Soil salinity

On web page lectures

Introduction

Soil salinity is the salt content in the soil. Salts occur naturally within soils and water.

The process of soils becoming salty is known as salinization or salination.

Salination can be caused by natural processes such as mineral weathering or by the gradual withdrawal of an ocean leaving salts behind.

It can also come about through artificial processes such as irrigation.

Salty (saline) soils are soils that have a high salt content. The predominant salt is normally sodium chloride (NaCl, "table salt"). Saline soils are therefore also *saline sodic soils.* However*,* there may be sodic soils that are not saline, but alkaline, owing to the presence of Soda (Na2CO3)

Appearance of salt on the soil as a result of a shallow water table

The primary method of controlling soil salinity is to permit 10-20% of the irrigation water to leach the soil,that will be drained and discharged through an appropriate drainage system. The salt concentration of the drainage water is normally 5 to 10 times higher than that of the irrigation water, thus salt export matches salt import and it will not accumulate.

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1. Causes


Salinized irrigated land with poor crop stand

Primary cause

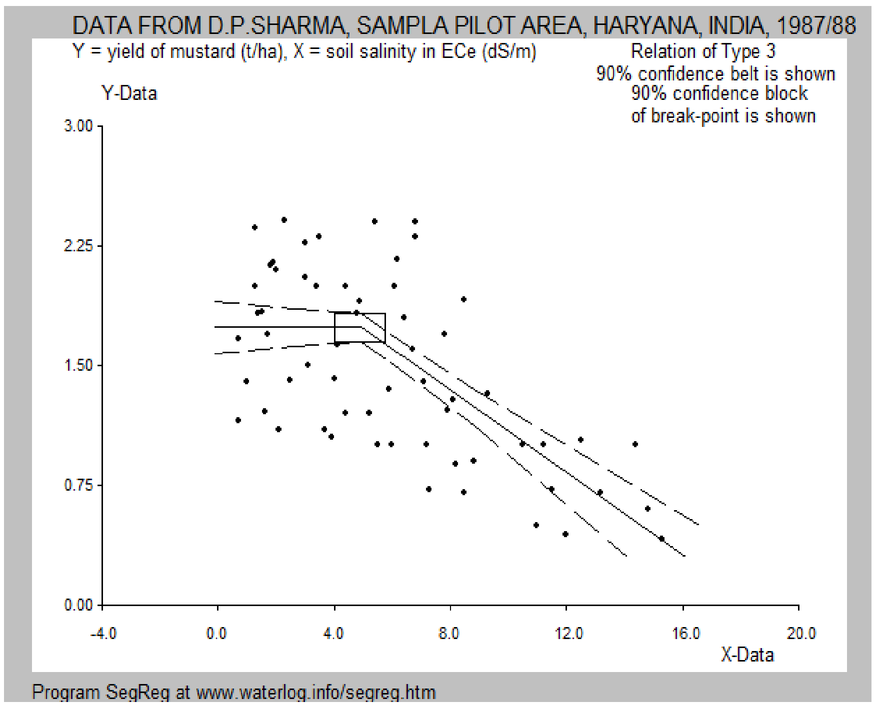
The primary cause of man-made salinization is the salt brought in with irrigation water. All irrigation water derived from rivers or groundwater, however 'sweet', contains salts that remain behind in the soil after the water has evaporated.

For example, assuming irrigation water with a low salt concentration of 0.3 g/l (equal to 0.3 kg/m3, corresponding to an electric conductivity, EC, of about 0.5 dS/m) and a modest annual supply of irrigation water of 10,000 m3/ha (almost 3 mm/day) brings 3,000 kg salt/ha each year. In the absence of sufficient natural drainage (as in waterlogged soils) and without a proper leaching and drainage program to remove salts, this would lead in the long run to a high soil salinity and reduced crop yields in the long run.

Much of the water used in irrigation has a higher salt content than in this example, which is compounded by that fact that many irrigation projects use a far greater annual supply of water. Sugar cane, for example, needs about 20,000 m3/ha of water per year. As a result, irrigated areas often receive more than 3,000 kg/ha of salt per year and some receive as much as 10,000 kg/ha/year.

Normally, the salinization of agricultural land affects a considerable area of irrigation projects, on the order of 20 to 30%. When the agriculture in such a fraction of the land is abandoned, a new salt and water balance is attained, a new equilibrium is reached, and the situation becomes stable.

