



International Desalination  
Association

World Congress on Desalination  
and Water Reuse



# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION

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***Desalination:  
Water for a Better Future***

***Bahrain  
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# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION

- INTRODUCTION
- SEA WATER QUALITY
- PRODUCT WATER SPECS FOR IRRIGATION
- EFFECT OF WATER QUALITY IN SOIL STRUCTURE
- EFFECT OF WATER QUALITY IN CONSUMPTION
- MEMBRANE SELECTION
- RO CONFIGURATION
- CONCLUSIONS



# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION

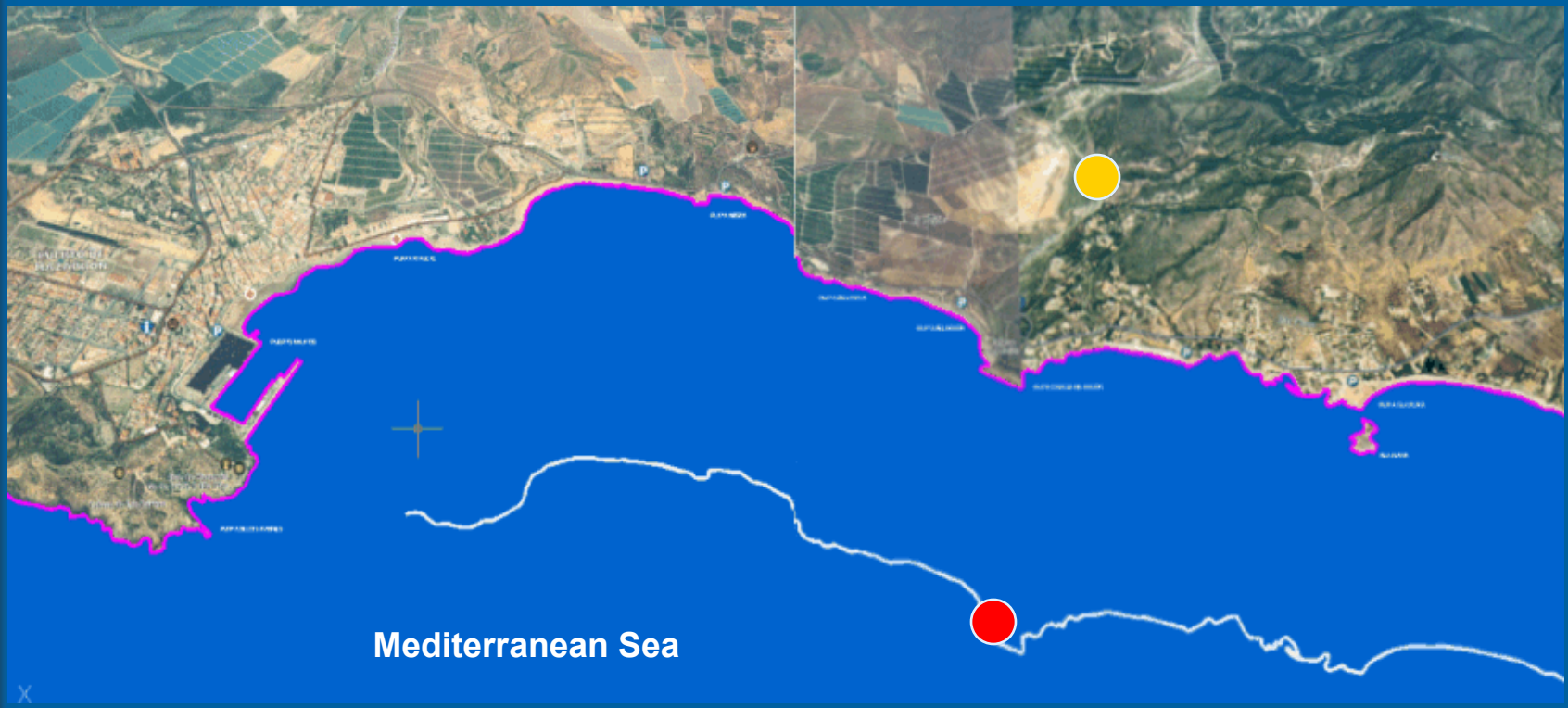
## 160.000 m<sup>3</sup>/day Campo de Cartagena SWRO Plant

- Seawater analysis campaign
- Open intake
- Mazarron Bay location
- Surface and depth samples
- T°, pH, CE, SDI on field
- Boron level



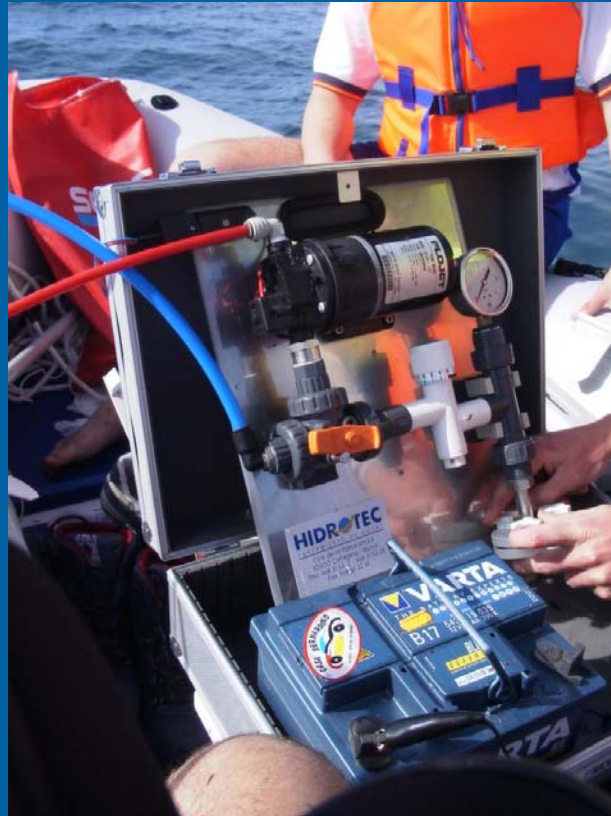
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160.000 m<sup>3</sup>/day Campo de Cartagena SWRO Plant

