has to be stressed that the study results deal only with the optimal use of the available waterresources out of the waterconservation point of vue. Social, economical and political factors have not been considered yet.

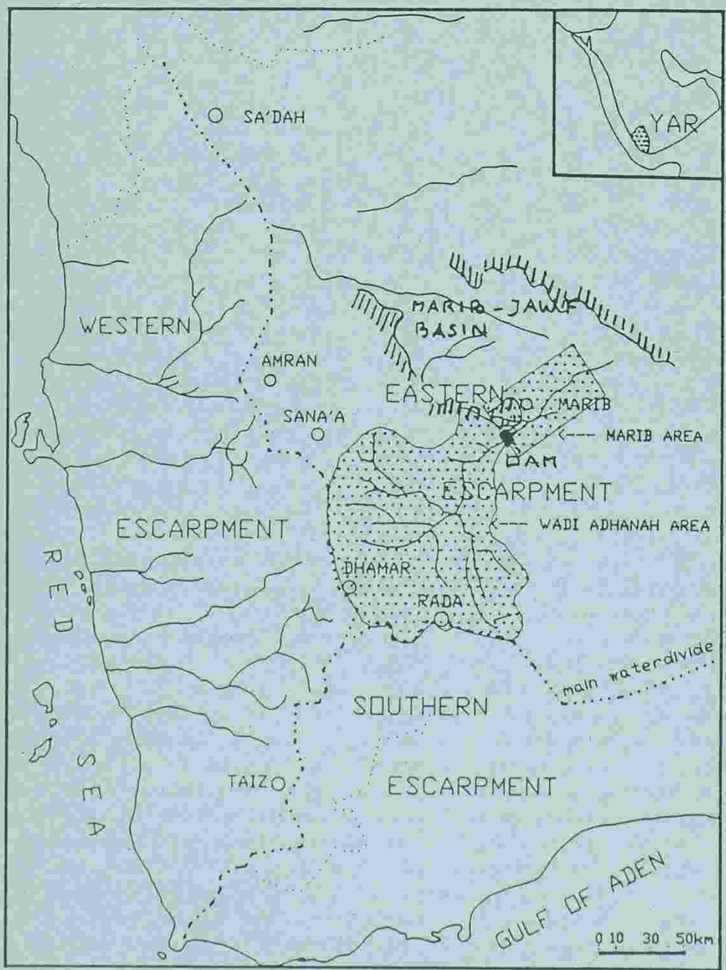

Fig. 1 Location of the wadi adhanah and marib area

WATERRESOURCES DEVELOPMENT IN THE MARIB AREA FROM THE PAST UNTIL PRESENT

"Ancient" Water Resources Development

The construction of the new dam and the new irrigation system has to be seen in historical perspective. Systematic use of surface water for irrigation at Marib is not new and probably started already in the middle of the third millenium BC. One of the most famous Arabian monuments are the ruins of the "Great Dam" of ancient Marib, which was the most famous town in ancient Yemen and the capital of the Kingdom of Saba. The remains of the old dam are found 2.5 km downstream of the new darn and for many centuries the inhabitants of Marib were able to irrigate an estimated maximum area of 9600 ha. The fertile oasis on the left and right bank (paradises according the Holy Koran) produced enough food for the inhabitants of the wealthy town, the dwellingplace of the Queen of Sheba, head of the powerful Sabaean Empire. The wealthy trade centre of Marib dominated the main trade route of the ancient world, the frankincense route which ran from the ports along the Gulf of Aden via Marib into northern Arabia, Egypt and the Meditarranean.

There is evidence that the Dam lasted for more than a millenium, before the "Great Dam" of Marib finally collapsed in the beginning of the seventh century AD. Besides through the labyrinth of ruins of the sluices and canals the irrigated area can easily be recognized by the thick silt deposits (thickness up to 20 m).

The period from the "old" to the "new" Marib Dam

During the centuries after the collapse of the "old" dam and until the introduction of modern groundwater abstraction methods, mainly spate irrigation was applied downstream of the high deposits of "ancient" irrigation silts. Depending on the wadi discharge the irrigated area varied from one season to another. From aerial photographs taken in 1973 it was estimated that the overall spate irrigated area was 3900 ha of which on average about 2000 to 3000 ha produced one crop every year (Figure 2).

