# Wastewater Reuse for Irrigation and Sea Water Intrusion in Cyprus: Evaluation of Salinity Effects on Soils

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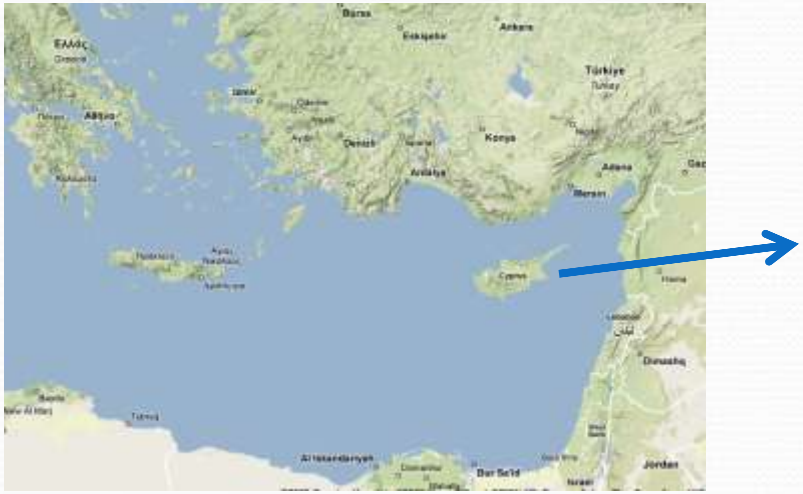
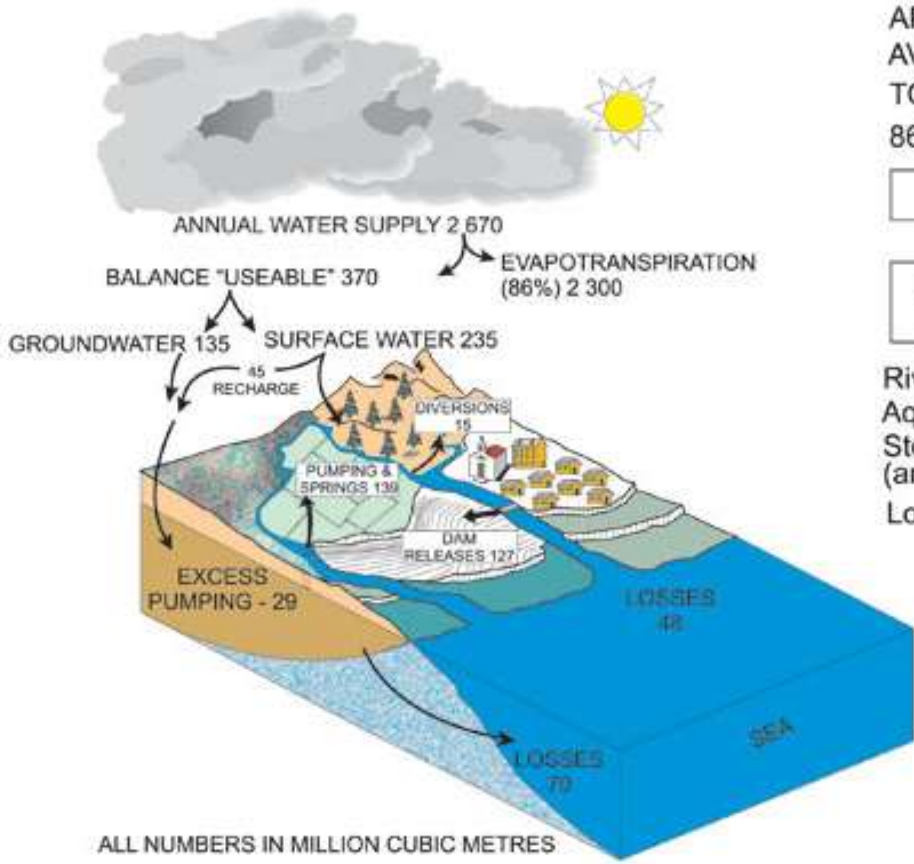
# Cyprus

