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SOLAR-POWERED DESALINATION OF BRACKISH WATER WITH NANOFILTRATION MEMBRANES FOR INTENSIVE AGRICULTURAL USE IN JORDAN, THE PALESTINIAN AUTHORITY AND ISRAEL(*AGRISOL*)

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Section I: Technical Progress

I. A)Research Objectives

Agriculture is a major source of livelihood for many rural communities in the Middle East, despite the severe lack of freshwater that affects the region. Brackish groundwater aquifers are often exploited as sources of irrigation water, but the practice is highly unsustainable, as large volumes of water are needed to leach the salts from the soil.

The AGRISOL project aims at advancing more sustainable, high-technology farming practices by developing a solar-powered desalination technology and by experimentally testing its potential to (1) reduce the current rates of groundwater abstraction, (2) increase current agricultural yields, and (3) enhance farmers' overall wellbeing by enlarging their currently available portfolio to cash crops with low salinity tolerance. Moreover, the project's advances the diffusion of renewable energy production technologies. If the project is successful, a positive feedback is expected in the medium and long term both on developing measures for climate change adaptation and on combating desertification, particularly for desert agriculture in salinization-prone, degrading, and remote areas with no access to electricity.

Our proposed approach involves developing and testing a new generation of solar-powered, low-pressure membrane desalination plants. The plants are fitted with recently developed nanofiltration membranes that operate at low pressure, improving the affordability of desalination in agriculture and compensating for the drawbacks of irrigation with reverse osmosis desalinated water. Two pilot plants will be designed and installed, one in Israel and one in Jordan, and agronomic experiments with different crops will be conducted to determine the technical and economical viabilities of the new technology.

The overriding technical objective of the AGRISOL project is to design, develop and test a cost-effective desalination system for application at farm-scale to the production of irrigation water and high value crops in semi-arid environments. To achieve this objective, we will build upon the results of two previous research projects (the CSPD-COMISJO and OASIS projects), in which some of the partner institutions collaborated on the theoretical calculations and modeling of solar desalination and the construction and testing of a first-generation solar desalination prototype unit located in the agricultural experimental station of Hatseva, Israel.

The overall goalwill be subdivided into the following specific tasks:

1) To optimize the design of solar NF desalination to achieve energy efficient and low maintenance units producing permeate water of suitable composition for crop irrigation;
2) To construct two solar-powered NF pilot desalination units with the optimized design, one in Israel and one in Jordan;

3) To evaluate the technical and economical sustainability of the two units for the cultivation of (at least) two different types of high-value crops over two seasons;
4) To disseminate the findings of the project to the farming communities in the Arava region of Jordan, The Palestinian Authority and Israel and the scientific community.

I. B) Research Accomplishments

a) The kickoff meeting:

The kick-off meeting was held at the Movenpick Hotel, Aqaba, Jordan, on December 2, 2014. It was organized by the kind help of Dr. Sireen Naoum (NCARE). The researchers were Dr. Rami Messalem of Ben Gurion University of the Negev (BGU), Dr. Sireen Naoum,Dr. Firas Alawneh and Eng. Mai Diab of NCARE and ARO Scientists as a side meeting between NCARE, Dr. Andrea Ghermandi of University of Haifa and Dr. Hurwitz Boaz, Dr. Rivka Offenbach and Dr. Ephraim Trepler of Arava Research and Development.

Theresearchers presented their respective institutions, and then moved to discuss the activities of the project, in relation to their respective work packages. They review and discuss the optimal design for the two pilot solar desalination plants, timetable of construction, installation and commissioning of the Jordanian pilot desalination plant,planning and setup of the agronomic experiments, crops and management.

