Economic Impacts of Groundwater Drawdown in Jordan

Draft Report

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1. Introduction

Groundwater resources in Jordan are being depleted 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 State 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 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 resource management.

Here we present research methods developed and results 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.

Two project tasks:

1) Estimate economic impacts a) and b) and assess their relative contribution to the overall impact using readily available data, and
2) 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 available, and recommended next steps. The report is part of work completed by Utah State University (USU) from July – December, 2011 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

As part of Task 1 to identify and forecast impacts of groundwater drawdown on increased pumping and well retrofit costs:

1. Dr. Peralta traveled to Jordan from July 20 to August 02, 2011 to identify data needs, make contacts with, and collect and assemble readily-available data from the Water Authority of Jordan (WAJ), Ministry of Environment, MWI, and technical experts. Experts included U.S. Geological Survey (USGS) staff who were in Jordan to identify 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 Jordan Valley and Highland areas as part of the ISSP. A trip memorandum sent to ISSP on August 9 outlines trip activities and outcomes (Peralta, pers. comm., 2011). Dr. Peralta collected and assembled nearly all and some, respectively, of the data needed for Tasks 1 and 2. At the trip end, the one missing data item to complete Task 1 was groundwater pumping costs which MWI/ISSP provided USU later 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) and groundwater level trend (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) 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)

2. Dr. Rosenberg used the MWI well inventory and paired each production well with the nearest monitoring well analyzed by the USGS. The USGS provided an average annual groundwater level trend (m per year) over the monitoring period for each monitoring well analyzed. The monitoring wells comprised a subset of the MWI well inventory.

3. Dr. Rosenberg used crop, water use, and profitability data from agricultural inventories (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 are 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 Jordan Valley 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.

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

Basin	Subarea	High Value (> 1.5 JD/m^3)			Medium Value (0.25 to 1.5 JD/m^3)			Low Value (< 0.25 JD/m^3)		
		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	Jordan Valley	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%

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.

4. Dr. Rosenberg then calculated a unit pumping cost (JD per m^3 per m lifted) for each well in the basin. This method differed slightly by basin based on the available data.

    a. In Azraq, Dr. Rosenberg calculated the unit pumping cost for each farm type 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). 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.

    b. 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. Dr. Rosenberg identified the depth to water (m) in each well from the MWI well inventory and divided the annual pumping cost by the annual production volume and depth to water to obtain the unit pumping cost. For each other pumping well in the basin, Dr. Rosenberg calculated a unit pumping cost as the average of unit pumping costs from the closet sample wells.

    In both cases the unit pumping cost represents actual farmer costs which reflect whatever government provided energy subsidies are in place for diesel (Azraq farmers only) or electricity (all basins).

5. Dr. Rosenberg then forecasted the number of years it will take the crop category to become unprofitable (zero profit). This forecast only considers additional pumping lift costs from groundwater drawdown and was made by dividing farm profitability (from Step 3) by the unit 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.

6. Dr. Rosenberg also forecasted the number of years it will take for the production 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, Dr. Rosenberg assumed the groundwater level was the same as the most recent reading (Summer 2011) in the nearest monitoring well. Note the forecasted number of years until a well becomes dry is conservative for two reasons. First, for steady pumping, the rate of groundwater level decline will increase as the saturated thickness decreases. And second, when the static groundwater level approaches the well bottom, an irrigator may cutback pumping or the well may produce less (or possibly no) water.

7. Next, Dr. Rosenberg compared the two forecast times (Step 5 and Step 6).

a. When reaching a lower water level and zero profit (Step 5) before the well went dry (Step 6), the analysis stopped and profitability was recorded as the limiting factor. 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, Dr. Rosenberg 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. 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 it 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 limiting factor. In this case, it would be uneconomical to retrofit the well once it went dry.

    ii. If remaining profit exceeded per donum retrofit costs, Dr. Rosenberg noted the new lower well bottom as the limiting factor. In this case, retrofitting and deepening the well could be profitable.