- Area=9.250 km² (government controlled=5.800km²)
- Population ≈ 1 million
- Mediterranean Climate: hot, dry summers and cool winters
- Limited water resources
- Precipitation= 460 mm/year and maximum rain input , (rain × total island area)=2670 MCM
- Balance "Useable"= 370 MCM



# WATER BALANCE FOR CYPRUS
(GOVERNMENT CONTROLLED AREAS)

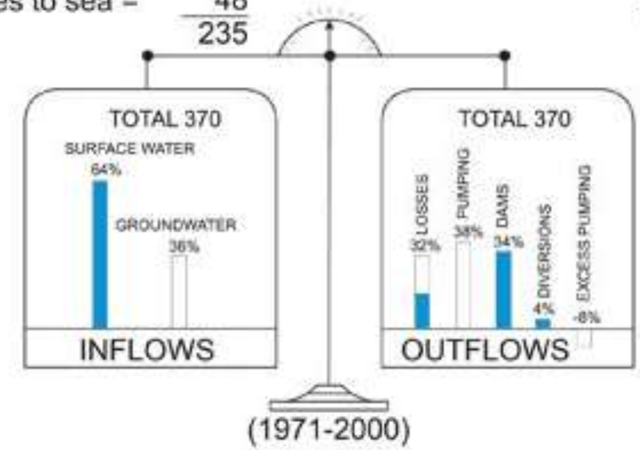



** Includes aquifer recharge from surface runoff*

AREA = 5 800 km$^2$
AVERAGE ANNUAL RAINFALL = 460 mm (1971-2000)
TOTAL ANNUAL WATER SUPPLY = 2 670 Mm$^3$
86% EVAPOTRASPIRATION = 2 300 Mm$^3$

BALANCE "USEABLE" = 370 Mm$^3$

| SURFACE WATER 235 | | GROUNDWATER 135 | |
|---|---|---|---|
| Rivers diversions = | 15 | Pumping / Springs | = 139 |
| Aquifer Recharge = | 45 | Losses to sea | = 70 |
| Stored in dams (and used) = | 127 | Excess pumping | = - 29 |
| Losses to sea = | 48 | | 180* |
| | 235 | | |



# Wastewater treatment plants

- Currently 25 WWTP producing about 20 MCM/year

⇒ 1.5 MCM were released to the sea
⇒ 10 MCM were supplied for irrigation (agriculture/parks)
⇒ 2 MCM diverted to dams
⇒ 3 MCM used for groundwater recharge

It is estimated that by the year 2012 about 30 MCM/year of treated wastewater will be available

# Irrigation Wastewater Characteristics

Table 1: Analyses of wastewater sample

RESULTS OF ANALYSIS SAMPLE: TERTIARY EFFLUENT

| | | | AVERAGE VALUE FOR THE MONTH | | | |
|---|---|---|---|---|---|---|
| **YEAR 2010** | **PARAMETER** | YEAR TO-DATE AVERAGE | **JAN** | **FEB** | **MAR** | **APRIL** |
| 1 | **Temperature** | 16,68 | 14,22 | 14,88 | 17,11 | 19,70 |
| 2 | **pH** | 7,23 | 7,23 | 7,24 | 7,17 | 7,29 |
| 3 | **Conductivity mS/cm** | 3,72 | 2,96 | 3,58 | 3,95 | 4,10 |
| 4 | **BOD5 (mg/l)** | 8 | 6 | 4 | 11 | 7 |
| 5 | **COD (mg/l)** | 34 | 43 | 44 | 26 | 29 |
| 6 | **Suspended Solids (mg/l)** | 12 | 14 | 13 | 12 | 14 |
| 7 | **NO3-N (mg/l)** | 6 | 9 | 5 | 6 | 6 |
| 8 | **NO2-N (mg/l)** | 4 | 5 | 5 | 3 | 3 |
| 9 | **NH3-N (mg/l)** | 9 | 1 | 8 | 11 | 15 |
| 10 | **Total Kjeldahl Nitrogen (mg/l)** | 13 | 3 | 10 | 17 | 14 |
| 11 | **Total Phosphorus (mg/l)** | 4 | 5 | 4 | 4 | 5 |
| 12 | **Free Chlorine (mg/l)** | 0,49 | 0,87 | 0,32 | 0,42 | 0,40 |
| 13 | **Chlorides mg/l** | 538 | 230 | 600 | 780 | 540 |
| 14 | **Boron mg/l** | 1 | 1 | 1 | 1 | 1 |
| 15 | **E-COLI / 100ml** | 0 | 0 | 0 | 0 | 0 |
| 16 | **Eggs of Intestinal Worms / 1L** | 0 | 0 | | | 0 |

