In cooperation with the U.S. Agency for International Development
and the U.S. Army Corps of Engineers

Groundwater level and salinity trends in the Azraq, Dead Sea, Hammad, Jordan Side Valleys, Yarmouk, and Zarqa groundwater basins, Jordan, 2011
Executive Summary

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Introduction

The U.S. Agency for International Development (USAID) is providing water-resources management support to Jordan. According to USAID (2010),

> Jordan is one of the ten most water-deprived countries in the world. Lack of water will be one of the most serious challenges to Jordan's future economic growth and stability. With population expected to double by 2029, the already low availability will be halved. USAID's water portfolio activities are designed to enhance Jordan's ability to manage its water resources wisely as well as in a more integrated and efficient manner. This helps support regional stability as it prevents conflict, provides quality water for the population and improves the overall economic prospects for the country. Specific activities are initiated in partnership with the Government of Jordan (GOJ) and focus on: improving environmental protection; optimizing the availability and use of water resources; strengthening water policies and systems; and improving resource allocation.

USAID/Jordan requested that USGS evaluate groundwater level and salinity trends in Jordan in order to

- Update a 2002 USGS groundwater trends study (Clark, 2002),
- Inform USAID's 5-year strategic plan,
- Evaluate trends using all available data from Jordan Ministry of Water and Irrigation (MWI),
- Transfer trends estimation technology to MWI staff, and
- Provide scientific information and tools that can be used to
    - Identify a time horizon for groundwater management planning,
    - Prioritize locations for groundwater management actions,
    - Provide a baseline for evaluating impacts of GOJ's reduction of over-pumping starting in 2014,
    - Help quality assure (QA) the data,
    - Improve groundwater model calibration,
    - Evaluate corresponding increases in groundwater supply costs (Rosenberg and Peralta, 2011), and
    - Increase public and stakeholder awareness on groundwater trends.

Groundwater levels and salinity and related information collected by the Ministry of Water & Irrigation, Jordan (MWI) was provided to USGS in March, 2011. Where the data were available, USGS estimated trends in the groundwater levels and salinity (electrical conductivity) at individual wells. Level and salinity data were evaluated for six groundwater basins in Jordan: Azraq, Dead Sea, Hammad, Jordan Side Valleys, Yarmouk, and Zarqa. (The Zarqa basin is also called "Amman-Zarqa".) Separate reports were prepared for water level trends and salinity trends, for each basin.

I am grateful for the technical guidance and helpful cooperation of Ali Subah, Assistant Secretary General for Technical Affairs, and Ayman Jaber, Director of the Water Resources Data Directorate, of the Jordan Ministry of Water and Irrigation, and for the support for this effort by Maysoon Zoubi, Secretary General of the Ministry of Water and Irrigation. I am also grateful for technical background information and data provided by Tobias El-Fahem and Ibraheem Hamdan of the MWI/BGR "Water Aspects in Landuse Planning" project.

Water level trends and forecasts

The Jordan Ministry of Water and Irrigation (MWI) maintains a database (Water Information System – WIS) that includes groundwater levels and other information for production, monitoring, and unused wells. Over time, the amount of data on water levels in wells has increased substantially, although there has been a small decrease in the number of measurements recently (fig. 1).