8. Dr. Rosenberg reported the shorter of the two forecast times (minimum of Step 5 and Step 6) and the limiting factor (Step 7) for the well.

9. Dr. Rosenberg repeated steps 2 – 8 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 also repeated the analysis for each of the three crop value categories and used monitoring well, crop, pumping cost, and well retrofit data specific to the basin, subarea, and crop category.

Attachment 4 shows example input data and forecast calculations for Steps 1 – 9. The example shows results for 6 wells and low value crops in the Azraq and Yarmouk basins.

For the Task 2 assessment of data available to estimate additional economic impacts of groundwater drawdown, Attachment 5 shows 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). However, we still require a much more expansive set of groundwater modeling input files and data to simulate future groundwater levels or project salinity concentrations.

3. Results

Forecasts of the times to zero farm profits and wells going dry show additional pumping costs from expected groundwater drawdown will soon make it unprofitable to use 80% of wells in the Azraq basin to cultivate low value crops like small, family owned olive farms (Figure 1). 79% of wells will become unviable for small olive farming within the next 10 years. And it will 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.

In the Hamad basin, the economic effects of groundwater drawdown on low value crops like olives and open field vegetables (tomato, melon, watermelon, lettuce, cabbage, cauliflower) are much less severe. Nearly all wells can continue operating over the next 30 years. Only then will the wells either (i) reach the water level where it no longer becomes economical to pump or (ii) the wells goes dry. The time delay compared to in Azraq is because groundwater pumping costs are lower in the Hamad basin (more pumps run by electricity).Given the time delay, there is less need to consider pump retrofits at present.

Many wells in the Dead Sea and Yarmouk basins used to cultivate low value crops like olives, grapes, peaches, dates, pears, etc. will either only go dry or see the water level fall below the break-even level after 30 years. However, zones encompassing the capital Amman and north of Mafraq will impact low value crops in the next 10 to 20 years and possibly sooner. The Amman and Mafraq zones comprise, respectively, 14% and 33% of the wells analyzed in the Dead Sea and Yarmouk basins. And within these zones, most wells will face zero profits before the well goes dry which will make it uneconomical to retrofit the well.

In contrast, forecast times are generally larger for medium value crops grown in all the basins (Figure 2). In Azraq, 13% of wells supplying olives intercropped with fruit trees will go dry within 10 years and 24% within 30 years. However, it appears to be economical for these well owners to retrofit and deepen their wells. In the Hamad basin, forecasts suggest few limitations over the coming 30 years and are the same as for wells supplying low value olives and open field crops. In the Dead Sea basin, 1% and 5% of wells will go dry within 10 and 30 years (these wells are all located within the Amman zone), but it will be financially worthwhile to retrofit and deepen these wells if they are used to cultivate medium value crops like tomatoes, clover, apples, potato, apricots, cauliflower, squash, water melon, lettuce, sweet melon, etc.. In the Yarmouk Basin, approximately 10% of wells will go dry within the next 10 to 30 years (again in the Mafraq zone) and it will be profitable to retrofit and deepen many of these wells if they are used to cultivate the same medium value crops grown 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 differences that limitations will occur further into the future and it will likely be economical to retrofit and deepen a larger percent of wells that go dry (Figure 3). Note, no wells are shown for the Azraq or Hamad basins because high value crops are not cultivated in those regions.