# Table 2: comments on the general analyses of the treated wastewater used

| Nr | Parameter | Value | Comments |
|---|---|---|---|
| 1 | Temperature | 16.68˚ C | OK. Does not exceed max 28˚C |
| 2 | pH | 7,23 | OK. between 6.5 - 8.4 normal |
| 3 | Conductivity mS/cm | 3.72 | **Severe Restriction on Use** (too conservative limit)<br>Yield potential: Corn (maize) ~78%; ~Alfalfa 70%<br>(Acceptable for tolerant and semi-tolerant crops) |
| 4 | BOD5 (mg/l) | 8 | According to the European norms it's OK |
| 5 | **COD (mg/l)** | 34 | |
| 6 | Suspended Solids (mg/l) | 12 | According to the European norms it's OK |
| 7 | $NO^3$-N (mg/l) | 6 | |
| 8 | $NO^2$-N (mg/l) | 4 | could be OK – under examination |
| 9 | $NH^3$-N (mg/l) | 9 | Normally: $NH_4$-N. Restrictions for use |
| 10 | Total Kjeldahl Nitrogen (mg/l) | 13 | under examination |
| 11 | Total Phosphorus (mg/l) | 4 | Some restrictions for use <3 |
| 12 | Free Chlorine (mg/l) | 0.49 | Under examination |
| 13 | Chlorides mg/l | 538 | Some restrictions <300 |
| 14 | Boron mg/l | 1 | OK. Maize – OK - Moderately tolerant (Toxicity > 2 mg/l)<br>Alfalfa – OK - Moderately tolerant (Toxicity > 4 mg/l) |
| 15 | E-COLI / 100ml | 0 | OK |
| 16 | Eggs of Intestinal Worms / 1L | 0 | OK |

# Table 3: The ion analyses and evaluation of TW

| Indicators | Dimension | | Restrictions on Use |
|---|---|---|---|
| **Electrical Conductivity (salinity of the applied irrigation water), $EC_w$** | mS/cm | 3.75 | **Severe Restriction on Use** (2 conservative limit) Yield potential: Corn (maize) ~78%; ~Alfalfa 70% (Acceptable for tolerant and semi-tolerant crops) |
| **Total Hardness** | mgeqv/$dm^3$ | 808 | **Very High** |
| **Sulphate ($SO4^{--}$)** | mg/$dm^3$ | 928 | **High concentration** (300 conservative limit). |
| **Carbonate ($CO_3^{--}$)** | mg/$dm^3$ | <6 | OK |
| **Bicarbonate ($HCO_3^-$)** ***(overhead sprinkling only)*** | mg/$dm^3$ | 296 | OK (300 conservative limit) Severe Restriction on Use (foliar injury) |
| **Sodium ($Na^+$)** | mg/$dm^3$ | 550 | **High concentration! Maize sensitive**; Alfalfa tolerant (foliar injury) (300 conservative limit). |
| **Potassium ($K^+$)** | mg/$dm^3$ | 29 | OK! |
| **Calcium ($Ca^{++}$)** | mg/$dm^3$ | 174 | OK! |
| **Magnesium ($Mg^{++}$)** | mg/$dm^3$ | 89 | OK! |
| **Iron (Fe)** | mg/$dm^3$ | <0.05 | OK! |
| **Manganese (Mn)** | mg/$dm^3$ | 0.13 | OK |
| **Lead (Pb)** | mg/$dm^3$ | <0.1 | **High concentration** Can inhibit plant cell growth at very high concentrations (0.05 conservative limit). |
| **Cadmium (Cd)** | mg/$dm^3$ | <0.025 | **High concentration** Conservative limits (0.01) recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans (0.01 conservative limit). |
| **Mercury (Hg)** | mg/$dm^3$ | 0.003 | **High concentration** 0.001 recommended conservative limit (0.001 conservative limit). |

