GROUNDWATER RESOURCES AND AVAILABILITY IN EAST JORDAN

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INTRODUCTION

The paper deals with the groundwater resources of East Jordan assessed within the framework of the National Water Master Plan of Jordan, a project of Technical Cooperation between the Hashemite Kingdom of Jordan and the Federal Republic of Germany. The objective was to provide data of groundwater resources for decisions in the fields of water planning and water resources allocation.

Information was needed in regard to :

- The amount of available groundwater resources
- The suitability of the groundwater for various purposes
- The location of potential groundwater exploitation areas.

To achieve these objectives, a mean annual groundwater budget of Jordan - subdivided into a number of groundwater balance areas - was established. The available annual groundwater resources and the available volume of stored groundwater in the defined areas were estimated on the basins of the relevant groundwater budgets.

All work has been undertaken in close cooperation and in mutual agreement with the personnel of the Groundwater section and the Spring Section, Water Resources Division of N.R.A., Amman.

AQUIFER SYSTEMS

In East Jordan, the following aquifer systems are of regional importance (figure 1).

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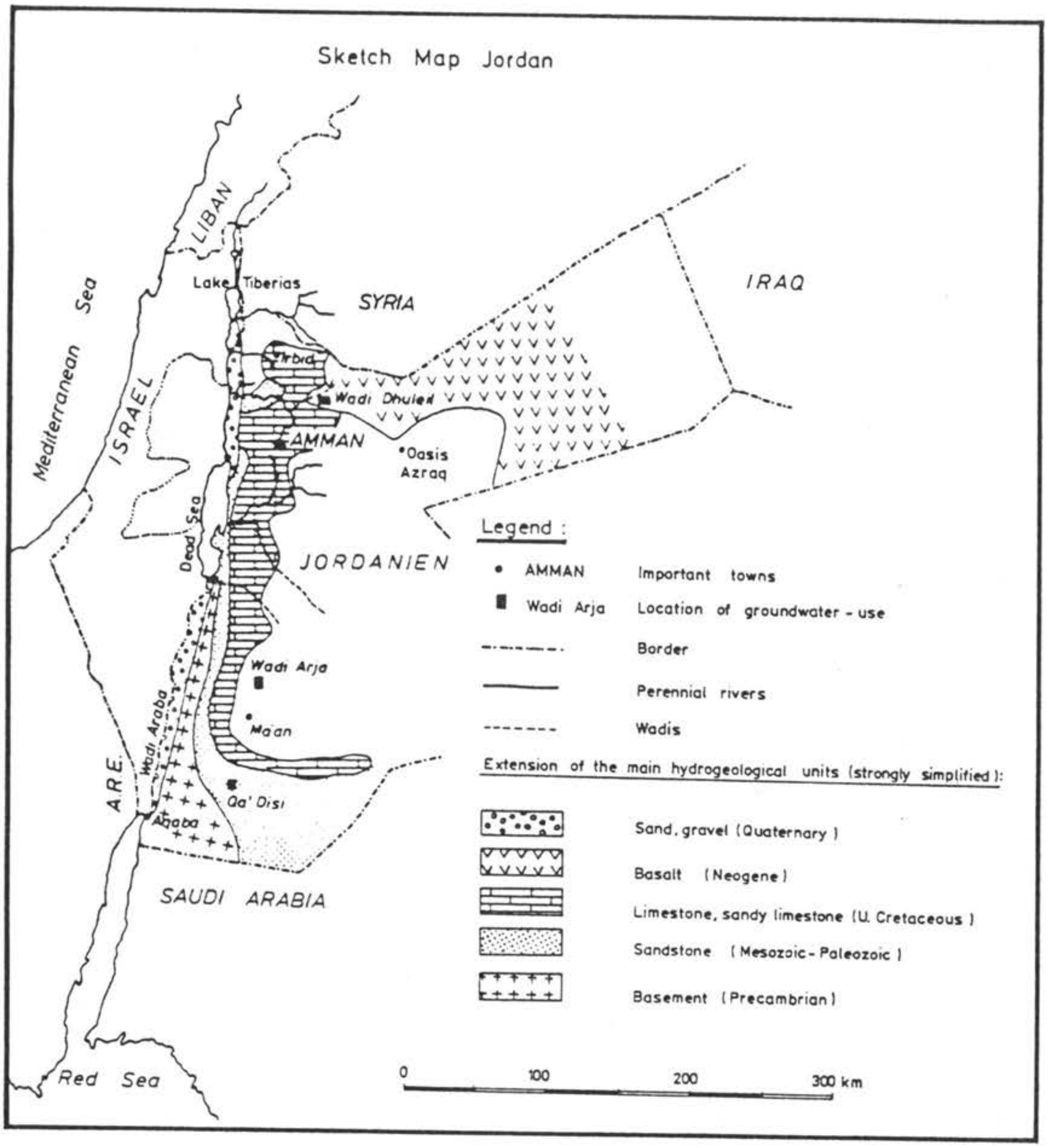

