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ECONOMIC IMPACTS OF GROUNDWATER DRAWDOWN IN JORDAN

Final Report

January 2012

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INSTITUTIONAL SUPPORT AND STRENGTHENING PROGRAM (ISSP)

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Economic Impacts of Groundwater Drawdown in Jordan

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EXECUTIVE SUMMARY

Jordan's groundwater resources are rapidly declining with many uncertainties on when major water supply aquifers will be degraded or depleted. Utah State University (USU) developed research methods to identify the economic impacts of groundwater level drawdown on Jordanian agricultural pumpers. The methods use readily available well inventory, groundwater level trend, farm activity, groundwater pumping cost, and well retrofit cost data provided by Jordanian and non-governmental agencies to estimate (a) increased pumping costs and (b) pump and well retrofit costs from groundwater level drawdown. USU used these estimates to forecast the future points in time when (i) additional pumping costs will exceed existing farm profits (zero profit), (ii) static groundwater levels will reach well bottoms (well bottom, no retrofit), and (iii) static groundwater levels will reach well bottoms and it is economical to retrofit and deepen wells (well bottom, then retrofit). USU analyzed approximately 1,400 production wells in the Azraq, Hammad, Dead Sea, and Yarmouk basins.

Forecasts show 79% of Azraq basin wells will see zero profit and become unviable for low-value small olive farming or open field vegetables in the next 10 years (Table ES-1). These crops and wells have low profit margins and a rapidly falling groundwater level. Additional pumping costs to withdraw water from lower depths will soon surpass crop profits. It will also be unprofitable to retrofit or deepen these wells since water levels will soon fall below the levels where it is profitable to withdraw water to supply low-value crops. In the Dead Sea and Yarmouk basins, concentrated zones of impacts will develop around Amman, north of Mafraq, in Mazraa (near the Dead Sea), and Suawaqa Al-Gharbiya (in the eastern Dead Sea basin) within the next 10 to 30 years for wells that supply low-value crops like olives, grapes, peaches, dates, and pears. It will also be unprofitable to retrofit these wells to continue growing low-value crops. In the Hamad basin, the onset of nearly all impacts is delayed until 30 years or later.

The onset of first impacts are also delayed for wells supplying medium value crops like olives intercropped with fruit trees (in the Azraq basin) and tomatoes, clover, apples, potato, apricots, cauliflower, squash, water melon, lettuce, and sweet melon (in the Dead Sea and Yarmouk basins). When the groundwater level falls to the well bottom, it also appears economical to retrofit and deepen wells supplying medium value crops.

Table ES-1. Forecast first impacts and onset of first impacts by basin and crop value category (% of total production wells in the basin)

Basin / First Impact	Low Value Crops			Medium Value Crops		
	Onset of First Impact (years)			Onset of First Impact (years)		
	0 to 10	10 to 30	30+	0 to 10	10 to 30	30+
Azraq (350 wells)						
Zero Profit	79%	6%	1%	0%	0%	20%
Well Bottom (no retrofit)	11%	0%	0%	0%	0%	8%
Well Bottom (then retrofit)	0%	0%	2%	14%	10%	46%
Dead Sea (702 wells)						
Zero Profit	4%	8%	50%	0%	0%	7%
Well Bottom (no retrofit)	1%	4%	30%	1%	1%	46%
Well Bottom (then retrofit)	0%	0%	1%	1%	4%	38%
Hamad (46 wells)						
Zero Profit	0%	0%	34%	0%	0%	0%
Well Bottom (no retrofit)	0%	0%	13%	0%	0%	4%
Well Bottom (then retrofit)	0%	2%	49%	0%	2%	91%
Yarmouk (303 wells)						
Zero Profit	0%	29%	38%	0%	0%	9%
Well Bottom (no retrofit)	1%	4%	27%	1%	8%	33%
Well Bottom (then retrofit)	0%	0%	0%	0%	5%	43%

Forecast results suggest several actions the United States Agency for International Development-Jordan (USAID-Jordan), International Resources Group (IRG), and Jordan Ministry of Water and Irrigation (MWI) can take to reduce economic impacts of groundwater drawdown. First, encourage farmers growing low-value crops to transition to higher-value crops or leave agriculture. Taking low value crops grown in the Azraq basin out of production may save 28.1 million cubic meters (MCM) per year. To estimate the water volumes potentially saved by taking low-value crops out of production in the Hamad, Dead Sea, and Yarmouk basins, USU still needs to know the extent of crop activities supplied by production wells in these basins. Second, inventory crop and other water-use activities supplied by production wells in these basins to show how activities are spatially distributed and predict water volumes potentially saved by shifting agricultural activities. Third, develop methods to estimate the additional impacts from dynamic groundwater level drawdown and salinity effects. And fourth, integrate the economic impact data and forecasts with existing MWI groundwater models for each basin. Then use the integrated economic-groundwater models to improve the spatial resolution of forecasts and forecast accuracy for individual production wells. Additionally, involve, train, and oversee MWI staff to use the integrated models to develop groundwater management plans.

Together, farmer education, inventorying crop and other activities supplied by groundwater, identifying additional impacts from dynamic drawdown and salinity effects, and integrated economic-groundwater modeling and management can help USAID-Jordan, IRG, and MWI include economic impacts of groundwater drawdown within a strategic plan for support to Jordan that will improve surface and groundwater resource management.

1. INTRODUCTION

Groundwater resources in Jordan are declining at a rapid rate (Clark 2002) due to growing population and lack of adequate surface water resources (Al-Salihi and Himmo 2003; Al-Zu'bi et al. 2002; Alkhaddar et al. 2005; Hussein 2002; Salameh 2008; Schmidt et al. 2008; Scott et al. 2003). Groundwater management actions have been limited because of uncertainty regarding the timeline for depletion or degradation of major water-supply aquifers. The United States Agency for International Development—Jordan (USAID-Jordan) is interested in predicting when it will no longer be economical for Jordanian farmers and other groundwater pumpers to use groundwater. This information can help the USAID-Jordan Mission, International Resources Group (IRG), and the Jordanian Ministry of Water and Irrigation (MWI) develop a strategic plan for support to Jordan that will improve water resources management.

Here we present research methods developed and results that identify the economic impacts of groundwater level drawdown and forecast the future point in time when it will be un-economical for Jordanian agricultural pumpers to use groundwater. Economic impacts include:

a) Increased pumping costs from groundwater level drawdown.

b) Pump and well retrofit costs from groundwater level drawdown.

c) Increased pumping costs from estimated individual pumping well drawdown (cones of depression) for target pumping wells, based on currently estimated water levels.

d) Increased pumping costs from estimated individual pumping well drawdown for target pumping wells based upon future water levels predicted via simulation model, and

e) Costs to treat or cope with saline water based upon projected concentrations.

Two project tasks:

- Estimate economic impacts a) and b) and assess their relative contribution to the overall impact using readily available data, and

- Assess the availability of geologic, water, and water quality data and recommend suitable approaches to estimate impacts c), d), and e).

This report presents the research methods developed, key findings for four basins where data was readily available, study limitations, recommended next steps, and key conclusions. The report is part of work completed by Utah State University (USU) from July 2011 to January 2012 under terms of reference for the Institutional Support and Strengthening Program (ISSP) with IRG (USAID Contract No. EPP-I-00-04-00024-00, Purchase Number 5009-USU-001; Attachment 1).

2. METHODS

This section details the approach taken to carry out this study to identify and forecast the impacts of groundwater drawdown on increased pumping and well retrofit costs.

Dr. Richard Peralta traveled within Jordan from July 20 to August 2, 2011 for data collection and consultations with the Water Authority of Jordan (WAJ), Ministry of Environment, Minstry of Water and Irrigation (MWI), and technical experts. Experts included U.S. Geological Survey (USGS) staff who were in Jordan to identify the overall and most recent groundwater level trends in numerous monitoring wells spread across the northern part of the country and Dr. Emad Karablieh who was identifying farm costs and profitability for numerous crop types in the Highland and Jordan Rift Valley (i.e., Lowland) areas as part of the ongoing ISSP Water Valuation Study. At the trip end, the one missing data item to complete Task 1 was groundwater pumping costs which MWI/ISSP provided to USU on September 18 (well locations) and December 7, 2011 (annual pumping costs and withdrawal volumes). Table 1 summarizes the data and data sources used in the analysis of increased pumping costs and pump and well retrofit costs from groundwater level drawdown (Task 1).

Table 1. Data and data sources used to identify increased pumping costs and pump and well retrofit costs from groundwater level drawdown (Task 1).

Basin	Well Inventory[a]	Monitoring Wells[b]	Farm Activities[c]	Groundwater Pumping Costs[d]	Well Retrofit Costs[e]
Azraq	MWI	USGS	Demilecamps and Sartawi (2010)	Demilecamps and Sartawi (2010)	MWI
Dead Sea	MWI	USGS	ISSP	MWI / ISSP	MWI
Hamad	MWI	USGS	Demilecamps and Sartawi (2010)	MWI / ISSP	MWI
Yarmouk	MWI	USGS	ISSP	MWI / ISSP	MWI

a.	Excel file with well ID, status, well head elevation (m), depth to water (m), well depth (m), bore diameter (in), screen diameter (in), and Palestine coordinates (UTM) for approximately 8,000 wells throughout Jordan
b.	Reports and Excel files with well ID, current depth to water (m), most recent and overall groundwater level trends (m/yr) for 125 monitoring wells in the Amman-Zarqa, Azraq, Dead Sea, Hamad, and Yarmouk basins
c.	Report (Demilecamps and Sartawi, 2010) and Excel files (Karbaliah, pers. comm., 2011) listing crops grown, water use (m^3/du/yr), average farm size (du), and farm profit (JD/du/yr or JD/m^3) for each crop activity
d.	Excel file listing well ID and annual energy cost (JD/yr) and withdrawal volume (m^3) for 59 production wells (MWI/ISSP) near 26 monitoring wells or average energy cost (JD/m^3) for farms (Demilecamps and Sartawi, 2010)
e.	Excel file listing fixed (JD) and variable mobilization, site preparation, drilling, casing, screening, etc. costs by distance from the nearest city (JD/km), well depth (JD/m), and well diameter (JD/in)

Dr. Rosenberg used the MWI well inventory and paired each production well with the nearest monitoring well analyzed by the USGS. The USGS provided overall (over the entire monitoring period) and the most recent (from the last three years) annual groundwater level trends (m per year) for each monitoring well analyzed. The monitoring wells comprised a subset of the MWI well inventory.

Crop type, water use, and profitability data were used from agricultural inventories (Al-Karablieh 2011; Demilecamps and Sartawi 2010; Karablieh, pers. comm., 2011) to characterize and differentiate crops by their water value (Table 2). This value is the difference between farm revenues and all capital, water tariff, labor, inputs, and other farm costs, and represents the remaining operational surplus (or profit) per m^3 water used. Since 70+ crops were inventoried, Table 2 lists only the 10 largest crops (by annual water consumption) for each basin/location. However, the planted area and water use columns estimate the % coverage and % water use by all crops within the crop value category for the basin and location. In the Azraq basin, approximately 19.5 and 59 million cubic meters (MCM) of water are used per year by all crops in, respectively, the Azraq and North Badia subareas (Demilecamps and Sartawi 2010). For the other basins, the planting area and water use percentages assume a uniform distribution of crop activities across all Lowland and Highland areas in the country since planting area and water use totals were only readily available for administrative units, not basins. Still, the percentages show the relative importance of each crop value category.