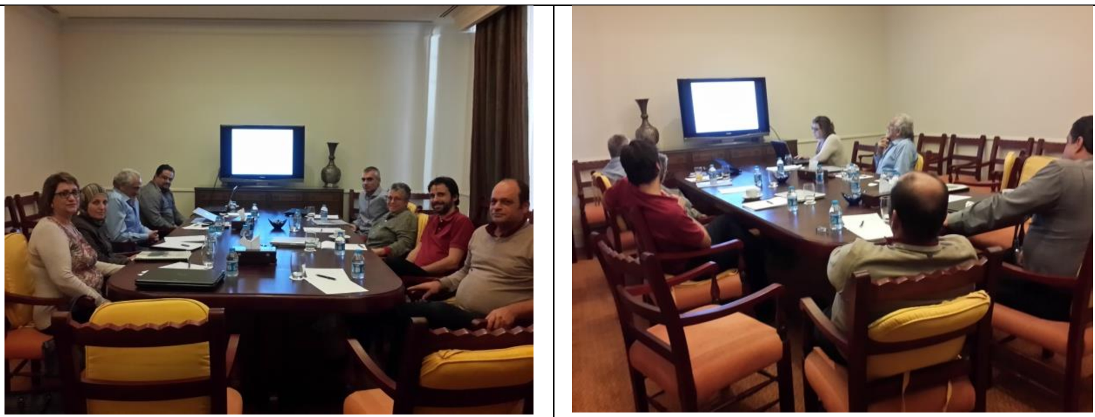


Fig.1: AGRISOL kickoff meeting at the Movenpick Hotel, Aqaba, Jordan

b) The Jordan pilot plan

The Jordanian pilot plant will be located at NCARE's Karama agricultural station (31°57.173'N, 35°34.65'E). This is an ideal site where to conduct the agronomic experiments in Jordan since the agricultural station disposes at this site of 10 ha of agricultural land, which is currently used for research projects in water and saline soil management and saline resistance of cultivars and varieties. The local soil is typical for the area, with a high sand content. Karama is located in the Jordan Valley, which comprises the most agricultural zone in

Jordan and where intensive and high-input production methods (mainly intensive vegetable production with high inputs related to irrigation, fertilization, and crop protection) are having a strong negative impact on the sustainability of natural resources. The strong connection established between the agricultural research station and the local community will facilitate the dissemination of the results of the project to the local farmers. Table 1 shows the concentration of the main ions in the local brackish water in Karama and Hatseva. In both locations, the water is extracted from a deep aquifer (400-500 m below ground level).Tables 1and 2 show soil and water analyses:

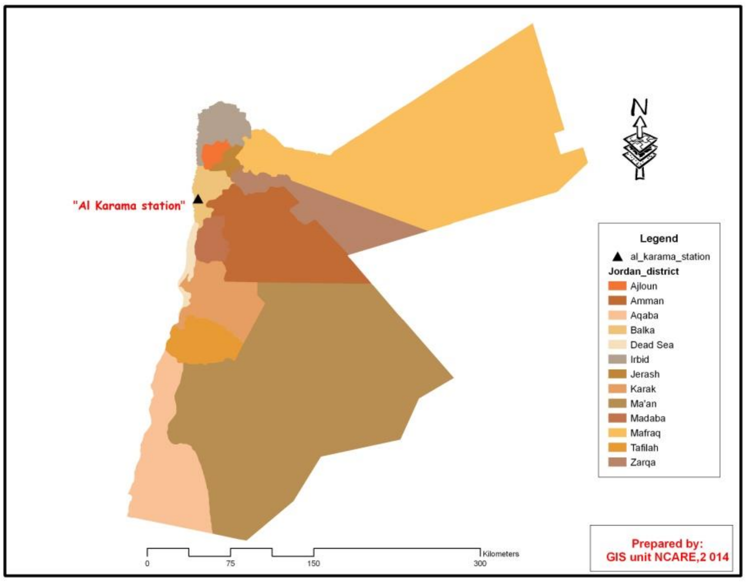


Fig.2. Location of Al Karama Station, Jordan

Table .1:Soil Analysis /Alkarameh 2013

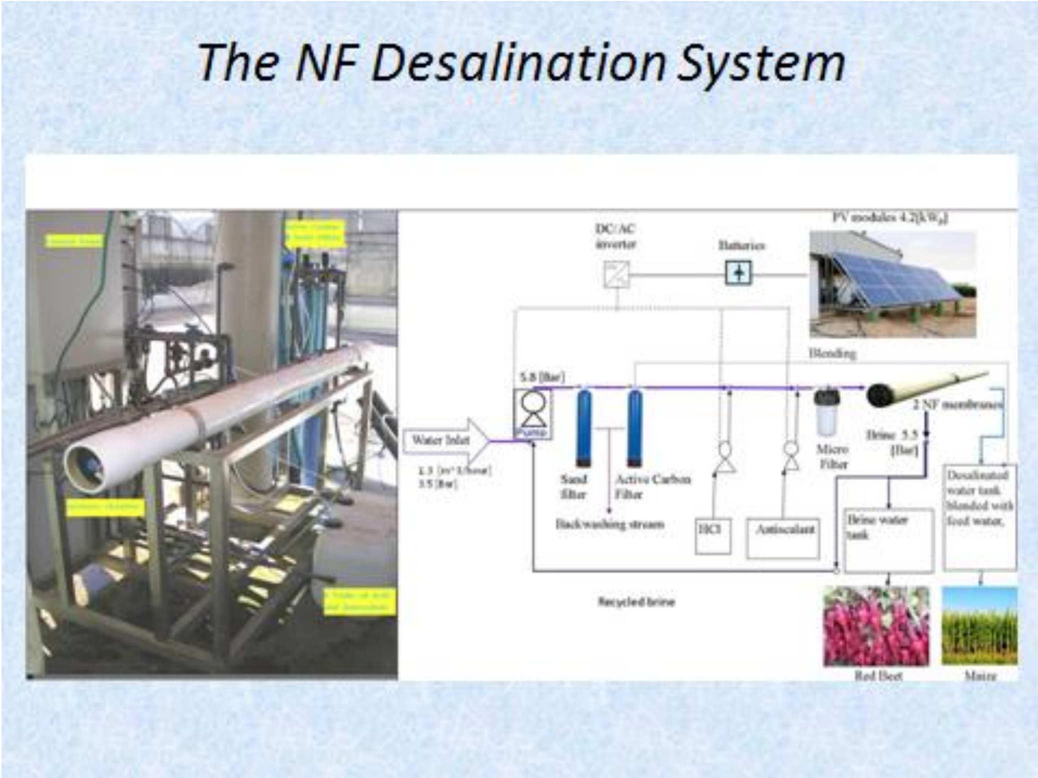
Sample	Extract		Meq/L				%			ppm		%		Total
no	PH	EC	Ca	Mg	Na	Cl	Na	SAR	ESP	P	K	O.M	N	Cation
1	8.1	1.00	4.6	4.5	2.22	2.50	19.62	1.04	0.27	49.1	498.5	0.82	0.109	11.32
2	7.8	3.77	20.0	10.70	4.76	7.50	13.43	1.22	0.52	83.7	489.2	1.87	0.120	35.46

Table .2:Water Analysis /Alkarameh 2014

PH	EC	Meq/L										SAR	ESP	ppm	
		Ca	Mg	Na	K	Cl	CO3	HCO3	SO4	Total Cation	Na %			Cd	Pb
7.9	1.84	2.56	2.79	14	0.9	13	0	4.6	2.65	20.25	69.15	8.56	9.98	<0.002	<0.01
7.1	5.51	10.49	20.65	30.13	2.05	46.5	0	5.4	11.42	63.32	47.59	7.64	8.89	<0.002	<0.01

c) The NF Desalination System at Hatseva

In 2010, a pilot project to desalinate brackish water using solar energy foragricultural use was installed in a Central Arava R&D station.This study examined the technical and economic feasibility (energy and construction cost) of brackish water desalination using photovoltaic panels (PV) for energy, in order to produce irrigation water and energy independence. It uses nanofiltration membranes (NF) to desalinate local brackish water and produce high quality irrigation water:



The crops selected for the study are staple crops that are suitable to be grown in developing countries (maize, potatoes, beets and millet). So far, it was shown that with this type of desalination, farmers could reduce

Pilot testing and agricultural experiments

	1st winter cycle (Nov 2010 – Mar 2011)	1st spring cycle (Mar – Jun 2011)	2nd winter cycle (Sep – Dec 2011)	2nd spring cycle (Mar – Jun 2012)
Crop	Potato (Mondial and Bellini)	Maize, millet, and sorghum	Maize	Maize
Irrigation water application rate	75% (E) 100% (C)	75% (E) 100% (C)	50/75/100% (E) 100% (C)	30/50/75% (E) 100% (C)
Nr of replicates	2	2-3	4	4
Fate of brine	Red beet	Red beet	Maize	Maize
Power source	Grid	Grid	Solar	Solar

E = experimental plots with desalinated water; C = control plots with brackish water

the amount of water used for irrigation by 50% without damaging the crops (maize) and reducing the yield. The brine flow is suitable for the irrigation of halophyte crops (plants that are tolerant to high water salinity), such as red beet.