4. Discussion

The forecast results for the Azraq, Dead Sea, Hamad, and Yarmouk basins identify three important economic impacts from groundwater drawdown and provide an entry point for

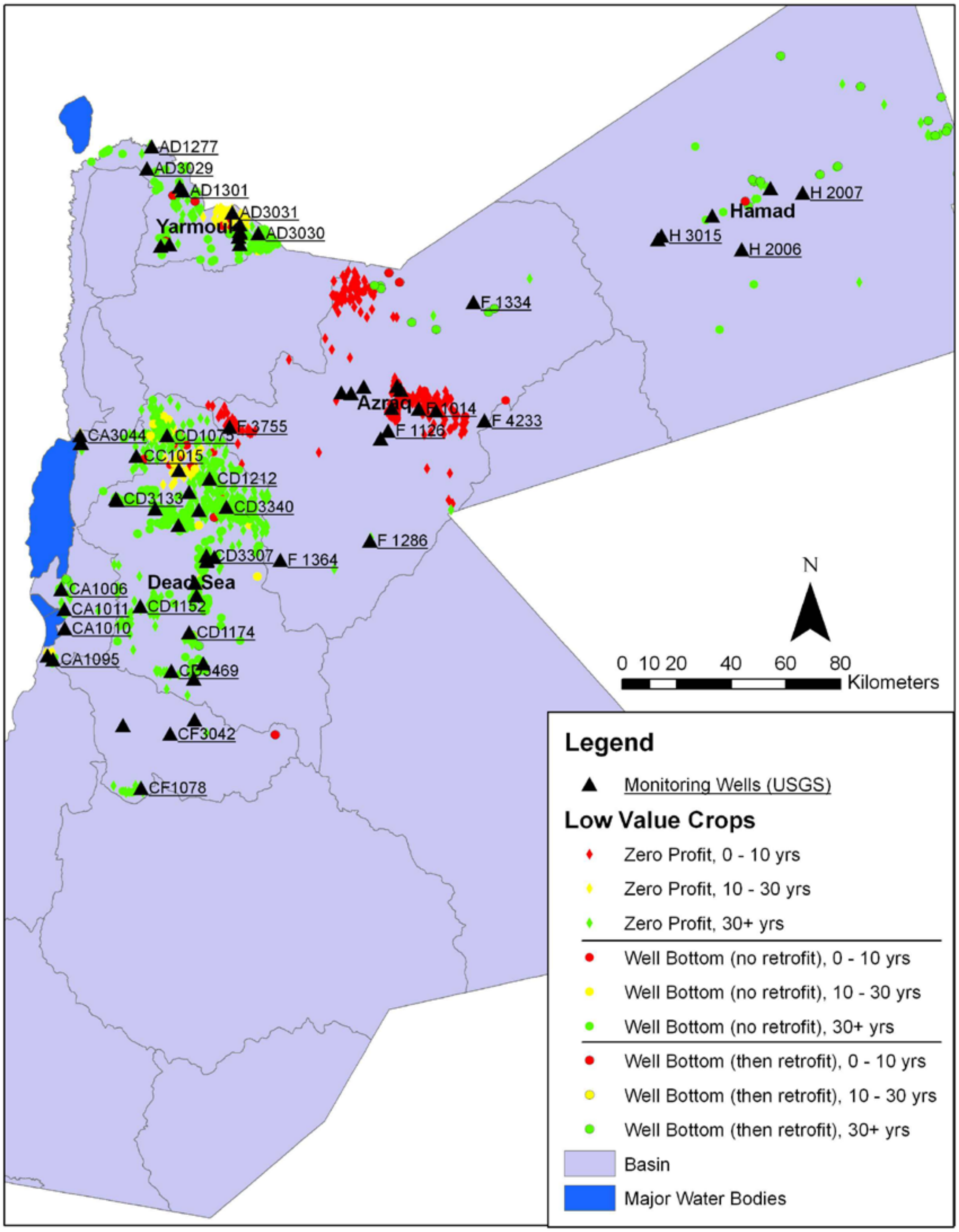

Figure 1. Forecasted number of years wells will remain viable to supply water to cultivate low value crops (return < 0.25 JD/m^3) in the Azraq, Dead Sea, Hamad, and Yarmouk basins. Diamond markers indicate farm profit will drop to zero (additional energy extraction costs exceed current profit) before the well goes dry. Circle markers indicate the well will first go dry. Circles with a black border indicate it will likely be profitable to retrofit and deepen the well after it goes dry.

