Development of prototype system for the treatment of brackish water coupled with hybrid renewable energy

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BRAWA: Main aim

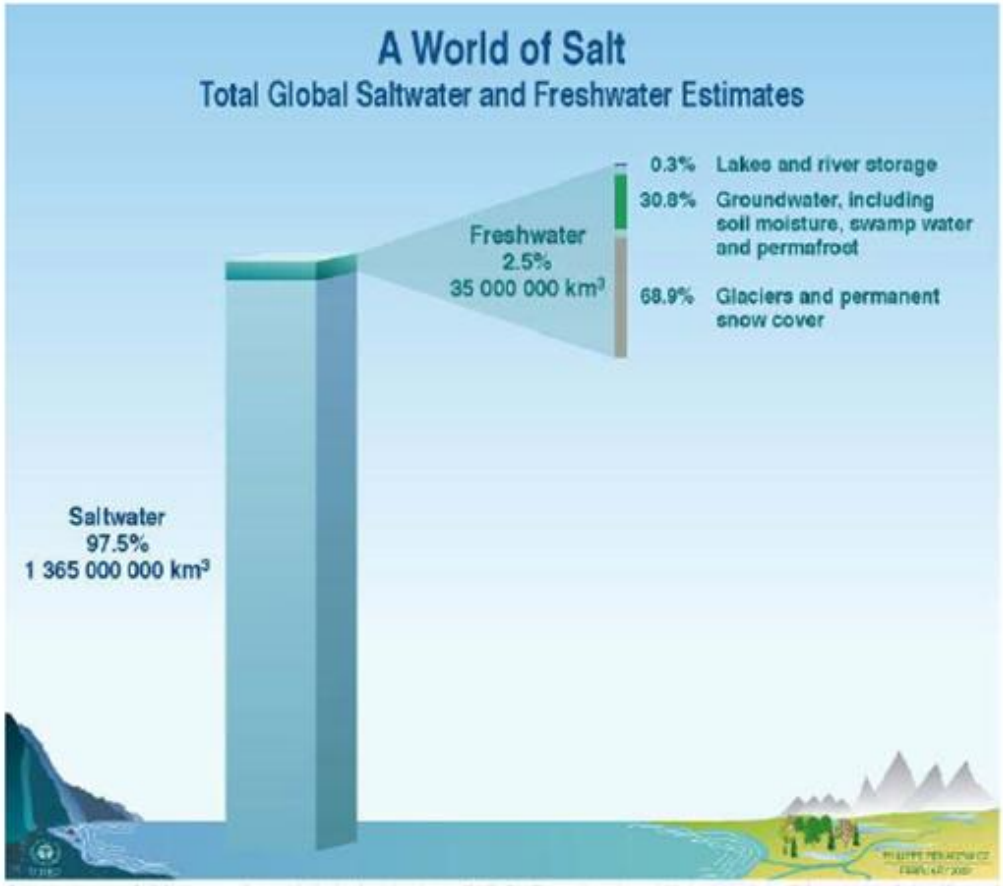
"The main objective of this project was the development of an **innovative, energy autonomous system for the treatment of brackish water system** in order to provide an isolated **Jordan community with clean water**"

Global Water Distribution & Water Classification

Water Natural Resources

- Surface water
- Groundwater
- Ocean Water

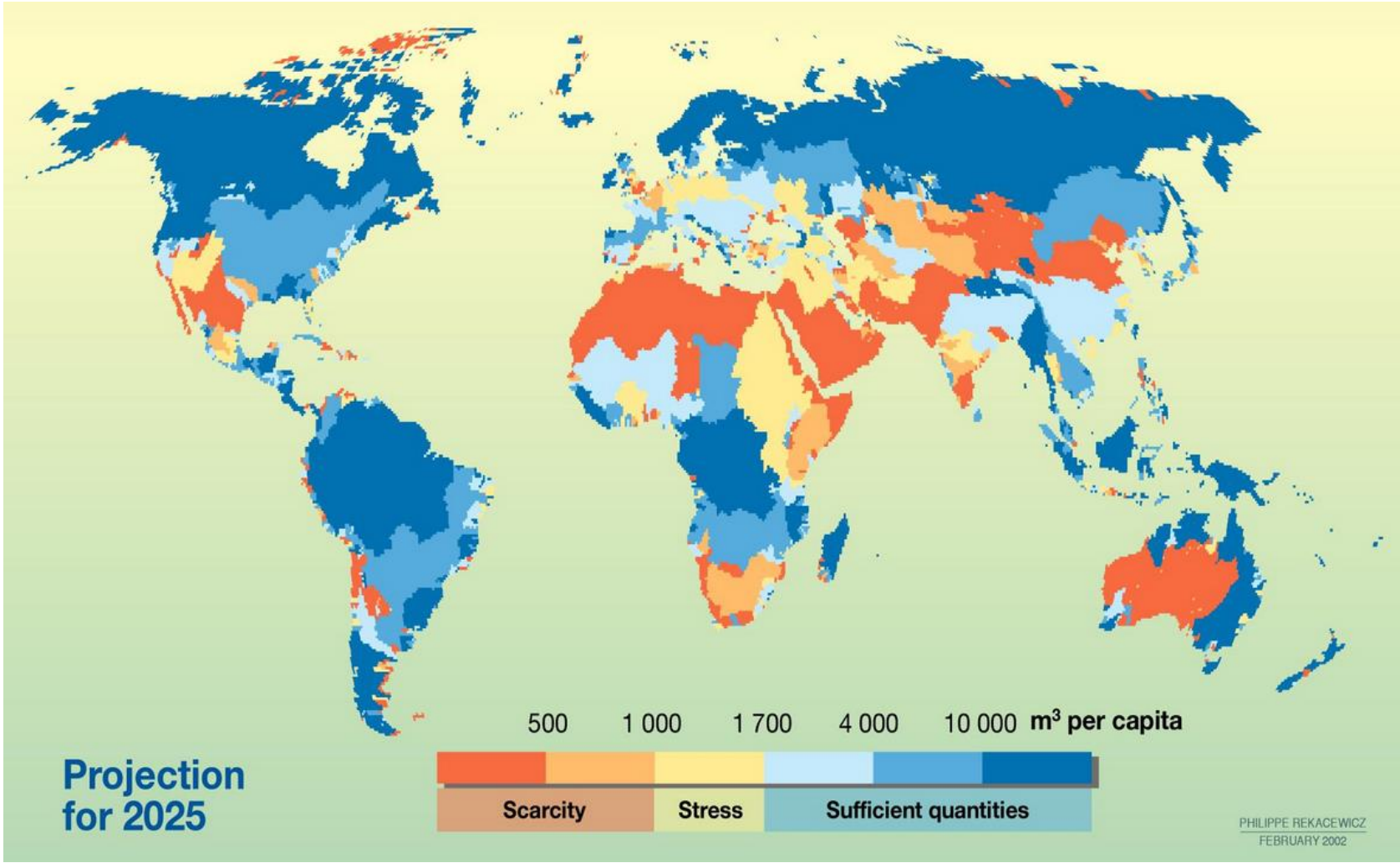
Water Source	Salt Concentration (mg/l)
Brackish Water	>1,000, high brackish, up to 11,000
Seawater	~35,000