The subsequent analysis of economic impacts from groundwater drawdown is performed separately for high, medium, and low crop value categories with results for a particular category applicable to all the crops within the category. These categories span the range of financial viability for crop activities in Jordan and include both the first (low value) and last (high value) crops to be impacted by groundwater drawdown.

Table 2. Characterizing high, medium, and low value crops by basin and location

Basin	Subarea	High Value (> 1.5 JD/m³)			Medium Value (0.25 to 1.5 JD/m³)			Low Value (< 0.25 JD/m³)		
		Crops	Planted Area (%)	Water Use (%)	Crops	Planted Area (%)	Water Use (%)	Crops	Planted Area (%)	Water Use (%)
Azraq	Azraq	NA	NA	NA	Olives + fruit trees	22%	10%	Small family olives, Specialty olives, Olives + alfalfa	75%	90%
Azraq	North Badia	NA	NA	NA	Stone fruit trees; vegetables + trees	70%	82%	Tomato, melon, water melon, lettuce, cabbage, cauliflower, large olive tree farms	29%	18%
Dead Sea	Highland	Cucumber, okra, string beans	1.5%	0.8%	Tomatoes, clover, apples, potato, apricots, cauliflower, squash, water melon, lettuce, sweet melon	43%	36%	Olives, grapes, peaches, dates, pears, sorghum, plums, prunes, lemons, barley	56%	64%
Dead Sea	Lowland	Cucumber, string beans	4.7%	2.4%	Tomatoes, bananas, eggplants, potato, squash, shamouti oranges, red oranges, jew's mallow, valencia oranges, okra	66%	56%	Dates, clementines, naval oranges, maize, mandarins, wheat, pummelors, clover, olives, dry onion	29%	41%
Hamad	Highland	NA	NA	NA	Stone fruit trees; vegetables + trees	70%	82%	Tomato, melon, water melon, lettuce, cabbage, cauliflower, large olive tree farms	29%	18%
Yarmouk	Highland	Cucumber, okra, string beans	1.5%	0.8%	Tomatoes, clover, apples, potato, apricots, cauliflower, squash, water melon, lettuce, sweet melon	43%	36%	Olives, grapes, peaches, dates, pears, sorghum, plums, prunes, lemons, barley	56%	64%

A marginal pumping cost was then calculated (JD per m^3 per m lifted) for each well in the basin that considers the energy costs to lift one cubic meter of water one meter in elevation. This method differed slightly by basin based on the available data.

In Azraq, the marginal pumping cost for each farm type was calculated by dividing average energy cost (JD per m^3) by the average depth to groundwater (m) for production wells reported by Demilecamps and Sartawi (2010) (see also Attachment 2). Average energy cost was a weighted combination of reported electric and diesel costs and was weighted by the fraction of farms using each energy source. In the North Badia area, energy costs were entirely electric as electricity is the sole energy source.

In the Dead Sea, Hamad, and Yarmouk basins, MWI provided annual pumping costs and production volumes for up to 3 sample pumping wells near each USGS monitoring well. USU identified the depth to water (m) in each sample well and divided the annual pumping cost by the annual production volume and depth to water to obtain the marginal pumping cost. For each other pumping well in the basin, a marginal pumping cost was calculated as the average of marginal pumping costs from the closet sample wells.

In both cases marginal pumping costs represent actual farmer costs and reflect existing government subsidies for diesel (Azraq farmers) or electricity (all basins).

Forecasts were then made for the number of years it will take for the static water level in a production well to reach the well bottom (well to go dry) by dividing the difference between the well depth and groundwater level by the groundwater level trend provided in Step 2. This forecast likewise assumes that the future groundwater level trend in the well will be similar to the past observed trend in the nearest monitoring well. In cases when the depth to groundwater for a well was missing from the well inventory, It was that assumed the groundwater level was the same as the most recent reading (Summer 2011) in the nearest monitoring well. It was also assumed that all pumps are located at the bottom of each well so pumping can continue until the well is dry. Note that the forecasted number of years until a well becomes dry will likely be longer than the actual time (or until it is no longer usable) for three reasons. First, for steady pumping, the rate of groundwater level decline will increase as the saturated thickness decreases and productive fractures are dewatered. Second, an irrigator may cutback pumping or the well may produce less (or possibly no) water when the static groundwater level approaches the well bottom. And third, salinity increases in some locations may make extracted water unsuitable for use.

The number of years it will take the crop category to become unprofitable (zero profit) was also calculated. This forecast only considers additional pumping lift costs from groundwater drawdown and was made by dividing farm profitability (from Step 3) by the marginal pumping cost (Step 4) and by the groundwater level trend (Step 2). This forecast assumes that the future groundwater level trend in the production well will be similar to the past observed trend in the nearest monitoring well.

Next, the two forecast times were compared (Step 5 and Step 6).

a. When reaching a lower water level and zero profit (Step 6) before the well went dry (Step 5), the analysis stopped and profitability was recorded as the first impact. In this case, the farmer could still withdraw water from the well, but the increased withdrawal cost would make the crop activity unprofitable.

b. When the well was forecast to first go dry, it was also determined whether it would be financially advisable to drill a new, deeper well to a lower depth where the crop activity would become unprofitable. This new, deeper depth when farm profit goes to zero was estimated as in Step 6, considers only the marginal costs of lifting water, and assumes there is suitable aquifer material with similar water abstraction properties down to the new, lower depth. Dr. Rosenberg estimated the well retrofit cost using the schedule of fixed and variable well service charges provided by the MWI drilling department (Attachment 3). Variable costs considered the mobilization distance to the well from the nearest governorate capital, the new well depth, and well diameter. The retrofit cost estimate assumed the new well would be the same diameter as the existing well. Dr. Rosenberg then divided the retrofit costs by the average farm size to express retrofit costs per donum and compared these per donum retrofit costs to the remaining profit the new well would likely yield over the time until the new well also went dry (the same time when and same groundwater level at which pumping for the crop activity would become uneconomical).

i. If per donum retrofit costs exceeded the remaining profit, Dr. Rosenberg noted the existing well bottom as the first impact (well bottom; no retrofit). In this case, it would be uneconomical to retrofit the well.

ii. If remaining profit exceeded per donum retrofit costs, Dr. Rosenberg noted the well bottom and retrofit as the first impact (well bottom; then retrofit). In this case, it could be profitable to retrofit and deepen the well.

The shorter of the two forecast times was then reported (minimum of Step 5 and Step 6) and the first impact (Step 7) for the well.

Steps 2 – 8 were repeated for 1,200 of the approximately 2,200 active production wells in the MWI well inventory in the Azraq, Dead Sea, Hamad, and Yarmouk basins for which the required data was available. He replicated the analysis for three crop value categories and for the overall and most recent groundwater level trends (3 x 2 = 6 scenarios). In each scenario, monitoring well, crop, pumping cost, and well retrofit data specific to the basin, subarea, and crop category were used.

Attachment 4 shows input data and forecasts (Steps 1 – 9) for 6 wells in the Azraq and Yarmouk basins. Forecasts are for medium value crops and the most recent groundwater level trends.

For Task 2 to assess the data available to estimate additional economic impacts of groundwater drawdown, the data collected during the field trip and subsequently provided by ISSP is nearly sufficient to estimate dynamic pumping lift at pumping wells (cones of depression and associated costs; Attachment 5). USU still needs to collect groundwater modeling input files and data from previous studies to simulate future groundwater levels or project salinity concentrations. Model application could provide both improved estimates of hydrologic trends and tools to evaluate hydrologic and economic effects of management strategies.

III. RESULTS

Forecasts of times for static groundwater levels to reach well bottoms that use recent groundwater level trends suggest only 14% of the wells analyzed will go dry within the next 30 years (Figure 1). However, impacted wells are concentrated in Azraq, the Yarmouk basin north of Mafraq, the capital Amman, and Suawaqa Al-Gharbiya (in the east Dead Sea basin).

Forecasts of the times to zero farm profits show many more wells that supply low value crops will first see economic impacts before the wells go dry (Figure 2). In Azraq, 79% of wells that supply low value crops such as olives at small, family owned farms and open field vegetables (tomato, melon, watermelon, lettuce, cabbage, cauliflower) will see additional pumping costs from groundwater drawdown exceed farm profits within the next 10 years and before wells go dry. These impacts will make it unprofitable to retrofit wells because water levels will soon drop below the level where it is economically profitable to withdraw water to cultivate olives. These forecasts also use the most recent groundwater level trends observed in nearby monitoring wells.

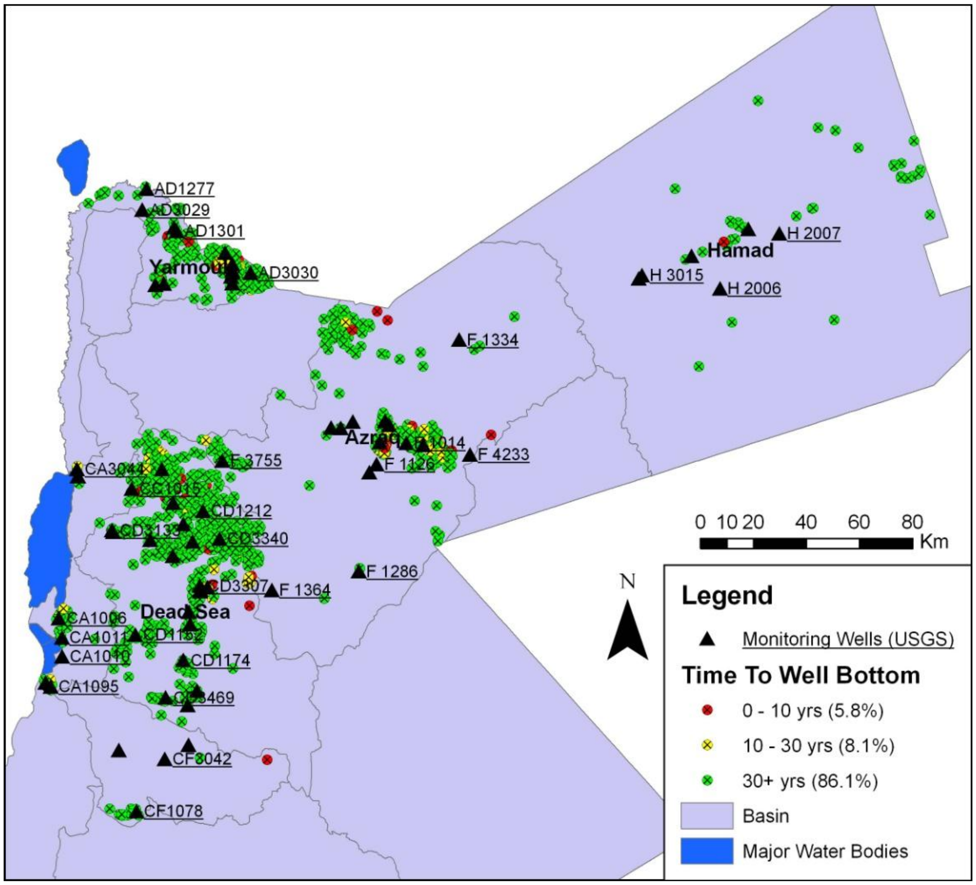

Figure 1: Forecasted time until wells go dry in the Azraq, Dead Sea, Hamad, and Yarmouk basins. Forecasts use the most recent groundwater level trend in the nearest monitoring well.