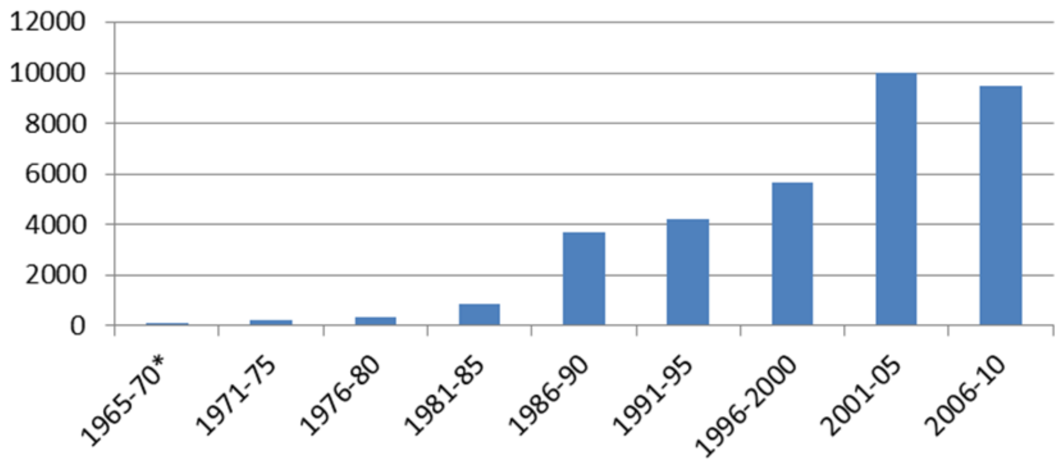

Figure 1. Number of groundwater levels for all wells in WIS database by 5-year period.

Water level trends were estimated using linear fits to all available data. In addition, the 'current' trend (c. 2010) was estimated using graphical linear fits to several years of recent data. Trends were not estimated for wells with less than 6 measurements separated in time, or with less than 4 years of data. Groundwater level trends were only estimated for wells having data in 2009 or later. Apparent data outliers, which may represent QA problems, were identified, but were not corrected in most cases. In some cases, these outliers were removed to estimate alternative trends. However, the statistics and maps developed used data as provided. Groundwater levels are forecast to 2030 using the current trend, and the saturated thickness in 2030 was estimated, where aquifer data were available. The aquifer saturated thickness is a measure of the amount of water stored in the aquifer. Saturated thickness forecasts were calculated as percentage of the total aquifer thickness or, for unconfined aquifers, as percentage of historic maximum saturated thickness. An example of hydrographs prepared for trend estimation and forecasts of saturated thickness is shown in figure 2. Hydrographs for all wells analyzed are provided in the appendix of each basin report.