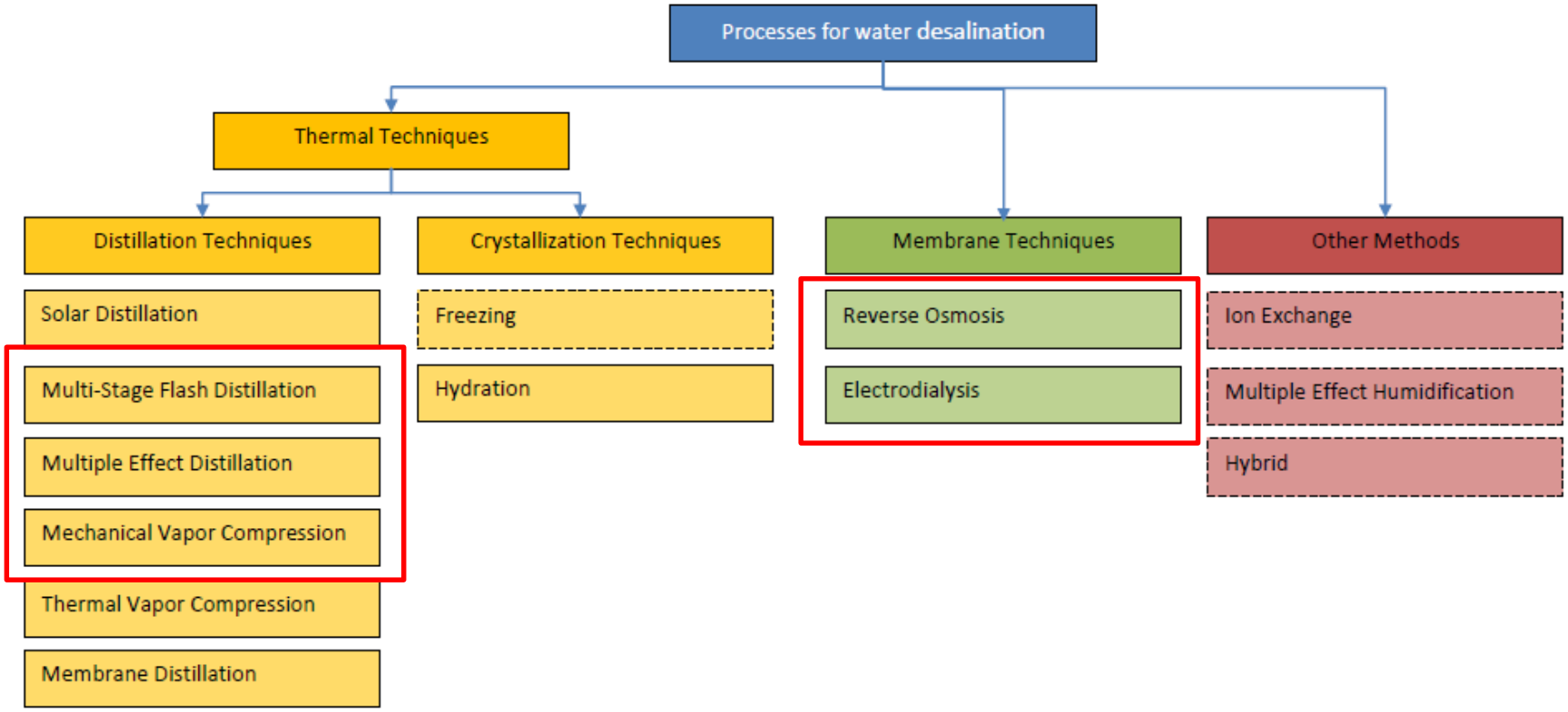
Water Supply & Desalination

- Although the absolute quantities of freshwater on earth have always remained approximately the same, the uneven distribution of water and human settlement continues to create growing problems **freshwater availability and accessibility**
- Seawater and brackish water desalination has been proven to be a technologically sound and promising option for combating the coming water crisis

Fresh Water Availability (2025)