Saline soils reduce the crop yield, see for example the figure below



SegReg program: yield of mustard (colza) and soil salinity

The graph was prepared with the computer program SegReg (https://www.waterlog.info/segreg.htm) for segmented regression

Secondary cause

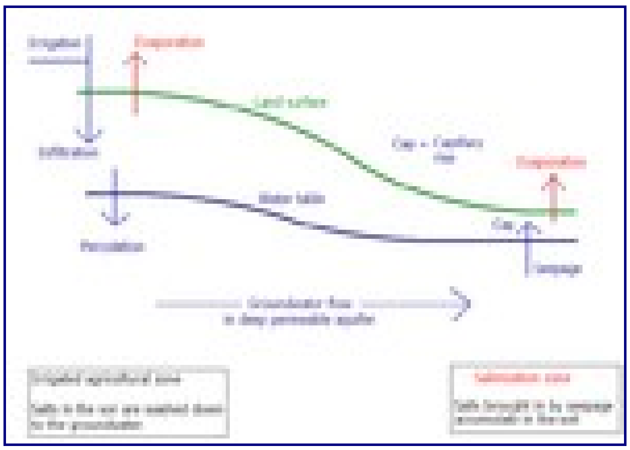
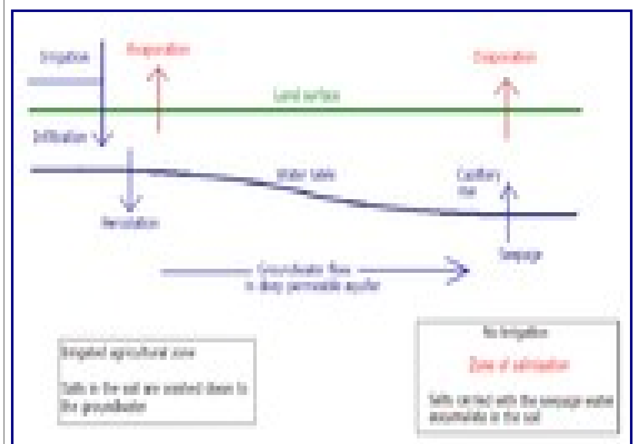
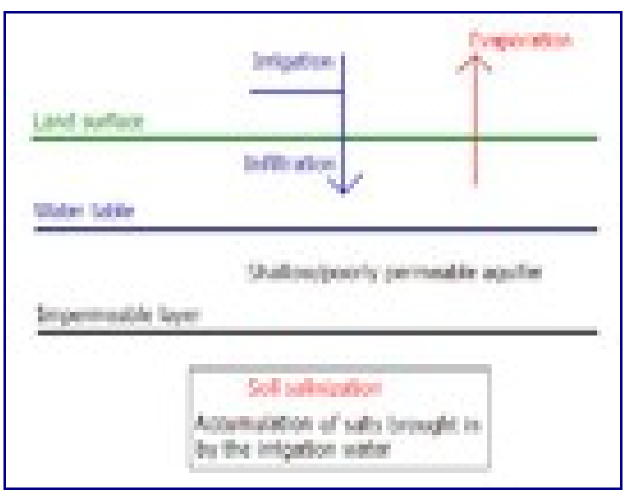
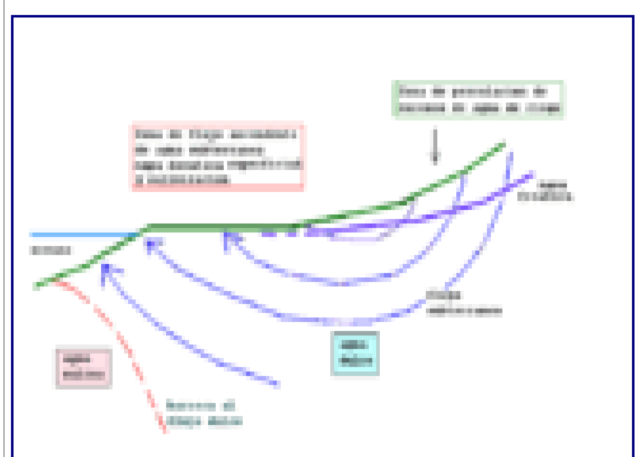
The secondary cause of salinization is waterlogging in irrigated land. Irrigation causes changes to the natural water balance of irrigated lands. Large quantities of water in irrigation projects are not consumed by plants and must go somewhere. In irrigation projects it is impossible to achieve 100% irrigation efficiency where all the irrigation water is consumed by the plants. The maximum attainable irrigation efficiency is about 70% but usually it is less than 60%. This means that minimum 30%, but usually more than 40% of the irrigation water is not evaporated and it must go somewhere.

