WATER AND SALT BALANCES ALONG RIVERS IN (SEMI)ARID ZONES, WHICH PROVIDE WATER FOR IRRIGATION AND RECEIVE RETURN FLOW

Irrigation, Drainage and Salinity Management

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1. Introduction

River water in arid and semi-arid zones may suffer from progressively increasing salinity. The main reason is that the river water is used for irrigated agriculture while the drainage water from the agricultural land is returned to the river downstream. As a result, the downstream irrigated agricultural lands can be affected by soil salinity.

This phenomenon is well known in the Indus river basin (Pakistan), Nile river basin (Egypt), and many other river basins in arid and semi-arid zones where river water is used for irrigation. In these basins, ground water plays an important role as there are deep and permeable aquifers. However in other basins, like the Karun river basin, Khuzestan province, Iran, there may be no significant aquifers. The presence or absence of important aquifers and pumping from wells may exert influence on the river salinity.

In the following, the principles of the processes leading to river salinization are briefly described. An excel spreadsheet has also been prepared with fictitious data to illustrate the phenomena quantitatively and how predictions may be made. The processes simulated in the spreadsheet have been reduced to the minimum whilst aiming at simplicity. The spreadsheet has not been automated and macros' are not used. However, if desired, anyone who knows how to handle spreadsheets can make use of the its structure to prepare a more realistic spreadsheet suiting the local conditions.

2. Salinity development

2.1 **Salt import**

All irrigation water contains salts such as sodium chloride even if the water is of good quality. When this water is applied to the agricultural land, the water evaporates and the salts remain behind. Without drainage, the soil salinity will increase until the land becomes so salty that becomes unproductive. The land is abandoned and irrigation is stopped.

For example, good quality water containing 0.5 g salt per liter (electric conductivity EC = 0.75 to 0.80 dS/m) brings 5000 kg or 5 T of salt per ha per year when the land is irrigated with 10 000 m3 of water per ha per year. When the water contains 1 g salt per liter (EC = 1.5 to 1.6 dS/m) and the annual application per ha is 20 000 m3, the annual supply of salt is 20 T/ha.

2.2 **Water and salt balances**

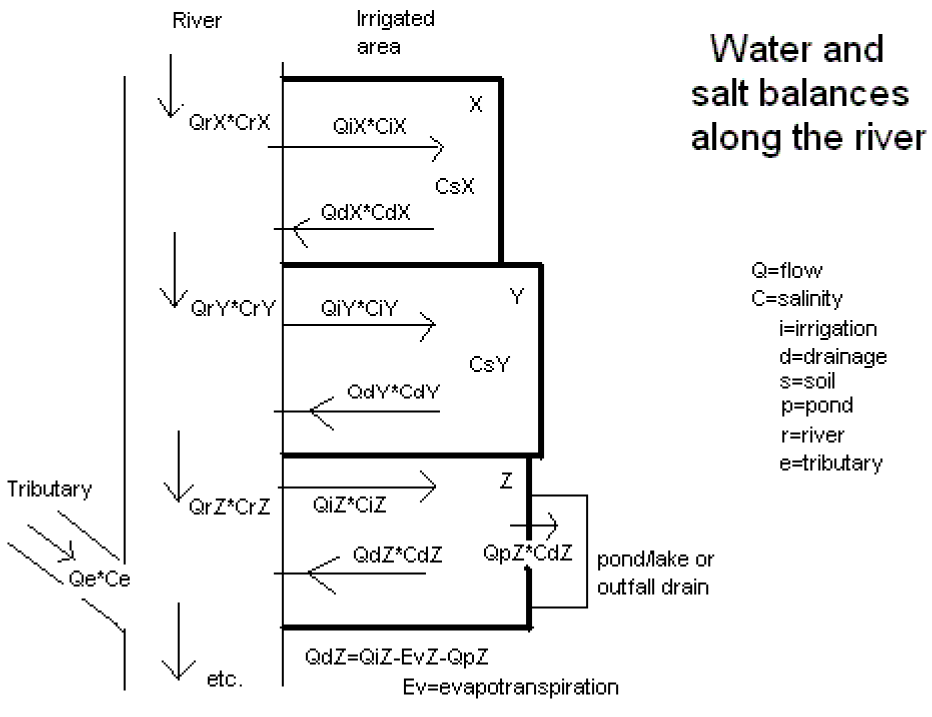
Along the rivers in Khuzestan province it should not be to difficult to set up water and salt balances and to find the salt concentration of the drainage water returning to the river. This can be done in a spreadsheet program, e.g. Excel.

A - The river should be divided in segments. In each segment one can find the amount of water and salt entering the segment and the amounts taken from the segment for irrigation. Then, by making a salt and water balance of the irrigated soil along this segment one can find the soil salinity and the salt concentration of the return flow (drainage).

B - By mixing the amounts of river water at the end of the segment with the return flow one can calculate the salt concentration of the river water at the end of the segment and this will be the same at the beginning of the following segment.

C- By completing this procedure for all the segments, one will get a picture of the quality of the river water and the soils all along the river. One will see that both the river water salinity and the soil salinity will increase in downstream direction.