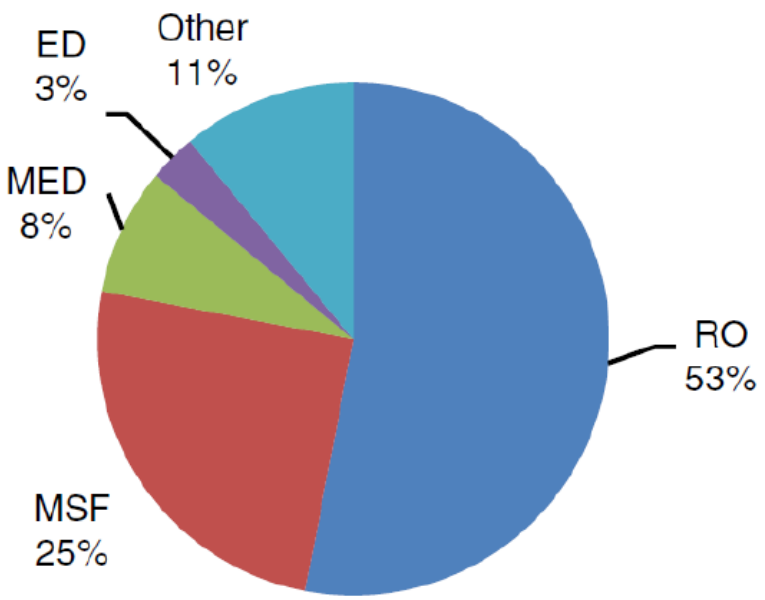


Processes for water desalination

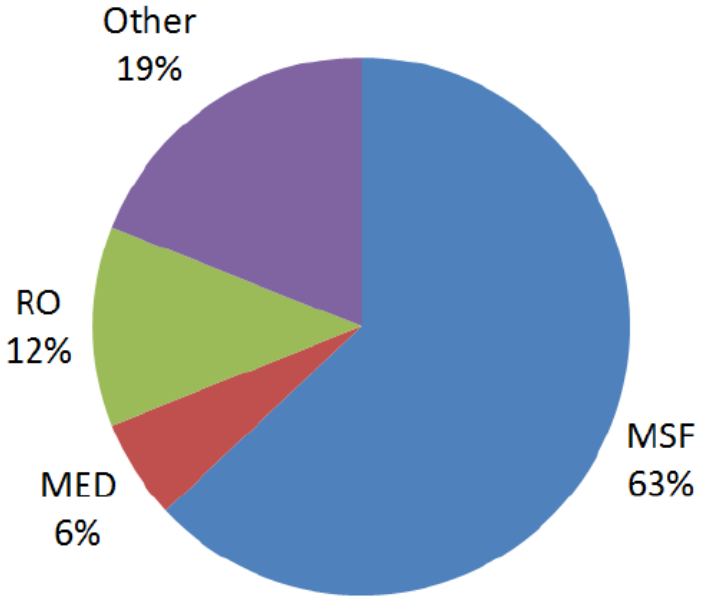


Note: The dashed boxes contain early R&D or not widely used technologies.

Installed desalination capacity by process



World **(Source: Mezher, 2011)**



United Arab Emirates **(Source: Mezher, 2011)**

Note			
ED	Electrodialysis	**MSF**	Multi-Stage Flash Distillation
MED	Multiple Effect Distillation	**RO**	Reverse Osmosis

Technical characteristics of the main desalination technologies

		Thermal		Mechanical	
Process		MSF	MED/TVC	MVC	RO
State of the art		Commercial	Commercial	Commercial	Commercial
Heat consumption	kJ/kg	250-330	145-390	-	-
Electricity consumption	kWh/m³	3-5	1.5-2.5	8-15	2.5-7
Plant cost	$/m³/d	1,500-2,000	900-1,700	1,500-2,000	900-1,500
Time to commissioning	months	24	18-24	12	18
Production unit capacity	m³/d	<76,000	<36,000	<3,000	<20,000
Conversion Freshwater/Seawater		10-25%	23-33%	23-41%	20-50%
Maintenance	cleaning per year	0.5-1	1-2	1-2	Several times
Pre-treatment of water		Simple	Simple	Very simple	Demanding
Operation requirements		simple	simple	simple	Demanding
Product water quality	ppm	<10	<10	<10	200-500

Source: (AQUA-CSP project, 2007)

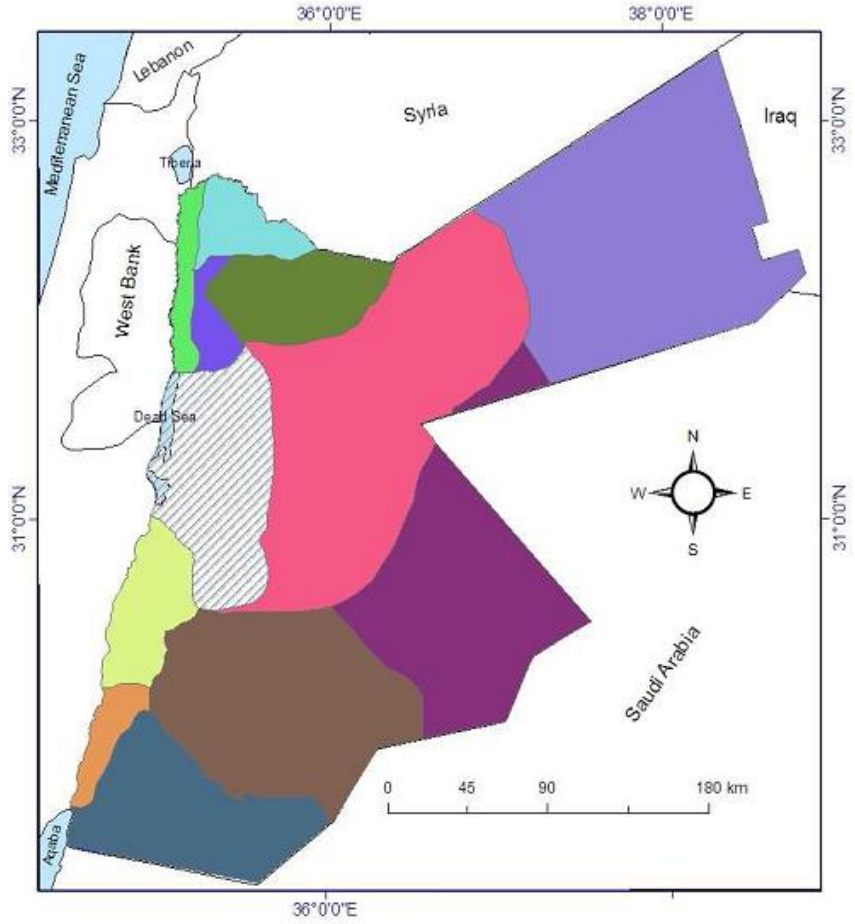
Note			
ED	Electrodialysis	MSF	Multi-Stage Flash Distillation
MED	Multiple Effect Distillation	RO	Reverse Osmosis

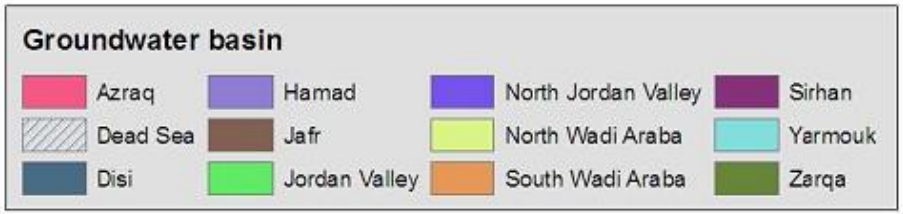
Electricity consumption in RO plants depending on feedwater quality

The per m^3 consumption of electric energy, depends on the feedwater as follows:

- Seawater: 4 - 7 kWh/m^3
- Brackish water: 1 – 3 kWh/m^3

Groundwater basins in Jordan





Desalination plants in Jordan

Location	Total capacity (m^3.d)	Unit	Process	Water quality	Construction Year
Amman	360	1	RO	Brackish	1979
Amman	3028	4	RO	Sea	1981
Amman	1200	1	RO	Brackish	1981
Amman	409	1	RO	Brackish	1981
	719	1	ED	Brackish	1982
Irbid	545	2	RO	Sea	1982
	1584	2	RO	Brackish	1983
Azraq	600	1	RO	River	1987
Aqaba	1100	1	VC	Sea	1997
	818	1	ED	Brackish	1998
	800	2	RO	Sea	2001
Aqaba	1	1	THE	Sea	1987
Hisban	4	1	RO	River	2001
TOTAL	11168	19	-	-	-

Currently, Jordan produces about **50 Million Cubic Meters** by desalination from over 10 desalination plants (the majority of which comprise reverse osmosis plants, see table on the left):

- ✓ **40 MCM** are being used for domestic purposes and
- ✓ **10 MCM** for irrigation

Sources of brackish water which can be utilized from different groundwater basins

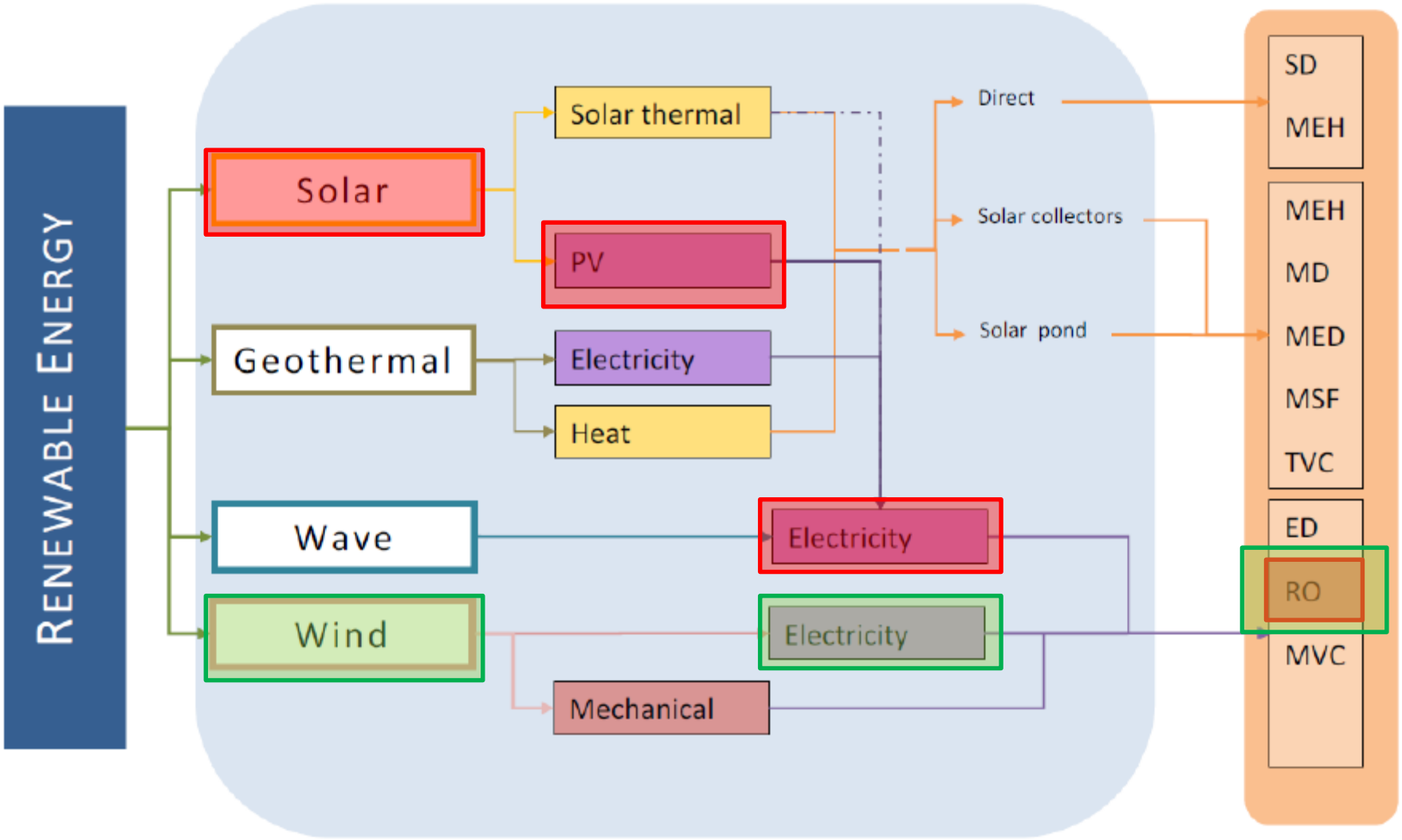
Ground water Basin	Aquifer	Storage amount of nonrenewable (billion m^3)	Assumed safe yield of renewable (MCM/a)	Salinity range (TDS) (mg/1)
Azraq	A7/B (North to central)	46		1.000 to 2.500
	A7/B2 (south)		10 to 12	1.000 to 1.700
	Kurnub	42		1.350 to 3.000
Jordan valley	A11		6	1.350 to 2.500
Dead sea	A7/B2		9 to 12	1.000 to 1.700
Wadi Araba	A1 (North to South)		8	1.000 to 7.000
Jafr	A7/B2	1.7		1.000 to 4.000
	Kurnub	12		1.400 to 3.000
	Khreim	88		1.200 to > 10.000
Sirhan	B4		5	1.000 to 2.500
	A2/B2	32		4.500 to 7.000
Hammad	B4/B5		7	1.000 to 3.000
	A7/B2	16		1.500 to 3.200
Total	-	237.7	55 to 60	-

Decentralized concept
Energy Autonomous Desalination Systems

- In Jordan, there is not only a water shortage problem but also the electricity is mainly produced by fossil fuels and in some case there is a lack of electricity grid connection.