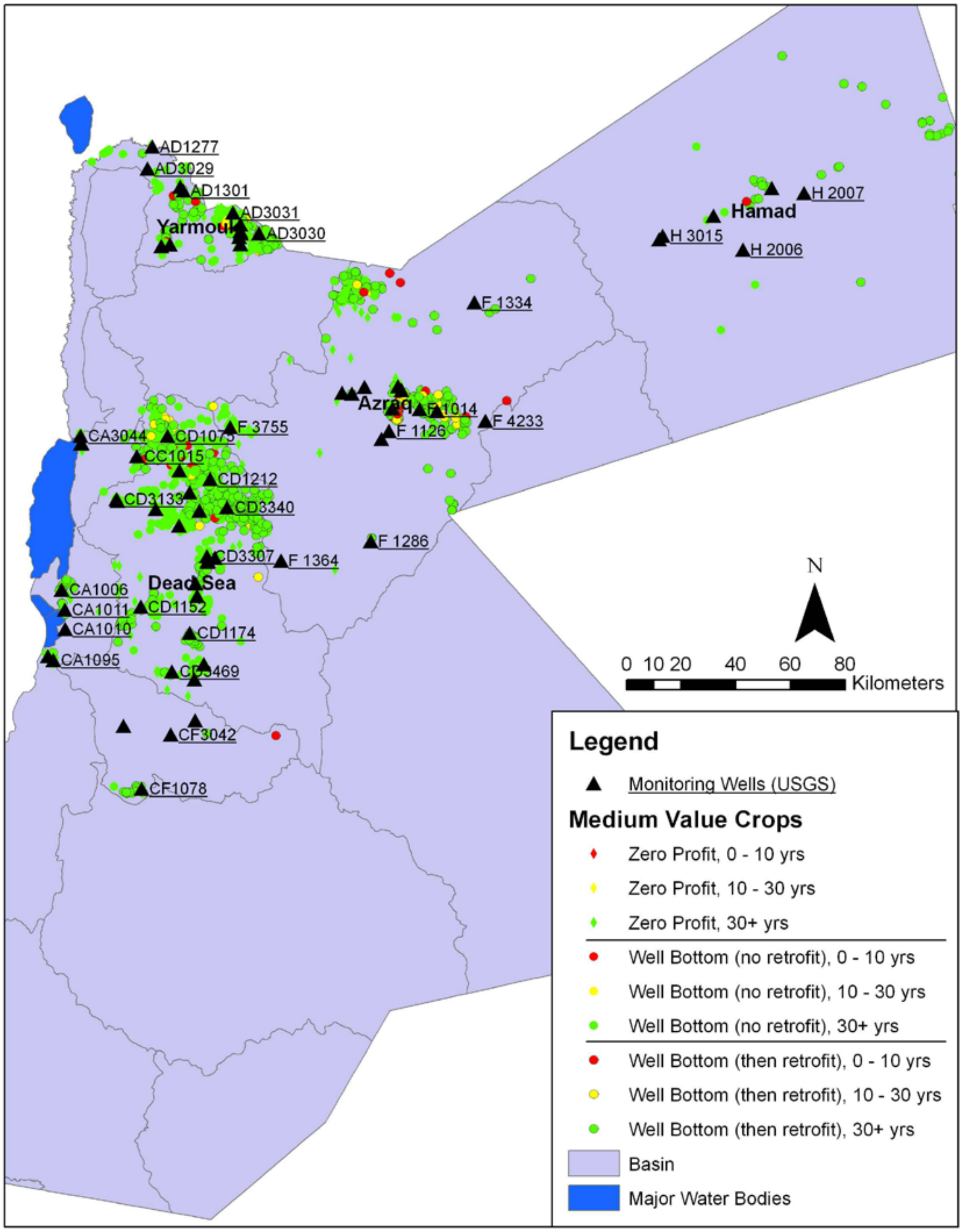

Figure 2. Forecasted number of years wells will remain viable to supply water to cultivate medium value crops (return between 0.25 and 1.5 JD/m^3) in the Azraq, Dead Sea, Hamad, and Yarmouk basins. Diamond markers indicate farm profit will drop to zero (additional energy extraction costs exceed current profit) before the well goes dry. Circle markers indicate the well will first go dry. Circles with a black border indicate it will likely be profitable to retrofit and deepen the well after it goes dry.