FIGURE 1

Sketch map of Jordan

Stratigraphically the deepest and oldest water bearing sediments are of the *Disi Group (Paleozoic)* and consist of sandstones and quartzites. They crop out only in the southern part of the country, forming here an important fresh-water aquifer. It is believed that this aquifer system underlies the whole area east of the Jordan Valley, but that a large part of it contains mineralized groundwater.

A second sandstone aquifer system, also extending almost over the whole country, is formed by the *Kurnub* and *Zerqa Groups* (Lower Cretaceous-Jurassic). It crops out in the lower Zerqa River basin and along the escarpment from the Highlands down to the Dead Sea and Wadi Araba overlying the Disi Group aquifer system. The two sandstone aquifer systems are separated by the Khreim Group, a sediment complex consisting of sandstones, siltstones and shales. On a large scale, the two sandstone aquifer systems are regarded as one basal aquifer complex and hydraulic system.

The system represents a huge groundwater reservoir of great extent in East Jordan. Restrictions on its exploitation are imposed by drilling depths, high pumping lifts and mineralization of the groundwater. It is mainly recharged in the large outcrop area on the southern border of the country and, to an unknown extend, by seepage from the upper carbonate aquifer. Part of the groundwater discharges as underground outflow to the east. The greater part reappears in the west along the rift valley as spring discharge and base flow. Apart from the recharge and discharge areas, the gradients are very low.

The most important aquifer system in Jordan consists of carbonate rocks (limestone, chert-limestone, sandy limestone) of Upper Cretaceous age and is called Amman-Wadi Sir (or A7 - B2) aquifer system. It forms the top layer of the Western Highlands, and in this area has the highest groundwater recharge rates in the country. To the east, the aquifer system is confined by thick marl layers (B3) of Upper Cretaceous and Lower Tertiary age. Transmissivity and well yield vary widely (0 - 1000 m^2/h), according to sedimentology and - more important - tectonic structure.

The groundwater flow in the A7 - B2 aquifer system is directed from the recharge mounds in the Western Highlands partly to the western escarpment and partly to the east, being turned back to the west by the draining effect of the important valleys - Yarmouk, Zerqa, Mujib, Hasa. Only a small amount of groundwater flows eastwards.

In the northeastern region of Jordan, the basalt extending from the Syrian Jebel Draze southwards to the Azraq and Wadi Dhuleil region forms an aquifer of high hydrogeological importance. It contains groundwater of very good quality, and in some regions, extremely high permeability makes it possible to extract large quatities of water.

Apart from the basalt, the shallow aquifer system consists of sedimentary rocks and alluvial deposits of Tertiary and Quaternary age, e.g. the valley fills of Jordan Valley and Wadi Araba, and limestone, chalk, marl and gravel layers in the eastern desert.

QUALITY OF THE GROUNDWATER

Most of the groundwater samples of East Jordan are of Ca bicarbonate type. With increasing salinity, sodium and magnesium becomes the dominant cations, and chloride the main anion.

Due to the Ca bicarbonate content, the S.A.R. and therefore the alkalinity hazard (U.S. irrigation quality standards) remains low even if the salinity hazard is considerable high. Only the water samples affected by recycled irrigation water (from the Jafr area and parts of the Jordan Valley) have a higher alkalinity hazard.