- Renewable energy driven desalination has been evaluated from different researchers as the most suitable option resulting from multi-criteria analysis under economic, technical, availability, reliability and environmental sustainability criteria

RES-Desalination Coupling



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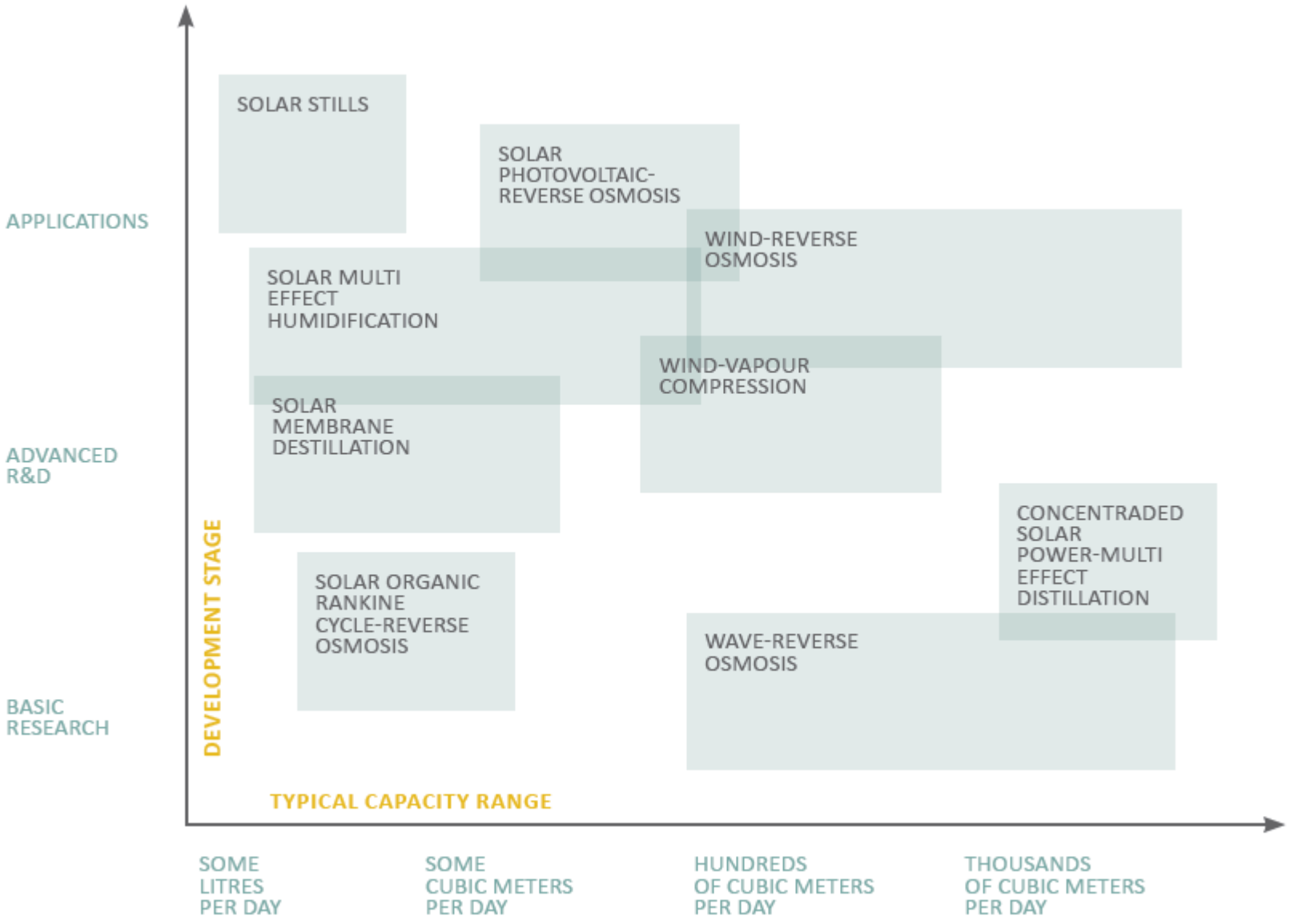
SOLAR STILLS
SOLAR PHOTOVOLTAIC-REVERSE OSMOSIS
WIND-REVERSE OSMOSIS
SOLAR MULTI EFFECT HUMIDIFICATION
WIND-VAPOUR COMPRESSION
SOLAR MEMBRANE DESTILLATION
CONCENTRADED SOLAR POWER-MULTI EFFECT DISTILLATION
SOLAR ORGANIC RANKINE CYCLE-REVERSE OSMOSIS
WAVE-REVERSE OSMOSIS
APPLICATIONS
ADVANCED R&D
BASIC RESEARCH
DEVELOPMENT STAGE
TYPICAL CAPACITY RANGE
SOME LITRES PER DAY
SOME CUBIC METERS PER DAY
HUNDREDS OF CUBIC METERS PER DAY
THOUSANDS OF CUBIC METERS PER DAY

Innovative, energy autonomous brackish water treatment plant (BRAWA system)

