Groundwater resources in the Lower Jordan Valley:
an integrated approach to the hydrogeological investigation of unconsolidated aquifers

Mathias Toll [a], Elias Salameh [b], Martin Sauter [a]

[a] Georg- August- University Göttingen, Faculty of Geosciences and Geography, Applied Geology

[b] Jordan University, Faculty of Geosciences

Abstract

In semi-arid areas groundwater systems are frequently not sufficiently characterized hydrogeologically and long term data records are generally not available. Long-term time series are necessary, however to design future groundwater abstraction scenarios or to predict the influence of future climate change effects on groundwater resources. To overcome these problems an integrated approach for the provision of a reliable database based on sparse and fuzzy data is proposed. This integrated approach is demonstrated in the lowermost area of the Jordan Valley.

The Jordan Valley is part of the Jordan Dead Sea Wadi Araba Rift Valley, which extends from the Red Sea to lake Tiberias and beyond with a major 107 km sinistral strike-slip fault between the Arabian plate to the east and the northeastern part of the African plate to the west. Due to extensional forces a topographic depression was formed. As a result of an arid environment it is filled with evaporites, lacustrine sediments, and clastic fluvial components. A subtropical climate with hot, dry summers and mild humid winters with low amounts of rainfall provide excellent farming conditions. Therefore the Jordan Valley is considered as the food basket of Jordan and is used intensively for agriculture. As a result hundreds of shallow wells were drilled and large amounts of groundwater were abstracted since groundwater is the major source for irrigation. Consequently groundwater quality decreased rapidly since the sixties and signs of overpumping and an increase in soil salinity could clearly be seen.

In order to achieve a sustainable state of water resources and to quantify the impact of climate change on water resources a proper assessment of the groundwater resources as well as their quality is a prerequisite. In order to sufficiently describe the complex hydrogeologic flow system an integrated approach, combining geological, geophysical, hydrogeological, historical, and chemical methods was chosen. The aquifer geometry and composition is described with the help of geological, hydochemical, and geophysical methods. As far as the water budget is concerned, the recharge to the considered aquifer is estimated with geological methods and available data sets, while the abstraction from the aquifer is estimated with the help of remote sensing techniques. A historical approach is used to detect the general conditions under which the groundwater system has been in the past. Afterwards this information is implemented into a flow model. On the basis of the findings a numerical 3-D transient model integrating all important features of the hydrogeological system was developed in order to be able to give reliable predictions about the impacts of climate change scenarios on the groundwater system the flow model was tested against stress periods depicted during the historical review of the test area.. These stress periods include periods of intense rainfall, of drought, and of anthropogenic impacts, like building of storage dams and of violent conflicts. Recommendations for future sustainable groundwater abstractions are given.

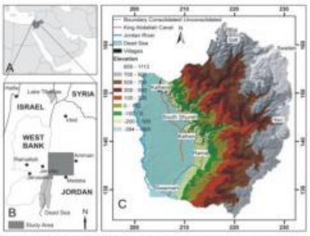


Fig. 1: Overview and Digital Elevation Model of the study area.

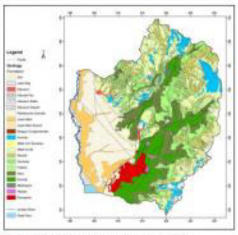


Fig. 2: Geology of the study area and its surroundings.

Period	Epoch	Group	Formation	Hydrogeol. Unit		Brief Description	Regional Thickness
Quaternary	Holocene / Pleistocene	Jordan Valley	Alluvium	Aquifer	Qal	[illegible]	
			Lisan	Aquitard	JV3	Marl, Clay, Evaporites	0 - 300m
Tertiary	Pliocene / Oligocene		Ghor el Katar / Shagur Conglomerate	Pleistocene Aquifer	JV2 / JV1	[illegible]	100 - 350m
Upper Cretaceous	Campanian / Santonian / Coniacian	Belqa	Amman al Hisa	Upper Aquifer	B2	[illegible]	100 - 350m
			Wadi Um Ghudran	Upper Aquifer	B1	[illegible]	20 - 80m
	Turonian	Ajlun	Wadi as Sir	Upper Aquifer	A7	[illegible]	60 - 340m
			Wadi Shu'aib	Aquitard	A5/6	[illegible]	40 - 120m
	Cenomanian		Hummar	Aquitard/ Aquifer	A4	[illegible]	30 - 100m
			Fuheis	Aquiclude	A3	[illegible]	30 - 80m
			Na'ur	Aquitard	A1/2	[illegible]	80 - 220m
Lower Cretaceous	Albian / Aptian / Neocomian	Kurnub	Subeihi	Kurnub Aquifer	K2	[illegible]	100 - 300m
			Aarda	Kurnub Aquifer	K1	[illegible]	
Angular unconformity							
Jurassic / Triassic / Permian		Zarqa	Azab	Aquitard	Z2	[illegible]	0 - 600m
			Main	Aquitard	Z1		0 - 1200m

Fig. 3: Stratigraphic table of rock units.