<u>Upgrading the NF Desalination System at Hatseva</u>

The NF water desalination facility requires upgrading of the control system and equipment. The least expensive option included renovation of plumbing and renovation of controllers: the overall cost of control and plumbing upgrade of the existing facility at Hatseva totals approximately $ 20,000.

d) EPRI – Gaza:

EPRI teamstarted to introduce agricultural extension and training program and workshop to the farmers about project concepts and safe and effective use of Water. This will promote the awareness among farmers and provide them with the needed skills and experience to deal water safely and reduce the misuse of water salinity. Therefore, farmers trained every three months and will be appointed during the period of the project to benefit from the data and study findings to apply it in agriculture field later on. Gaza Strip divided into 5 Governorates in each Governorate. The Team will introduce scientific sound solutions to the water problems, agriculture issues, distribute educational materials, perform workshops, and cross seminars to train the farmers about water salinity and problems.

Moreover, the farmers in each Governorate will be invited to a workshop to learn more about our work progress and to benefit from project data. Training and workshops will be performed each 3 months in all locations to overview the common problems and find suitable solutions in the field of water and agriculture.

e) Identification and characterization of end-users for the proposed innovation:

The final beneficiaries of the proposed technology are small farming communities and individual farmers in areas that suffer from scarcity of high quality freshwater but dispose of marginal quality sources, such as brackish groundwater. The system is specifically designed for decentralized applications in remote and rural regions.As part of the activities concerning the evaluation of the potential of the proposed innovation to be implemented by farmers in an economically viable way, the team has started to collect information regarding the end-users in Israel and Jordan, including their current water sources and agricultural practices.

Jordan

In Jordan, the proposed innovation will benefit from the policies to promote the use of renewable energies that are supported by the Jordanian Government. As of January 2014, the Agricultural Credit Corporation, with the support of the Jordanian government, has started to provide low-interest, easy-term loans to farmers to move away from fuel-generated energy and use solar power. The share of renewable energy in the total energy mix is anticipated to reach 7% by 2015 and 10% by 2020.

Moreover, Jordan is one of the world's most water scarce countries and agriculture, as the main water user, contributes substantially to the unsustainable water balance primarily through overexploitation of groundwater aquifers. Its public sector has consistently demonstrated over time its readiness to support also financially the establishment of long-term solutions to alleviate the country's water scarcity problems (see for instance its commitment to promote the Dead Sea – Red Sea water conveyance project). As highlighted in a recent report released in March 2014 by the UN Food and Agriculture Organization during the Investing in Efficiency: Water along the Food Chain in Jordan Forum the need to increase water productivity and thus the sustainability of agriculture is a high priority. The report specifically calls for producers "to switch to new crops and markets that will allow them to produce more value without increasing the use of water. Producers also need to invest in energy efficiency improvement and enhancement of labour productivity since these are currently the most problematic issues affecting future sector development, undermining investment attractiveness" and highlights areas of investment from the private sector and opportunities for coordination between the private and public sector.

The national water policy in Jordan is particularly suitable for the development of partnerships with the private sector aiming at favoring the market penetration of the innovation described in this application. The national strategy outlined by the Ministry of Agriculture in the Jordanian National Report on "Harnessing salty water to enhance sustainable livelihoods of the rural poor in four countries in West Asia and North Africa: Egypt, Jordan, Syria and Tunisia" (August 2004) explicitly encourages the private sector to develop aquifers of marginal water quality for use in irrigation. Moreover, the private sector is also encouraged "to develop fossil and renewable aquifers in remote areas for agricultural uses with the intention of promoting technology transfer and the creation of job opportunities". Finally the document observes how desalination of brackish groundwater by the private sector shall be promoted, compatibly with the environmental impacts of such activities, particularly the safe disposal of brines. The aforementioned report concludes that "there are no social, economic, or technical constraints to use saline water resources for agriculture in Jordan, as this would relief other fresh water resources for domestic uses, but all technical and environmental considerations should be regarded".

Groundwater is a major (and sometimes the only) water resource in many areas in Jordan. Agriculture is a main user of groundwater. According to AQUASTAT, 53% of the area under irrigation countrywide was irrigated with groundwater. Exploitation of the aquifers is responsible for the rapid expansion of irrigation in areas such as the highlands.

There is evidence that the resources are overexploited and, at the current over-abstraction rate, the Ministry of Agriculture estimates that the usable time for groundwater resources in Jordan can be as short as 40 years. Increased water salinity is already observed in the WadiDuhleil and Azraq basins, with potential negative future effects on irrigated agriculture.