Most of the water lost this way is stored underground which can change the original hydrology of local aquifers considerably. Many aquifers cannot absorb and transport these quantities of water and so the water table rises leading to water logging.

Waterlogging causes three problems:

- The shallow water table and lack of oxygenation of the root zone reduces the yield of most crops
- It leads to an accumulation of salts brought in with the irrigation water as their removal through the aquifer is blocked
- With the upward seepage of groundwater more salts are brought into the soil and the salination is aggravated

Aquifer conditions in irrigated land and the groundwater flow have an important role in soil salinization, as illustrated here :

 Soil salinization in the unirrigated parts of flat land with a good aquifer	 Soil salinization in the unirrigated parts of flat land with a good aquifer
 Soil salinization in irrigated flat land without an aquifer	 Soil salinization in a coastal delta from irrigation higher up

2. Global presence

Case studies:

A - In **India** 2.189.400 ha have been reported to suffer from waterlogging in irrigation canal commands. Also 3.469.100 ha were reported to be seriously salt affected here. (ref. 1, 2)

B - In the Indus Plains in **Pakistan**, more than 2 million hectares of land is waterlogged. The soil of 13.6 million hectares within the Gross Command Area was surveyed, which revealed that 3.1 million hectares (23%) was saline. 23% of this was in Sindh and 13% in the Punjab (Ref: Green Living Association Pakistan, Environmental Issues).

More than 3 million ha of water-logged lands have been provided with tube-wells and drains at the cost of billions of rupees, but the reclamation objectives were only partially achieved. (ref. 3)

The Asian Development Bank (ADB) states that 38% of the irrigated area is now waterlogged and 14% of the surface is too saline for use. (ref. 4);

3 - In the Nile delta of **Egypt,** drainage is being installed in millions of hectares to combat the water-logging resulting from the introduction of massive perennial irrigation after completion of the High Dam at Assuan (ref. 5).

5 - In Mexico, 15% of the 3.000.000 ha of irrigable land is salinized and 10% is waterlogged. (See: https://www.waterlog.info/pdf/mexican.pdf)

6 - In Peru some 300.000 ha of the 1.050.000 ha of irrigable land suffers from the salinity problem.

Reference: https://en.wikipedia.org/wiki/Irrigation_in_Peru

7 - Estimates indicate that roughly one-third of the irrigated land in the major irrigation countries is already badly affected by salinity or is expected to become so in the near future. Present estimates for Israel are 13% of the irrigated land, Australia 20%, China 15%, Iraq 50%, Egypt 30%. Irrigation-induced salinity occurs in large and small irrigation systems alike.

8 - FAO has estimated that by 1990 about 52 x 106 ha of irrigated land will need to have improved drainage systems installed, much of it subsurface drainage to control salinity (ref. 6)