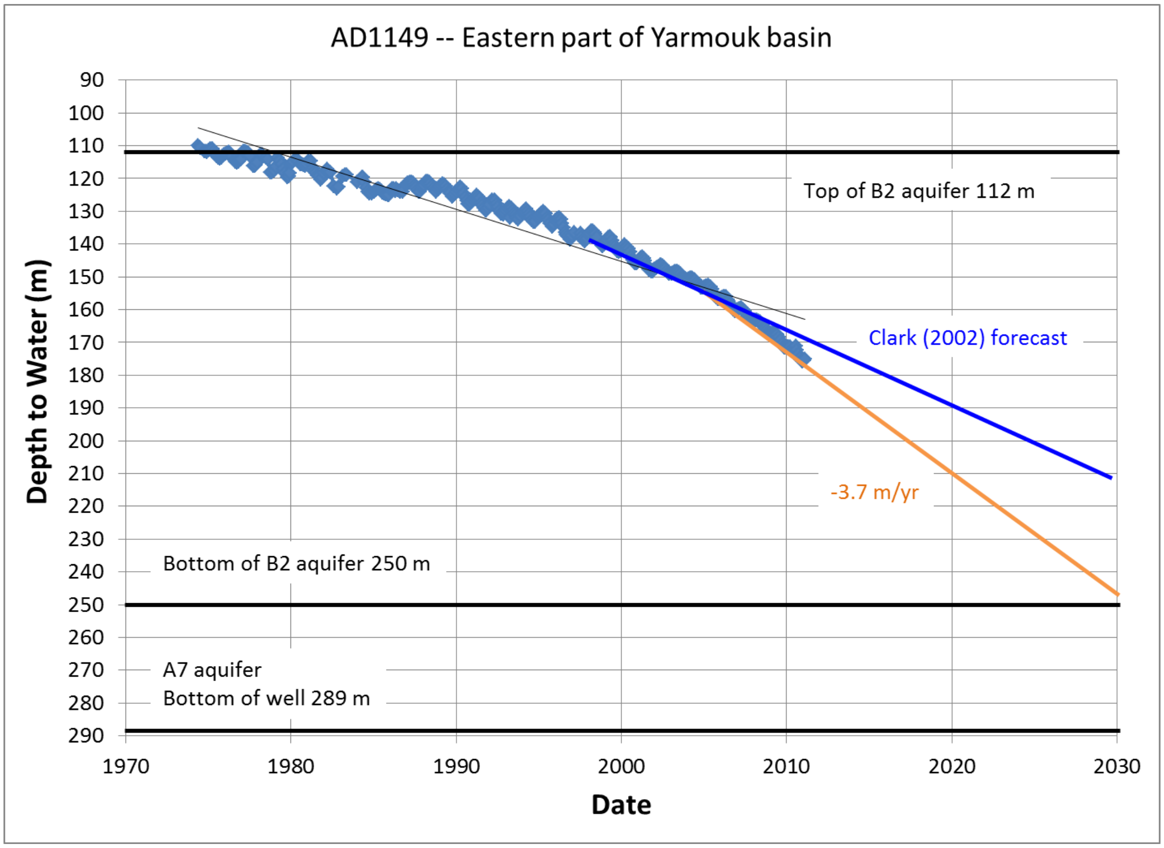

Figure 2. Groundwater hydrograph and trend lines for well AD1149 in the eastern part of the Yarmouk groundwater basin, Jordan. Data provided by Ministry of Water & Irrigation, Jordan.

The current groundwater level trend, averaged for each basin, ranges from 0 to -1.9 meters per year (m/yr) (Table 1). Four of the six basins have an average trend close to -1.0 m/yr, yielding a forecast average water level decline of about 20 meters by 2030 in these basins. Hammad has no trend, on average, and the average water level decline is fastest in the Jordan Side Valleys basin, at -1.9 m/yr, and thus the forecast average water level decline in this basin is about 38 meters by 2030. The maximum current trend at an individual well in each basin ranges from -0.2 to -9 m/yr. The forecast average saturated thickness in 2030 ranges from 61 to 98 percent. The average saturated thickness is forecast to remain relatively unchanged in the Hammad basin, while all other basins will have substantial declines in saturated thickness. Some locations in three of the basins are forecast to have zero saturated thickness by 2030.

Table 1. Summary of groundwater level trends and forecast saturated thicknesses.

Groundwater Basin	# Wells	Groundwater Level Trend 2010 (m/yr)		Forecast 2030 Saturated Thickness (%)		# Wells Dry in 2030
		Average	Maximum	Average	Minimum	
Azraq	15	-0.8	-2.3	69	14	
Dead Sea	30	-0.8	-9	61	0	3
Hammad	4	0	-0.2	98	93	
Jordan Side Valleys (Wadis)	9	-1.9	-9	64	20	
Yarmouk	11	-1.1	-3.7	66	0	1
Zarqa	48	-1.1	-4.2	67	0	2

Groundwater levels are declining in most wells in Jordan (fig. 3). (Hammad basin is not shown; see separate section on Hammad water levels.) Largest rates of decline occur near major pumping centers. Trends are variable in that wells with rapid decline are located near wells with modest declines, no trends, or small increases. Explanation of these differences may be related to the different depths or aquifers that the wells penetrate, but these local conditions were not explored in this study. Adequate data are not available to evaluate the groundwater level trend in some areas of heavy pumping, such as the eastern parts of the Yarmouk and Zarqa basins (fig. 3).