Overall, 67 saline water springs have been identified in Jordan (the majority being in the Jordan River Basin and Dead Sea Basin) with an estimated total average discharge of 46 MCM/year (out of estimated 700 MCM/year that are used in the agricultural sector overall). Farmers regularly use brackish water for irrigation in the Jordan Valley and NE parts of the country for the cultivation of a range of crops several of which are rated by FAO as sensitive or medium sensitive crops (e.g., bananas, cabbage, corn, eggplant, muskmelon, pepper, pistachio, squash, and tomatoes). Some of these crops are identified by the Jordanian Ministry of Agriculture as high priority crops for its national agricultural strategy since their level of self-sufficiency is low (e.g., grain crops and pistachios). According to the Ministry's estimates, increasing production of these crops will help to improve both the rural livelihoods and the national economy.

According to the AQUASTAT database maintained by FAO, the total population active in agriculture in Jordan in 2005 amounted to 194,000 individuals, corresponding to 9.8% of the total economically active population. Women constituted the majority of the population active in agriculture (70.1%). In the Jordan River Valley, around 350 000 people benefit directly or indirectly from irrigated agriculture and women form an important component of the labor force. The agricultural sector in Jordan is characterized by very fragmented farm holdings. Most farm units in the Jordan River Valley range between 3 and 5 ha in size, which makes the farm-scale solution proposed in the present application very suitable. The AQUASTAT 2008 report on "Irrigation in the Middle East in figures" reports a total number of 10,916 farm units in the Jordan River Valley.

The innovation proposed by AGRISOL targets the entire agricultural sector in Jordan that depends, directly or indirectly, on groundwater that is saline or experiences salinity increases. The Jordan River Valley is of particular appeal to the proposed technology because: (1) estimated 23 saline water springs are located here, which are used to provide irrigation water for agriculture; (2) more than 10,000 farm units, most of which of small to very small extent are located here; (3) this is a key region for the country's agricultural sector (over 60% of the country's agricultural produce is grown here) and in particular for high-value export products, some of which are salt-sensitive crops such as tomatoes (the country's most highly valued export crop, with exports estimated in $225 million in 2011), cucumber (the country's second most highly valued export crop, with exports estimated in $121 million in 2011), and eggplants ($36 million in exports in 2011).

Israel

Irrigation with brackish water is widely practiced in the Negev and Arava Valley of Israel, but requires volumes largely exceeding crops evapo-transpirative requirements to soil salinization. Leaching water percolates to the shallow aquifer, contaminating it with increasing salt content. The Israeli experience has shown that brackish water irrigation can be sustained over decades without soil salinization, if appropriate management measures are implemented. It is widely perceived as a limitation to the sustainable development of the region because: (1) it exploits aquifers beyond their natural replenishment capacity and leads to progressive water quality deterioration; (2) it results in lower than optimal yields, depending on salinity and salt-sensitivity of the crop; (3) it limits the choice of crops at the expense of cash crops with higher returns; (4) it uses water largely in excess of plant requirements to leach salts and avoid accumulation in the root zone; (5) when coupled to drip irrigation, it requires frequent replacement of pipes clogged by scaling.

The Arava basin is extremely arid, with average annual precipitation of about 50 mm. Only ephemeral streams run into the valley. Rainstorms are infrequent and limited to a short period in the winter. Excluding the city of Eilat, the Israeli Arava Valley hosts 20 communities with an estimated population of about 50,000 inhabitants. Economic activities in the region rely heavily on the exploitation of the local brackish aquifers for highly intensive agriculture, and export of off-season horticultural crops to the European markets. Other economic activities include dairy production, aquaculture, tourism, small businesses, and renewable energy production (Sagie et al., 2013).

The vast majority of water sources in the region are brackish, with an estimated 53% of the water from local wells, presenting an electro-conductivity between 2.65 and 3.4 dS/m. Only 3% of the water sources have an electroconductivity of less than 1.9 dS/m, while 2% have an electroconductivity equal or higher than 5.2 dS/m. High concentration of iron ([Fe^{3+}] > 0.3 mg/L) or hydrogen sulfide ([H_2S > 0.5 mg/L) is found in about 7% of the water resources. Brackish water irrigation with salinities of 2–3.5 dS/m and no prior desalination is practiced as a rule in the region.