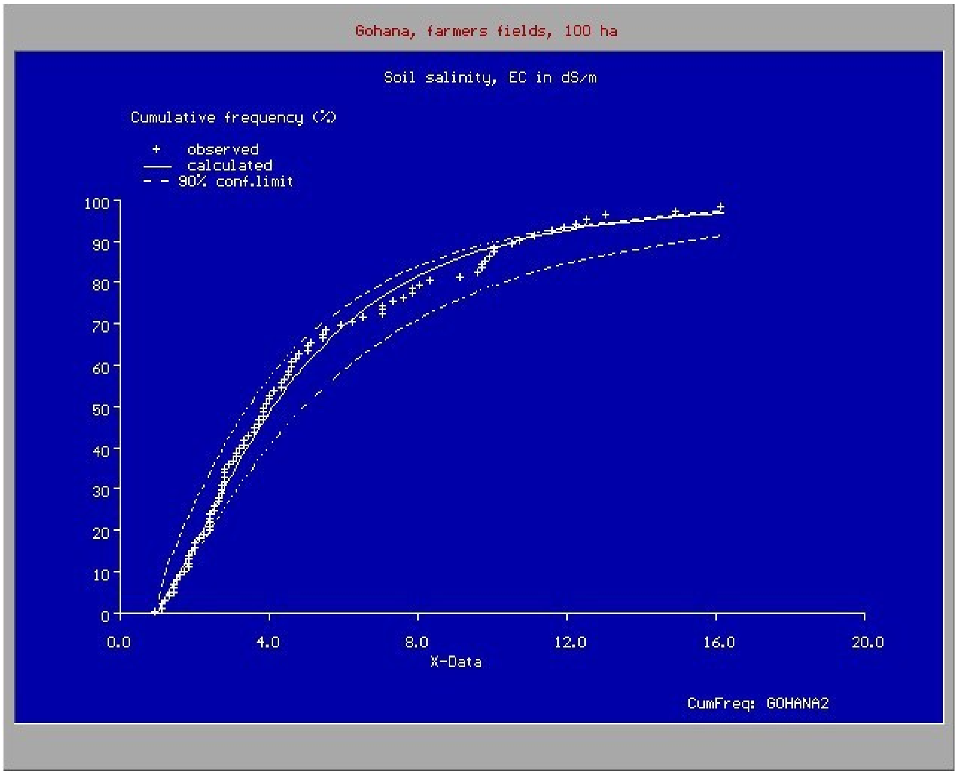
A regional distribution of the 3,230,000 km² of saline land worldwide is shown in the following table derived from the FAO/UNESCO Soil Map of the World.

Region	**Area (10^6 ha)**
Australia	84.7
Africa	69.5
Latin America	59.4
Middle East	53.1
Europe	20.7
Asia	19.5
Northern America	16.0

Spatial variation

Although the principles of the processes of salinization are fairly easy to understand, it is more difficult to explain why certain parts of the land suffer from the problems and other parts do not, or to predict accurately which part of the land will fall victim. The main reason for this is the variation of natural conditions in time and space, the usually uneven distribution of the irrigation water, and the seasonal or yearly changes of agricultural practices. Only in lands with undulating topography is the prediction simple: the depressional areas will degrade the most.

The preparation of salt and water balances (ref. 7) for distinguishable sub-areas in the irrigation project, or the use of agro-hydro-salinity models (ref. 8) can be helpful in explaining or predicting the extent and severity of the problems.



CumFreq program: spatial variation of soil salinity

3. Diagnosis

Measurement

Soil salinity is measured as the salt concentration of the soil solution in tems of g/l or electric conductivity (EC) in dS/m. The relation between these two units is about 5/3 : y g/l => 5y/3 dS/m. Seawater may have a salt concentration of 30 g/l (3%) and an EC of 50 dS/m.

The standard for the determination of soil salinity is from an extract of a saturated paste of the soil, and the EC is then written as ECe. The extract is obtained by centrifugation. The salinity can more easily be measured, without centrifugation, in a 2:1 or 5:1 water:soil mixture (in terms of g water per g dry soil) than from a saturated paste. The relation between ECe and $EC_{2:1}$ is about 4, hence : ECe = 4 $EC_{1:2}$. (ref 9)

Classification

Soils are considered saline when the ECe > 4. When 4 < ECe < 8, the soil is called moderately saline, when 8 < ECe < 16 it is called saline, and when ECe > 16 severely saline. (ref. 10)

Crop tolerance

Sensitive crops lose their vigor already in moderately saline soils, most crops are negatively affected by (moderately) saline soils, and only salinity resistant crops thrive in severely saline soils. The University of Wyoming and the Government of Alberta report data on the salt tolerance of plants. (ref. 11, 12)

A description of salt tolerance of crops as measured in farmers'fields can be found in:

https: //www.waterlog.info/croptol.htm

4. Salinity control

Drainage is the primary method of controlling soil salinity. The system should permit a small fraction of the irrigation water (about 10 to 20 percent, the drainage or leaching fraction) to be drained and discharged out of the irrigation project. (ref. 13)

n irrigated areas where salinity is stable, the salt concentration of the drainage water is normally 5 to 10 times higher than that of the irrigation water. Salt export matches salt import and salt will not accumulate.