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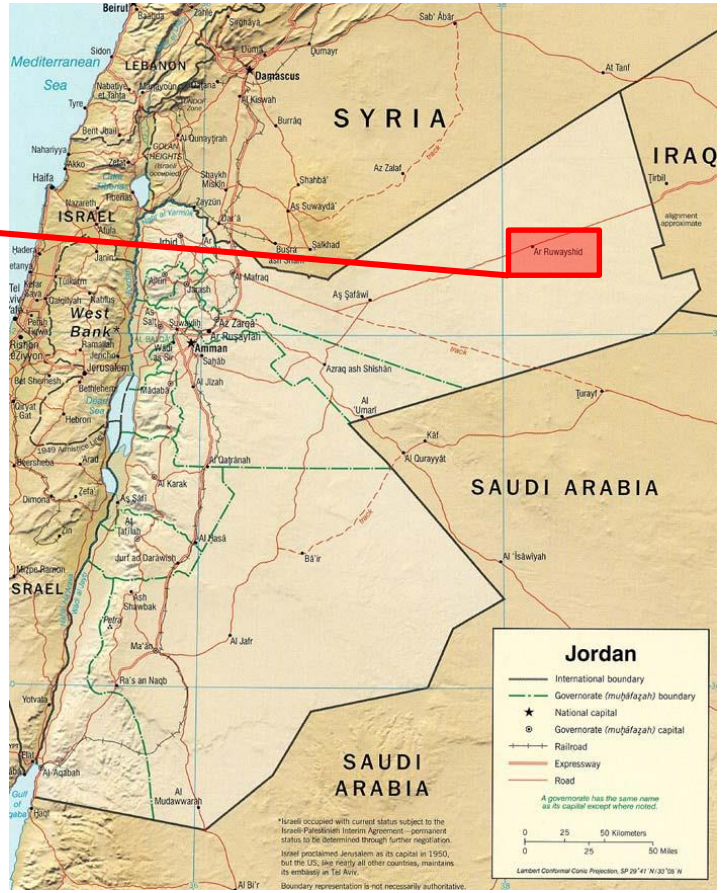
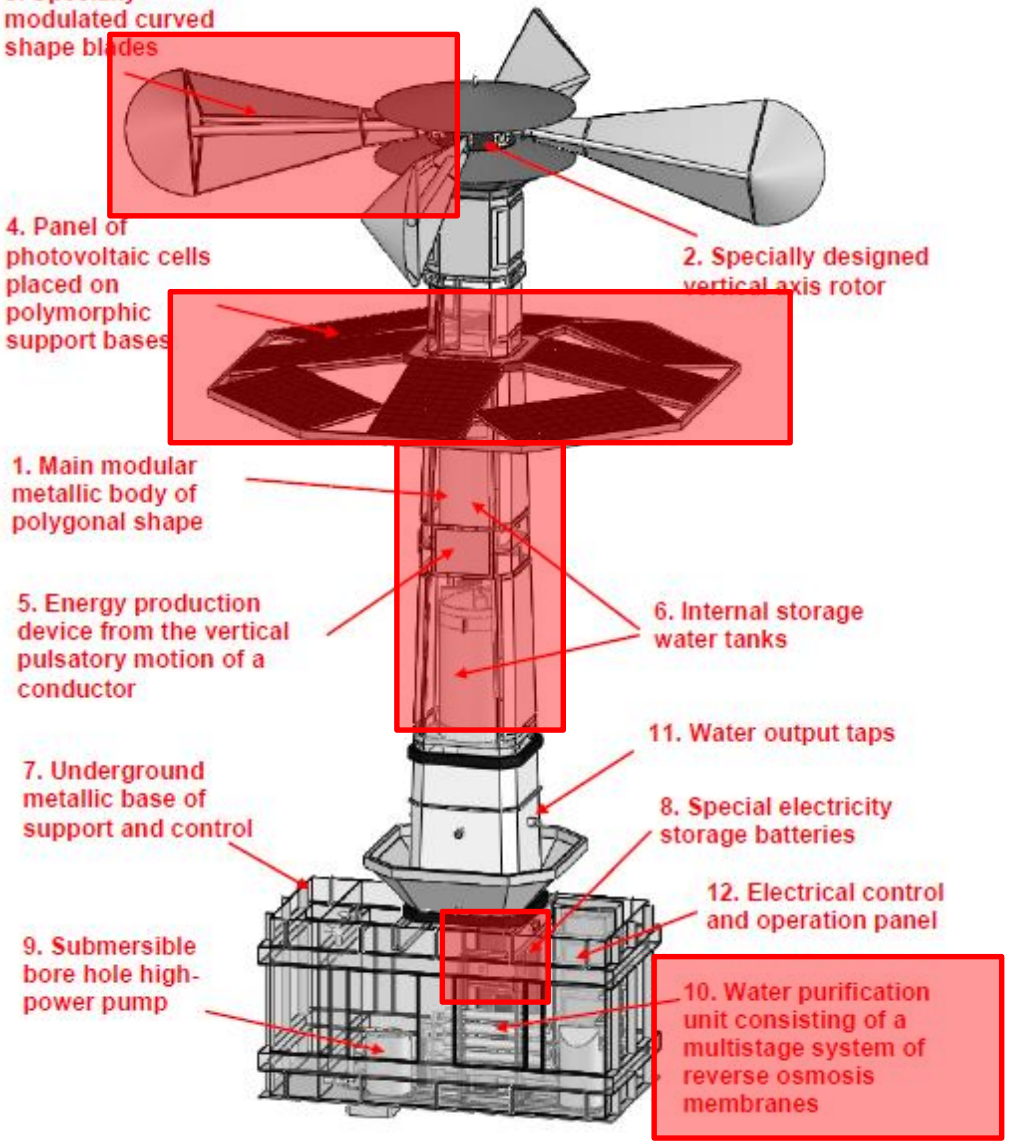
Implementation Region

- The implementation region is Salhiyyat Al-Naeem Village of the Rwaished Municipality, in the eastern Jordan (distance from Rwaihsed to Salhiyyat Al-Naeem: ~35 km)





Components:

- Reverse Osmosis membrane unit (*RO*)
- Photovoltaic System (PV)
- Wind turbine system
- Vertical pulsatory motion of a conductor (patented system)
- Storage water tanks
- Batteries

All basic and auxilliary equipment has been succesfully installed on site.

BRAWA system: Renewable Energy Capacity (KW)

The hybrid system has installed capability of 25 kW, utilizing renewable energy sources.

Specifically, the distribution of energy produced by the system is as follows:

- From the wind energy, using the specially designed vertical axis rotor, up to **10kW (Wind Part)**
- From solar energy through the use of photovoltaic (solar) cells, up to **2kW (Solar Part)**
- From the vertical pulsatory motion of a conductor inside a magnetic field (natural magnet), in water under pressure, up to **13kW (Patented system)**

Wind Part (1/2)

- Nominal Capacity: **10kW**
- Design: Vertical axis, four curved shape blades

The mechanical energy produced from the rotation of the blades, is converted (after speed change with a gear box) to electricity. This conversion is realized through the use of energy converters and the energy produced is stored to the batteries system which is installed in the underground support metallic base.

Wind Part (2/2)

- Different views of the Wind power system

Solar Part (1/2)

- Nominal Capacity: **2kW**
- Design: Single-crystalline Silicon
- Mounting: Under the rotor, on the main body (8 photovoltaic panels)

The slope of the support bases and the connection of photovoltaic panels ensure maximum output per surface. The power produced from the solar system is stored to the batteries system which is installed in the underground support metallic base.