From a hydrochemical point of view, one can distinguish three major groundwater types in the Arava Valley: the Northern Arava basin, the Central Arava basin, and the Southern Arava basin (Hassid and Adar, 2004). The Northern Arava basin includes the communities north of Idan and around the southern Dead Sea region, including wells in the NeotHakikar, MahteshKatan well field, Ofarim-Yorkeam, Admon-Zin, and Amiaz. Water in this region is used mainly for agriculture and in the phosphate mining industry. Areas in the Central Arava aquifers are extensively developed for agriculture. The AGRISOL case-study location of Hatzeva is located within this region. Finally, water in the Southern Arava basin is primarily used for aquaculture farms, irrigation of palm trees, and feedwater for the brackish water reverse osmosis desalination plant in Eilat. An overview of the water quality in the water bodies of the Arava Valley and Negev desert is provided in Table 3. Dropping groundwater levels and deteriorating water quality (i.e., increasing water salinity) have been consistently documented and can be attributed both to anthropogenic and climatic factors (Bruins et al., 2012).

According to estimates of the Central and Northern Arava R&D, in May the population of the Central-Arava basin comprised approximately 700 families, of which 530 are farmers, for a total population of about 3,360 people. In addition, estimated 120 families, of which 110 are farmers, for a total of about 550 people live in the Sodom Valley region in Tamar. The arable land in the 2012/13 season comprised of 3,643 hectares, of which 82% were cultivated with vegetables, 16% with fruit trees plantation (mainly dates) and 2% with cut flowers. The pepper (*Capsicum*) is the major crop in the region and holds 50% of the total arable land and 66% of the vegetables area. Other crops that are cultivated in the region include melon (13.3% of the vegetables area), watermelon (9%), tomato (4%), cut herbs (3%), eggplant (2%), squash (1.2%), onion (1.1%), and cherry tomatoes (0.7%). Bio-organic farming holds about 10% of the growing area.

The majority of the cultivation is carried outin net houses, tunnels and greenhouses, while only a small portion of the crops are cultivated in open fields. The Arava region produces about 60% of the total Israeli export of fresh vegetables and about 10% of the cut flowers export.

Further research within AGRISOL will be focused on disaggregating the current water use for agricultural purposes in the Arava region, based on water source (i.e., water quality and salinity) and type of crop cultivated. Such analysis will allow for the identification of the areas where implementation of the AGRISOL innovation could be particularly advantageous due to the concomitant presence of high brackish water salinity and cultivation of salt-sensitive crops.

I. C) Scientific Impact of Cooperation

The immediate outcome of the cooperation is the good discussions carried out between all the parties resulting in mutual visits, such as formal invitations from Hatseva R & D Center to the project partners to participate in the upcoming Agricultural Exhibition that will take place on January 28-29 in Hatseva.

I. D) Description of Project Impact

It is too early to observe and describe any impact of the project.