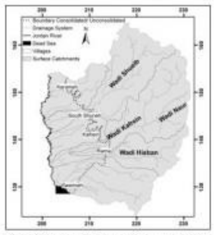


Fig. 4: Surface catchment areas and drainage lines of the studied unconsolidated aquifers.

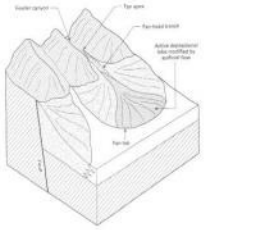


Fig. 5: Morphological elements of the study area.

Historical Information:

Historical information was collected to delineate changes in water usage (construction of dams and canals etc.), irrigation techniques (change from manual/ furrow irrigation to drip irrigation), crop agriculture, historical events that influenced water usage (i.e. settlement of refugees after 1948 and 1967, freeze of almost all agricultural activities between 1968 and 1971).

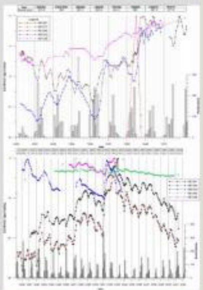


Fig. 6: Groundwater levels 1962-71 along with yearly and monthly precipitation values; note the influence of the „six-day war" on groundwater levels.

Fig. 7: Groundwater levels 1980-02 along with yearly and monthly precipitation values; note the influence of a new allochthonous water resource on groundwater levels.

Hydrogeology:

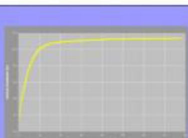


Fig. 8: Single well tests. Recovery curve of well in the east of the study area. No water meter could be installed. Estimates of Q were done on different basis.

Fig. 9: Transmissivity Distribution. A clear trend indicating the shape of an alluvial fan can be seen. Highest values are found close to the apex. Values decrease towards the west. However outcrop and sieve analysis indicated that the reduced values can be attributed to an increased portion of lacustrine sediments and not to a decrease in grain seize of the alluvial sediments.

Satellite Images:

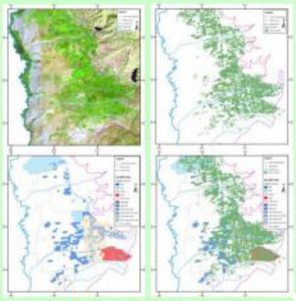


Fig.10: LandSat Image (541) of the study area (spring 2002).

Fig.11: Irrigated areas (derived from a supervised classification of the LandSat image).

Fig.12: Water sources of irrigated land in southern Jordan Valley. (after Gtz 2003).

Fig.13: Identification of irrigation water sources of the irrigated land (spring 2002).

=> Calculation of minimum water abstraction rates (planted crops are known) for different years (1973 onwards)

Sedimentology

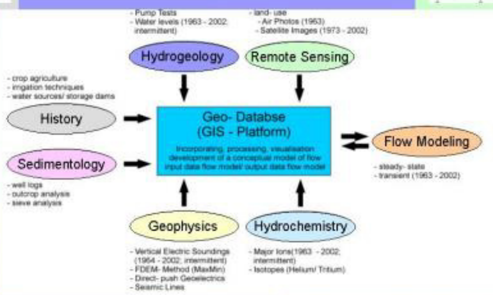
Fig.14: Well drilled proximal of the fan apex (Ionides Well No. 18)

Fig.15: Well drilled distal from the fan apex (Ionides Well No. 12)

Fig.16: Proximal alluvial deposits (right)

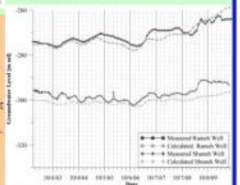
Fig.17: incised channel filled with alluvial deposits (secondary process)

Fig. 18: Lacustine, saline Lisan Formation (left)