In the Hamad basin, the economic effects of groundwater drawdown are less severe on low value crops like olives and open field vegetables (tomato, melon, watermelon, lettuce, cabbage, cauliflower). Nearly all wells are financial viable over the next 30 years and it will likely be economical to retrofit or deepen wells that do go dry. Forecast times are longer in the Hamad than Azraq because Hamad groundwater pumping costs are lower (more pumps run by electricity) and water levels are declining less rapidly.

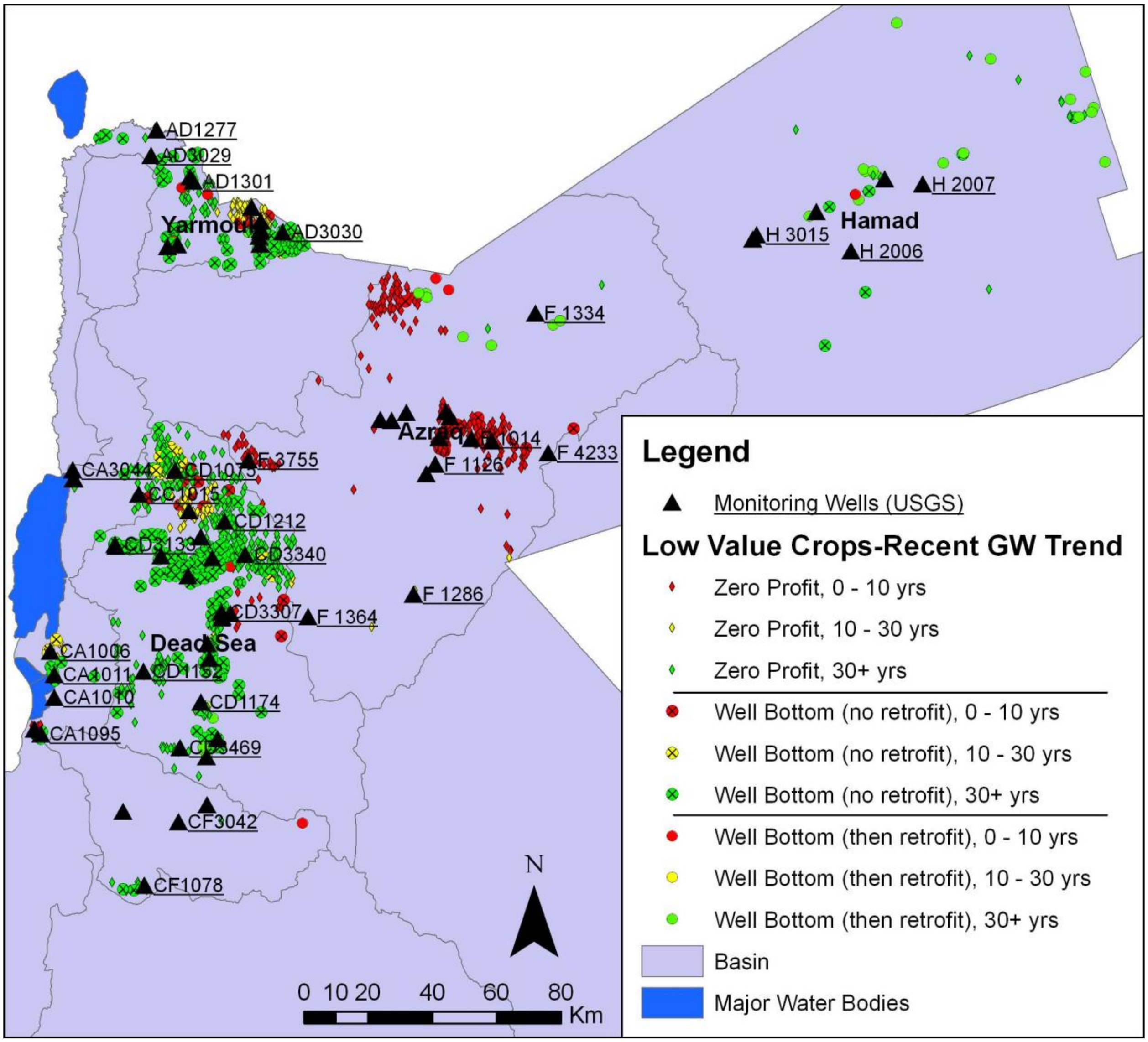

Figure 2: Forecasted time (marker color) to first impact (marker shape) for wells supplying water to low value crops (return < 0.25 JD/m3) in the Azraq, Dead Sea, Hamad, and Yarmouk basins.

Figure 2 above shows the forecasted time (marker color) to first impact (marker shape) for wells supplying water to low value crops (return < 0.25 JD/m^3) in the Azraq, Dead Sea, Hamad, and Yarmouk basins. Diamond markers indicate farm profit will first drop to zero (additional energy extraction costs exceed current profit) before the well goes dry. Circle markers with an X indicate the well will first go dry while plain circles indicate it will likely be profitable to retrofit and deepen wells forecast to go dry. Forecasts use the most recent groundwater level trend in the nearest monitoring well.

Approximately 81% of wells in the Dead Sea and 65% of wells in the Yarmouk basins used to cultivate low value crops like olives, grapes, peaches, dates, and pears can likely continue to operate for 30 years or longer. However, declining water levels in zones encompassing the capital Amman, north of Mafraq, Mazraa (near the Dead Sea), and Suawaqa Al-Gharbiya will make it uneconomical to supply water to low value crops in 10 or 20 years or sooner. These zones comprise 17% and 34% of the wells analyzed in, respectively, the Dead Sea and Yarmouk basins. Within these zones, most wells will experience zero profits before wells go dry.

Forecast times to zero profit are longer for medium value crops grown in all the basins (Figure 3). In Azraq, forecast times to zero profit for wells supplying olives intercropped with fruit trees are longer than forecast times for wells to go dry and mean it appears economical for many well owners cultivating medium value crops to retrofit and deepen their wells when the wells go dry. In the Hamad basin, forecasts suggest few impacts within the next 30 years like for wells supplying low value olives and open field crops. In the Dead Sea basin, 7% of wells will go dry within the next 30 years (these wells are primarily located within the three zones), but it will be financially worthwhile to retrofit and deepen many of these wells if they supply water to medium value crops like tomatoes, clover, apples, potato, apricots, cauliflower, squash, water melon, lettuce, sweet melon, etc.. In the Yarmouk Basin, approximately 14% of wells will go dry within the next 30 years (again in the Mafraq zone) and it will likely be economical to retrofit and deepen about one third of these wells if they supply the same medium value crops as in the Dead Sea basin.

Forecasts for high value crops (>1.5 JD/m^3) like cucumber, okra, and string beans grown in the Dead Sea and Yarmouk basins are similar to forecasts for medium value crops with the difference that the onset of economic impacts are further into the future and it will likely be economical to retrofit and deepen a larger percent of wells that go dry (Figure 4). No wells are shown for the Azraq or Hamad basins because high value crops are not cultivated there.

Table 3 summarizes the forecast onset of impacts discussed above by basin, impact type, and crop value category. The forecasts use the most recent groundwater level trend in the nearest monitoring well. Sensitivity analysis shows forecasts for three additional scenarios that instead use the overall groundwater level trend observed in nearby monitoring wells are nearly identical to forecasts that use the most recent trend (Attachment 6). For select wells the smaller overall trend further delays the onset of forecasted impacts.

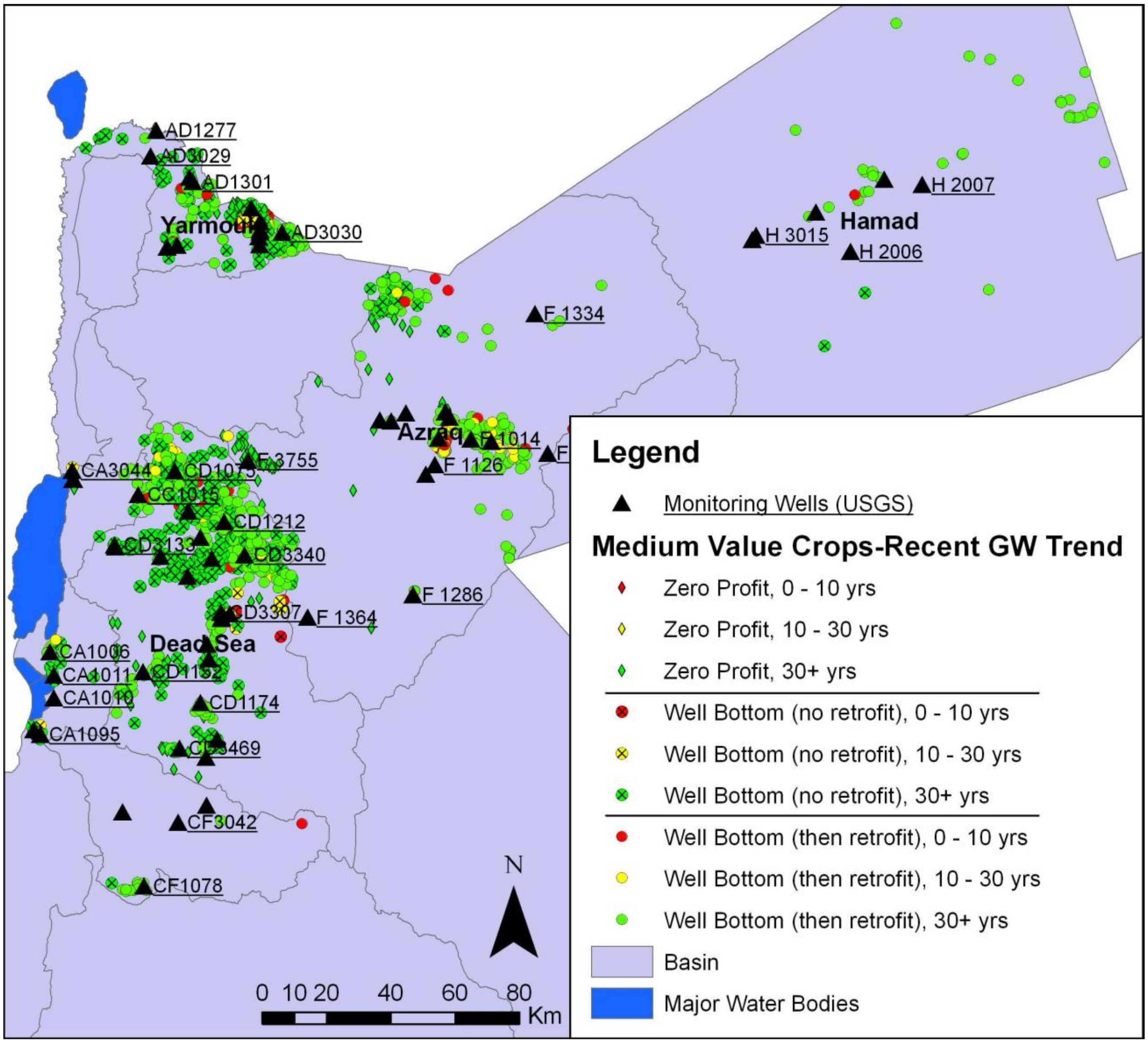

Figure 3. Forecasted time (marker color) to first impact (marker shape) for wells supplying water to medium value crops (return between 0.25 and 1.5 JD/m^3) in the Azraq, Dead Sea, Hamad, and Yarmouk basins. Diamond markers indicate farm profit will drop to zero (additional energy extraction costs exceed current profit) before the well goes dry. Circle markers with an X indicate the well will first go dry while plain circles indicate it will likely be profitable to retrofit and deepen the well. Forecasts use the most recent groundwater level trend in the nearest monitoring well.