Name group	pH	Electro-conductivity (dS/m)	Total Dissolved Solids (mg/L)	Cl (mg/L)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	B (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	H_2S (mg/L)
Amiaz	6.3	18.2	11247.9	5042.4	2044	1047.7	546.1	133.9	5.7	233.7	1072.6	
Beer Sheva - Shoket	7.4	1.1	797.2	207.5	127.3	74.6	38.5	4.4	0.2	238.4	100.6	0.2
Efae	7	4.8	3977.5	813	538.2	214.6	82.2	35.6		282.1	646	0.6
Eilat North	7.3	9.9	6747.1	2964.8	979.4	913.6	129.8	15.6	0.7	49.2	636.1	0.6
Eilat South				2655.6	1016	570.4	258.1	29	1.2	67.2	991.8	
EinYahav - Zofar East	6.9	2.1	1577.1	257.3	174.4	184.9	77.2	15.5	0.3	300	540.3	1.4
EinYahav (limestone)	7	3.1	1907.1	546.1	281.3	194.8	98.8	23.1	0.4	269.7	517	3.4
Evrona (alluvial)	7.2	5.3	3540.1	1493.7	595	339.7	170.3	23	0.8	102.3	711.3	
Grofit (limestone)	6.7	7.3		984.5	680	797.5	131	29.3	0.4	158	782	
Hazeva - Idan North	7.3	1.8	1178	304.2	160.2	133.8	59.9	7.5	0.4	176.2	348.7	0.1
Hazeva - Idan South	7.1	2.2	1409.7	291.4	188.7	161.3	75	10.9	0.3	237.4	496.9	0.1
HazevaShezaf	7.1	2.7	1859.3	682	298.7	209.2	109.5	11.7	24.5	186.3	476.5	0.1
Mashabe Sade	7	4.8		1352.5	802.8	168.3	80.4	32.9	1.2	293.9	518.5	4
NeotHaKikar	7.1	4.7	2337.8	785.2	389.2	200.8	122.5	22.9	0.5	208.4	567.3	0.1
Nevatim	7.6			1194.1	694.7	145	104.9	11		257.2	407.9	
Nizana	7.1	7.2		1999.3	1166.6	261.3	113.8	28.9	2.2	306.8	547.8	24.8
Paran - Zofar (alluvial)	7.2	1.6	1024.7	228.9	135.5	126.9	55.1	7.6	0.3	218.6	320.1	0.2
Springs	7.1	4.7	3408.6	1204.6	621.6	300.4	149	20	0.6	330.5	692.1	
Timna - Samar	7.1	0.7	2402.7	770.5	378	227.5	133.9	14.9	0.6	168.5	697.6	
Timna (alluvial)	6.8	7.2	4666.3	1958.4	675.9	668.7	139.2	26.5	0.8	171.7	843.8	
Yaalon	6.9	2.8	1834.4	451	227.8	222.3	109.8	15.1	0.5	270.3	673.5	
Yaalon (limestone)	7	2.4	1402.9	408.8	198.8	166.3	91.7	12.7	0.4	265.2	445	
Yorkeam - Ofarim	6.9	3.2	1918.8	637.2	383.3	168	69.7	21.8	0.8	275.4	433.8	2.2
Yotveta (alluvial)	7.2	2.8	2001.7	534.4	299.8	231.2	131.4	11	0.6	168.6	863.2	
Yotveta	7	4.7	3118.1	734	434.6	265.5	171.4	19.9	0.9	238	1003.7	
ZavarHaBakbuk	7.2	1.7	1069.5	234.6	139.1	137.9	51.1	6.8	0.3	203.4	349.2	0.2
Zin - Admon	7.3		3855.1	1992.2	1102.5	325.8	173.7	50.4	2.5	265.1	813.5	
Zofar - Paran Kur	6.8	7.2	2163.9	2016.4	697	587.3	136.7	51.5	0.9	184.9	685.3	1.2
Zofar - Paran Tur	7	2.7	1582.9	404.6	212.5	204.7	96.9	32.3	0.5	342.7	547.2	8.7

Table 3. Principal hydro-chemical characteristics of water bodies in the Negev and Arava Valley (Hassid and Adar, 2004).

I. E) Strengthening of Middle Eastern Institutions

Although the study was planned in a way that each team can perform the work plan and discuss the activities together, a true effort will be made to use this joint study as a tool for broader meetings between all the research teams and not only between the principal investigators. When the political situation allows, coordinators, farmers, and all teams will be invited for joint scientific meetings at which results and discussions will be transferred. If the political situation does not enable such meetings, the information and data will be transferred by *e*-mail and phone calls.

One method we are applying to strengthen institutions is to combine as many institutions and research centers to work together in this project, and holding meetings to the researchers discussing the project and transferring experiences to each other.

I. F) Future Work

We are starting the first year of the original 4-year project. We have finished processing of any official paperwork and the project starting date is March 2014. We expect to start our design and installation of the system starting from January 2015.

Section II. Project Management and Cooperation

II. A) Managerial issues

1. Sub-contracts signed in the end of September 2014 between partner institutions.
2. 2014 was spent on official paper work and delays due to Gaza war.
3. January 2015 will start the Jordanian design and installation.

<u>Meetings, regional and international:</u>

The war in Gaza in summer 2014 had severe repercussions on the starting of the project; a decent kickoff meeting was scheduled and postponed a number of times, because it was not possible to meet in Israel, as suggested. On December 2, the meeting finally took place in Aqaba, Jordan. All partners but Prof. Safi form EPRI were present.
Dr. Rami Messalem from BGU, Israel and Prof. Jamal Safi from EPRI, Gaza met on December 18, 2014 at Ben-Gurion University to discuss the progress of the project and coordinate the work plan.

<u>II. B) Cooperation</u>

The kick-off meeting and the organizing between the researchers forecast that the Cooperation is good, and the project will proceed smoothly.