# Table 4:Treated Wastewater Risk Assessment

| No | Risk Estimation Equations | Treated WW value | Criteria | Risk Estimation |
|---|---|---|---|---|
| 1 | $\frac{Ca + Mg}{Na + 0.23.C_{a}}$ | 0.45 | >1 | Sodium risk<br>YES |
| 2. | $\frac{100.(Ca + Mg)}{Na}$ | 48 | >60% | Sodium risk<br>YES |
| 3. | $\frac{100.Mg}{Ca + Mg}$ | 34 | <50% | Magnesium risk<br>NO |
| 4. | $\frac{288}{Na + 4.Cl}$ | 0.11 | 6-18 | Chloridization<br>risk<br>YES |
| 6. | $\frac{6620}{Na + 2.6Cl}$ | 3.4 | <1.2 | Chloridization<br>risk<br>YES |
| 7. | $\frac{(Na + K).100}{Ca + Mg + Na + K}$ | 69 | <66% | Alkalinization<br>possible |
| 8. | $\frac{Na.100}{Ca + Mg + Na + K}$ | 65 | <60% | Alkalinization<br>possible |
| 9. | $\frac{Na}{Ca + Mg}$ +Na | 0.68 | <0.6 | Alkalinization<br>possible |
| 10. | $\frac{Na}{Ca + Mg}$ | 2.1 | <0.7 | Alkalinization<br>possible |
| 12. | $\frac{Na + K}{Ca + Mg}$ | 2.2 | <1-No<br>1-4 -<br>possible<br>>4 - Yes | Alkalinization<br>possible |
| 12 | $\frac{8.Na}{Ca + Mg}$ | 20 | <8 | Alkalinization<br>possible |
| 13 | $SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$ | 6.83 | <10 | Danger<br>proximity |

# Summary of key values for TW

⇒EC level is very high (3.75 mS/cm)