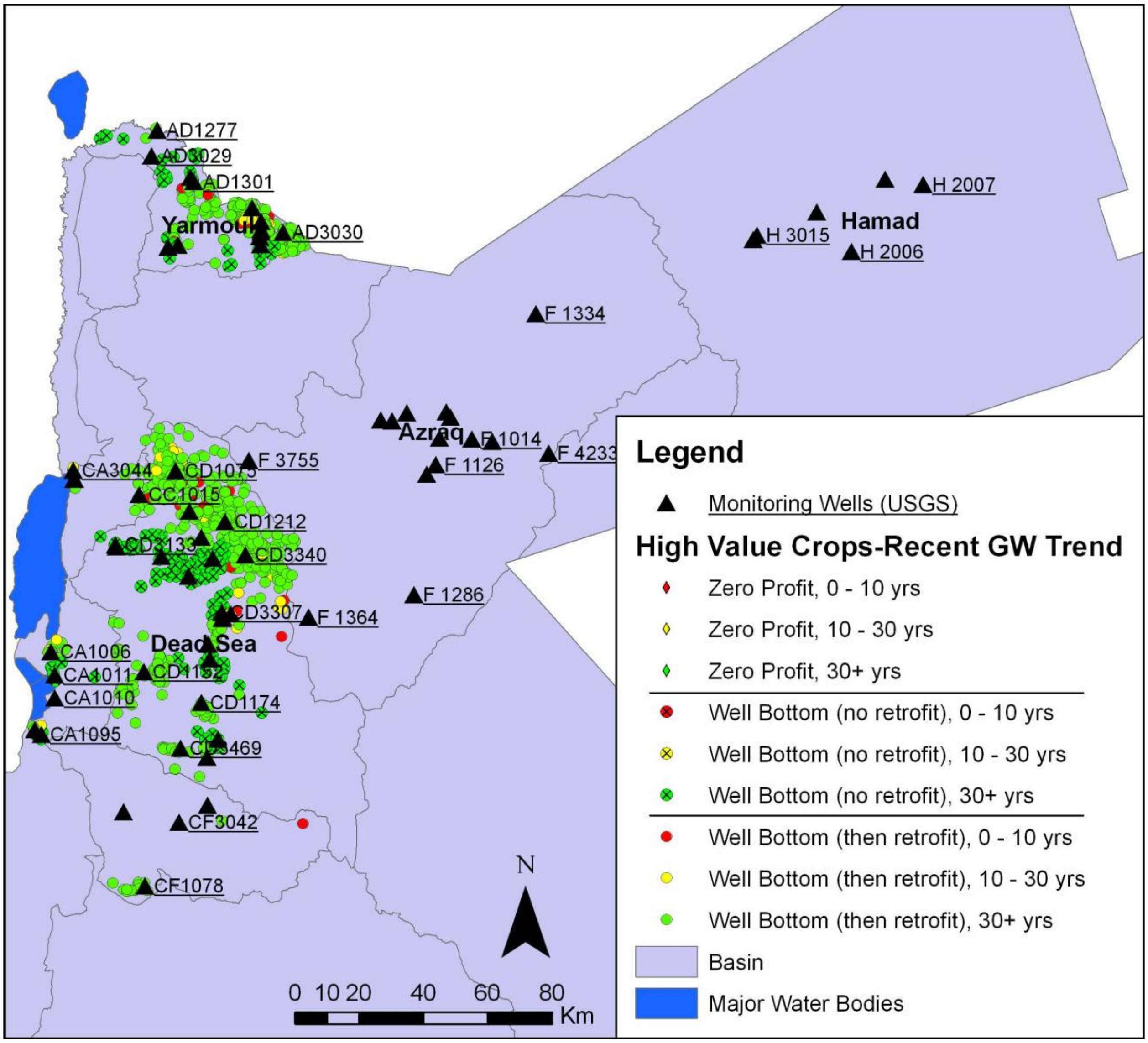

Figure 4. Forecasted time (marker color) to first impact (marker shape) for wells supplying water to high value crops (return > 1.5 JD/m^3) in the Dead Sea and Yarmouk basins. Diamond markers indicate farm profit will drop to zero (additional energy extraction costs exceed current profit) before the well goes dry. Circle markers with an X indicate the well will first go dry while plain circles indicate it will likely be profitable to retrofit and deepen the well. Forecasts use the most recent groundwater level trend in the nearest monitoring well.

Table 3. Forecast first impacts and onset of first impacts by basin and crop category (% of wells analyzed in each basin). Forecasts use the most recent groundwater level trend in the nearest monitoring well.

Basin / First Impact	Low Value Crops			Medium Value Crops			High Value Crops		
	Onset of First Impact (years)			Onset of First Impact (years)			Onset of First Impact (years)		
	0 to 10	10 to 30	30+	0 to 10	10 to 30	30+	0 to 10	10 to 30	30+
Azraq (350 wells)									
Zero Profit	79%	6%	1%	0%	0%	20%			
Well Bottom (no retrofit)	11%	0%	0%	0%	0%	8%		NA	
Well Bottom (then retrofit)	0%	0%	2%	14%	10%	46%			
Dead Sea (702 wells)									
Zero Profit	4%	8%	50%	0%	0%	7%	0%	0%	0%
Well Bottom (no retrofit)	1%	4%	30%	1%	1%	46%	0%	0%	24%
Well Bottom (then retrofit)	0%	0%	1%	1%	4%	38%	1%	6%	68%
Hamad (46 wells)									
Zero Profit	0%	0%	34%	0%	0%	0%			
Well Bottom (no retrofit)	0%	0%	13%	0%	0%	4%		NA	
Well Bottom (then retrofit)	0%	2%	49%	0%	2%	91%			
Yarmouk (303 wells)									
Zero Profit	0%	29%	38%	0%	0%	9%	0%	0%	0%
Well Bottom (no retrofit)	1%	4%	27%	1%	8%	33%	0%	0%	15%
Well Bottom (then retrofit)	0%	0%	0%	0%	5%	43%	1%	13%	69%

IV. DISCUSSION

The forecast results for the Azraq, Dead Sea, Hamad, and Yarmouk basins identify three important economic impacts from groundwater drawdown. These impacts provide an entry point to understand how drawdown is affecting the northern part of Jordan and how groundwater management can be improved. First, Azraq farmers will soon find it uneconomical to pump water to grow low value crops like olives and olives intercropped with alfalfa. Existing profit margins are extremely low, groundwater is falling at a rapid rate, and the additional pumping costs to withdraw water from a lower depth will surpass crop profits within the next 10 years. Below this groundwater level of zero profit, it will be uneconomical to retrofit or drill new, deeper wells to continue cultivating these low value crops. Low value crops now comprise 75% of the planted land in the Azraq area and use 90% of the water or about 17.5 MCM per year. North of the Azraq area in the North Badia, low value crops comprise 29% of the land area and 18% of the water use or about 10.6 MCM per year. These impacts may foretell a widespread abandonment of agriculture (and possible reduction of water abstractions) and/or transition to higher value crops.

Second, zones of impacts in the Dead Sea and Yarmouk basins around the capital Amman, north of Mafraq, Mazraa (near the Dead Sea), and Suawaqa Al-Gharbiya (in the eastern Dead Sea basin) are also emerging for wells supplying low value highland crops like olives, grapes, peaches, dates, pears, sorghum, plums, prunes, lemons, and okra plus low value lowland crops like dates, clementine, navel oranges, maize, mandarins, wheat, clover, olives, and dry onion. Profit margins for these crops are low and additional pumping costs to withdraw water from a lower depth will surpass crop profits within the next 10 to 30 years. Forecast times to zero profits are either similar to or slightly longer than in Azraq. And, as in Azraq, when impacts arise and wells go dry, it is generally uneconomical to retrofit or drill new, deeper wells to continue cultivating low value crops. These low value crops comprise 56% and 29% of the planted areas in, respectively, the highland and lowland areas. These crops also consume 64% and 41% of the total water use in highland and lowland areas. The widespread planting of low value crops and short times to likely impacts on wells suggest targeted transitions to higher value crops may soon be warranted or significant water volumes can be saved by abandoning these crops.

Third, impacts in all basins are much smaller and are delayed for medium and high value crops (like olives intercropped with fruit trees, stone fruit trees, tomatoes, clover, apples, potato, apricots, cauliflower, squash, water melon, lettuce, bananas, eggplants, cucumber, okra, string beans, etc.). When wells supplying these crops do go dry, it is generally economical to retrofit and drill a new, deeper well.

V. LIMITATIONS

The forecast economic impacts use only readily available data (supplied by MWI, ISSP, USGS, and existing reports) and are based upon linear extrapolation of recent groundwater level decline rates. The forecasts assume future decline rates will be similar to the most recent or overall historical decline rates. Forecasts also assume that future pumping, marginal costs, returns, and government subsidies will stay the same. Forecasts also only consider the additional pumping costs from drawing down the static groundwater level and retrofitting or drilling new, deeper wells. Forecasts do not consider dynamic pumping lift (the additional pumping costs when the static water level declines at a well that is pumping) or salinity effects. Forecasts also assume that, for retrofitting, marginal pumping costs for the retrofit well are the same as the existing well and the aquifer material underlying the existing well has the same water extraction characteristics as the material in which the existing well is drilled. Further, forecasts for several wells use ground water level and pumping cost data from nearby monitoring or production wells and aggregate crop value and water use data for subareas within a basin. The former omissions mean we may actually observe larger impacts sooner from dynamic drawdown and salinity effects. The latter assumptions make possible forecasts for an entire basin but mean a forecast and impact estimate for an individual production well can be subject to errors and uncertainties such as large variability in groundwater levels over short distances, local variations in well retrofit costs, or non uniform crop activities. Table 4 summarizes variability in depths to groundwater and remaining saturated thicknesses among and across the monitoring and production wells analyzed. In the Azraq subarea, depths to groundwater in production wells are greater than in monitoring wells, but remaining saturated thicknesses are smaller. Thus, economic impacts will be seen more quickly than when considering the monitoring wells alone.