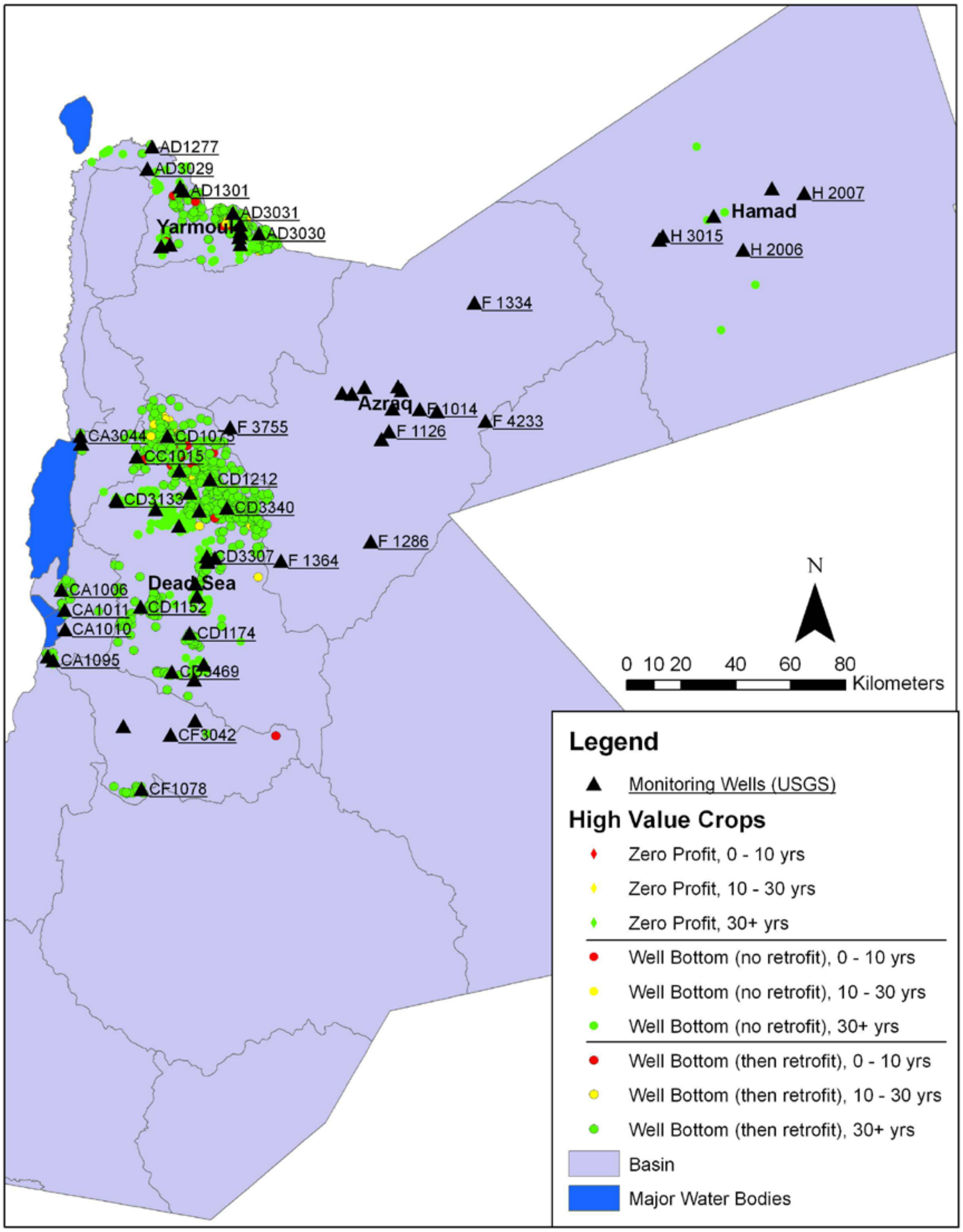

Figure 3. Forecasted number of years wells will remain viable to supply water to cultivate high value crops (return > 1.5 JD/m^3) in the Dead Sea and Yarmouk basins. Diamond markers indicate farm profit will drop to zero (additional energy extraction costs exceed current profit) before the well goes dry. Circle markers indicate the well will first go dry. Circles with a black border indicate it will likely be profitable to retrofit and deepen the well after it goes dry.

understanding how drawdown is affecting the northern part of Jordan. First, impacts are imminent and most severe in Azraq for farmers growing low value crops like olives and olives intercropped with alfalfa. Existing profit margins are extremely low, groundwater is falling at a very fast rate, and the additional pumping costs to withdraw water from a lower depth will surpass crop profits within the next 10 years. It will be uneconomical to retrofit or drill new, deeper wells to continue cultivating these crops. The crops now comprise 75% of the planted area in Azraq and use 90% of the water (some 17.5 MCM/year). These impacts may foretell a widespread abandonment of agriculture (and possible reduction of water abstraction) and/or transition to higher value crops.

Second, zones of impacts in highland areas surrounding Amman and north of Mafraq in the Dead Sea and Yarmouk basins are also emerging for wells supplying low value highland crops like olives, grapes, peaches, others, dates, pears, sorghum, plums, prunes, lemons, okra, etc. Like in Azraq, 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 until impacts are slightly longer than in Azraq because groundwater levels are falling at slower rates. However, 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 64% of the planted area and water use in highland areas and suggest targeted transitions to higher value crops may soon be warranted.

Third, impacts in all basins are much smaller and 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.). And when wells supplying these crops do go dry, it is generally economical to retrofit and drill a new, deeper well.