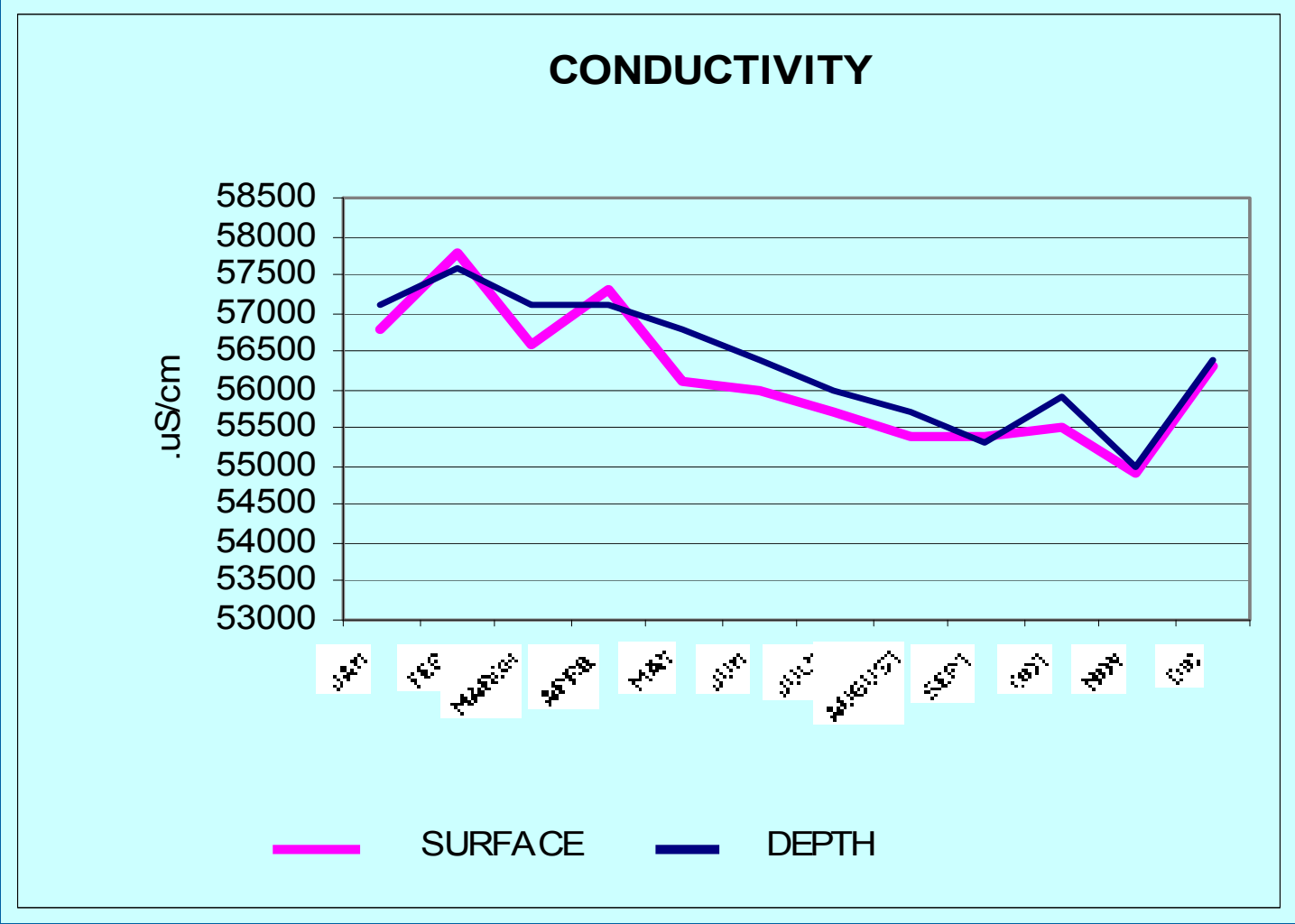


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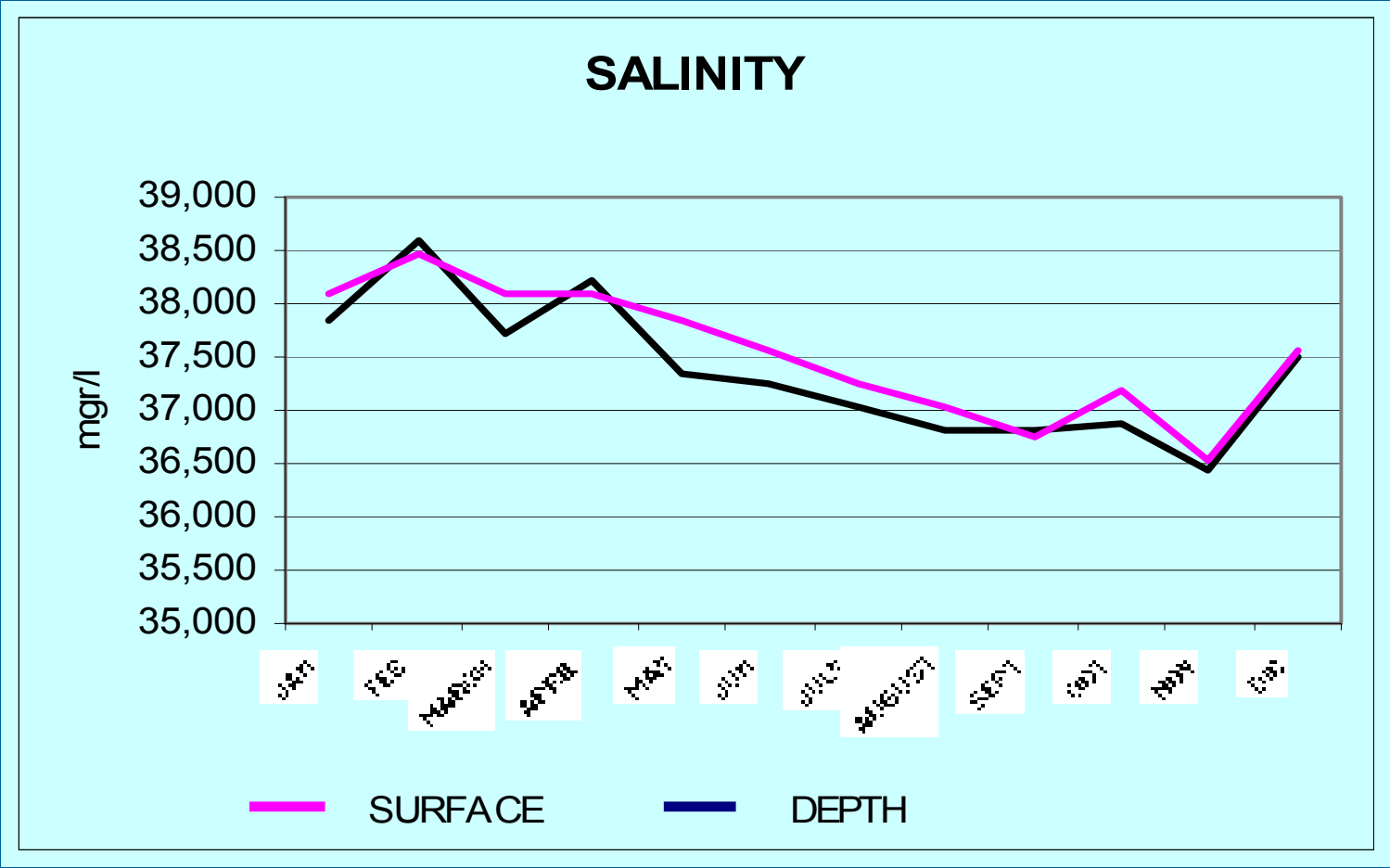
- Portable SDI meter