The analysis presumes errors and uncertainties are random across the production wells included in the MWI well inventory rather than systematic (and will thus tend to cancel one another out when considering a large number of production wells such as the 1,400 wells considered in this study). If systematic errors exist, addressing them will require more carefully pairing each production well to a monitoring well (to ensure both wells are drilled into and screened within the same aquifer strata, etc.) and associating each production well with one or (possibly) more crop activities. We can make these adjustments, but they will require more than the readily available well and farm data provided to date.

Table 4. Variability in monitoring and production well groundwater levels and well depths

Basin	Subarea	Monitoring Wells			Production Wells		
		Number	Depth to Water[a] (m)	Saturated Thickness[a] (m)	Number	Depth to Water[a] (m)	Saturated Thickness[a] (m)
Azraq	Azraq	13	70.8 (85.7)	124.0 (121.4)	290	169.2 (160.6)	87.7 (198.7)
Azraq	North Badia	1	178.8 (--)	187.2 (--)	12	306.6 (151.2)	133.5 (75.4)
Dead Sea	Highland	26	132.5 (64.7)	99.7 (48.9)	581	199.0 (73.4)	120.9 (447.6)
Dead Sea	Jordan Valley	8	26.8 (17.2)	34.1 (27.1)	47	34.0 (50.4)	51.0 (74.1)
Hamad	Highland	6	147.5 (65.3)	162.0 (119.7)	47	203.8 (79.5)	123.5 (94.5)
Yarmouk	Highland	13	147.8 (76.4)	131.1 (101.0)	262	214.5 (74.2)	117.5 (290.1)

a. Lists average value and standard deviation in parenthesis

Recognizing these limitations, the results are used to recommend future groundwater management actions.

VI. RECOMMENDATIONS

The forecasts and economic impacts associated with groundwater drawdown suggest seven actions USAID-Jordan, IRG, and MWI can take to improve groundwater management and reduce the economic impacts from groundwater drawdown.

a. Immediately help Azraq farmers who are growing low-value crops like olives to either transition to higher-value crops or leave agriculture all-together.

b. Raise awareness among farmers who are growing low value crops in the Dead Sea and Yarmouk basins that they will likely face problems in up to 10 years time. Encourage these farmers to transition to higher value crops and deepen their wells as wells go dry.

c. Identify additional impacts associated with dynamic drawdown (cones of depression). This dynamic drawdown is the distance the static water level (analyzed in Task 1) declines at a well that is pumping. Dynamic drawdown is greater (sometimes much greater) than static drawdown. USU recommends to:

   - Select a target pair of production and nearby monitoring wells that are both screened solely in the same aquifer stratum.
   - Estimate dynamic drawdown at the target production well by applying the analytical equation appropriate for the aquifer stratum and well-specific design and pumping information.
   - Estimate dynamic lift as the sum of static lift and dynamic drawdown.

   Considering dynamic drawdown can potentially shorten the long forecast times predicted from static water levels for several crop value categories in several basins.

d. Inventory agricultural and other water-use activities associated with production wells to show how crop activities are spatially distributed, where impacts will be concentrated, and how to improve forecast accuracy for individual production wells. This inventory will also allow us to quantify the water volumes saved in the Hamad, Dead Sea, and Yarmouk basins when farmers who grow low value crops leave agriculture.

e. Estimate additional costs to treat or cope with saline water for wells that show increasing salinity trends.

f. Integrate forecasts, economic data, and calculations with existing MWI groundwater models for each basin. Use the integrated economic-groundwater models to:

   - Improve the spatial resolution of forecasts,
   - More accurately forecast impacts for individual production wells, and
   - Identify sets of wells to take out of production to achieve groundwater management goals such as: (i) prolong the life of groundwater, (ii) protect municipal groundwater supplies, (iii) minimize all private & public water supply costs, and/or (iv) maximize employment.

g. Involve MWI staff in model integration, train MWI staff to use the integrated economic-groundwater models, and oversee staff to use the integrated models to develop groundwater management plans for one or more basins.

VII. CONCLUSIONS

Jordan's groundwater resources are rapidly declining and there are many uncertainties on when major water supply aquifers will be degraded or depleted. USU developed research methods to identify the economic impacts of groundwater level drawdown on Jordanian agricultural pumpers. USU used readily available well inventory, water level trend, farm activity, groundwater pumping cost, and well retrofit cost data provided by the MWI, USGS, ISSP, and published reports to estimate (a) increased pumping costs, and (b) pump and well retrofit costs from groundwater level drawdown. USU used these estimates to forecast the future points in time when (i) additional pumping costs will exceed existing farm profits (zero profit), (ii) static groundwater levels will reach well bottoms (well bottom, no retrofit), and (iii) static groundwater levels will reach well bottoms and it is economical to retrofit and deepen wells (well bottom, then retrofit). USU analyzed approximately 1,400 production wells in the Azraq, Hammad, Dead Sea, and Yarmouk basins.

Forecast results for the Azraq basin show 79% of wells will see zero profit from low-value small olive farming or open field vegetables within the next 10 years. It will also be unprofitable to retrofit these wells since the water level will soon drop below the level where it is economically profitable to withdraw water to cultivate olives or open field vegetables.

In the Dead Sea and Yarmouk basins, zones of impacts will develop within the next 10 to 30 years for wells supplying low value crops around Amman, north of Mafraq, Mazraa (near the Dead Sea), and Suawaqa Al-Gharbiya (in the eastern Dead Sea basin). It will also be unprofitable to retrofit these wells since the water level will soon drop below the level at which it is economically profitable to withdraw to cultivate low value crops.

In all basins, forecast times to zero profits are delayed for wells supplying medium and high value crops. When wells go dry, it generally appears economical to retrofit and deepen them.

The forecast results suggest several actions USAID-Jordan, ISSP, and MWI can take to reduce the economic impacts of groundwater drawdown. First, encourage farmers growing low-value crops to transition to higher-value crops or leave agriculture. Taking low value crops grown in the Azraq basin out of production may save up to 28.1 MCM per year. USU still needs to know the extent of crop activities supplied by production wells in the Hamad, Dead Sea, and Yarmouk basins to estimate the water potentially saved by taking low-value crops out of production. Second, inventory the crop and other water-use activities associated with production wells in these basins to show how crop activities are spatially distributed and predict water volumes potentially saved by shifting agricultural activities. Third, develop methods to estimate the additional impacts from dynamic groundwater level drawdown and salinity effects. And fourth, integrate the forecasts and economic impact data with existing MWI groundwater models for each basin and use the integrated economic-groundwater models to improve the spatial resolution of forecasts and forecast accuracy for individual production wells. Also, involve, train, and oversee MWI staff to use the integrated models to develop groundwater management plans.

Together, farmer education, inventorying crop and other activities supplied by groundwater, identifying additional impacts from dynamic drawdown and salinity effects, and integrated economic-groundwater modeling and management can help USAID-Jordan, IRG, and MWI include economic impacts of groundwater drawdown within a strategic plan for support to Jordan that will improve surface and groundwater resource management.

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ATTACHMENT I

USU Terms of Reference and Statement of Work

The objective of this project is to assist USAID's strategic planning for management of water resources in Jordan. The project will focus on research methods that can identify the economic impacts of groundwater level drawdown and forecast the future point in time when it will be un-economical for Jordanian agricultural pumpers to use groundwater. Economic impacts include:

a) Increased pumping costs from groundwater level drawdown.

b) Pump and well retrofit costs from groundwater level drawdown.

c) Increased pumping costs from estimated individual pumping well drawdown (cones of depression) for target pumping wells, based on currently estimated water levels.

d) Increased pumping costs from estimated individual pumping well drawdown for target pumping wells based upon future water levels predicted via simulation model, and

e) Costs to treat or cope with saline water based upon projected concentrations.

Project tasks are to:

1) Estimate economic impacts a) and b) and assess their relative contribution to the overall impact using readily available data,
2) Assess the availability of geologic, water, and water quality data and recommend suitable approaches to estimate impacts c), d), and e).

A desk study will be conducted to estimate the economic impacts associated with increased pumping and pump retrofits due to observed changes in head at monitoring wells. The study will also assess the availability of geologic, water, and water quality (current and projected) data to estimate and predict economic impacts due to head and salinity changes. As part of the assessment, we will recommend approaches to proceed with the analysis based on available data.

Task 1 addresses economic impacts a) increased pumping costs from groundwater level drawdown and b) pump and well retrofit costs. It will cover all the monitoring and withdrawal wells that have the required data (listed below) and that are located in one of the four northern groundwater basins in Jordan (Amman-Zarka, Yarmouk, Hamad, or Azraq). Required data for the selected basin will include:

- Depths to groundwater in observation wells and temporal trends (work currently being undertaken by the U.S. Geological Service[USGS]),
- Farm revenue per unit water input (USAID), and
- Well logs with screened intervals of withdrawal wells (USGS)

A 12-day trip to Amman, Jordan will be undertaken to collect additional required data from the relevant Jordanian institutions including the Water Authority of Jordan (WAJ), Jordan Ministry of Water and Irrigation (MWI), and National Resources Association (NRA). Required data will include:

- Unit pumping costs (WAJ), and
- Fixed and unit well drilling costs (WAJ)

USU will employ available groundwater level data with unit pumping costs provided by WAJ to estimate the economic impacts of groundwater drawdown. We will use either current or projected groundwater levels based on existing data. USU will similarly use groundwater levels and fixed and unit well drilling costs provided by WAJ to estimate pump and well retrofit costs.

Total costs will be compared to farm revenue per unit water input provided by ISSP Jordan to identify areas where groundwater pumping is currently uneconomical, or locations where and when it will no longer be economical. USU will summarize results in maps that show the overall economic impact and economic impacts by cost component.

Task 2 will assess the availability of data to reasonably predict individual withdrawal well water levels (based upon current monitored or model-projected water levels) and estimate salinity effects. It will also address one of the four northern groundwater basins in Jordan (Amman-Zarka, Yarmouk, Hamad, or Azraq). During the 12-day trip to Amman, Jordan discussed in Task 1, USU will also visit Jordanian institutions to assess the availability and quality of required data and if available, collect it. This data will include:

- Set of target coupled pumping and monitoring wells in same aquifer strata (WAJ),
- Historic pumping, head, and pump-test data for target pumping wells (MWI, WAJ),
- Pumping well efficiency information (WAJ),
- Data and methods to convert groundwater head to groundwater depth at pumping wells (MWI, WAJ), and
- Basin geology reports (USAID, WAJ, MWI, NRA)

Based on the data assessment, USU will recommend methods to proceed with analysis to identify the additional economic impacts of individual withdrawal well water levels and salinity effects. If practical, USU will also crudely estimate the physical and economic effects of pumping well drawdown at selected individual wells.

USU will prepare a short report that presents:

- the groundwater and economic data used in the analysis,
- analysis methods, including the groundwater pumping economic analysis,
- maps showing either current or projected total economic impacts, and cost components,
- assessments of data available to evaluate cone-of-depression and salinity effects, and
- recommendations for how to proceed with analyzing cone-of-depression and salinity effects.