Minor constituents and trace elements are not known to involve special problems.

Therefore, the suitability of the groundwater for most purposes can be shown by the total salinity, which is measured in the laboratory or the field with a conductivity meter.

In general, East Jordan consists of four regions of good groundwater quality in terms of salinity. These regions are identical or closely connected with the main recharge areas.

The regions of poor groundwater quality are the central axis of the Jordan Valley and the Wadi Araba in the West, the whole eastern region except the extreme north and south, and a connection between these regions, extending from the Dead Sea to the east.

However, within these regions of overall highly mineralized groundwater, possibilities of finding a local source of acceptable water quality still exist. Besides, it is not known how far the fresh water in the deep sandstone aquifer system extends from the southern to the eastern desert.

Pollution by sewerage and waste water is clearly visible in the main population area of East Jordan, the Amman-Zerqa-Salt region, marked by increasing chloride, sodium, and nitrate ion content and bacteriological contamination of the groundwater. The local aquifer system consists of gravel beds and carbonate rock without significant confining layers. Its high permeability allows most of the waste and sewerage water from septic tanks and river beds to reach groundwater. Additionally, there are many factories using sink holes and wells to deliver waste water into the underground. In the near future, it will become necessary for the urban water supply of this region to tap new water resources from unpolluted aquifers or to intensify water treatment.

GROUNDWATER BUDGET

The general equation for the groundwater balance of a region may be written as follows :

recharge + import + change of storage = discharge + export

As shown in figure 2, the equation is composed of the following items :

recharge-side :

- natural recharge
- return flow
- artificial recharge
- underflow from other aquifer
- underflow from other area
- change in groundwater storage

discharge-side :

- spring discarge, measured
- spring discharge and seeps, unmeasured

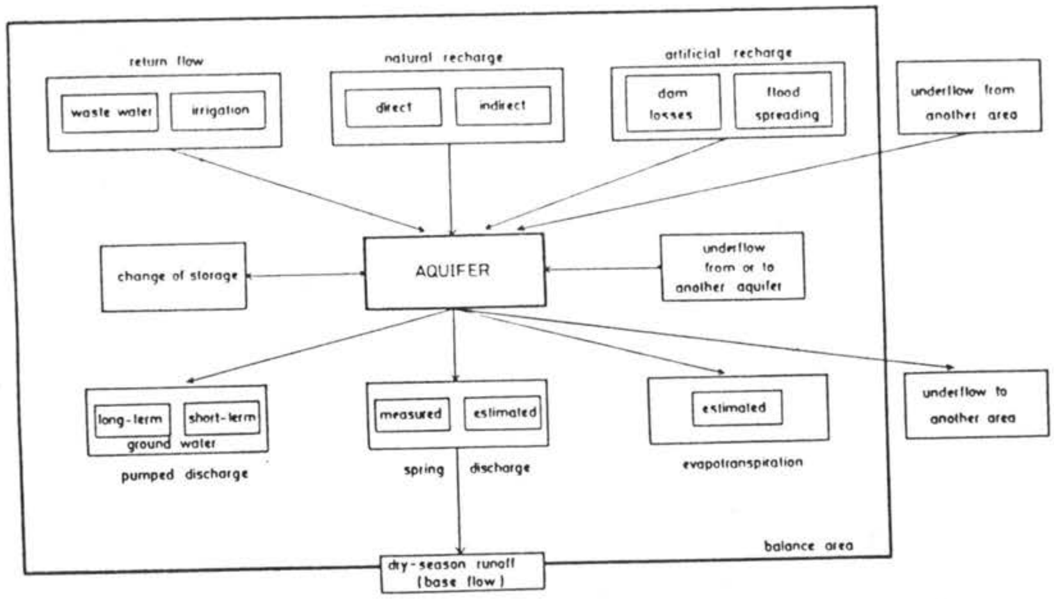

FIGURE 2

Parts of the groundwater-budget

well discharge, which is considered to have direct influence on spring discharge ("short-term groundwater")

well discharge, which is considered to have no direct influence on spring discharge ("long-term groundwater")

evapotranspiration from groundwater

underflow to other aquifer

underflow to other area.