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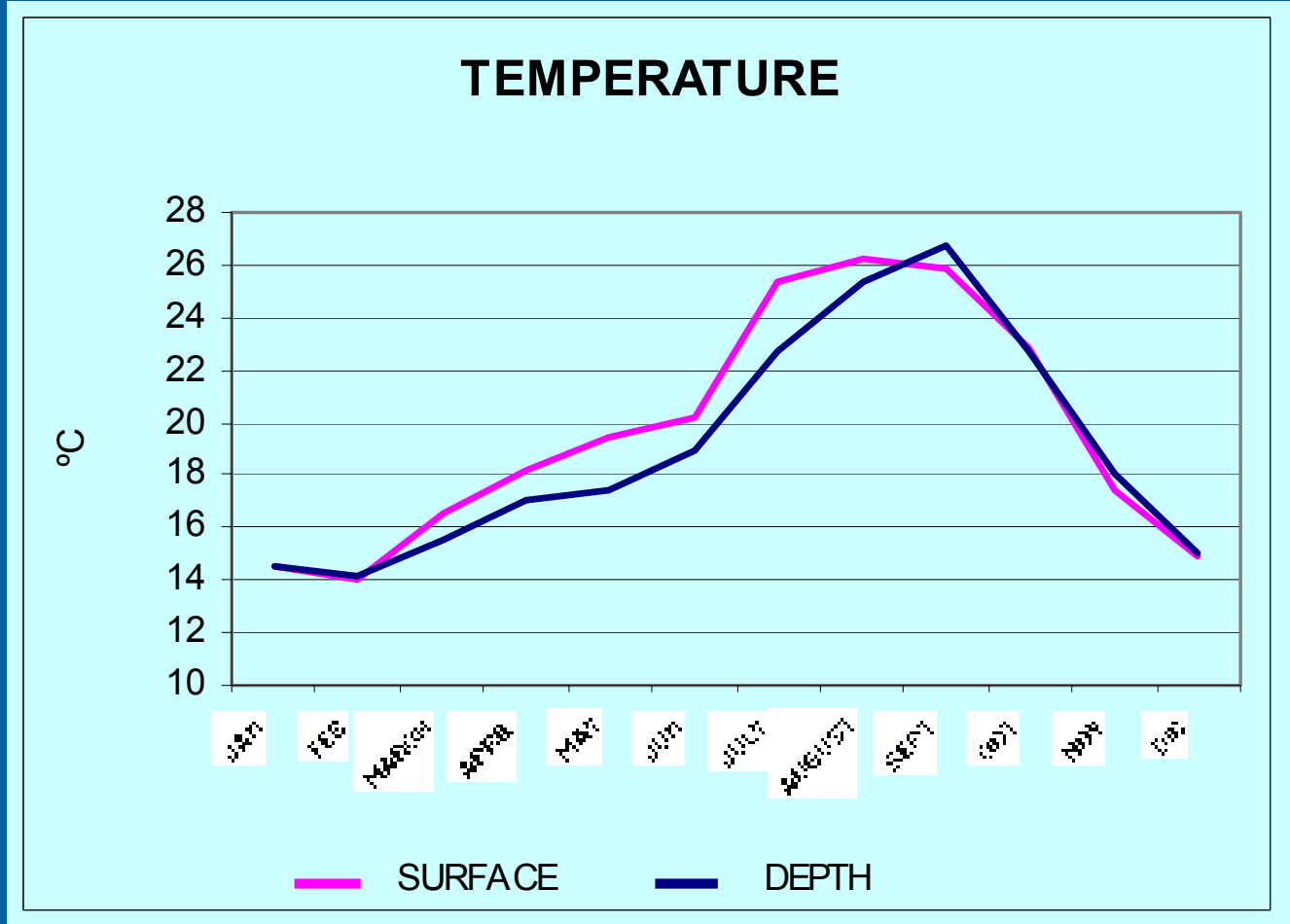


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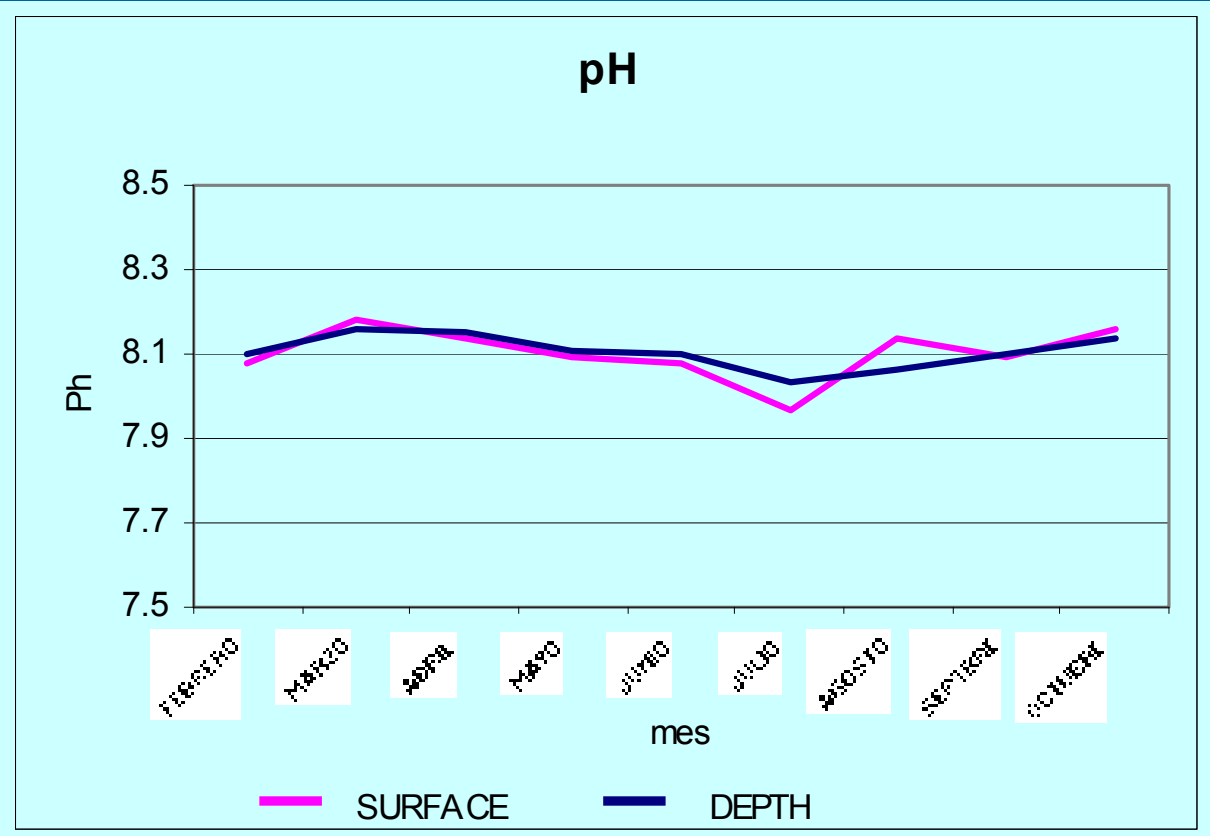