Solar Part (2/2)

- Different views of the Solar power system

Patented System (1/2)

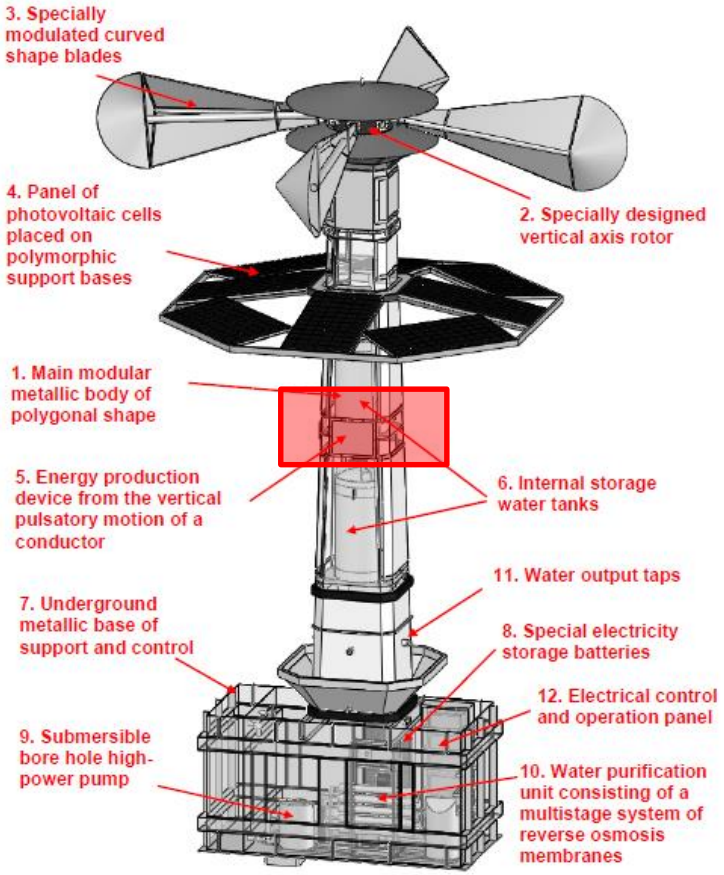
- Nominal Capacity: **13kW**

The main part of renewable energy is generated (13kW) through the use of a conductor device installed in the main body.

This device takes advantage of the vertical pulsatory motion of a conductor in water under pressure, inside a magnetic field.

It is noted that this unique power generation system has introduced an additional innovation to the BRAWA system and holds a Patent (*Patent No. 1006179*). This provides an exceptional advantage over conventional renewable power systems.

Patented System (2/2)



- Energy production device from the vertical pulsatory motion of a conductor

Reverse Osmosis System (1/7)

Brackish water treatment system	
Reverse osmosis Capacity:	2 m^3/hr
Recovery rate	65%
Feed pressure	6-12 bar
Produced water conductivity:	< 400 µS/cm (drinkable water specifications)

Typical Feedwater quality (2/7)

Date		pH unit	EC uS/cm	TDS mg/L	Hard mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	SO_4^{2-} mg/L	CO_3^{2-} mg/L	HCO_3^- mg/L	NO_3^- mg/L	Turb NTU	SiO_2 mg/L	NH_4^+ mg/L	PO_4^{3-} mg/L	Mo mg/L	Sb mg/L
Sample 1	18/12/2010	7,23	2730	1775	882	162	108,42	229,8	11,8	300	459,4	0	392	0,6	41,5	19,04	2,6	0,15	<0.01	
Sample 2	18/12/2010																			
Sample 1	19/12/2010	7,23	2720	1768	907	182	109,51	208,4	10,9	295	457,9	0	384	<0.20	45,7		2,5		<0.01	
Sample 2	19/12/2010																			
Sample 1	20/12/2010	7,21	2710	1762	972	198	115,68	223,8	12,7	300	477,1	0	383	0,47	44,6		1,9		<0.01	
Sample 2	20/12/2010																			

Source	Date	Fe mg/L	Mn mg/L	Cu mg/L	Pb mg/L	Cr mg/L	Cd mg/L	Zn mg/L	Ni mg/L	S mg/L	F mg/L	Odor TON	ABS mg/L	Ag mg/L	Al mg/L	Se mg/L	As mg/L	CN mg/L	Ba mg/L	TotalColi MPN/ 100ml
Sample 1	18/12/2010	1,15	0,05	<0.01	<0.01	<0.01	<0.003	<0.06	<0.01	16,4	<0.20		<0.02	<0.01	<0.01	0,006	<0.005	<0.05	0,08	<1.8
Sample 2	18/12/2010																			<1.8
Sample 1	19/12/2010	1,1	0,05	<0.01	<0.01	<0.01	<0.003	<0.06	<0.01	15,8	<0.20		<0.02		<0.01	0,007	<0.005			<1.8
Sample 2	19/12/2010																			<1.8
Sample 1	20/12/2010	2,96	0,06	<0.01	<0.01	<0.01	<0.003	<0.06	<0.01		<0.20		<0.02							<1.8
Sample 2	20/12/2010																			<1.8

Reverse Osmosis system (3/7)

Reverse Osmosis System (4/7)

Pre-treatment stage

- Pre-chlorination dosimeter (sodium hypochlorite solution for removal of soluble iron and manganese)
- Multi-layer sand pyrolusite filter (removal of suspended particles and iron ions
- Multi-layer activated carbon filter (removal of free chlorine and residual iron)

Figure: Multi-layer activated carbon filter

Reverse Osmosis System (5/7)

Treatment stage

- Stainless steel high-pressure pump
- Six (6) Reverse Osmosis membranes
- Pressure vessels containing the membranes:
  - Number: 3 vessels (2 membranes per vessel)
  - Maximum pressure: 21 bar