⇒Also very high values in sulphates, sodium, cadmium and mercury

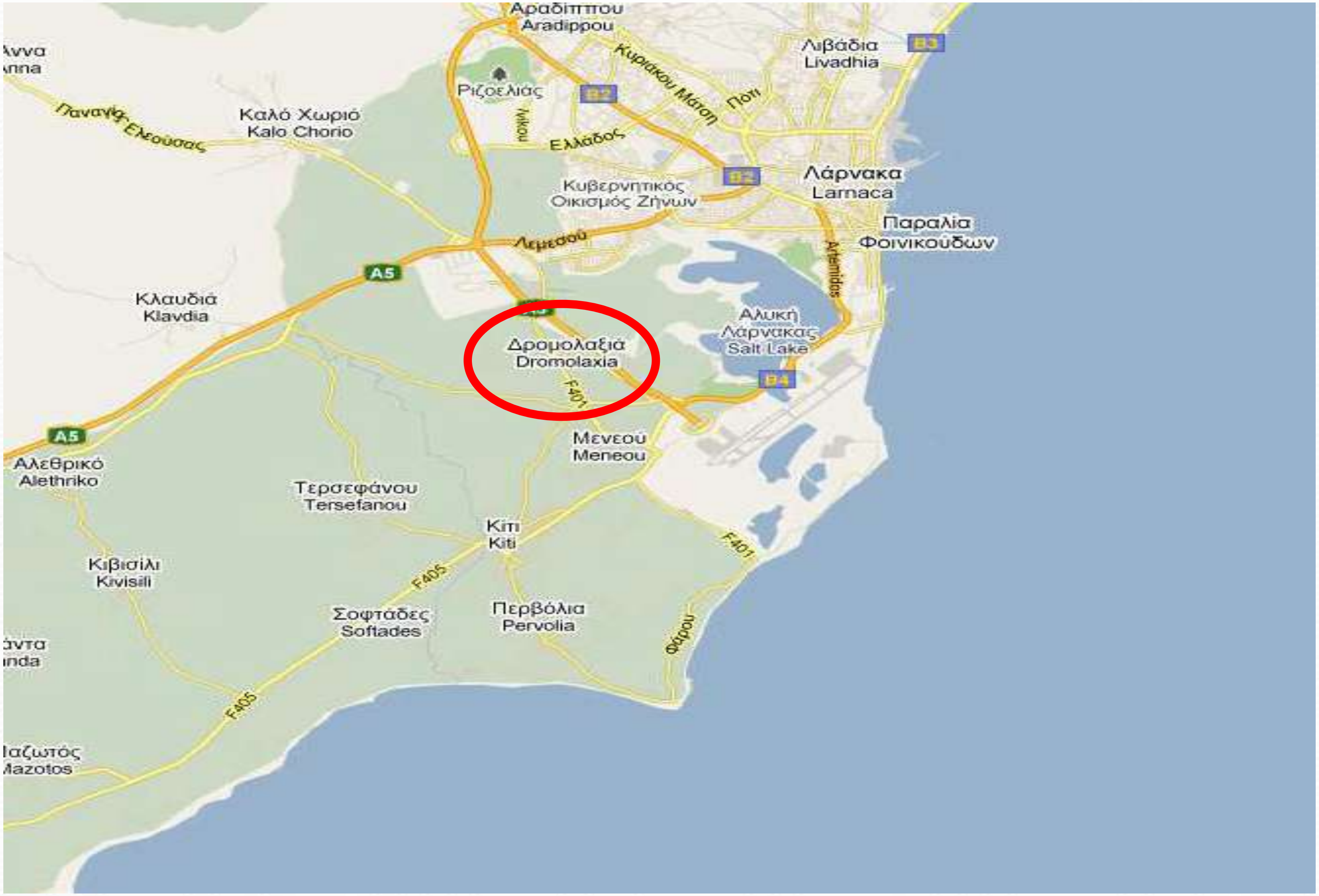
⇒Risk analysis show serious sodium risk, chloridization risk and possible alkalinization

⇒Calculated SAR ratio is 6.83 (acceptable but approaching dangerous levels)

⇒pH = 7.3

# Soil Evaluation

# Investigation site: Dromolaxia



# Investigation site – Different quality water irrigation


Not irrigated (yellow cl)=control

# Soil Salinity investigation

- Village of Dromolaxia selected: ample agricultural land irrigated with treated wastewater (TW) originating from the Larnaca WWTP.
- Other nearby fields are irrigated with freshwater (FW).
- After some years of irrigation , profile samples were taken at incremental depths (7.5, 27.5, 55 and 85 cm – root zone) from both irrigation fields, TW and FW, and also from non irrigated soil.

# Electrical Conductivity EC (mS/cm)

- Salinity is a soil property referring to the amount of soluble salts in the soil. It is generally a problem of arid and semiarid regions. Electrical conductivity (EC) is the most common measure of soil salinity and is indicative of the ability of an aqueous solution to carry an electric current. Plants are detrimentally affected, both physically and chemically, by excess salts in some soils and by high levels of exchangeable sodium in others. Electrical conductivity of the soil solution extracted from a saturated example of soil can give an indication of the salt levels.