USU will brief USAID at the end of the in-country data collection trip. USU will also prepare a manuscript for submission to a peer-reviewed scientific journal that presents the key findings of the economic analysis and will include as co-authors sponsors, collaborators, and data providers that contribute significantly to the project work.

Additional analyses of hydrological, geological, and environmental issues relevant to natural resource management in Jordan requested by USAID and/or USGS may be added to this statement of work by agreement of USU, USAID, and USGS.

Deliverables

Reporting Requirements (Activities and/or Outputs)	**To be Completed by no later than these Due Dates**	**Delivery Instructions** (# of copies, paper/electronic transmittals, formats, names of reviewers, etc)
Jordan Trip Report (Richard Peralta)	August 10, 2011	Email to Glen Anderson and Barbara Rossmiller upon return.
Draft desk study	October 20, 2011	Email desk study to Glen Anderson and Barbara Rossmiller
Final Report	November 28, 2011 (with USAID and IRG feedback to USU on the draft report by November 10, 2011)	Email final report to Glen Anderson and Barbara Rossmiller

Deliverables to be prepared as noted:

1. Trip report should be in memo format and describe activities carried out and persons met during the assignment based on the standard ISSP template. The report shall also include as an attachments any written materials produced.
2. All deliverables shall be provided in electronic format and conform to USAID and IRG report standards.

ATTACHMENT 2

Azraq Pumping Cost Data

This attachment summarizes the farm data for Azraq (Demilecamps and Sartawi 2010) and calculations that were used to develop unit pumping costs (Column G) for different crops grown in the basin (Table A). The table also shows the operational surplus/value (Column H) for each crop and classifies this water value into a low, medium, or high category (Column I) using the value ranges presented in the main report.

Table A. Marginal pumping costs and values for different crops grown in the Azraq basin

Location (A)	Crops (B)	Water Use (m^3/du/yr) (C)	Avg. Depth to Water (m) (D)	Energy Cost (JD/m^3) (E)	Profit (JD/du/yr) (F)	Marginal Pumping Cost (JD/m^3/m) (G)	Water Value (JD/m^3) (H)	Value Category (I)
Azraq	Small family olives	1,160	35	0.08	9	0.0023	0.01	Low
Azraq	Specialty olives	905	35	0.10	20	0.0030	0.02	Low
Azraq	Olives + fruit trees	390	35	0.09	130	0.0026	0.33	Medium
Azraq	Olives + alfalfa	1,040	35	0.03	78	0.0010	0.07	Low
N. Badia	Fruit trees	1,295	350	0.14	1,000	0.0004	0.77	Medium
N. Badia	Vegetables + trees	1,315	350	0.14	460	0.0004	0.35	Medium
N. Badia	Tomato, melon, lettuce, etc.	1,600	350	0.14	370	0.0004	0.23	Medium
N. Badia	Large olive tree farms	570	350	0.14	60	0.0004	0.11	Medium
Column G = (Column E)/(Column D)								
Column H = (Column F)/(Column C)								

ATTACHMENT 3

Well Retrofit Costs

This attachment presents the cost schedule provided by the drilling department of the Water Authority of Jordan and used to estimate costs to retrofit and drill new, deeper wells (Table B). There are both fixed and variable costs associated with these actions. Variable costs are a function of the distance to the well from the nearest governorate capital, the well depth, and well diameter. Starred services (*) indicate cost items considered in the analysis.

Table B. Price analysis for services and works done by Drilling Dept. of WAJ starting on 9 July, 2008 (WAJ board decision number 291)

No.	Description	Range	Cost (JD)
1.	*Mobilization of Rotary Rig with tools	0 to 100 km	3,900
		100 to 250 km	4,800
		250+ km	5,800
2.	*Hammering Rig Mobilization, or test pump with tools	0 to 100 km	1,000
		100 to 250 km	1,900
		250+ km	2,900
3.	*Shooting (filming) car mobilization	0 to 100 km	200
		100 to 250 km	300
		250+ km	400
4.	*Shooting (filming) car		1,500
5.	*Rotary drilling site		775
6.	*Air Drilling site		300
7.	*Hammering drilling site		675
8.	*Drilling per meter	0 to 6 in	50
		6 to 9 in	60
		9 to 12 in	80
		12 to 15 in	90
		15 to 18 in	110
		24 to 26 in	135
9.	*Preparing documents of drilling well		970
10.	Extra hours after 100 pumping hours/h		80

No.	Description	Range	Cost (JD)
11.	*Lowering and installing casing pipes and pipe base screen/m run excluding the pipes costs	0 to 7 in	11
		10 to 11 in	20
		13 to 14 in	30
12.	*Striped casing pipes	0 to 7 in	11
		10 to 11 in	20
		13 to 14 in	30
13.	*Pouring concrete behind casing pipes	13 to 14 in	30
		19 to 20 in	40
14.	*Pouring concrete and preparing the wellhead		300
15.	*Geophysical imaging	0 to 150 m	11
		500+ m	15
16.	*Development of wells by Air	0 to 150 m	80
		150 to 350 m	100
		350 to 500 m	135
		500+ m	195
17.	Cleaning well by testing pump/h		30
18.	*Test pump for 100 hours	150 to 350 m	5,792
		350 to 500 m	7,772
		500+ m	11,583
19.	*Supply and install a lead Backer thread for casing pipes	0 to 7 in	780
		10 to 11 in	1,160

No.	Description	Range	Cost (JD)
20.	Lifting casing pipes from wells /m run		30
21.	*Cleaning a cased well /m run	0 to 150 m	40
		150 to 350 m	50
		350 to 700 m	60
22.	Remove an obstacle from wells / L.S	0 to 150 m	1,930
		150 to 350 m	2,900
		350 to 700 m	3,900
23.	Cleaning uncased wells/m run		70
24.	Rescue dropped pump inside the well		1,940
25.	Cleaning wells with acid excluding the material cost	0 to 150 m	100
		150 to 350 m	1,900
		350 to 700 m	3,900
26.	*Supply and install pipe base screen/m run	0 to 7 in	425
		7 to 10 in	680
27.	Pumping cost and supply gravel pack		100
28.	Lifting casing pipes from wells/ m run		30
29.	*Supply and install casing pipes /m run	0 to 7 in	50
		10 to 11 in	90
		13 to 14 in	105
		14 to 19 in	110
		20+ in	115

ATTACHMENT 4

Sample Economic Impact Calculations

This attachment presents the calculations used to estimate the economic impacts of groundwater drawdown in 4 basins in Jordan. The calculations are organized into an Excel workbook wherein each row represents a well from the MWI well inventory and each column represents a characteristic of the well. Tables C1, C2, and C3 show results for 6 of the approximately 2,200 wells analyzed and represent the case of medium value crops using the most recent groundwater level trend in the nearest monitoring well. 3 wells (rows 996 – 998) are in the Azraq basin and 3 wells (rows 999 – 1001) are in the Dead Sea basin. Table B1 shows results for Columns A through Q, Table B2 for Columns W through AN, and Table B3 for columns AO through AU. Some columns have supplemental data and are hidden. A column listing explains how each column is calculated.

Column	Explanation
A	Well ID of target production well
B	Well ID of nearest Monitoring Well to target extraction well
C	Groundwater basin of the monitoring well
D	Governorate of the target production well
E	Distance of the production well from the capital city of the governorate (m)
F, G	Palestinian coordinates of the target production well (UTM)
H,I,J,K	Associated data for target pumping well from MWI well inventory
L,M	Associated data for monitoring well from MWI well inventory
N	Most recent depth to water measurement in monitoring well (provided by USGS)
O	Groundwater level trend in monitoring well across all monitoring observations (provided by USGS)
P	Most recent groundwater level trend in monitoring well (provided by USGS)
Q	Is 1 if the Trend2010 (Column P) is steeper than the average trend (Column O), 0 if not (provide by USGS)
W	Location of production and monitoring wells within the basin
X	Maximum bore diameter of production well as listed in the MWI well inventory
AC	Unit pumping cost for the farm category as shown in Attachment 2 (for wells in Azraq) or as calculated from energy cost and production volume data provided by MWI

AD	Water value for the farm category as shown in Attachment 2 (for wells in Azraq or Hamad) or provided by Karablieh (for wells in the Dead Sea or Yarmouk basins)
AE	Average water use for the farm category as shown in Attachment 2 (for wells in Azraq or Hamad) or provided by Karablieh (for wells in the Dead Sea or Yarmouk basins)
AF	Water depth to use. Is the extraction well water level (Column K) if a level is specified. Otherwise, this depth = H – (L – N)
AG	Well depth to use. Is either the screened depth (Column AB, not shown) or the well depth (Column J), whichever is shorter.
AI	Groundwater level trend to use. This column equals Column P if the most recent trend is used in the analysis. Otherwise, this colun equals Column O.
AJ	Forecast time to zero farm profit = AD / [(AC)(-AI)]
AK	Forecast time to well will go dry = (AG – AF)/(-AI)
AL	Forecast of water level when there will be zero farm profit = AF + (-AI)(AJ)
AM	Well diameter to use is the larger of the bore diameter (Column X) or casing Diameter (Column Z, not shown)
AN	Well retrofit cost. Is a function of the fixed and variable costs shown in Attachment 3 with variable costs calculated from the distance to the capital (Column E), the new well depth (Column AL), and well diameter (of the existing well; Column AM). The retrofit cost is only calculated if AK > AJ (forecast time to zero profit is longer than time to well bottom)
AO	Average farm size for the farm category as shown in Attachment 2 (for wells in Azraq or Hamad) or provided by Karablieh (for wells in the Dead Sea or Yarmouk basins)
AP	Well retrofit cost per donum = (AN)/(AO)
AQ	Annual profit for the farm category once the groundwater level drops to the bottom of the existing well = [AD – (AK)(AC)(-AI)](AE)
AR	Recoverable profit if deepen the well to the water depth where profit becomes zero = (0.5)(AQ)(AJ-AK)
AS	Shorter of the two forecast times = minimum(AJ, AK)
AT	Indicates the limiting factor.
AU	Indicates range in which the shortest forecast time (Column AS) falls. 1: less than 10 years 2: 10 to 30 years 3: greater than 30 years

Table C1. Input data and forecast calculations for 6 wells supplying medium value crops in the Azraq and Dead Sea basins

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Target Well	Monitoring Well	GW_Basin	GOVERNORATE	Distance From Capital (m)	PALESTINE _NORTH	PALESTINE _EAST	ALTITUDE	WELL_STATUS	WELL DEPTH (m)	WATER LEVEL (m)	MON_Altitude (m)	Mon_Well _Depth	DTW (m)	Trend (m/yr)	Trend2010 (m/yr)	Steeper
996	F 4293	F 3979	Azraq	AL MAFRAQ	46,226	1178350	306700	766	Used	560	284	558	100	53.31	-0.53	-0.53	0
997	F 4294	F 3979	Azraq	AL MAFRAQ	44,259	1186500	307450	900	Used	525	410	558	100	53.31	-0.53	-0.53	0
998	F 4295	F 3979	Azraq	AL MAFRAQ	51,394	1182373	313710	923	Used			558	100	53.31	-0.53	-0.53	0
999	AB124	CA3044	Dead Sea	AL BALQA	34,077	1132925	205990	-340	Unknown	33	6	-349	36	12.68	-0.3	-0.75	1
1000	AB132	CC1015	Dead Sea	MADABA	5,956	1131750	224500	800	Used	450	240	735	300	220.9	-0.65	-0.65	0
1001	AB316	CA1100	Dead Sea	AL BALQA	40,219	1125700	207000	-390	Used	80	6.78	-380	28	27.8	-0.07		

Table C2. Input data and forecast calculations for 6 wells supplying medium value crops in the Azraq and Dead Sea basins (cont).