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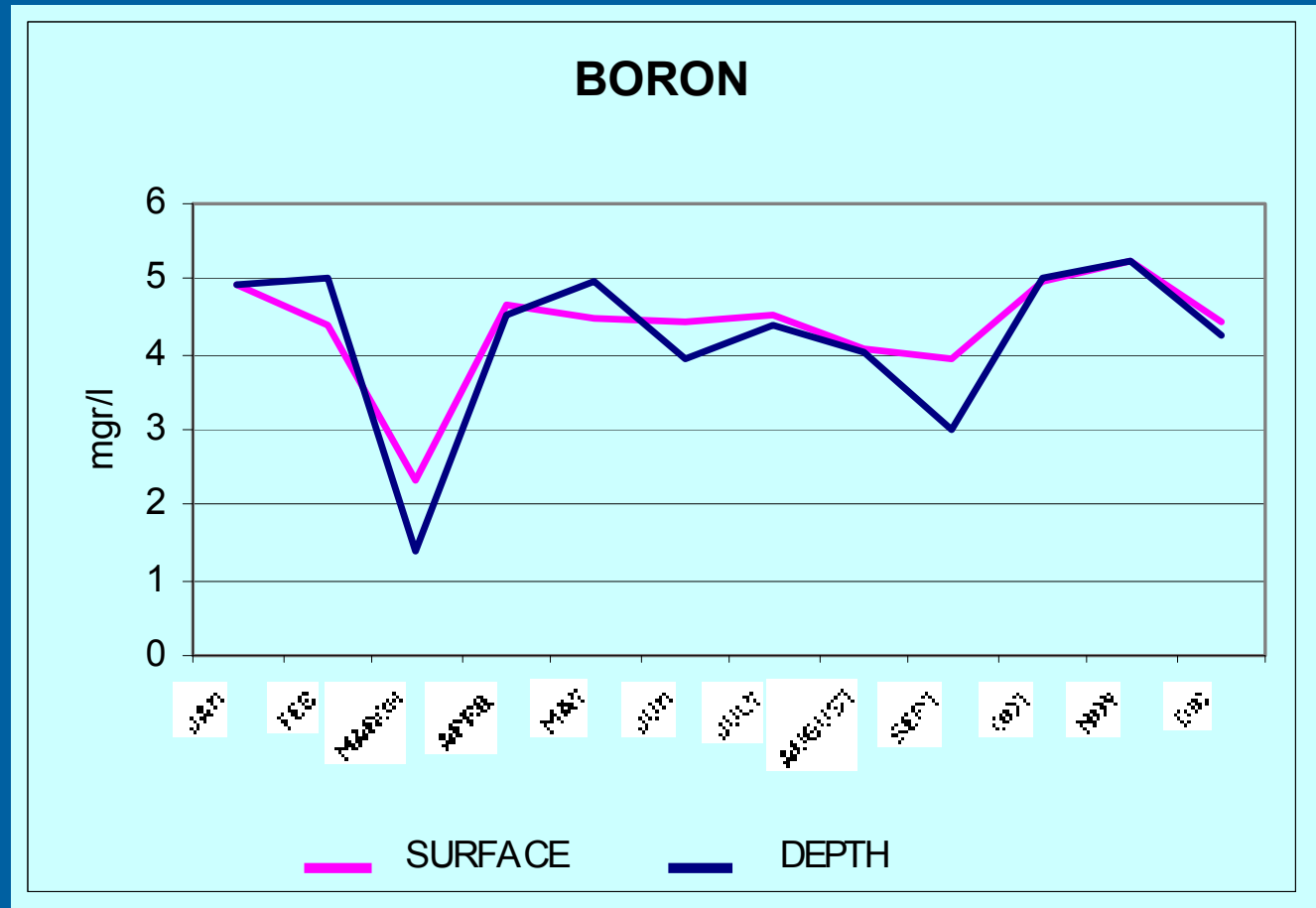




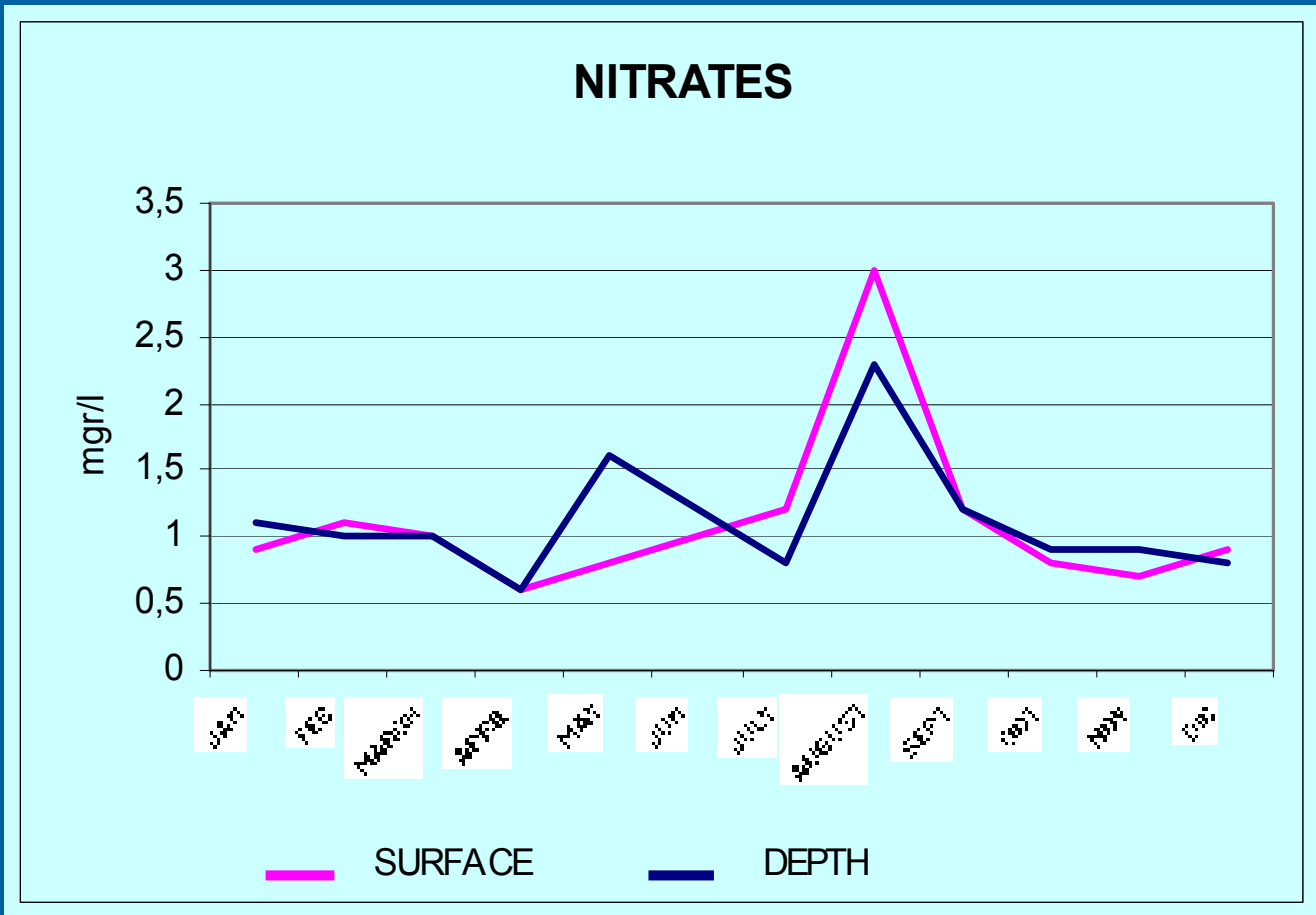
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# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION

- TDS — Conductivity —————→ CROP
- Sodium Absorption Rate (SAR) —————→ SOIL
- Specific Toxicity —————→ CROP
  - Chloride
  - Sodium
  - Boron
- PH —————→ CROP/SOIL



# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION

Chloride tolerance ppm	
Lemon	355
Orange	355
Lettuce	355
Onion	355
Cabbage	525
Tomato	825
Broccoli	875
Cotton	1675

Tanji, Kk. (1990)



# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION

Boron levels ppm			
Water quality	Excelent	Good	Inapropiate
Cotton	< 0.67	0.67 - 1.33	> 2.50
Brccoli	< 1	2 - 3	> 3.75
Cabbage	< 1	2 - 3	> 3.75
Lettuce	< 1	2 - 3	> 3.75
Onion	< 1	2 - 3	> 3.75
Tomato	< 0.67	0.67 - 1.33	> 2.50
Lemon	< 0.33	0.67- 1.25	> 1.5
Orange	< 0.33	0.67- 1.25	> 1.5

Leeden. (1990)



# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION

USE RESTRICTION		NONE	MODERATE	SEVERE
EC	dS/m	< 0.7	0.7 - 3.0	> 3.0
TDS	mgr/l	< 450	450 - 2000	> 2000
<b>SAR</b>				
0 - 3 y EC		> 0.7	0.7 - 0.2	< 0.2
3 - 6 y EC		> 1.2	1.2 - 0.3	< 0.3
6 - 12 y EC		> 1.9	1.9 - 0.5	< 0.5
12 - 20 y EC		> 2.9	2.9 - 1.3	< 1.3
20 - 40 y EC		> 5.0	5.0 - 5.9	< 2.9
Sodium (Na)				
Surface irrigation	SAR	< 3	3 - 9	> 9
<b>Chlorides(Cl)</b>				
Surface irrigation	mgr/l	< 140	140 - 355	> 355
<b>Boron (B)</b>				
	mgr/l	< 0.7	0.7 - 3.0	> 3.0
<b>pH</b>		6.5 - 8.4		

Source: FAO



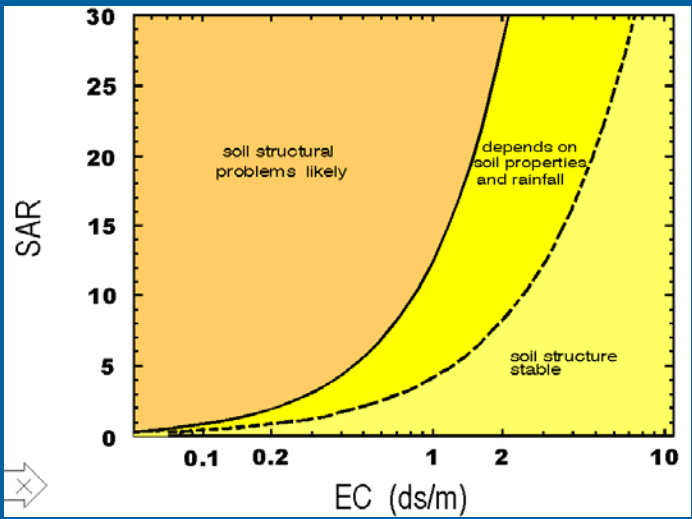
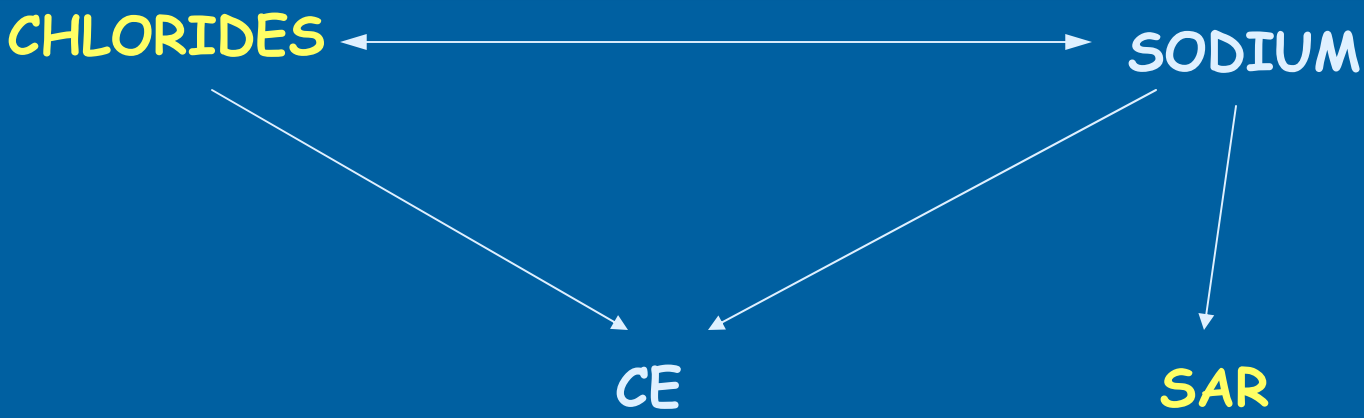


# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION

	SEAWATER . 50 %		
	RAW WATER	PERMEATE	%
Ca <sup>++</sup>	400	1.0	2.59
Mg <sup>++</sup>	1500	3.3	0.86
Na <sup>+</sup>	12500	136.6	<b>35.40</b>
K <sup>+</sup>	397	6.0	1.55
Sr <sup>++</sup>	0.1	0.001	
CO <sub>3</sub> <sup>--</sup>			
HCO <sub>3</sub> <sup>-</sup>	200	2.9	0.75
SO <sub>4</sub> <sup>--</sup>	3500	5.2	1.35
Cl <sup>-</sup>	20015	221.8	<b>57.47</b>
NO <sub>3</sub> <sup>-</sup>		0.1	0.03
TDS	<b>38513</b>	<b>387</b>	100
pH	8	5.9	



# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION



SOIL STRUCTURE EFFECT



# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION

- AGRICULTURE IN MURCIA

- CITRUS AND VEGETABLES
- LOAN AND CLAY SOILS

- DESALTED WATER FOR IRRIGATION

- CHLORIDES  $\longrightarrow$  300 ppm
- SAR  $\longrightarrow$  < 8
- BORON  $\longrightarrow$  < 1 ppm