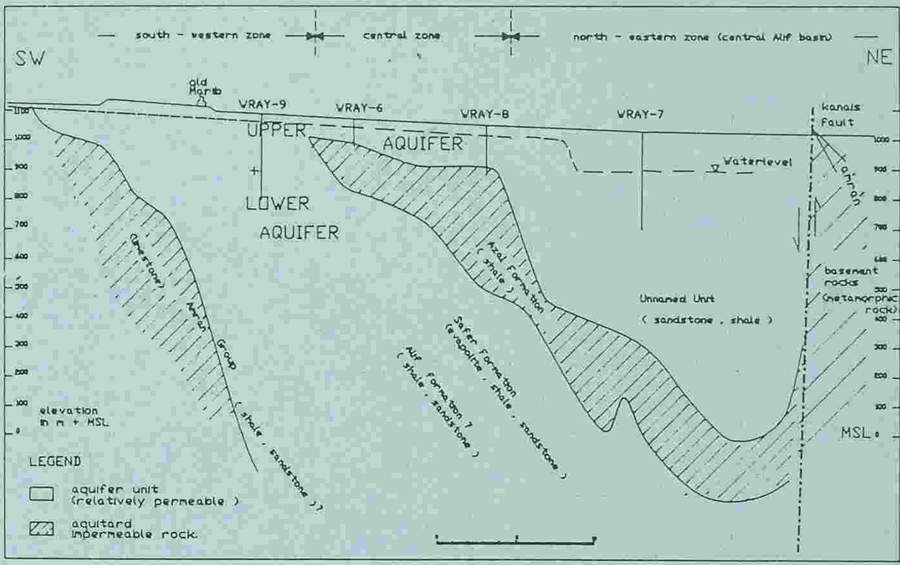

Fig. 3 Hydrogeological cross-section through the Marib area (location profile see Figure 5)

Groundwaterdevelopment

After the end of the revolution in 1968, groundwater pumps driven by diesel engines were introduced. This emerges together with the increasing use of cable tool drilling rigs in the eighties in a rapid increase of groundwaterirrigation (Figure 2).

After the completion of the Marib Dam in 1986 the runoff from the wadi Adhanah is retained by the newly constructed Marib Dam which has stopped spate irrigation completely. Presently and probably this situation will continue until the completion of the secondary canals, exept for 350 ha connected to diversion A, irrigation will depend almost completely on groundwater. The total groundwaterabstraction in 1987 amounted about 136 Mm^3 while the annual increase of groundwaterabstraction during the last 3 years is estimated at some 20 Mrn^3. In Februari 1989 the gross irrigated area was approximately 10,000 ha (from aerial photographs).