	A	B	C	W	X	AC	AD	AE	AF	AG	AI	AJ	AK	AL	AM	AN
1	Target Well	Monitoring Well	GW_Basin	LOCATION	Max Bore Diameter (in)	Unit Water Cost (JD/m3/m)	Operational Surplus (JD/m3)	Water Use (m3/du/yr)	Water Depth to Use (m)	Well Depth to Use (m)	Trend to Use (m/yr)	Time to Zero Profit (yr)	Time to well bottom (yr)	Water Depth at 0 profit (m)	Well Diameter To Use (in)	Well Retrofit Cost (JD)
996	F 4293	F 3979	Azraq	Azraq		0.0026	0.3333	390	284.0	560.0	-0.53	244	520.8	413.1	20.0	
997	F 4294	F 3979	Azraq	Azraq		0.0026	0.3333	390	410.0	420.0	-0.53	244	18.9	539.1	10.8	153,492
998	F 4295	F 3979	Azraq	Azraq		0.0026	0.3333	390	418.3		-0.53	244		547.4	20.0	
999	AB124	CA3044	Dead Sea	Jordan	10	0.0150	0.2500	457	6.0	33.0	-0.75	22	36.0	22.7	10.0	
1000	AB132	CC1015	Dead Sea	Highland		0.0007	0.2500	391	240.0	450.0	-0.65	580	323.1	616.7	10.0	172,914
1001	AB316	CA1100	Dead Sea	Jordan		0.0150	0.2500	457	6.8	80.0	-0.07	239	1046.0	23.5	20.3	

Table C3. Input data and forecast calculations for 6 wells supplying medium value crops in the Azraq and Dead Sea basins (cont).

	A	B	C	AO	AP	AQ	AR	AS	AT	AU
1	Target Well	Monitoring Well	GW_Basin	Avg. Farm Area (du)	Well Retrofit Cost (JD/du)	Profit At Well Bottom (JD/du/yr)	Recoverable Profit if Deepen (JD/du)	Time (yrs)	Limiting Factor	Year Clas
996	F 4293	F 3979	Azraq	240				243.5	Zero Profit	3
997	F 4294	F 3979	Azraq	240	640	120	13,470	18.9	Well Bottom (then retrofit)	2
998	F 4295	F 3979	Azraq	240						
999	AB124	CA3044	Dead Sea	33				22.3	Zero Profit	2
1000	AB132	CC1015	Dead Sea	50	3,458	43	5,546	323.1	Well Bottom (then retrofit)	3
1001	AB316	CA1100	Dead Sea	33				238.7	Zero Profit	3

ATTACHMENT 5

Assessment of Data Available to Estimate Task 2 Impacts

This attachment assesses the data collected and available to estimate increased pumping costs due to dynamic pumping lifts (within cones of depression) at pumping wells, increased pumping costs from estimated individual pumping well drawdown for target pumping wells based upon future water levels predicted via simulation model, and costs to treat or cope with saline water based upon projected concentrations. In addition to well inventory, monitoring well trend, farm activity, groundwater pumping costs, and well retrofit cost data collected for Task 1, USU possesses an inventory of the aquifer layers in which each well in the well inventory is located. Using this data, USU can develop more formal pairings between production and monitoring wells and estimate dynamic pumping lifts (cones of depression) and the associated increased pumping costs. USU will need the following data items to estimate (i) increased pumping costs based upon future water levels predicted via a simulation model and (ii) costs to treat or cope with saline water based on projected concentrations:

A. Pump tests and drilling logs of target coupled pumping and monitoring wells (to obtain aquifer parameter information for cone of depression determination).
B. The type (confined, semiconfined unconfined) of the aquifer tapped by target production and monitoring wells (possibly estimable from pumping test data).
C. Well and pump system efficiencies (expectedly obtainable from BGR or GIZ).
D. Basin geology reports (expectedly obtainable from BGR or GIZ).
E. Basin groundwater simulation model reports and head projections (expectedly obtainable from BGR or GIZ).
F. Water quality of pumped groundwater and treated wastewater used for irrigation (developed by Ministry of Environment)

ATTACHMENT 6

Forecasts Using Overall Groundwater Level Trends in Monitoring Wells

This attachment presents additional forecasts that instead use overall groundwater level trends (Column O in Attachment 4) rather than the most recent trends (Column P in Attachment 4) shown in the main report. The USGS developed the overall trends using all available observations over the observation period for a monitoring well. Overall trends sometimes differ from the most recent trends which use only the most recent observations (Table D). Forecasts using the overall groundwater level trend also provide a sensitivity analysis and show how the rate of groundwater level decline affects forecast results. Resulting forecasts that use the overall groundwater level trend for low (Figure A), medium (Figure B), and high (Figure C) value crops are nearly identical to forecasts that use the most recent trend (Figures 2, 3, and 4). For a few wells, the overall trend delays the onset of a forecasted impact to a later time range.

Table D. Recent and Overall Trends for Monitoring Wells (provided by USGS)

Basin	Well	Observation Period (yr)	Nearby Production Wells	Recent Trend (m/yr)	Overall Trend (m/yr)
Azraq	F 1002	8	2	-0.50	-0.41
Azraq	F 1014	15	31	-0.79	-0.79
Azraq	F 1022	27	60	-0.80	-0.60
Azraq	F 1043	26	19	-0.42	-0.78
Azraq	F 1060	26	50	-0.79	-0.79
Azraq	F 1126	15	4	-0.53	-0.41
Azraq	F 1145	12	2	-0.76	-0.76
Azraq	F 1280	27	19	-0.90	-0.69
Azraq	F 1286	14	20	-0.14	-0.11
Azraq	F 1334	15	10	-0.66	-0.74
Azraq	F 3755	13	29	-2.30	-3.10
Azraq	F 3979	16	84	-0.53	-0.53
Azraq	F 4120	9	4	-1.00	-0.95
Azraq	F 4233	4	16	-0.43	-0.43
Dead Sea	CA1006	16	14	-0.75	-0.07
Dead Sea	CA1011	21	9	0.26	-0.09
Dead Sea	CA1038	26	11	-0.82	-0.32
Dead Sea	CA1095	13	13	0.00	0.00
Dead Sea	CA1100	18	1		-0.07
Dead Sea	CA3044	11	4	-0.75	-0.30
Dead Sea	CC1015	10	21	-0.65	-0.65
Dead Sea	CD1010	13	15	-9.00	-1.30
Dead Sea	CD1021	6	12	0.00	0.00
Dead Sea	CD1075	28	118	-1.90	-1.90
Dead Sea	CD1097	27	11	0.20	0.20
Dead Sea	CD1106	27	12	-1.40	-1.40
Dead Sea	CD1126	7	8	-0.22	-0.22
Dead Sea	CD1132	27	3	-1.00	-1.00
Dead Sea	CD1136	22	27	0.00	-1.90
Dead Sea	CD1137	22	12	-0.07	-0.07
Dead Sea	CD1152	26	55	-0.37	-0.17
Dead Sea	CD1174	22	19	-1.00	-1.00
Dead Sea	CD1182	25	5	-0.15	-0.15
Dead Sea	CD1197	25	54	-2.80	-2.80
Dead Sea	CD1212	24	60	-1.50	-1.40
Dead Sea	CD1213	24	17	0.00	0.00
Dead Sea	CD1214	33	25	0.00	0.00
Dead Sea	CD3125	13	23	0.00	0.00
Dead Sea	CD3133	18	17	0.00	0.00
Dead Sea	CD3307	7	14	0.00	0.00
Dead Sea	CD3340	11	95	-1.30	-0.69
Dead Sea	CD3469	8	13	-0.22	-0.22
Dead Sea	CF1074	25	1	-0.18	-0.18
Dead Sea	CF1078	37	13		-0.65

Basin	Well	Observation Period (yr)	Nearby Production Wells	Recent Trend (m/yr)	Overall Trend (m/yr)
Hamad	H 1012	10	15		-1.29
Hamad	H 2006	12	2		0.00
Hamad	H 2007	4	19	-0.14	-0.14
Hamad	H 2017	41	10	-0.21	0.11
Hamad	H 3015	18	0	0.00	0.00
Yarmouk	AD1120	14	11	-2.20	-2.20
Yarmouk	AD1148	38	7	-0.68	-0.53
Yarmouk	AD1149	38	26	-3.70	-1.59
Yarmouk	AD1150	38	25	-1.80	-1.40
Yarmouk	AD1233	21	5	0.00	0.00
Yarmouk	AD1277	20	2		-0.22
Yarmouk	AD1301	9	33	-0.58	-0.58
Yarmouk	AD3014	14	11	-0.96	-0.96
Yarmouk	AD3027	14	11	0.25	0.25
Yarmouk	AD3028	9	11	0.00	0.00
Yarmouk	AD3029	15	20	0.00	0.00
Yarmouk	AD3030	11	73	-2.00	-2.00
Yarmouk	AD3031	9	68		-2.50