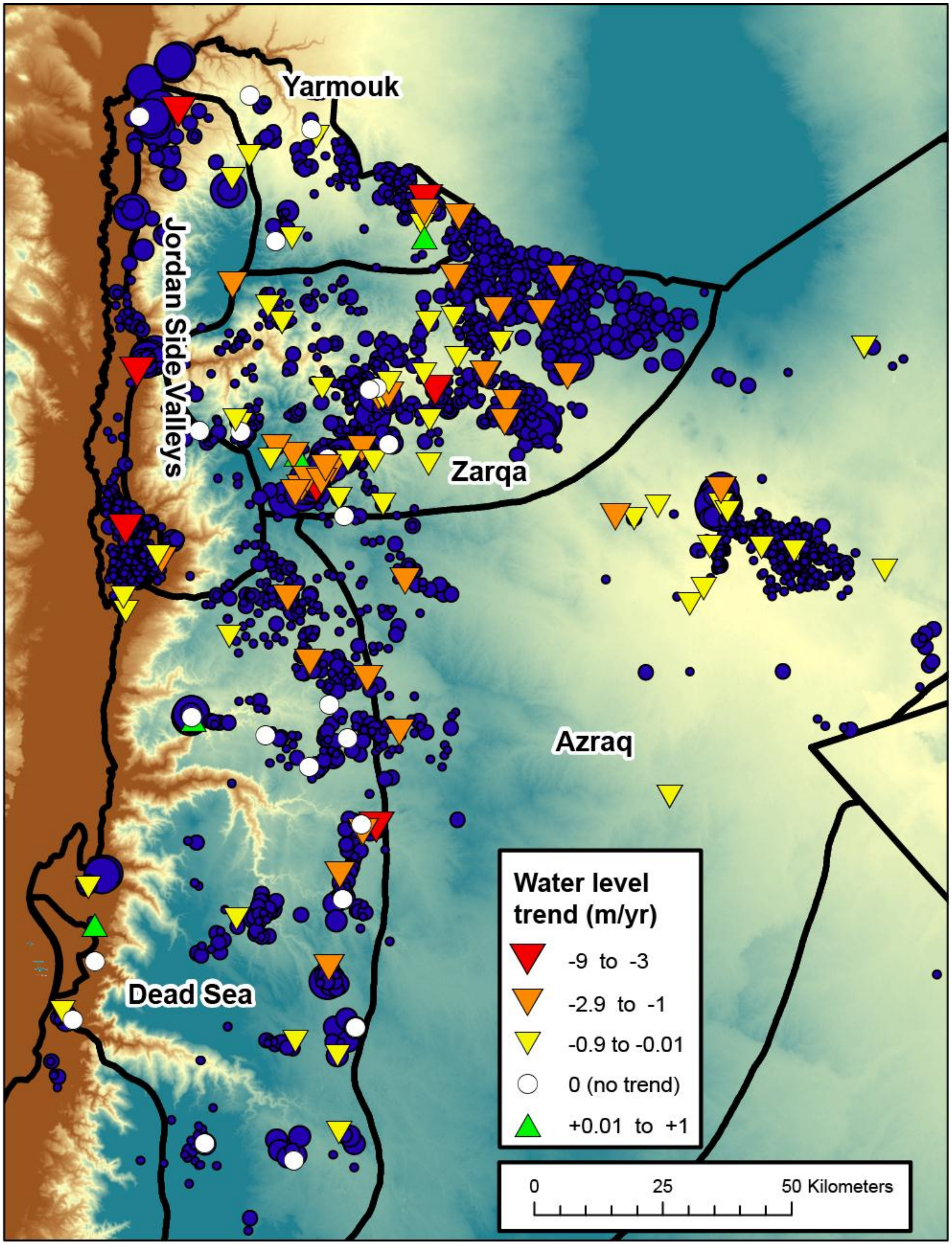

Figure 3. Trends in groundwater levels in Jordan. Color background is land surface altitude in meters, from less than 0 (brown) to more than 1000 (blue). The groundwater level trend, in meters per year, is shown for all monitoring wells with data in 2009 or later. Negative trends indicate lowering of the water level. The dark-blue dots are production wells, and the size of the dot represents the volume pumped from each well in 2009.