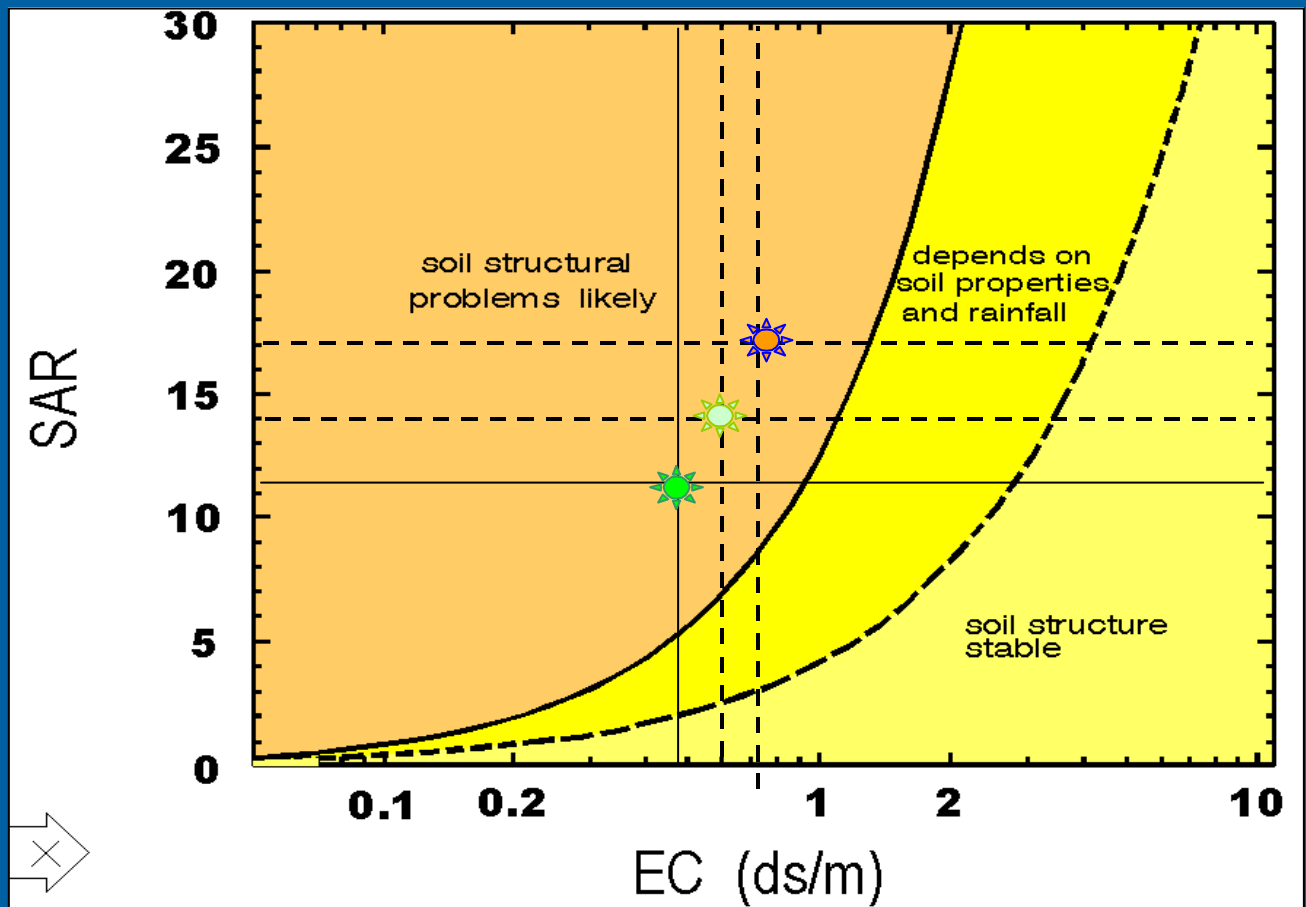


# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION

		PERMEATE		
		R1	R2	R3
Magnesium	ppm	5	5	5
Calcium	ppm	1.6	1.6	1.6
Sodium	ppm	130	162	195
Chloride	ppm	<b>200</b>	<b>250</b>	<b>300</b>
TDS	ppm	336.5	418.9	501.4
Ca added	ppm			
<b>SAR</b>		<b>11.4</b>	<b>14.3</b>	<b>17.1</b>
TDS final	ppm	336.5	418.9	501.4
<b>CE</b>	μS/cm	<b>480.7</b>	<b>598.5</b>	<b>716.3</b>



# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION



-  R1
-  R2
-  R3

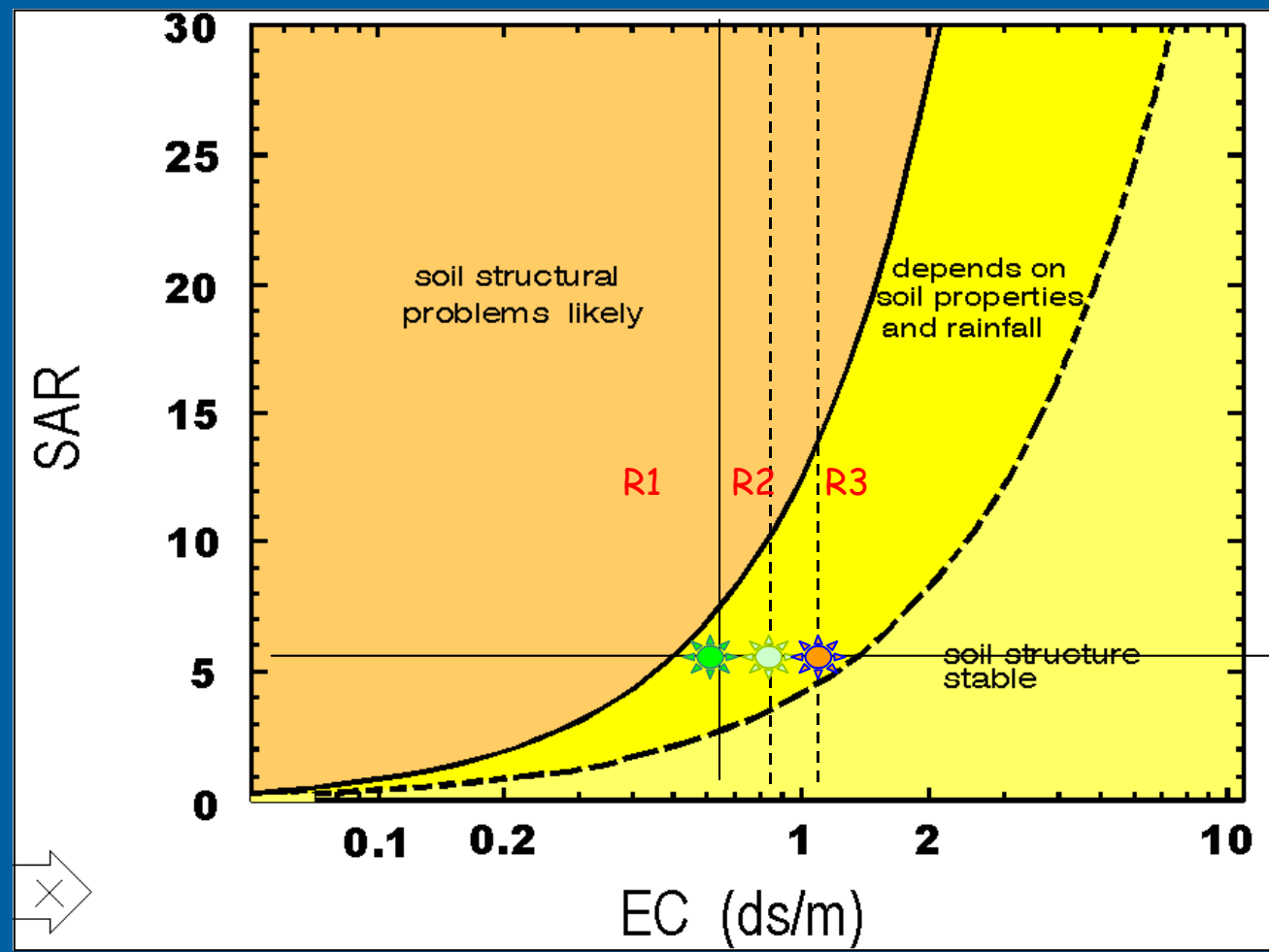


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		PERMEATE		
		R1	R2	R3
Magnesium	ppm	5	5	5
Calcium	ppm	1.6	1.6	1.6
Sodium	ppm	130	162	195
Chloride	ppm	200	250	300
TDS	ppm	336.5	418.9	501.4
Ca added	ppm	<b>45</b>	<b>75</b>	<b>115</b>
<b>SAR</b>		<b>4.8</b>	<b>4.8</b>	<b>4.8</b>
TDS final	ppm	381.5	493.9	616.4
<b>CE</b>	μS/cm	<b>545.0</b>	<b>705.6</b>	<b>880.6</b>



# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION





# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION

## GUIDELINES FOR DRINKING WATER

		SPAIN		EUROPE	WHO	EPA
		Guide level	Max.			
Conductivity	μS/cm	400 a 20 °C	-	2500 a 20 °C		-
TDS	mgr/l	-	-	-	600* 1000	-
Chloride	mgr/l	25	-	250	250*	-
Sodium	mgr/l	20	150	200	200*	-
Boron	mgr/l	1	-	1	0.5**	-
pH		6.5 - 8.5	9.5	6.5 - 9.5	6.5 - 9.5	-

\* Límits set by taste proprieties



# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION

- Drinking water limits are based on taste properties
- What's the utility of TDS maximum for irrigation?
- Lower TDS means higher cost
  - R1 quality (TDS < 400 ppm) worst quality for irrigation (soil structure)

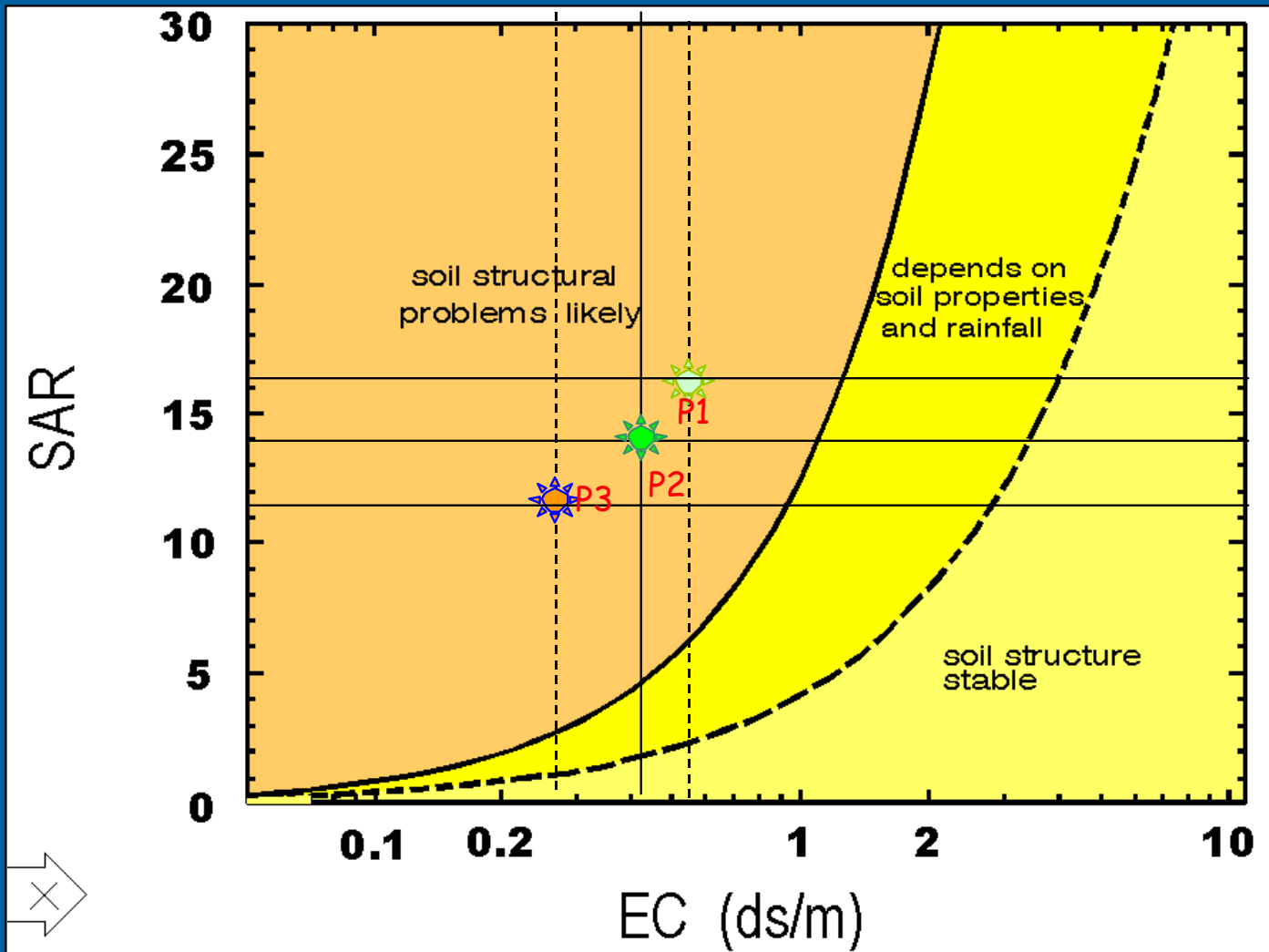


# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION

		PERMEATE		
		P1	P2	P3
Magnesium	ppm	2.7	3.5	1.8
Calcium	ppm	0.8	1.1	0.6
Sodium	ppm	116	154	78
Chloride	ppm	179	237.6	120
TDS	ppm	298.5	396.5	199.3
<b>Boron</b>	ppm	<b>&lt; 1</b>	<b>&lt; 1</b>	<b>&lt; 0.5</b>
<b>SAR</b>		<b>14.04</b>	<b>16.2</b>	<b>11.3</b>
TDS final	ppm	298.5	396.5	199.3
<b>CE</b>	$\mu\text{S/cm}$	<b>426.3</b>	<b>566.4</b>	<b>284.8</b>



# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION



# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION

		CONFIGURATION		
		P1	P2	P3
Stages		Double	Double	Double
Pass		Simple	Simple	Double
N° membranes		1022	1092	1272
N° pvs		146	156	186
Feed pressure	Bar	64.5	61.5	62.6
Booster pressure	Bar	12	12	12
2 <sup>nd</sup> pass pressure	Bar			16
Recovery	%	50	50	50 (85)
<b>Consumption</b>	kWh/m <sup>3</sup>			<b>3.91</b>
	kWh/m <sup>3</sup>			<b>1.22</b>
	kWh/m <sup>3</sup>	<b>4.03</b>	<b>3.84</b>	<b>5.13</b>



# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION

- WATER QUALITY FOR IRRIGATION
  - SALINITY
    - Chloride concentration < 300 ppm
  - SODIUM ABSORTION RATE < 8
  - SPECIFIC ION TOXICITY
    - Boron concentration < 1 ppm



# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION

- MEMBRANE SELECTION

M	Model	Production		Area		SR	Test conditions			
		Gpd	M3/d	Ft2	M2	%	Psi	Gr/l	T°	pH
A	A1	6200	23.5	315	29.26	99.0	800	32.0	25	7
	A2	5900	22.3	370	34.37	99.6	800	32.0	25	7
B	B1	6000	22.7	360	33.45	99.6	800	32.8	25	7.5
	B2	8200	31.0	370	34.37	99.6	800	32.8	25	7.5
C	C1	6000	23	300	27.87	99.1	800	32.0	25	8
	C2	6000	23	380	35.30	99.6	800	32.0	25	8
D	D1	5280	20	355	32.98	99.7	800	35.0	25	6.5
	D2	5020	19	345	32.05	99.7	800	35.0	25	6.5





# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION

## RO CONFIGURATION

B MANUFACTURER	1	2	3	4	5	6	7	8	9	10	11	12	13	
Model	B1	B2	B2	B2	B2	B1	B1	B2	B2	B2	B2	B2	B2	
Stage	simple	simple	simple	double	double	double	double	double	double	double	double	double	double	
Permeate flow	10000	10000	10000	11000	11000	11000	10000	10000	10000	10000	10000	10000	10000	m3/d
Recommended pump pressure	75	68.4	76.2	70.1	67.2	75.5	65.1	58.2	58.1	52.8	52	56.5	55.2	bar
Feed pressure	73	66.4	74.2	68.1	65.2	73.5	63.1	56.2	56.1	50.8	50.8	54.5	53.2	bar
Booster pump				10	15	15	20	20	25	30	25	25	25	bar
Brine pressure	72.5	66	73.7	75.7	77.7	86.1	81.1	74.3	78.9	78.2	72.5	77.2	76	bar
Average flux rate	12.7	12.4	13.6	13.6	13.6	14	11.9	11.6	12.4	12.4	11.6	12.4	11.9	l/m2-hr
Recovery	45	45	50	50	50	50	50	50	50	50	47	50	50	%
TDS permeate	342	426	416	395	390	314	365	452	416	393	427	417	434	mg/l
N° of membranes	980	980	980	980	980	980	1050	1050	980	980	1050	980	1022	
pvs	140	140	140	80/60	80/60	80/60	80/70	80/70	80/60	80/60	75/75	70/70	73/73	
<b>HIGH PRESSURE PUMP</b>														
FLOW PER PUMP	925.93	925.93	833.33	916.67	916.67	916.67	833.33	833.33	833.33	833.33	886.52	833.33	833.33	m3/h
PRESSURE	750	684	762	701	672	755	651	582	581	528	520	565	552	m
PERFORMANCE	85	85	85	85	85	85	85	85	85	85	85	85	85	%
POWER HYD.	2300	2097	2103	2128	2040	2292	1796	1606	1603	1457	1527	1559	1523	kW
MOTOR PERFORMANCE	94	94	94	94	94	94	94	94	94	94	94	94	94	%
MOTOR POWER	2446	2231	2237	2264	2170	2438	1911	1709	1706	1550	1624	1659	1620	kW
CONSUMPTION	5.87	5.35	5.37	4.94	4.73	5.32	4.59	4.10	4.09	3.72	3.90	3.98	3.89	kWh/m3
<b>BOOSTER</b>														
FLOW	593	593	533	587	587	587	533	533	533	533	567	533	533	m3/h
PRESSURE	0	0	0	100	150	150	200	200	250	300	250	250	250	m
PERFORMANCE	84	84	84	84	84	84	84	84	84	84	84	84	84	%
POWER HYD.	0	0	0	190	285	285	346	346	433	519	460	433	433	kW
MOTOR PERFORMANCE	94	94	94	94	94	94	94	94	94	94	94	94	94	%
MOTOR POWER	0.0	0.0	0.0	202.5	303.7	303.7	368.1	368.1	460.1	552.1	489.5	460.1	460.1	kW
<b>ERT</b>														
FLOW	509	509	417	458	458	458	417	417	417	417	470	417	417	m3/h
PRESSURE	725	660	737	757	777	861	811	743	789	782	725	772	760	m
PERFORMANCE	86	86	86	86	86	86	86	86	86	86	86	86	86	%
POWER HYD.	995	906	828	935	960	1063	911	834	886	878	918	867	853	kW
TOTAL POWER HYD	1305	1191	1275	1193	1080	1228	886	772	717	579	609	692	670	kW
ELEC. POWER	1388	1268	1357	1471	1453	1610	1310	1189	1223	1168	1137	1197	1173	kW
CONSUMPTION	3.33	3.04	3.26	3.21	3.17	3.51	3.15	2.85	2.94	2.80	2.73	2.87	2.81	kWh/m3



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- ENERGY REQUIREMENTS OF MEMBRANES

M	Model	Stage	Consumption	Consumption simple vs. double	consumption differences
			kWh/m3	%	%
A	A1	S	3.1	1.61	15.81
	A1	D	3.05		14.43
	A2	S	3.16	6.33	17.41
	A2	D	2.96		11.82
B	B1	S	3.33	5.41	21.62
	B1	D	3.15		17.14
	B2	S	3.04	10.20	14.14
	B2	D	2.73		4.40
C	C1	S	3.04	-2.30	14.14
	C1	D	3.11		16.08
	C2	S	3.04	0.33	14.14
	C2	D	3.03		13.86
D	D1	S	3.03	9.57	13.86
	D1	D	2.74		4.74
	D2	S	3.00	13	13.00
	D2	D	2.61		0.00



# DESIGN OPTIMIZATION OF SWRO PLANTS FOR IRRIGATION

## CONCLUSIONS

- Differences between Irrigation Water and Drinking Water  
LOWER TDS ~~————→~~ BEST WATER
- SWRO Plants for irrigation depends on crops and soils
- Ion Toxicity, EC & SAR ~~————→~~ design criteria
- Operational cost reduction based on membrane selection, configuration and required water quality