D. – Now one has a tool for irrigation, drainage and salinity management. By changing these factors, one can predict the effects and select the most suitable combination (see figure).



Examples (see also the Excel spreadsheet SaltLecture.xls)
The following examples are given for equilibrium conditions, i.e. when certain irrigation and drainage practices have continued for a fairly long time (e.g. 10 years) and the soil salinity is more or less constant. It is also assumed that the leaching efficiency of the soil is 100%. It would be easy to make adjustments if this is not so. The results for soil salinity give only the average situation. However, soil salinity often has a wide spatial variation. Such variation can be accounted for using the standard frequency distribution applied in SaltMod.

2.3 **Example 1**: water use efficiency Ewu = 0.9 (90%)

Assuming that 90% of the water is used for crop consumption (evapo-transpiration) and 10% is drained back to the river, then the salt concentration of the drainage water (Cd) must be 10 times the salt concentration of the irrigation water (Ci). Hence, Cd = 10Ci.
Then, the salt concentration of the soil moisture (Cs) must also be 10Ci.

Assuming that Ci=1 dS/m, then Cd=10 dS/m (quite salty) and Cs=10 dS/m. In most agricultural lands the value Cs=10 dS/m is just acceptable.

If, in the same case, Ci= 2 dS/m, then Cd=20 dS/m and Cs=20 dS/m. Compared to sea water (50 dS/m) the drainage water is brackish. The value of Cs is critical. Many areas will give poor crop production. Some salt tolerant crops (e.g. barley) may grow satisfactorily.

2.4 **Example 2**: Ewu = 0.6 (60%), Ci = 1 dS/m

Assuming that 60% of the water is used for crop consumption (evapo-transpiration) and 40% is drained then the salt concentration (Ewu = 60%) and 40% is drained back to the river, then the salt concentration of the drainage water is 2.5 times the salt concentration of the irrigation water (Cd = 2.5 Ci) and also the soil salinity Cs = 2.5 Ci.

Although the concentration of the drainage water is less than in example 1, the amount of drainage water is higher and the total amount of salt returned to the river is equal. The water level in the soils, however will be higher. When the quality of the irrigation water is good, irrigation efficienciy should be as high as possible.

2.5 **Example 3**: Ewu = 0.6 (60%), Ci = 4 dS/m

Of course, when the irrigation water is more salty, as occurs in the lower end of the rivers, a lower irrigation efficiency (i.e. more flushing of the soil) can be helpful to control the soil salinity at a safer level. When Ci = 4 dS/m, the salt concentrations Cd and Cs will be 10 dS/m.

Compared to the result in example 1 (Ewu = 0.9, Ci = 2 and Cs = 20 dS/m), the result of Cs in example 3 is much better, even though Ci is twice as high!

2.6 When one wishes to check the changes of salinity from season to season instead of considering only the equilibrium situation, the calculations become more complex and one may us SaltMod repeatedly for each block of irrigated land along the river segments.

3. Downstream saline soils

3.1 **General**

In the previous example we have seen that it is advantageous to give extra irrigation water in downstream saline agricultural lands to maintain an acceptable soil salinity. A disadvantage is that this will require a high capacity of the irrigation and drainage systems. It will also have to be seen if enough irrigation water is available, because in arid and semi-arid irrigated areas the availability of irrigation water in the downstream part of the rivers will often be strongly reduced.

Further downstream, the quality of the river water may deteriorate so much that it is hardly possible to provide enough irrigation water for salinity control. This means that the end of the irrigation project area is reached.

Yet, to improve the quality of the irrigation water, one may think of halting the discharge of drainage water into the river and rather storing the drainage water in evaporation ponds/lakes or discharging the drainage water through a separate outfall drain to the sea, if possible. This practice, of course, reduces the river flow.

To obtain insight in where the practice of evaporations ponds/lakes or the excavation of an outfall drain should begin, it would be useful to have a tool of calculating salt and water balances discussed in paragraph 2.2 at hand. This paper is accompanied by a preliminary spreadsheet program (RiverSalt.xls) that gives an example for 20 river segments. The spreadsheet can be adjusted to other situations changing the input data and using the cell equations shown in the spreadsheet. In future, the adjustments can be automated through the use of macro's.

3.2 **Use of rainfall**

Low rainfall zones
When periods with relatively high rainfall occur and the rivers are swollen, it would be useful drain the downstream saline soils to restore the salt balance of the soil. As the water level in the rivers are relatively high, it may be required to lift the drainage water with pumps.

When the rainfall is insufficient to produce much drainage flow, it could be supplemented with irrigation water, even when irrigation is not required.

Medium rainfall zones
As an example we use the situation in Haryana state, India. The land surface in the state is bowl shaped and the low lying lands suffer from problems of water logging and salinity. Subsurface drainage systems have proved to be effective to control these problems. Discharge of the poor quality drainage water into the bordering Yamuna river meets with objections because this would deteriorate the quality of the river water, which is used downstream in households, industries and for irrigation.