Key findings – Groundwater levels

- Data quality is very good, but some areas are not adequately monitored.
- Groundwater levels continue to decline about -1 m/yr in Jordan's major renewable basins.
- In most cases, rates of decline are constant or increasing (faster decline).
- If these rates of decline continue, average aquifer saturated thicknesses are forecast to have declined by 30 – 40 percent in 2030.
- Aquifers are forecast to be dewatered by 2030 in 5% of the locations evaluated.
- Shallow wells that do not fully penetrate the aquifer are forecast to continue to go dry, and more frequently where rates are increasing.
- Water level trends generally suggest that pumping rates have increased in recent years.
- Less water will be available from aquifers in Jordan as groundwater levels decline.

Salinity trends

The WIS database contains water-quality measurements, including electrical conductivity (EC), which is a surrogate for salinity (total dissolved solids, TDS). The amount of data on EC in wells in the WIS database increased after 1970, but there has been a substantial decrease in the number of measurements since 2000 (fig. 4).

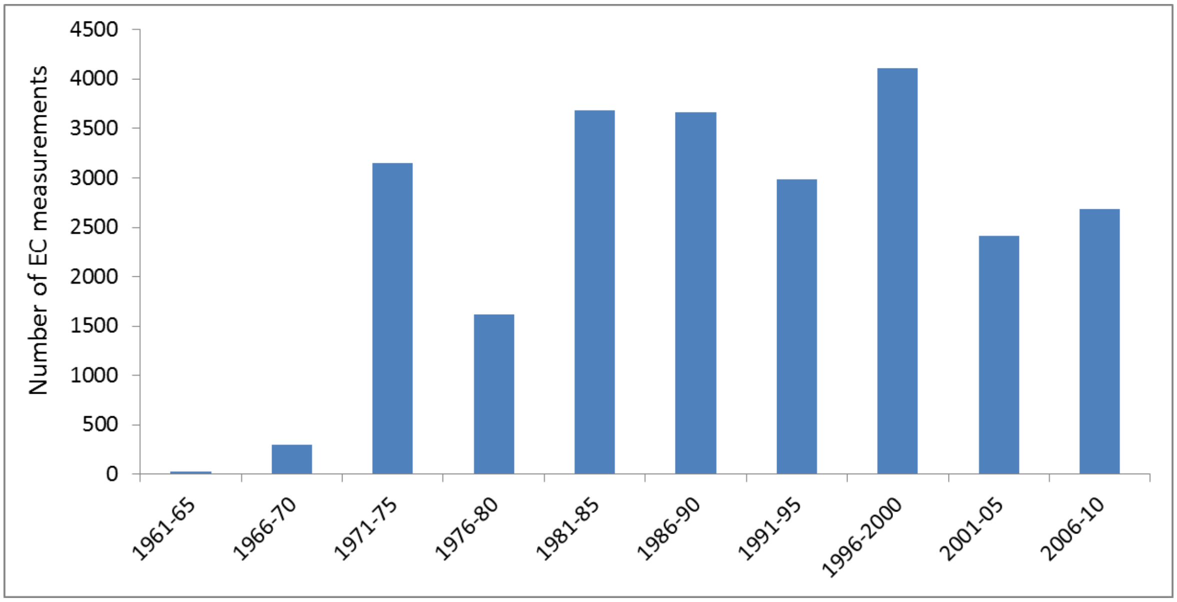

Figure 4. Number of groundwater electrical conductivity (EC) measurements for all wells in WIS database (as of March 2011) by 5-year period.

Electrical conductivity trends are estimated using linear fits to all available data. Current trends and forecasts are not evaluated due to the high variability of the available data. Trends were not estimated for wells with less than 6 measurements separated in time, or with less than 4 years of data. Groundwater EC trends were only estimated for wells having data in 2009 or later, or for Azraq, Hammad, and Jordan Side Valleys basins in 2006 or later. Apparent data outliers, which may represent QA problems, were identified, but were not corrected in most cases. In some cases, these outliers were removed to estimate alternative trends. However, the statistics and maps developed used data as provided. An example of graphs prepared for trend estimation is shown in figure 5. Graphs for all wells analyzed are provided in the appendix of each separate basin EC report.