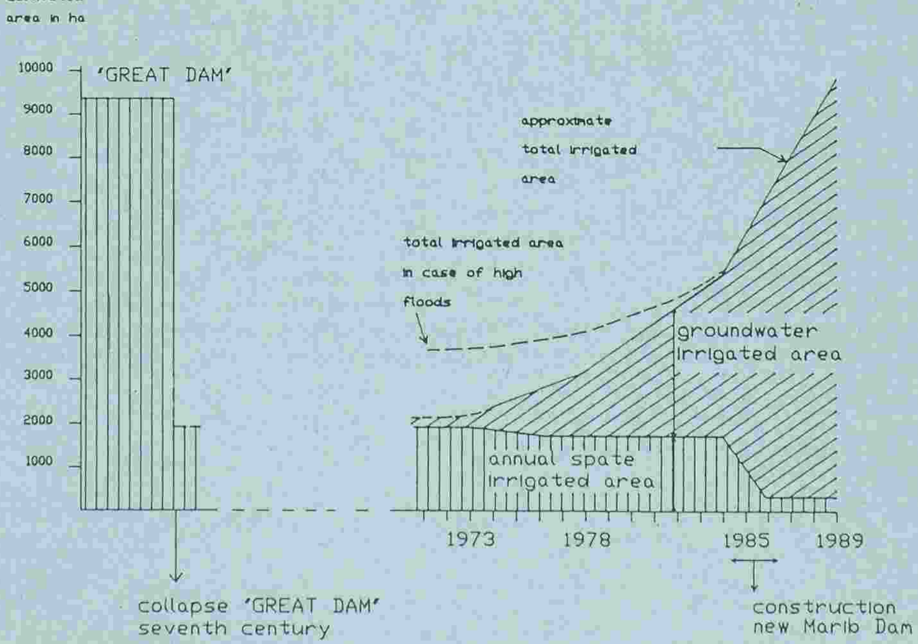

Fig. 2 Development of groundwater irrigated area

GEOHYDROLOGY OF THE MARIB AREA

The geohydrological system of the Marib area

The general aquifer system is shown in the schematic hydrological crossection presented in Figure 3. The Crossection runs more or less through the centre of the project area from southwest to northeast and includes the 4 WRAY exploratory borehole locations (Figure 4).

The Marib aquifersystem belongs to the hydraulically interconnected basin fill deposits of the Marib-Jawf Basin, which is a structural trough, trending northwest-southeast, as shown in Figure 1. Faultzones trending east-west and southeast-northwest divide the basin into several subbasins. Displacements of more than 3000 m occur along the fault zones. The basin fill deposits consist of a sequence of clastic sediments and evaporites, shales, limestones (Cretaceous and Jurassic) and in the upper part semi consolidated sands and silts

(Cretaceous). Throughout the whole basin, except for some small outcrops of older formations, recent alluvial and aeolian sediments overlie the older formations.

The sub-basin division has a major effect on the groundwater flowsystem. Especially the presence of the impermeable Azal shale (Cretaceous) Formation (see Figure 4), is defining the groundwater flowsystem. Probably the formation can be considered as an underground dam. According the outcomes of the seismic lines the top of the layer at his southwestern boundary is found at depth of 65 to 70 m only. This implies a major constrain on the groundwater flow and for the position of the groundwater levels in the southwestern and central part of the Marib Area. The groundwater has to flow over the underground "barrier" and this results in relative undeep groundwater levels in the central and southwestern zones of the arae.

In the north-eastern sub-basin the Azal Formation dips down to great depth and in