- Pump Tests
- Water levels (1963 - 2002; intermittent)
- land- use
- Air Photos (1963)
- Satellite Images (1973 - 2002)
Hydrogeology
Remote Sensing
- crop agriculture
- irrigation techniques
- water sources/ storage dams
History
Geo- Databse
(GIS - Platform)
Incorporating, processing, visualisation development of a conceptual model of flow input data flow model/ output data flow model
Flow Modeling
Sedimentology
- steady- state
- transient (1963 - 2002)
- well logs
- outcrop analysis
- sieve analysis
Geophysics
Hydrochemistry
- Vertical Electric Soundings (1964 - 2002; intermittent)
- FDEM- Method (MaxMin)
- Direct- push Geoelectrics
- Seismic Lines
- Major Ions(1963 - 2002; intermittent)
- Isotopes (Helium/ Tritium)

Flow Modeling:

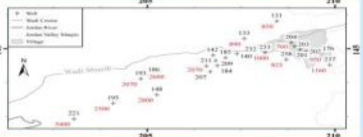
In order to give recommendations about sustainable abstraction of water resources a transient flow model is essential. Within the area of interest precipitation is highly variable. Therefore a modeling period of at least 15 to 30 years was chosen. This period incorporates seasons of minor, major and intermediate rainfall. Fig. 19 shows calculated vs. observed GW-levels for the period 1963 until 1970.

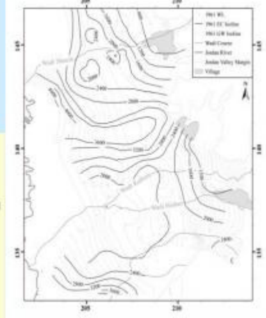


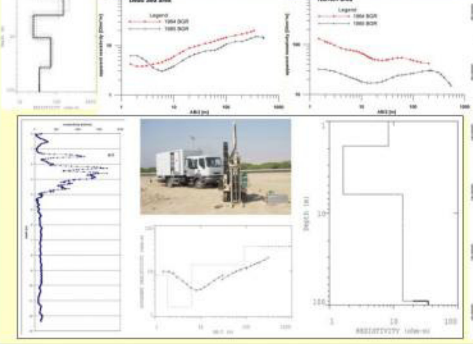
Hydrochemistry:

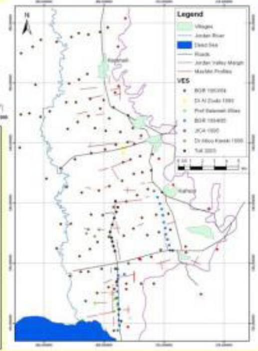
Fig.25: In red colours: electric conductivity values [μS/cm] of groundwater samples. Groundwater flow direction is east to southwest. An increase in salinity along the flow path is clearly visible.

Fig. 26: Relationship between groundwater contour lines (middle gray color) and iso-electrical conductivity lines (in μS/cm; black color) of well water samples taken 1961. The gray dots represent gw level measurements locations at the different wells (based on the data given by Tleel 1963). The results of the analysis together with its location are the base of the interpolated lines. GW contour lines are not labeled for better visibility of the iso- EC contour lines. GW flow is from east to west; GW contour intervals are 5 m.









Geophysical investigations:

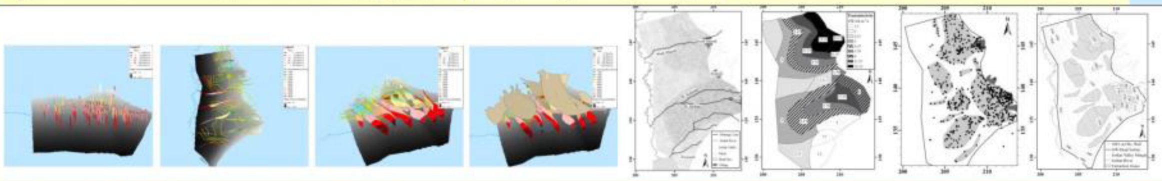
Fig.20: Problem of ambiguity, especially in salt dominated environments.

Fig.21: Two VES sounding curves in the vicinity of the Dead Sea. Shots are taken at the same location. They indicate increased salt content within the soil and/or groundwater.

Fig.22: Two VES curves taken in the vicinity of a major fan apex.

Fig.23: Direct- push geoelectric vs. VES. With the help of direct- push geoelectric the problem of ambiguity in VES can be minimized, or even eliminated.

Fig.24: Location of geophysical investigations within the study area.



Development of the model geometry for the unconsolidated aquifer (from left to to right):

Acknowledgements:

The authors would like to express their thanks to the German Ministry of Education and Research (BMBF) and to the Israeli Ministry of Science (MOS) for supporting and funding the project: Water Resources Evaluation for a Sustainable Development in the Jordan Rift Basin, German – Israeli – Jordanian - Palestinian Joint Research Program. Project Number 02WT0161.