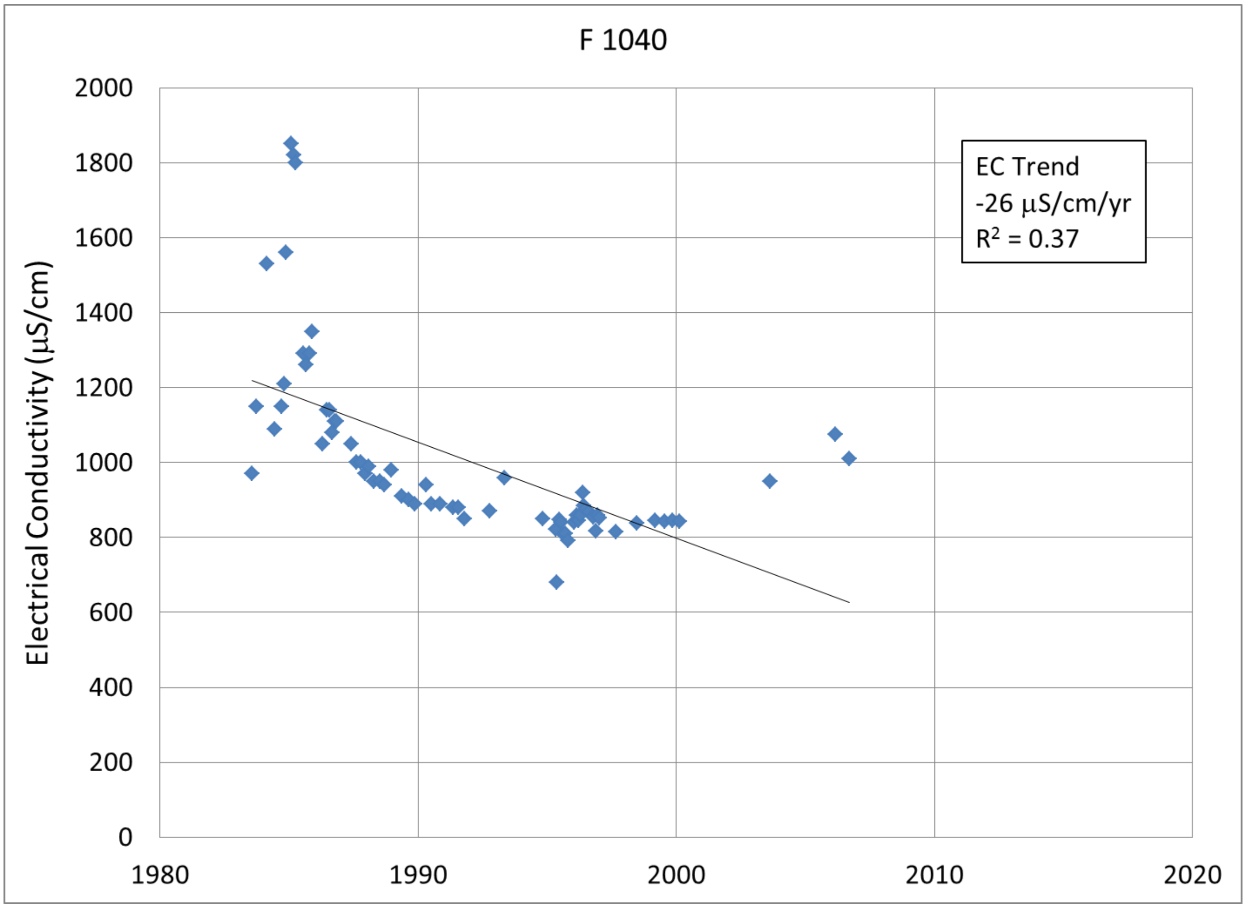

Figure 5. Groundwater electrical conductivity and trend line for well F 1040 in AWSA wellfield of Azraq groundwater basin, Jordan. Data provided by Ministry of Water & Irrigation, Jordan.