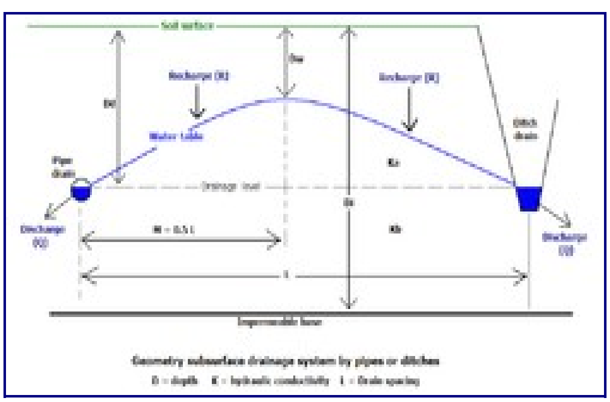
When reclaiming already salinized soils, the salt concentration of the drainage water will initially be much higher than that of the irrigation water (for example 50 times higher). Salt export will greatly exceed salt import, so that with the same drainage fraction a rapid desalinization occurs. After one or two years, the soil salinity is decreased so much, that the salinity of the drainage water has come down to a normal value and a new, favorable, equilibrium is reached.

In regions with pronounced dry and wet seasons, the drainage system may be operated in the wet season only, and closed during the dry season. This practice of checked or controlled drainage saves irrigation water.

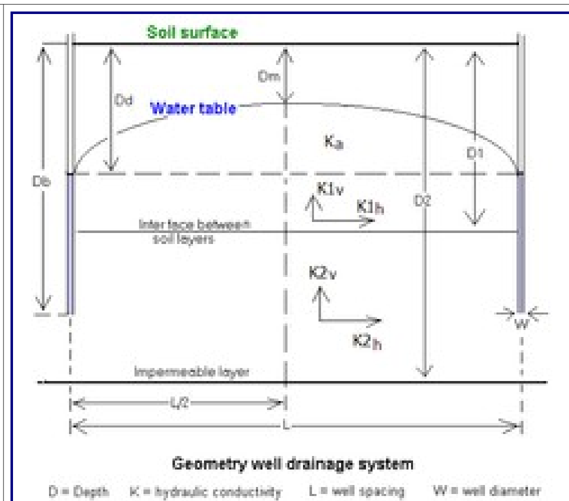
The discharge of salty drainage water may pose *environmental problems* to downstream areas. The environmental hazards must be considered very carefully and, if necessary mitigating measures must be taken. If possible, the drainage must be limited to wet seasons only, when the salty effluent inflicts the least harm.

Drainage systems

Land drainage for soil salinity control is usually by *horizontal drainage system* (figure left), but *vertical systems* (figure right) are also employed.



Parameters of a horizontal drainage system



Parameters of a vertical drainage system

The drainage system designed to evacuate salty water also lowers the water table. To reduce the cost of the system, the lowering must be reduced to a minimum. The highest permissible level of the water table (or the shallowest permissible depth) depends on the irrigation and agricultural practices and kind of crops.

In many cases a seasonal average water table depth of 0.6 to 0.8 m is deep enough. This means that the water table may occasionally be less than 0.6 m (say 0.2 m just after an irrigation or a rain storm). This automatically implies that, in other occasions, the water table will be deeper than 0.8 m (say 1.2 m). The fluctuation of the water table helps in the breathing function of the soil while the expulsion of carbon dioxide (CO_2) produced by the plant roots and the inhalation of fresh oxygen (O_2) is promoted.

The establishing of a not too deep water table offers the additional advantage that excessive field irrigation is discouraged, as the crop yield would be negatively affected by the resulting elevated water table, and irrigation water may be saved.

The statements made above on the optimum depth of the water table are very general, because in some instances the required water table may be still shallower than indicated (for example in rice paddies), while in other instances it must be considerably deeper (for example in some orchards). The establishment of the optimum depth of the water table is in the realm of agricultural drainage criteria. (ref. 14).