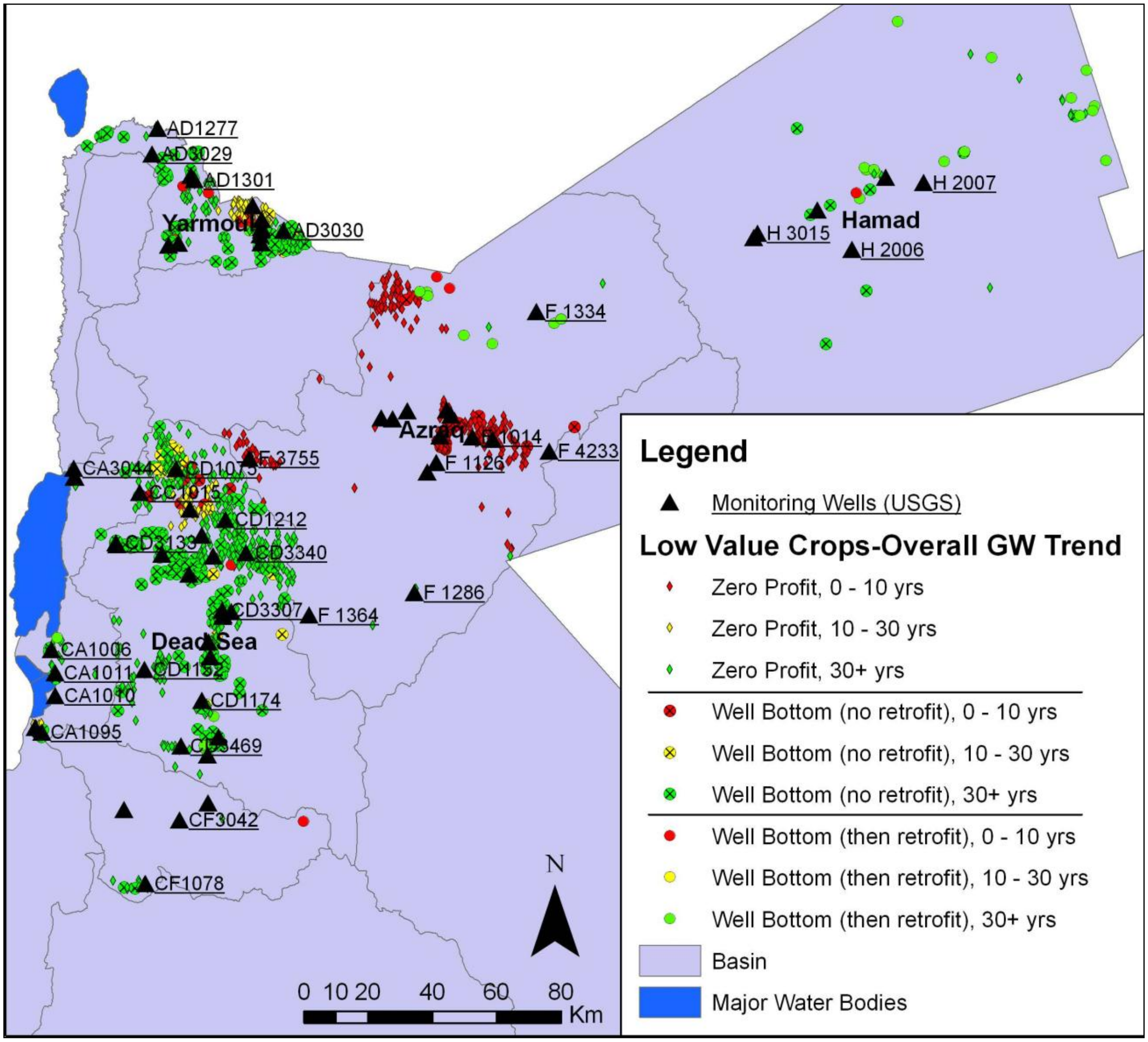

Figure A. Forecasted number of years wells will remain viable to supply water to low value crops (return < 0.25 JD/m3) in the Azraq, Dead Sea, Hamad, and Yarmouk basins. Diamond markers indicate farm profit will drop to zero (additional energy extraction costs exceed current profit) before the well goes dry. Circle markers with an X indicate the well will first go dry while unfilled circles indicate it will likely be profitable to retrofit and deepen the well. Forecasts use the overall groundwater level trend in the nearest monitoring well.

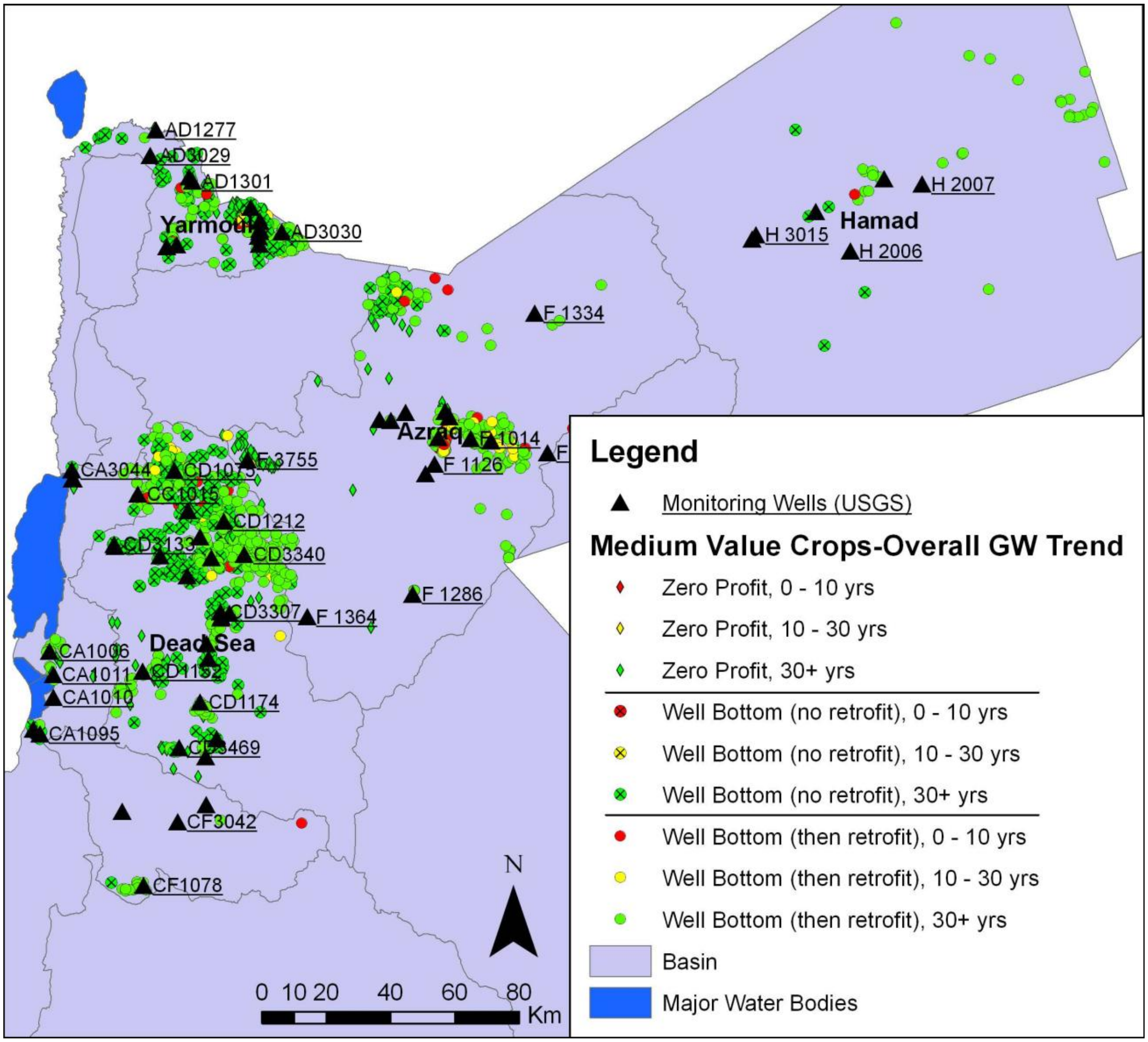

Figure B. Forecasted number of years wells will remain viable to supply water to medium value crops (return between 0.25 and 1.5 JD/m^3) in the Azraq, Dead Sea, Hamad, and Yarmouk basins. Diamond markers indicate farm profit will drop to zero (additional energy extraction costs exceed current profit) before the well goes dry. Circle markers with an X indicate the well will first go dry while unfilled circles indicate it will likely be profitable to retrofit and deepen the well. Forecasts use the overall groundwater level trend in the nearest monitoring well.

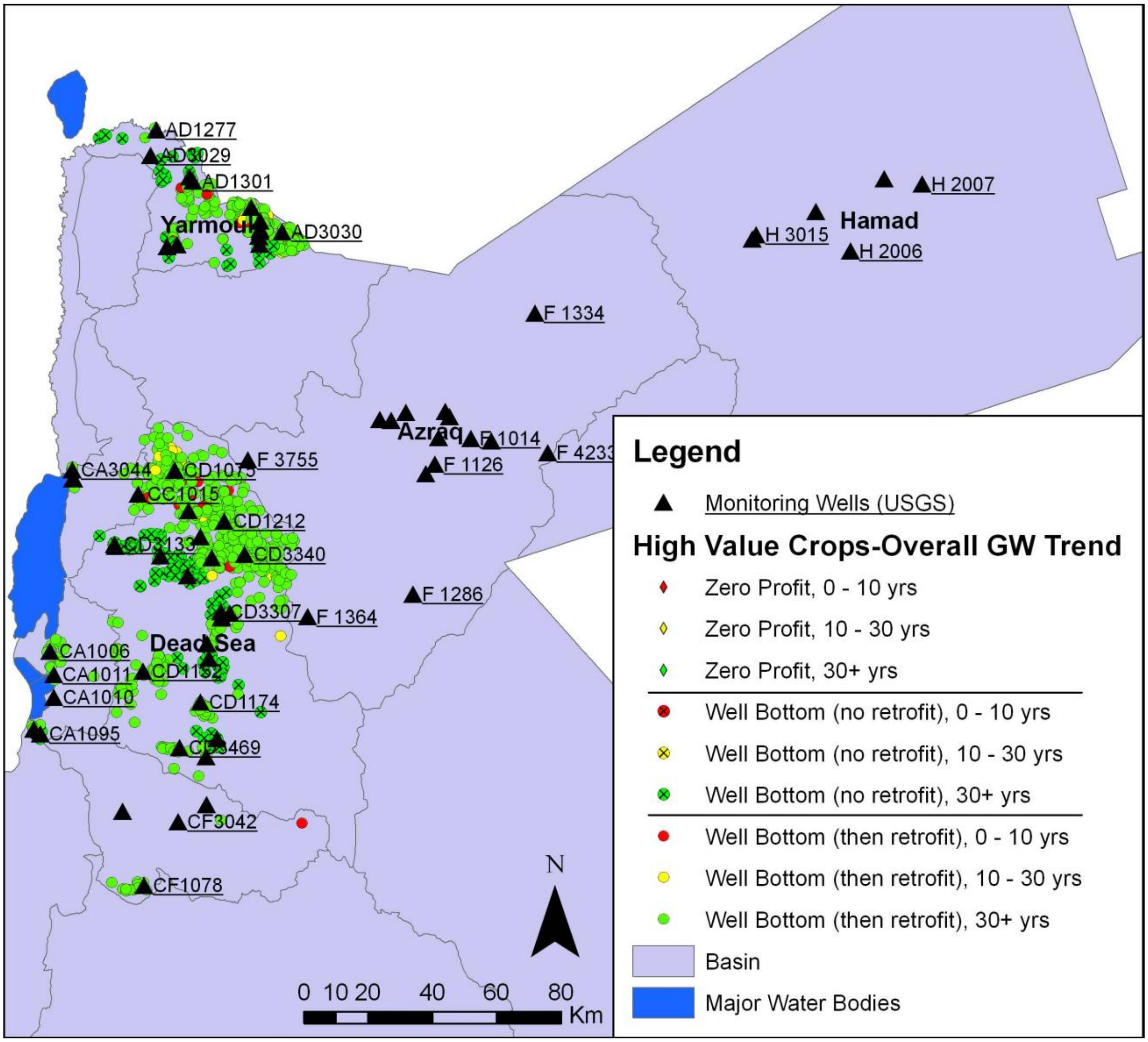

Figure C. Forecasted number of years wells will remain viable to supply water to cultivate high value crops (return > 1.5 JD/m³) in the Dead Sea and Yarmouk basins. Diamond markers indicate farm profit will drop to zero (additional energy extraction costs exceed current profit) before the well goes dry. Circle markers with an X indicate the well will first go dry while unfilled circles indicate it will likely be profitable to retrofit and deepen the well. Forecasts use the overall groundwater level trend in the nearest monitoring well.

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