Groundwater EC is a surrogate for total dissolved solids (TDS), the "salinity". Electrical conductivity is normally a field measurement, and is used because the measurement is very simple, using an electronic probe. In Jordan, the rule of thumb for converting EC to TDS is

TDS (mg/L) = 0.6 x [EC (µS/cm)] .

Thus, the trends in EC (µS/cm/yr) in this report can be converted to approximate trends in TDS (mg/L/yr) by multiplying by 0.6. Salameh (1996) identifies an EC of 1500 µS/cm as an upper limit of freshwater suitable for all common uses.

The long-term linear trend in groundwater electrical conductivity, averaged by basin, ranges from -2.8 to +27. The Jordan Side Valleys basin is the only basin with an average decrease in electrical conductivity. A trend of + / - 5 µS/cm/yr is considered flat (no substantial trend) for summary purposes. The proportion of wells where EC is increasing more than +5 µS/cm/yr ranges from 19 to 66 percent, with the highest percentage in the arid Hammad basin. (Note that groundwater levels are not declining rapidly in the Hammad basin, and only 6 wells have current EC data.) The heavily pumped Zarqa basin has many wells with current EC data, has the 2nd highest current EC, also has the 2nd highest average rate of EC increase, and the EC trend is greater than +5 µS/cm/yr for 58 percent of the wells analyzed.

Table 2. Groundwater electrical conductivity trends.

Groundwater Basin	# Wells	Most Recent Electrical Conductivity (µS/cm)	Long-Term Linear Trend (µS/cm/yr)	Percentage of Wells with Trend Greater Than +/- 5 µS/cm/yr	
		Average	Average	% +	% -
Azraq	25	1290	+ 27	26	20
Dead Sea	28	1180	+ 10.5	43	25
Hammad	6	1590	+ 4.9	66	16
Jordan Side Valleys (Wadis)	24	989	- 2.8	19	25
Yarmouk	16	990	+ 3.5	19	19
Zarqa	106	1487	+ 16	58	14

Groundwater EC trends are highly variable in Jordan (fig. 6). (Hammad basin is not shown; see separate section on Hammad EC trends.) Most wells with rapidly increasing EC are located at lower elevations in the basins which represent discharge areas, away from freshwater recharge. As noted by Salemeh (1996), "Generally, the water salinity increases in the direction of groundwater flow; from the areas adjacent to the recharge areas to the discharge areas." For example, EC trends are rapidly increasing in the central part of the Zarqa basin, and the oasis area of the Azraq basin. Likewise, a few wells near the Dead Sea show large positive trends. Trends are variable in that wells with rapid increases are located near wells with flat or decreasing EC trends,. Explanation of these differences may be related to the different depths or aquifers that the wells penetrate, but these local conditions were not explored in this study. Salinity may also be impacted by local irrigation and wastewater leakage. Adequate data is not available to evaluate the groundwater EC trend in some areas of heavy pumping (fig. 6).