As there are some terms on the discharge side of the groundwater balance equation which can be measured, but none on the recharge side, the discharge side of the equation is usually more important for the assessment of the groundwater budget of an area than the recharge side.

The most important part of the total groundwater discharge in many areas is the water reappering as surface flow in the area (presently being abstracted or still available). However, water that would have appeared as surface flow if it had not been intercepted before by wells (short-term groundwater) must be added to the measured base flow in the groundwater balance equation. The sum of this estimated figure and the base flow discharge is called total natural base flow.

For the purpose of budgeting the groundwater, 12 major groundwater basins or groundwater balance areas were defined. They are bounded by the flow lines or the groundwater divides of the appropriate, most important, regional aquifer system, by the limits of an aquifer, or important topographic features.

Some of these areas can be considered as groundwater basins insofar as the groundwater is being completely recharged and discharged within their boundaries. But due to the presence of at least two different hydraulic complexes in most of the areas, the boundaries of a groundwater basin in respect to one aquifer will not coincide with those of the other aquifer.

The major basins were subdivided into smaller units and single aquifers. In total about 120 separate groundwater-budgets were established and interconnected with each other.

RESOURCES BASED ON THE GROUNDWATER BUDGET

Once the groundwater balance of an area is defined using all appropriate information on the area itself and the surrounding areas, the total amount of groundwater flow in that area amounts to the sum of recharge plus the change of storage.

Basing on the groundwater balances, a map was constructed which describes the groundwater resources of Jordan. For each area it shows the mean annual total recharge per unit area (mm per year or thousand cubic meters per year per km^2), the total volume of discharge per area and the subdivision of the discharge into various parts. In addition, the map illustrates the constraints on groundwater use allowing a first impression of which part of the groundwater discharge would probably be diminished by additional exploitation of groundwater. In this map, groundwater quality is not taken into consideration. The total annual groundwater replenishment in East Jordan amounts to 580 MCM (million cubic meters).

AVAILABLE GROUNDWATER RESOURCES

Most of the groundwater flow in East Jordan, especially in the northwestern part, discharges as surface runoff. By exploiting the groundwater in these areas, the water originally flowing to the springs will be intercepted and sooner or later the spring discharges of the region will diminish. Thus surface water and groundwater resources are identical to a certain extent and may not simply be added.

In order to avoid this duplication, the base flow is considered to belong to the surface water resources only. The net "groundwater resources" amount to the total annual recharge minus the present groundwater discharge into surface runoff. They consist of the underground outflow, the evapotranspiration [1] and the presently pumped abstractions which are not taken from storage. Out of the total annual groundwater replenishment in Jordan (about 580 MCM) some 380 MCM appear at the surface as dry season runoff leaving a rest of about 200 MCM per year as net "groundwater rescurces" based on the water budget.

There are two contradictions in this definition of groundwater resources:

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(1) Evapotranspiration from the groundwater.

1) in areas where the groundwater development is highly advanced resulting in a diminished base flow, the groundwater resources seem to be greater than in undeveloped areas which still have the total natural base-flow discharge.

2) in areas not defined by groundwater divides (than means areas receiving or exporting underground flow), high groundwater potential is calculated based on underground flow which may be used in the adjacent area also. Thus, the groundwater resources of such areas based on this definition may not be added to get a total sum of groundwater resources of a region.

Therefore, another term called available groundwater resources was introduced. This figure is that part of the technically exploitable resources of an area which is thought to be abstractable and usable without medium and short-term dangerous effects (practical sustained yield).

The available groundwater resources have been calculated to amount to 40-60 % of the total groundwater flow, depending on the aquifer characteristics and the type of groundwater discharge. Necessarily connected to the value for the available resources is a description of the limitations and constraints on exploitation with respect to the water balance or water quality.

The total sum of the available annual groundwater resources in East Jordan amounts to some 250 MCM. In this volume some groundwater resources of areas connected with each other through underground flow are counted twice if a significant effect on the adjacent areas due to pumpage seems to be impossible.