However, it was found the drainage systems need to be operated only during periods of high rainfall, even when the rainy spells do not occur every year. This would not cause undue salinity build up and the occasional drainage brings the salinity down again. In winter time ("rabi" season) irrigation water is scarce and by closing the drainage system (i.e. no pumping is done from the drainage sumps to which the drains are connected), the water level in the soil is kept relatively high so that the crops can use the groundwater to supplement their evaporation demand. Hence, precious irrigation can be saved and used elsewhere whilst irrigation efficiency is increased. No farmer would apply ample irrigation water to his crop land when the water table is relatively shallow, because he would experience that the water table would come too close to the soil surface and the yields reduce.

All this has led to the option to discharge the drainage water only during very wet periods during the rainy season (monsoon). At such times, the river would carry much water and the quality deterioration from drainage water would hardly be noticeable. Moreover, at such times, much of the river water reaches the sea, i.e. the Bay of Bengal.

Presence of dams and storage reservoirs

When the rivers count with large upstream dams and storage reservoirs, it could be that the greater part of the excess rainfall is captured in the reservoirs. In that case, the excess rainfall does not produce much runoff through the river, and the use of excess rainfall to benefit the soil salinity in the downstream region is restricted.

For example, the water flow in the Indus river is controlled so much by large dams in the Himalayas that the river seldom discharges water into the sea. In addition, many irrigated areas in the downstream region of the Sindh province in Pakistan, have no drainage systems, so it would be useless to use excess water, if any, for leaching of the soils because leaching would not occur and the water would only stagnate at the soil surface and lead to a water logging problem. To make things worse, farmers with lands nearby irrigation canals dump the excess water into these canals so that the lower lands suffer from still more water logging.

For these situations it appears difficult to find a solution to the salinity problem.

3.3 **Outfall drain**

To improve the situation in Sindh, a large outfall drain was constructed from Mardan to the sea, almost 700 km long, the so called Left Bank Outfall Drain (LBOD). Plans exist to extend this drain even further upwards. This drain now discharges salty drainage water, so it contributes somewhat to the salinity control. I have not seen a detailed analysis of salt and water balances of Sindh, so I do not know if the LBOD warrants its investment cost.

Of old, the Nile Delta in Egypt has a considerable number of outfall drains. Also Egypt is faced with the problem of increasing salinity of the irrigation water downstream. Fortunately, the capacity of the High Dam at Aswan is so high that soil leaching is possible and the salty leaching water is transported in the outfall drains to the coast, where it is pumped into the Mediterranean sea. Further drainage can be done through the lower branches of the Nile river, because a minimum water level is maintained in these for shipping purposes.

The Nile Delta has an important aquifer which acts as a natural drain which helps to control salinity, but near the sea coast the aquifer water, which has become somewhat more salty due to drainage of the lands, seeps up to the soil surface and affects the soil salinity negatively.

Despite the favorable situation in Egypt, there are still considerable soil salinity problems in the agricultural lands near the Mediterranean sea. The solution of the problem is complicated because the irrigation resources are coming under stress due to the large demand for extension of the irrigated area into the desert.

3.4 **Evaporation ponds and land sacrifice**

Evaporation ponds are used in the Murray river basin (Victoria state, Australia), USA and Punjab province (Pakistan). In principle, evaporation ponds are equipped with high bunds (embankments, dikes), and the drainage water needs to be pumped into it when its water level is high. However, in Pakistan one often uses natural land depressions for this, so that the water can reach it by gravity. Also natural lakes are used as evaporation ponds.

A similar effect with evaporation ponds can be obtained by land sacrifice or land retirement. These are parts of the land that are left uncultivated. This originates groundwater flow from the irrigated lands, where the water table is higher due to the deep percolation of irrigation water, to the un-irrigated land, where the ground water evaporates after capillary rise occurs and salt accumulation occurs. Strip cropping falls also under this category. The un-irrigated land safeguards the irrigated parts of the land because the land can be leached and the salts are moved through the groundwater to the un-irrigated land.

Sacrificial land drainage is applicable when a deep and permeable aquifer is present. Evaporation ponds deserve probably preference when no significant aquifer occurs, as in the lower parts of Khuzestan province, Iran.

When the option of sacrificial land drainage is used, the return flow of water to the river by drainage diminishes. This will affect farmers at the downstream end of the river.

All in all, the differences between sacrificial land, evaporation ponds (that also sacrifice land), natural depressions and wetlands are not always very sharp.

4. Conclusion

The management of irrigation, drainage and salinity control in areas along a river from which water is taken for irrigation and to which the drainage flow is returned is not straightforward but it requires weighing of advantages and limitations connected to each proposed measure.

For example, the provision of an outfall drain reduces the return flow to the river. This may reduce the river discharge and lower its water level, so that salt intrusion from sea water into the mouth of the river may increase.

Another example can be the increase of irrigation efficiency. This results in a lesser abstraction of water from the river and in a smaller return flow, which has a higher salt concentration. Whether this gives an improvement of the river regime in terms of discharge and quality depends much on local conditions.

It is hoped that the calculation principles used in the accompanying spreadsheet RiverSalt.xls can be a useful tool to reach a decision on management options. In the spreadsheet various options can be introduced and the results in terms of water quantity and quality as well as of soil salinity are shown immediately.