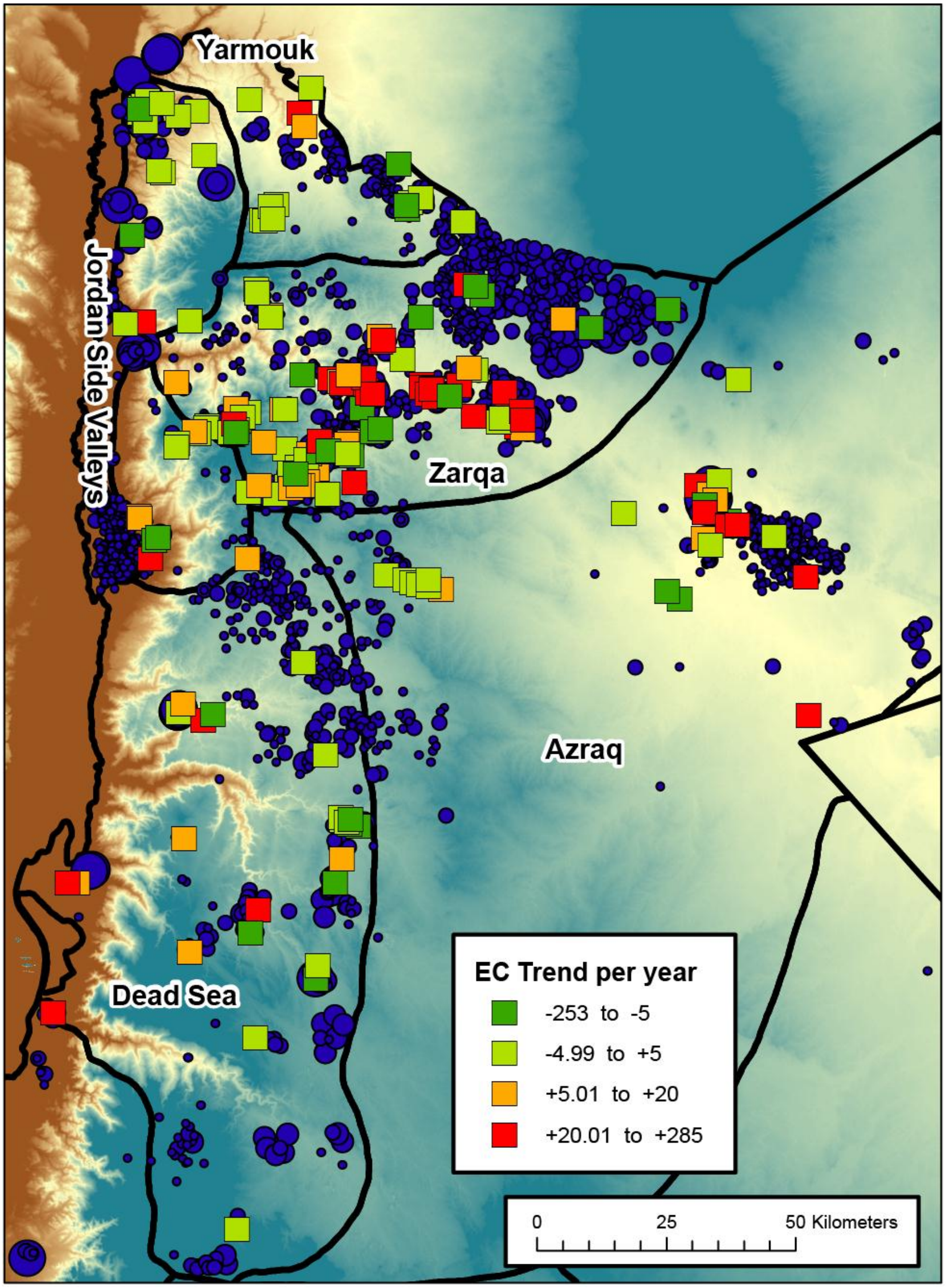

Figure 6. Trends in groundwater electrical conductivity (EC) in Jordan. Color background is land surface altitude in meters, from less than 0 (brown) to more than 1000 (blue). The EC trend, in microsiemens per centimeter per year, is shown for all monitoring wells with data in 2009 (2006 in Azraq and Jordan Side Valleys) or later. The dark-blue dots are production wells, and the size of the dot represents the volume pumped from each well in 2009.

Key findings – Groundwater salinity

- Salinity data are much more variable and sparse than water levels, thus the estimated trends have high uncertainty.
- Recent data are missing from the WIS database.
- Salinity is not increasing rapidly in most wells, except in Zarqa and Hammad basins.
- Salinity is increasing in lower parts of basins, in discharge areas, and generally near heavy pumping.
- Changes in pumping patterns or blending necessitated by salinity will likely occur more frequently in the future where salinity is increasing.
- Water level decline is not well-correlated with salinity trends; geologic setting, amount of recharge, and position within the aquifer flow system are more important in determining high salinity levels and trends.
- Less freshwater will be available from aquifers in Jordan as groundwater salinity increases.

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