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 historical decline rates. Uncertainties should be. Forecasts also assume that future pumping, unit 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. 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 can make forecasts conservative and we may observe significantly 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 3 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 so economic impacts will be seen more quickly than when considering the monitoring wells alone.

Table 3. 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

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 1,200 considered to date). 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 acquired to date.

5. Recommendations

Based on the results and analysis, USU recommends:

- Take immediate action to help Azraq farmers growing low-value crops like olives to either transition to higher-value crops or leave agriculture all-together.
- Raise awareness among farmers growing low value crops in the Dead Sea and Yarmouk basins that they will likely face problems in about 10 years time. Encourage these farmers to transition to higher value crops and/or deepen their wells as the wells go dry.
- Identify additional impacts associated with dynamic drawdown (cones of depression). Task 1 identified economic impacts associated with changes in the static groundwater level. Dynamic drawdown is the distance the static water level declines at a well that is pumping. Dynamic drawdown is greater (sometimes much greater) than static drawdown. We recommend considering the economic impacts of dynamic drawdown by:
    - selecting a target pair of production and nearby monitoring wells, that are both screened solely in the same aquifer stratum.
    - estimating dynamic drawdown at the target production well by applying the analytical equation appropriate for the aquifer stratum, and well-specific design and pumping information.

- estimating dynamic lift by summing 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.

- Inventory the agricultural activities associated with production wells to show how crop activities are spatially distributed, locations where impacts will be concentrated, and improve forecast accuracy for individual production wells.