# Sodium Adsorption Ratio (SAR)

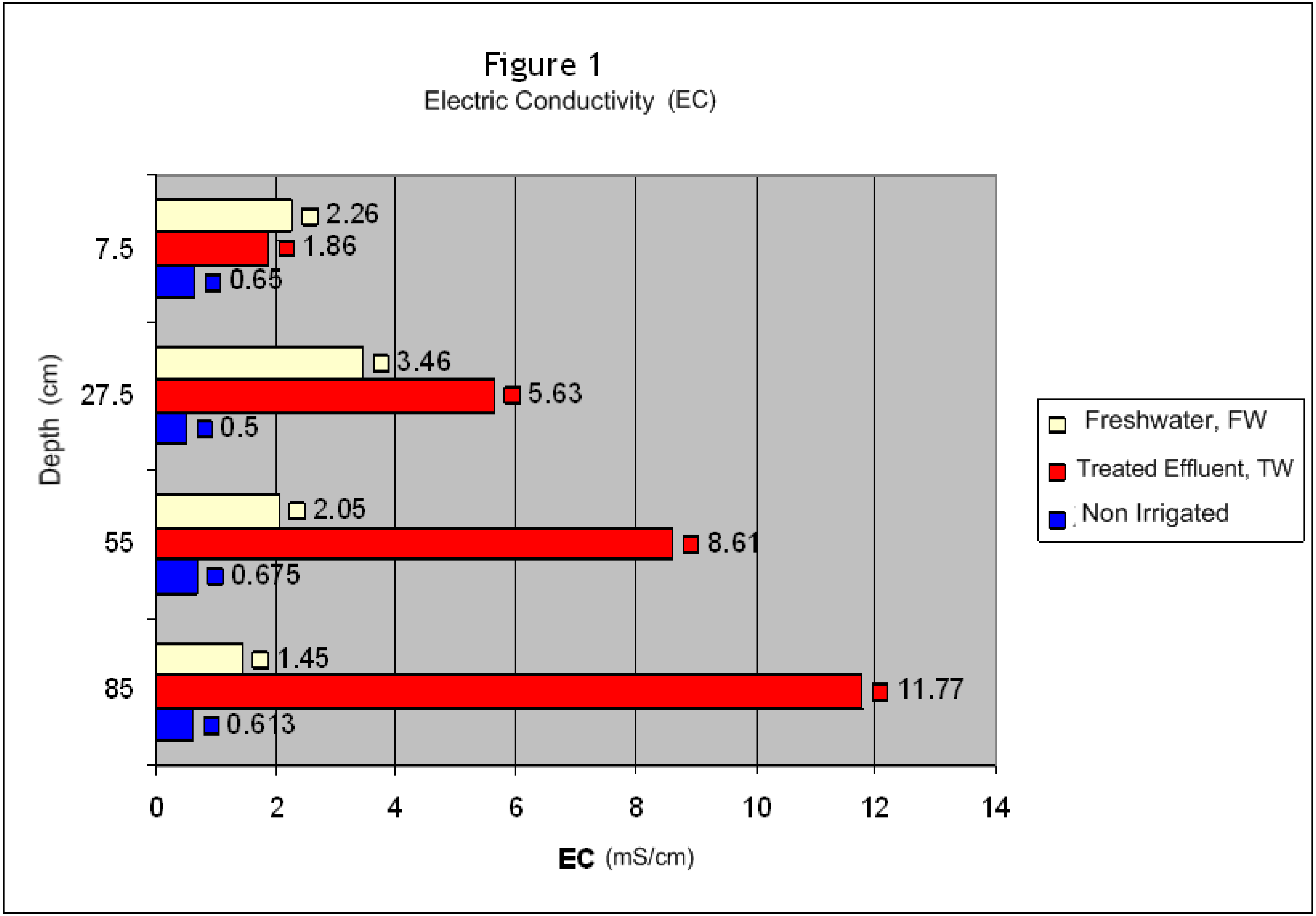
- A method for estimating the sodium hazard (in soils or water) is the **Sodium Adsorption Ratio (SAR),** which is the proportion of sodium (Na) ions compared to the concentration of calcium (Ca) plus magnesium (Mg):
- In general, the higher the sodium adsorption ratio, the less suitable the water is for irrigation. Irrigation using water with high sodium adsorption ratio may require soil amendments to prevent long-term damage to the soil.

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

- =>

where [Na+], [Ca2+] and [Mg2+] are the concentrations (in milliequivalent per liter) of the sodium, calcium, and magnesium ions in the soil solution.