5. Leaching

The vadose zone of the soil below the soil surface and the watertable is subject to four main hydrological inflow and outflow factors: (ref. 15)

- Infiltration of rain and irrigation water (Irr) into the soil through the soil surface (Inf) :
- Inf = Rain + Irr
- Evaporation of soil water through plants and directly into the air through the soil surface (Evap)
- Percolation of water from the unsaturated zone soil into the groundwater through the watertable (Perc)
- Capillary rise of groundwater moving by capillary suction forces into the unsaturated zone(Cap)

In steady state (i.e. the amount of water stored in the unsaturated zone does not change in the long run) the water balance of the unsaturated zone reads: Inflow = Outflow, thus:

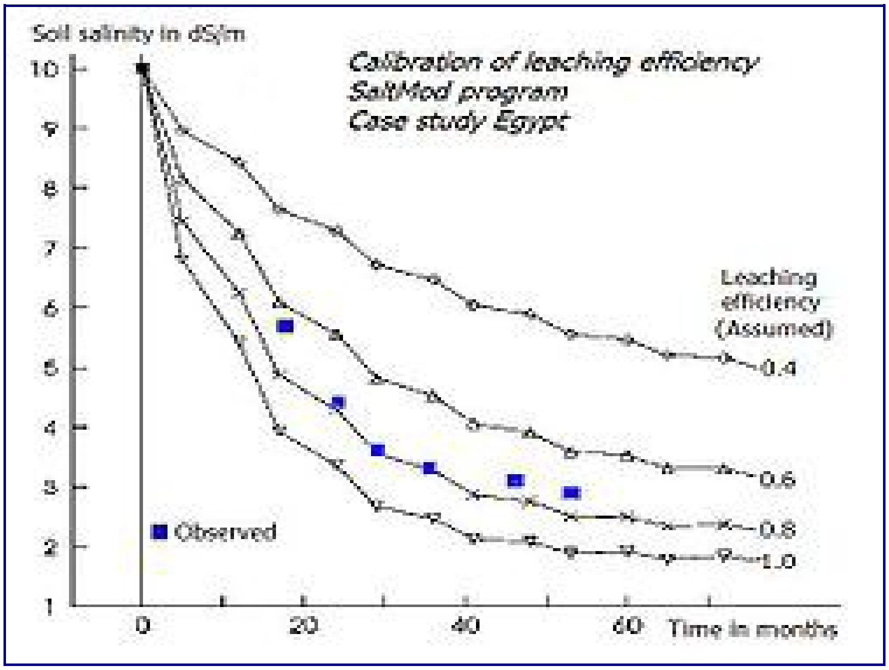
- Inf + Cap = Evap + Perc   or :
- Irr + Rain + Cap = Evap + Perc

and the *salt balance* is

- Irr.Ci + Cap.Cc = Evap.Fc.Ce + Perc.Cp + Ss

where Ci is the salt concentration of the irrigation water, Cc is the salt concentration of the capillary rise, equal to the salt concentration of the upper part of the groundwater body, Fc is the fraction of the total evaporation transpired by plants, Ce is the salt concentration of the water taken up by the plant roots, Cp is the salt concentration of the percolation water, and Ss is the increase of salt storage in the unsaturated soil. This assumes that the rainfall contains no salts. Only along the coast this may not be true. Further it is assumed that no runoff or surface drainage occurs.

The amount of removed by plants (Evap.Fc.Ce) is usually negligibly small: Evap.Fc.Ce = 0



Leaching curves, calibrating leaching efficiency

The salt concentration Cp can be taken as a part of the salt concentration of the soil in the unsaturated zone (Cu) giving: Cp=Le.Cu, where Le is the leaching efficiency. The leaching efficiency is often in the order of 0.7 to 0.8 (ref. 16), but in poorly structured, heavy clay soils it may be less. In the Leziria Grande polder in the delta of the Tagus river in Portugal it was found that the leaching efficiency was only 0.15. (Ref. 17, 18)

Assuming that one wishes to avoid the soil salinity to increase and maintain the soil salinity Cu at a desired level Cd we have:
Ss = 0, Cu = Cd and Cp = Le.Cd. Hence the salt balance can be simplified to:

- Perc.Le.Cd = Irr.Ci + Cap.Cc

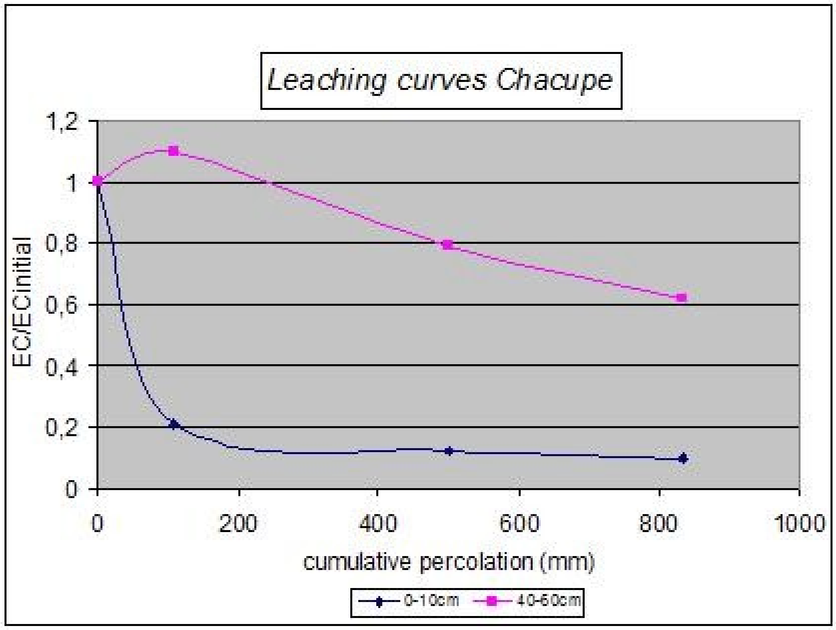
Setting the amount percolation water required to fulfill this salt balance equal to Lr (the *leaching requirement*) it is found that:

- Lr = (Irr.Ci + Cap.Cc) / Le.Cd .

Substituting herein Irr = Evap + Perc − Rain − Cap and re-arranging gives :

- Lr = [(Evap−Rain).Ci + Cap(Cc−Ci)] / (Le.Cd − Ci)

With this the irrigation and drainage requirements for salinity control can be computed too.
In irrigation projects in (semi)arid zones and climates it is important to check the leaching requirement, whereby the *field irrigation efficiency* (indicating the fraction of irrigation water percolating to the underground) is to be taken into account.



Leaching experiences from the pilot area Chacupe, Peru

6. Soil salinity models

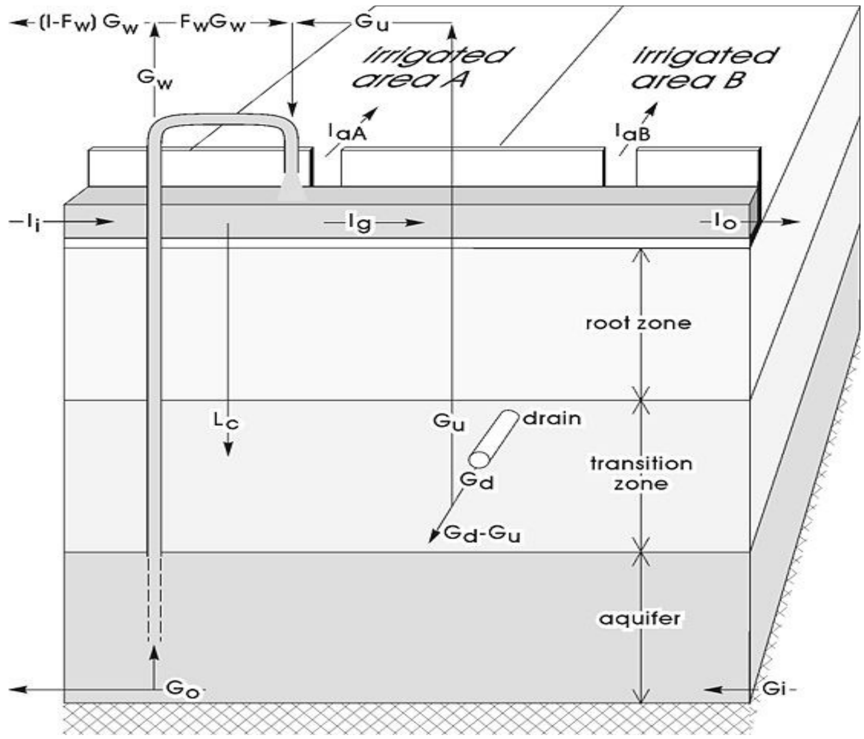
The majority of the computer models available for water and solute transport in the soil (e.g. SWAP, (ref. 19), DrainMod-S (ref. 20), UnSatChem (ref. 21), and Hydrus (ref. 22) are based on Richard's differential equation for the movement of water in unsaturated soil in combination with Fick's differential convection–diffusion equation for advection and dispersion of salts.