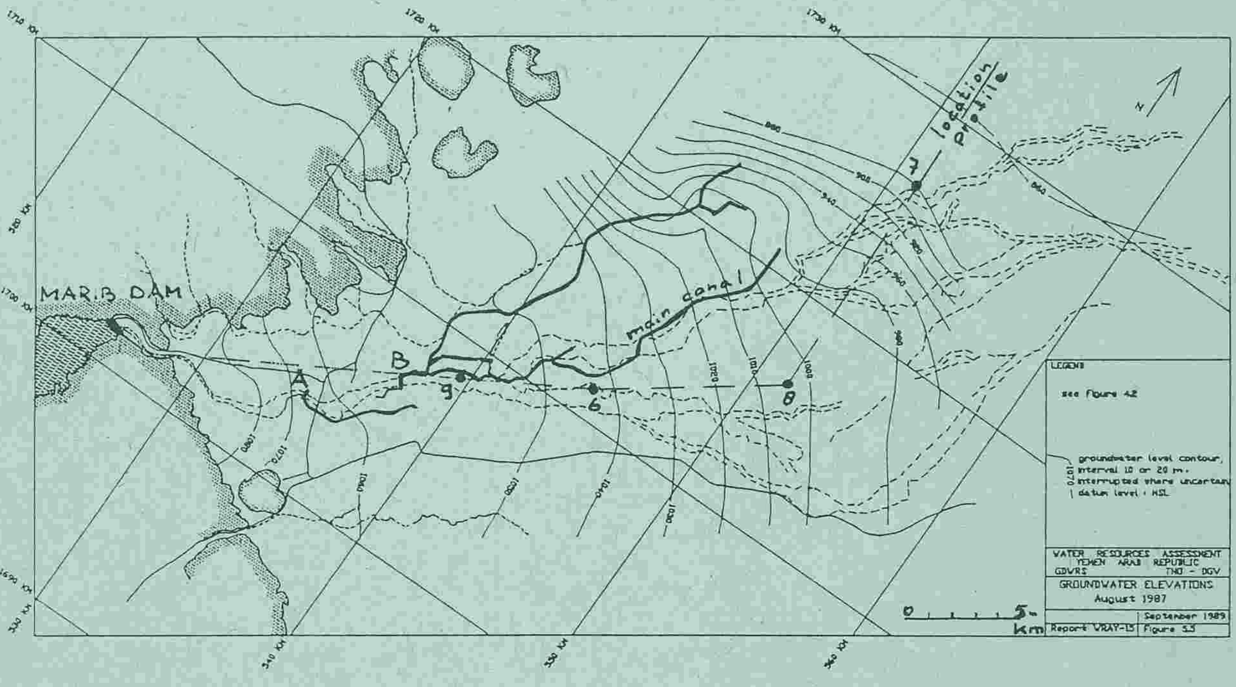

Fig. 4 Marib project area, with Marib Dam, diversions A and B, main canals, groundwater level contours and location profile in Figure 4

the permeable basin fill deposits of the Urmamed Unit of the Tawilah Group (Cretaceous) the groundwater levels are found below 135 m, making groundwater abstraction in this less fertile part of the area much more expensive.

The major conductive zones are the upper 10 to 20 meter (depth 15 to 70 m) of the saturated zone in the southwestern and central part. It forms the major heavily exploited aquifer in the area. Also the explored upper part of the northeastern (Alif) subbasin has a good hydraulic conductivity. However groundwaterlevels are low. The third probably "very" interesting zone from exploration and watermanagement point of vue could be the sandy lower formations in the south-western part (lower aquifer in Figure 4). One exploration borehole and the outcomes of the geophysical survey suggest very permeable zones in this area and down to unknown depth. The stored volume of fresh groundwater in this area has to be explored further and it could play an important role in future watermanagement plans.

Groundwater recharge, storage and discharge

Recharge

The main recharge component is infiltration and subsequent percolation of streamnow through the wadi beds. Natural strearnflow in the wadis occurs only for short periods, as storm runoff, during and immediately after rainstorms in the different catchments. However, since the completion of the Marib Dam, only a few minor wadis (with a total catchment of 1220 km2) drain into the Marib plain. Before the conslruction of the dam, the principal recharge source used to be the streamflow of the Wadi Adhanah (which a total runoff generating catchment of 8200 km2) which is called Wadi As Sudd after entering the basin and its eastern extensions, the Wadis Abrad and Abida. Recharge now depends mainly on how much water is released through the gate of the dam and depends donc on the operation of the dam and the reservoir. By manipulating the release rate of flow through the gate and the gates at the diversion structures the recharge areas could possibly be restricted to the wadibeds upstream of the diversion structures. This option could be very interesting out of watermanagement point of vue.

The second most important recharge component is returnflow from irrigated areas. Locally where the soils are very sandy and the tertiary canals long, the "irrigation losses" could be considerable. For the budgetcalculations it is estimated at 30% of the total groundwaterabstraction. Other recharge components like infiltration and subsequent percolation of local rainfall and groundwater inflow are probably very small and can be neglected when compared to the other components.

Discharge

Groundwater withdrawal by wells and natural groundwater outflow are the main discharge components. The groundwater withdrawal is estimated at 136 million m^3 in 1987 and the annual increase at some 20 Mm^3 per year during the last three years. The natural groundwater outflow has been estimated from groundwater level contour pattern and the measured transmissivities. The amount involved is approximately 60 Mm^3 per year.

Storage

During the investigation period 1986-1988 the total groundwater storage has been reduced by an amount of about 326 Mm^3 (109 Mm^3 per year), indicating a considerable depletion of the reservoir, which was confirmed by the observed declining groundwater levels.

It is estimated that, very roughly a total volume of 40,000 million3 of fresh groundwater is stored in the Marib aquifer system. Taking into account the clayey and silt layers, probably around 10,000 million can potentially be extracted by pumping. The extractable volume is in the order of 100 times the present annual depletion of groundwater.

GENERAL SYSTEMS APPROACH TO WATER RESOURCES MARIB AREA

The impact of the construction of the Marib Dam and irrigation canals on the available water resources has been considered in a picture of the whole water resources system, a general systems approach as shown in Figure 5.