Although the figures of the two approaches to calculate the groundwater resources may differ widely in the various areas, the totals come up to nearly the same amount.

It is therefore concluded that the mean value of about 220 MCM per year can be considered as the available groundwater resources of East Jordan.

AVAILABLE VOLUME OF STORED GROUNDWATER

Because it is necessary to decrease the groundwater level in the vicinity of the wells, any groundwater withdrawal from wells will take some of the storage. While pumping a quantity less than the total flow, a new groundwater balance will be established after a certain time because the amount of water taken from storage and simultaneously the amount of natural discharge will decrease with time.

Pumping an amount greater than can be provided by the groundwater flow to the area will cause a continuously decreasing water level. In the water balance, this so-called overdraft situation is related to an entire balance area. There may be a small, heavily overpumped area because of the local flow conditions, while the region as a whole is within the range of natural replenishment.

Pumping from storage entails continuously increasing pumping heads and energy costs. Only a part - usually small - of the total stored water volume can be used economically. The available storage is calculated as that volume per area which can be withdrawn by a regional lowering of the piezometric head to 150 m below surface.

The development of stored groundwater resources causes negative effects on the existing hydraulic conditions and use of groundwater. By decreasing the water level, springs may dry up and wells may have to be deepened.

The available storage as defined above is not the permissive mining yield according to Walton (1970) and U.N., Water Resources Series (1972). Values for the latter term would have to be determined where needed in any future groundwater development project.

IMPACTS ON CURRENT GROUNDWATER USE

Groundwater abstraction by pumping water from a well is not possible without affecting the groundwater budget in the vicinity of the well. The type and the extent of the influence (drawdown of the groundwater level in other wells, decrease of springflow, changes in groundwater quality) depends on the aquifer conditions, the existing groundwater use, the quantity of the additional abstraction, and the time. Therefore, a simple classification of the potential negative effects an additional groundwater exploitation would cause in an area cannot be made. Areas have been delineated on a map where additional exploitation of groundwater is thought to cause the smallest negative effect possible.

Yet final groundwater potentials in the proposed areas are still not known. For each of them, special exploratory work have to be undertaken to determine the groundwater flow, the optimum annual extraction rates and the effects the pumping would cause.

In some regions it is quite obvious that the groundwater potential has decreased already during the past few years. Since all the water flowing underground is part of the total water circuit, a decision has to be made about how the water resources are to be used (e.g. by pumping groundwater or using springflow) in all regions where important groundwater abstractions take place or are planned.

There is no aquifer system or groundwater area, which does not appear to have been tapped by exploratory or production wells. The distribution and potential of groundwater in Jordan is now fairly well-known. The main problem is to optimize the utilization of the groundwater resources and protect them agains depletion and pollution.

REFERENCES

ARSALAN, F.A., Geologie und Hydrogeologie der Azraq-Depression (Ost-Jordanien). Thesis (T.U. Aachen), 185 p., Aachen, Fed. Rep. Germany, 1976.

CONOVER, C.S., Groundwater in the arid and semiarid zone; its source, development and management. IASH publication N° *56*, 513-529, Gentbrugge, 1961.

METEOROLOGICAL DEPARTMENT, Climatological Atlas, Amman, 1970.

UNITED NATIONS, Water Resources Studies. Water Resources Series N° 41, p. 137-142, New York, 1972.

WALTON, W.C., Groundwater Resource Evaluation. New York, 1970.

WIESEMANN, G., The Potential of Natural Resources in Jordan (Phosphate - Soil - Groundwater). Natural Resources and Development, Vol. 3, p. 56-71, Tübingen, 1976.

The work based mainly on a number of unpublished reports available at N.R.A., Amman dealing with the water resources of Jordan and elaborated by several international agencies and consultings. It is incorporated in the report "National Water Master Plan of Jordan" prepared in cooperation between the German Agency for Technical Cooperation Ltd. (GTZ) and the Natural Resources Authority (N.R.A.) Amman, by Agrar- und Hydrotechnik GmbH, Essen (AHT) and Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Hannover.