Figure 1: Electric conductivity values of the soil profile

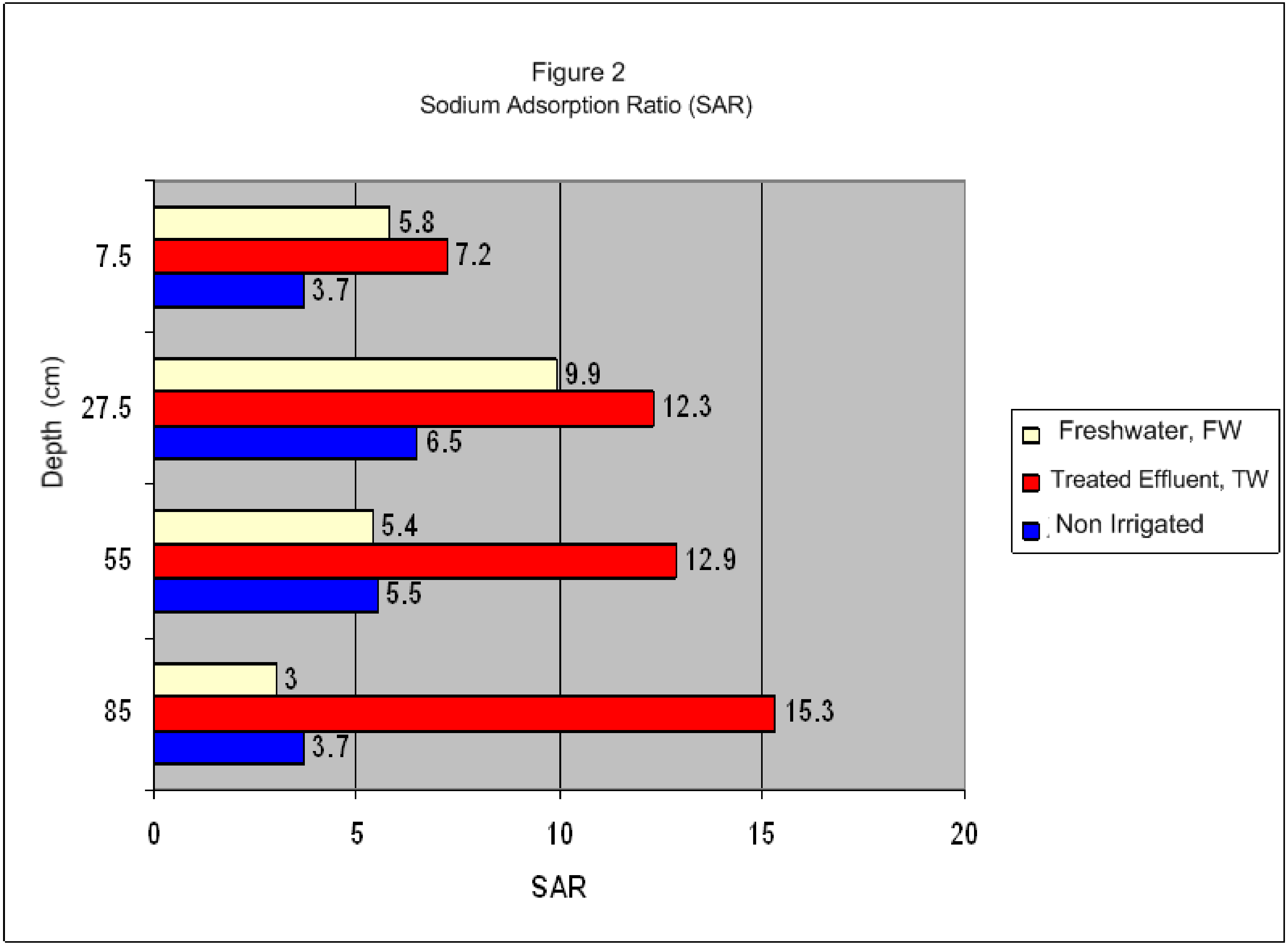


# Analyses of Results I

From fig.1, it is clear that:

- This treated wastewater applied as irrigation to soils for the number of years irrigated, raises the EC to very high levels, compared to soils irrigated with normal fresh water on non irrigated soils. In samples irrigated with treated wastewater, the EC values range from 1, 86 mS/cm at the surface layer to 11,77 mS/cm at the bottom zone while values of non irrigated soil, show minimum and maximum values ranging from 0, 5 to 0,675 mS/cm.
- Non irrigated soils, have EC values within the range of 0-2 mS/cm (fig.1), and as shown in table 6 below, they are classified as ‘non saline soils’ with ‘salinity effects negligible’.
- When the same soil is irrigated with treated wastewater, and after evaluation of the root zone (EC = roughly 7.0 mS/cm-fig.1), they move (table 6), to the range of ‘moderately saline’ where ‘yields of many crops are restricted’, and is approaching the next range of more severe effects.