The models require input of soil characteristics like the relations between variable unsaturated soil moisture content, water tension, water retention curve, unsaturated hydraulic conductivity, dispersivity and diffusivity. These relations vary to a great extent from place to place and from time to time and are not easy to measure. Further, the models are difficult to calibrate under farmer's field conditions because the soil salinity here is spatially very variable. The models use short time steps and need at least a daily, if not an hourly, data base of hydrological phenomena. Altogether this makes model application to a fairly large project the job of a team of specialists with ample facilities.

Simpler models, like SaltMod, based on monthly or seasonal water and soil balances and an empirical capillary rise function, are also available. They are useful for long-term salinity predictions in relation to irrigation and drainage practices.

LeachMod, using the SaltMod principles, helps in analyzing leaching experiments in which the soil salinity was monitored in various root zone layers while the model will optimize the value of the leaching efficiency of each layer so that a fit is obtained of observed with simulated soil salinity values.

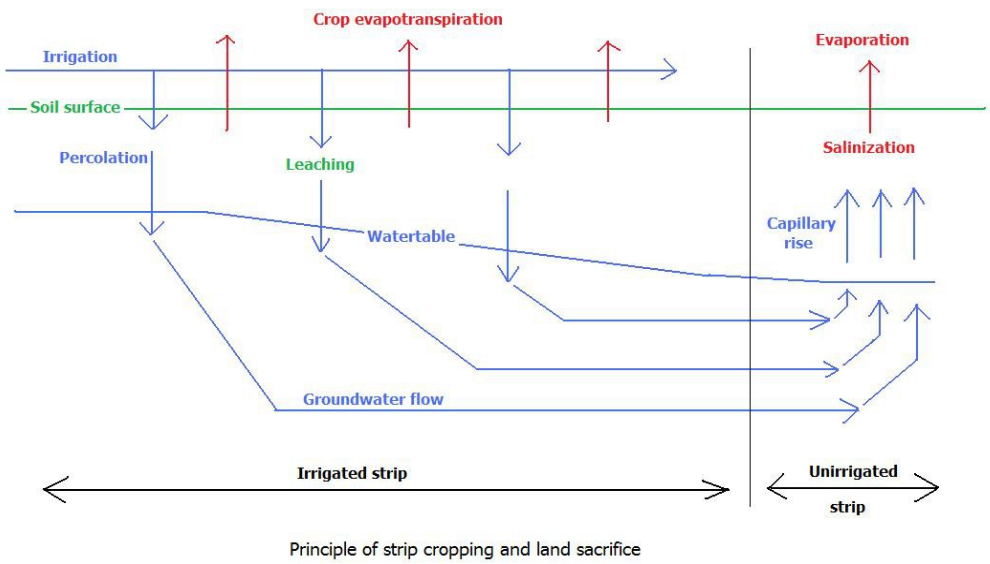
Spatial variations owing to variations in topography can be simulated and predicted using salinity cum groundwater models, like SahysMod.



SaltMod components

7. Strip cropping: an alternative

In irrigated lands with scarce water resources suffering from drainage (high water table) and soil salinity problems, strip cropping is sometimes practiced with strips of land where every other strip is irrigated while the strips in between are left permanently fallow. (ref. 23)



Hydrological principles of *strip cropping* to control the depth of the water table and the soil salinity

Owing to the water application in the irrigated strips they have a higher watertable which induces flow of groundwater to the unirrigated strips. This flow functions as subsurface drainage for the irrigated strips, whereby the water table is maintained at a not-too-shallow depth, leaching of the soil is possible, and the soil salinity can be controlled at an acceptably low level.

In the unirrigated (sacrificial) strips the soil is dry and the groundwater comes up by capillary rise and evaporates leaving the salts behind, so that here the soil salinizes. Nevertheless, they can have some use for livestock, sowing salinity resistant grasses or weeds. Moreover, useful salt resistant trees can be planted like Casuarina, Eucalyptus or Atriplex, keeping in mind that the trees have deep rooting systems and the salinity of the wet subsoil is less than of the topsoil. In these ways wind erosion can be controlled. The unirrigated strips can also be used for salt harvesting.

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