Figure: Pressure vessels containing the RO membranes

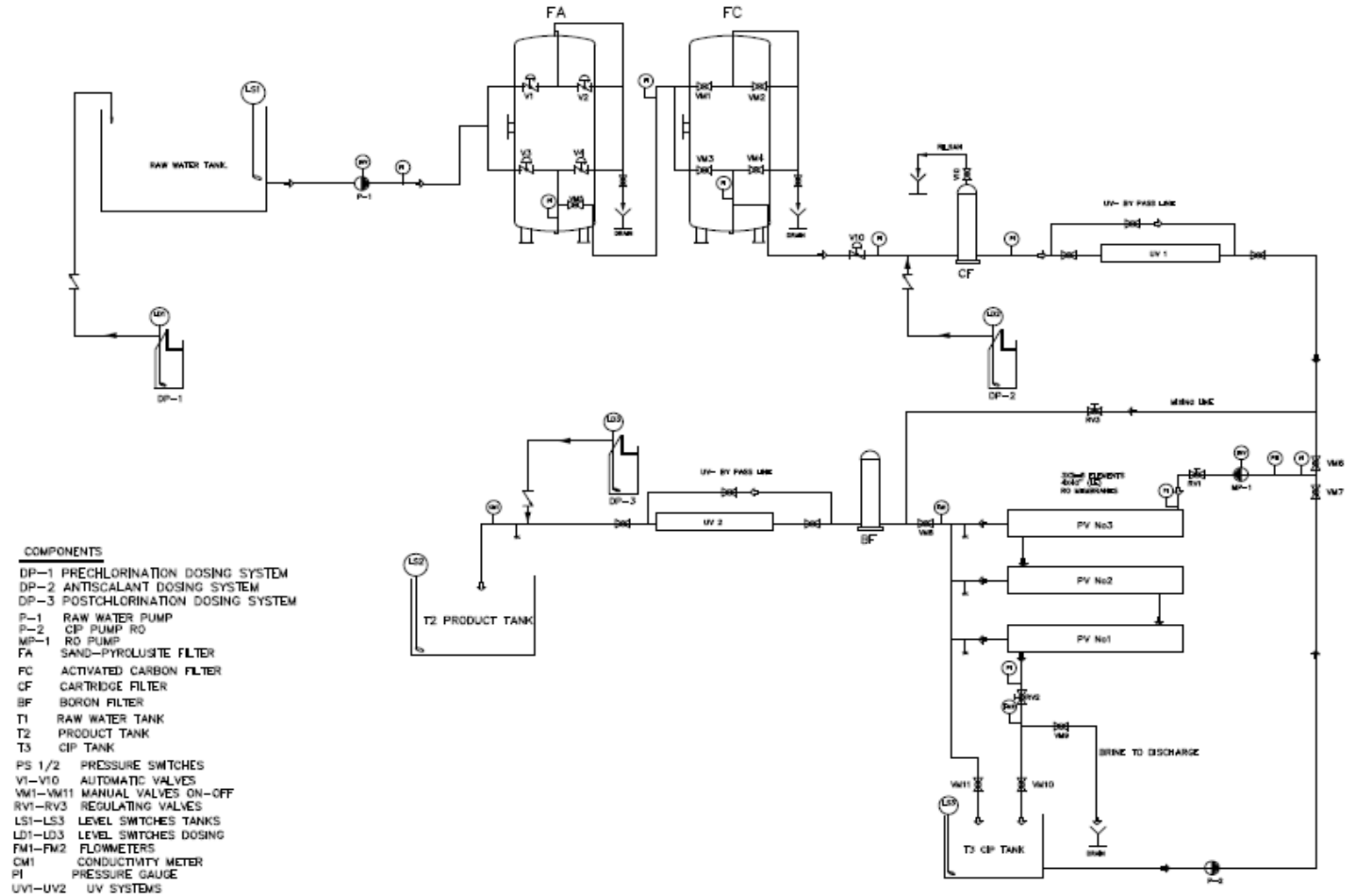
Reverse Osmosis System (6/7)

Post-treatment: Permeate rehardening stage

- Ultraviolet radiation (UV) device for the disinfection of remixing current (filtered feeding water). The UV unit is stainless steel with a capacity of 1.8m^3/h.
- Dosimeter feeding system of sodium hypochlorite solution (chlorine) for the protection of stored distributed water from microorganisms. It includes 200lt PE (polyehtylene) tank with dosing pump

Fresh Water Production System (7/7)

- Water output taps


FA
FC
RAW WATER TANK
P-1
CF
DP-1
DP-2
DP-3
UV 1
UV 2
BF
PV No3
PV No2
PV No1
T2 PRODUCT TANK
T3 CIP TANK
BRINE TO DISCHARGE
COMPONENTS
DP-1 PRECHLORINATION DOSING SYSTEM
DP-2 ANTISCALANT DOSING SYSTEM
DP-3 POSTCHLORINATION DOSING SYSTEM
P-1 RAW WATER PUMP
P-2 CIP PUMP RO
MP-1 RO PUMP
FA SAND-PYROLUSITE FILTER
FC ACTIVATED CARBON FILTER
CF CARTRIDGE FILTER
BF BORON FILTER
T1 RAW WATER TANK
T2 PRODUCT TANK
T3 CIP TANK
PS 1/2 PRESSURE SWITCHES
V1-V10 AUTOMATIC VALVES
VM1-VM11 MANUAL VALVES ON-OFF
RV1-RV3 REGULATING VALVES
LS1-LS3 LEVEL SWITCHES TANKS
LD1-LD3 LEVEL SWITCHES DOSING
FM1-FM2 FLOWMETERS
CM1 CONDUCTIVITY METER
PI PRESSURE GAUGE
UV1-UV2 UV SYSTEMS

WHO Drinking water standards

WHO Standards for drinking Water	Contents in mg/l	
	min acceptable	max permissible
Total dissolved solids, TDS	500	**1500**
Cl	200	600
SO_4^{2+}	200	400
Ca^{2+}	75	100
Mg^{2+}	30	150
F^-	0.7	1.7
NO_3^-	<50	100
Cu^{2+}	0.05	1.5
Fe^{3+}	0.10	1.0
NaCl	250	-
pH	7.0-8.5	6.5-9.2

Drinking water quality from RO

Component	Results	Jordan standards
Residual Chlorine	1.3 mg/l	1.5
Turbidity	0.47 NTU	5.00
Ammonium as NH4	<0.2 mg/L	0.2
Escherichia coli	Absence	
Total coliforms	Absence	
Iron	0.10 mg/l	1.00
Manganese	0.058 mg/l	
Color	<15 CU	15
Aluminum	<0.01 mg/l	0.10
Anionic Surfactants	<0.02 mg/l	0.20
Odor	No odor	
pH	6.8 unit	6.50-8.50
Nitrate as NO3	<0.25 mg/l	

Drinking water quality from RO

Component	Results	Jordan Standards
Sulfate	10.94 mg/l	
Chloride	37.83 mg/l	
Temperature	30.90 Celsius	
Electrical conductivity	550 Us/cm	
Calcium	80mg/l	
Magnesium	35 mg/l	
Sodium	24 mg/l	200 mg/l
Potassium	3,23 mg/l	
Carbonate	0 mg/l	
Bicarbonate as HCO3	56 mg/l	
Hardness as CaCO3	67 mg/l	

Photos & Video from the construction (1/2)

Photos & Video from the construction (2/2)


X30M W P20 BAR

Water from well and after carbon filter

Photos

Photo from the installed system for the treatment of brackish water in Rwaished, Jordan

Thank you for your attention!