**Figure 2. SAR values of the soil profile**



# Analyses of Results II

Figure 2 shows a great increase of the SAR over our profile under investigation.
Actually the increase was from an average profile value of 4.85 before irrigation, to the average profile value of 11.93 after about 10 years of irrigation with treated wastewater, and 'average' increase of 246%.
The SAR values of irrigated with treated wastewater soil, range from 7.2 at the surface to 15.3 at the bottom of our profile. When evaluation these numbers in terms of actual risks, table 5, we note that, soils that non irrigated soils are very close to the 'normal soils' category (average values SAR 4.85, EC 0.6 and pH 7.96.). Soils irrigated with treated wastewater, (average profile values SAR 11.93, EC 6.97 and pH 7.94), fall into the 'saline' category, with close proximity to the 'saline-sodic' zone. The bottom of the irrigated with treated wastewater soil profile, with an SAR of 15.3, actually falls into this 'saline-sodic zone.

**Table 5. Properties of normal soils compared to Acid, Saline, Sodic, and Saline-Sodic soils**

| Soil | Common PH | Electric conductivity EC (dS/m) | SAR |
|---|---|---|---|
| **Normal** | 6.5-7.2 | <4 | <13-15 |
| **Acid** | <6.5 | <4 | <13-15 |
| Saline | <8.5 | >4 | <13-15 |
| **Saline-Sodic** | <8.5 | >4 | >13-15 |
| **Sodic** | <8.5 | <4 | >13-15 |

Table 6. Soil salinity classes or categories

| Soil Salinity Class | Conductivity of the Saturation Extract (dS/m) | Effect on Crop Plants |
|---|---|---|
| **Non saline** | **0 - 2** | **Salinity effects negligible** |
| Slightly saline | 2 - 4 | Yields of sensitive crops may be restricted |
| **Moderately saline** | **4 - 8** | **Yields of many crops are restricted** |
| Strongly saline | 8 - 16 | Only tolerant crops yield satisfactorily |
| Very strongly saline | > 16 | Only a few very tolerant crops yield satisfactorily |

# Key findings

- The effects of the increase of salinity in the soils irrigated with treated wastewater as compare to the soils irrigated with fresh water is very clear in this investigation. Great increase of salt levels, EC and SAR in all layers of these soil profiles is detected.

- If irrigation water with a high SAR is applied to a soil for years, the sodium in the water can displace the calcium and magnesium in the soil. This will cause increase of soil SAR, eventually decreasing the ability of the soil to form stable aggregates with a loss of soil structure and cultivation potential. This also leads to a decrease in infiltration and permeability of the soil profile to water, leading to problems with crop production.

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# Conclusions

The effects of the increase of salinity in the soils irrigated with treated wastewater as compare to the soils irrigated with fresh water is very clear in this investigation. There is a great increase of salt levels, EC and SAR in all layers of these soil profiles. If irrigation water with a high SAR is applied to a soil for years, the sodium in the water can displace the calcium and magnesium in the soil. This will causes increase of soil SAR, eventually decreasing the ability of the soil to form stable aggregates with a loss of soil structure and cultivation potential. This also leads to a decrease in infiltration and permeability of the soil profile to water, leading to problems with crop production

Some possible improvement measures including the adaptation of proper irrigation management strategies are:

-Mixing of the TW with FW or desalinated water in order to lower total EC to 2.5 or below.

-Apply 'leaching' between irrigation periods,

-Improve sewerage collection pipes – control of infiltration.

-Crop selection- select crop tolerant to salinity.

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*Thank you for your attention*

**GRACIAS POR SU ATENCIÓN**