6. Outstanding Actions

We intend to complete three additional actions while revising this draft report and before submitting the final project report.

a. Acquire ArcGIS layer files (*.lyr) the USGS used to annotate monitoring well, DEM, stream course, extraction well, and other data to consistently present results across maps that show groundwater level trends and economic impacts.

b. If available, substitute more recent groundwater level data for extraction wells.

c. Incorporate feedback from IRG, USAID, and USAID personnel.

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Attachment 1
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:

10. Increased pumping costs from groundwater level drawdown.

11. Pump and well retrofit costs from groundwater level drawdown.

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

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

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

Project tasks are to:

3) Estimate economic impacts a) and b) and assess their relative contribution to the overall impact using readily available data,
4) 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. Unit 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)	Unit 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 shows results for 6 of the approximately 2,200 wells analyzed. 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 R, Table B2 for Columns W through AN, and Table B3 for columns AN through AT. 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)
R	Percent of well depth that will still be saturated in 2030 (provided 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	Forecast time to zero farm profit = AD / [(AC)(-O)]
AJ	Forecast time to well will go dry = (AG – AF)/(-O)
AK	Forecast of water level when there will be zero farm profit = AF + (-O)(AI)
AL	Well diameter to use is the larger of the bore diameter (Column X) or casing Diameter (Column Z, not shown)
AM	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 AK), and well diameter (of the existing well; Column AL). The retrofit cost is only calculated if AJ > AI (forecast time to zero profit is longer than time to well bottom)
AN	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)
AO	Well retrofit cost per donum = (AM)/(AN)
AP	Annual profit for the farm category once the groundwater level drops to the bottom of the existing well = [AD – (AJ)(AC)(-O)](AE)
AQ	Recoverable profit if deepen the well to the water depth where profit becomes zero = (0.5)(AP)(AI-AJ)
AR	Shorter of the two forecast times = minimum(U, V)
AS	Indicates the limiting factor.

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	R
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	SatThick2030
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	0.136
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	0.136
998	F 4295	F 3979	Azraq	AL MAFRAQ	51,394	1182373	313710	923	Used			558	100	53.31	-0.53	-0.53	0	0.136
999	AB124	CA3044	Dead Sea	AL BALQA	34,077	1132925	205990	-340	Unknown	33	6	-349	36	12.68	-0.3	-0.75	1	80
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)	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)	Avg. Farm Area (du)
996	F 4293	F 3979	Azraq	Azraq		0.0026	0.3333	390	261.3	560.0	244	563.6	390.4	20.0		240
997	F 4294	F 3979	Azraq	Azraq		0.0026	0.3333	390	395.3	420.0	244	46.6	524.4	10.8	47,302	240
998	F 4295	F 3979	Azraq	Azraq		0.0026	0.3333	390	418.3		244		547.4	20.0		240
999	AB124	CA3044	Dead Sea	Jordan	10	0.0150	0.2500	457	21.7	33.0	56	37.7	38.4	10.0	21,647	33
1000	AB132	CC1015	Dead Sea	Highland		0.0007	0.2500	391	285.9	450.0	580	252.5	662.6	10.0	184,389	50
1001	AB316	CA1100	Dead Sea	Jordan		0.0150	0.2500	457	17.8	80.0	239	888.6	34.5	20.3		33

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	AN	AO	AP	AQ	AR	AS	AT
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	197	105	10,351	46.6	Well Bottom (then retrofit)	3
998	F 4295	F 3979	Azraq	240						
999	AB124	CA3044	Dead Sea	33	656	37	330	37.7	Well Bottom (no retrofit)	3
1000	AB132	CC1015	Dead Sea	50	3,688	55	9,020	252.5	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 basins (expectedly obtainable from BGR or GIZ).
E. Basin groundwater simulation model reports and head projections basins (expectedly obtainable from BGR or GIZ).
F. Water quality of pumped groundwater and treated wastewater used for irrigation (developed by Ministry of Environment)

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