The different subsystems and their interrelations are depicted in the figure. It indicates the main source of water (Wadi Adhanah catchment), and shows the major reservoirs (groundwater basin Marib Area and the Marib Dam Reservoir), the major water conveyance conduits (aquifer and canal system) and the major demand sectors (irrigation and domestic use). The figure also shows how the elements are

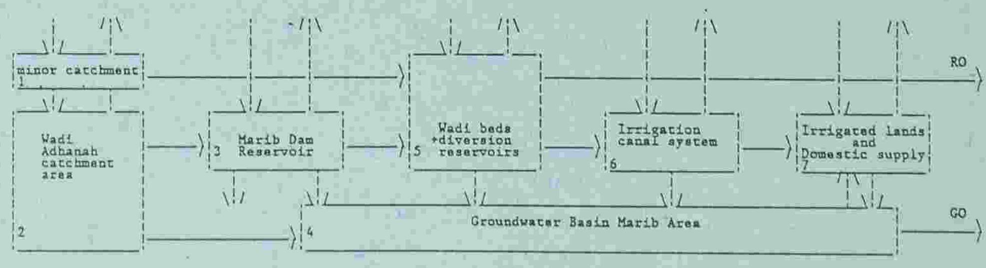

Fig. 5 General systems approach to water resources Marib area

interrelated, as far as inflows and outflows of water are concerned. It can be observed that "losses" of water from one subsystem may constitute "gains" for another subsystem. On the other hand, other losses may be interpreted as "definitive" losses, e.g. all evapo(transpi)ration losses, runoff outflow beyond the Marib area and the groundwateroutflow passing the boundaries of the Marib area.

The figure shows the impact of the Dam and irrigation canals, one reservoir (Marib reservoir) and one conveyance conduit (canal system) have been added. As result, more inand outflow components are introduced. Especially important are the the introduction of new losses (e.g. evaporation from the lake surface and the canal system) and the introduction of flow components, that can be manipulated. From the water conservation point of view it is important to know whether "gains" of useablc water are also obtained. This question will be tackled below, by exarnining water balances of different scenarios and by ascertaining the water resources available and the consequences of manipulating certain components.

The results of four waterbalances are presented in Table 1.

The waterbalance components for 1986-1988 have been measured or estimated. A considerable amount of water has been lost from the lake. At the end of the considered period about 78 million m^3 had been stored in the lake.

The other figures concerns three possible scenarios for the future. The inflow is equal to the average inflow measwed during the period 1986-1989. The highest lake losses occur when the dam is used as a storage dam and the lowest when the dam is used as floodcontrol dam.

Development of the Water resources according a scenario that approximates the use of the dam as flood control dam seems to be preferable from the water conservation point of view. However the amount of water available for surface water irrigation is highest in case of a storage dam. But in the latter scenario the total losses from the system are exceeding the total waterinflow into the system.

Groundwater development or not?

In all cases groundwater is being mined, which will have negative consequences such as declining groundwater levels, exhaustion of certain zones, increasing costs of groundwaterexploitation and deterioration of groundwater quality in certain zones. Morerover, because of the high amount of groundwater outflow the groundwater resources system constitutes a very inefficient system.

Than the question rises whether the option to use the dam as storage dam is the most efficient one? The water budget calculations have pointed out that the losses are considerable and that finally from 90 million inflow into the lake only 41 million is reaching the fields. This seems not to be an amount to restore the Sabaean gardens, when apparently 9600 ha was irrigated.

However why not making use of the stored groundwater and investigate the possibility to increase the efficiency of the groundwater reservoir, making use of the existing aquifer system which has interesting possibilities. The probably impermeable barrier which is formed by the Azal shale Formation can be considered as a subsurface dam with an enormous storage capacity (Figure 3). This barrier can be used as a storage dam. This option should be investigated further and different groundwater abstraction scenarios should be considered to find the most optirnal configuration of wells to abstract water from the reservoir. Subsurface storage has also the adventage that no water will be lost by evaporation.

Implementation of such a scenario needs a very strong central power like the powerful Sabaean Empire 2000 years ago. It is maybe the only way to restore the fertile gardens of "ancient Marib".

Table 1. – Summary of principal water budget components.

scenario	total inflow into lake	lake losses	wadi + canal system evapotrans piration	available surface water for irrigation	groundwater depletion	groundwater outflow
1986-1988	104	34	2	3	107	60
floodcontrol dam	90	3	4	2	80	60
storage dam	90	39	3	41	115	60
flood/ storage dam	90	11	4	35	88	60

all values in million m3 per year
all calculations for water demand situation 1988

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