Table of Contents

Go Back

FEEDBACK COMPLEXITY OF WATERLOGGING AND SALINIZATION ON IRRIGATED LANDS

Ali K. Saysel

University of Bergen, Department of information science, 5020 Norway

ali@ifi.uib.no

I. Problem Context and Model Purpose

Waterlogging and salinization affect many of the world's large-scale irrigation systems, imposing farm-level and public costs in the form of lost production and conservation efforts (UNEP 1997). Saline and waterlogged soils naturally exist in many places but irrigation elevates the areal extend of the problem. Most salinization processes result from poor irrigation. Leakage from poorly lined canals and reservoirs, excessive water application and inadequate drainage are the primary causes. Saline irrigation water and the high groundwater depths are the accelerating factors (Johnson and Lewis 1995), (Barrow 1991). The areal extend of the problem is increasing worldwide primarily as a result of the rapid expansion of irrigated fields since 1950. According to (World Bank 1992) irrigation caused salinization affects about 60 million ha, or 24% of all irrigated lands. Severe production decline observed on 24 million ha irrigated land. (Umali 1993) reports that salinization affects 28% of irrigated lands in US, 23% in China, 21% in Pakistan, 11% in India and 10% in Mexico. New irrigated areas are being degraded faster than the older soils are being reclaimed (WB 1992).

Public programs to reduce this problem include construction of regional drainage systems, operation of public tubewells and farm level incentives to reduce water consumption and deep percolation by improving irrigation methods. Recent policy recommendations focus on the water management alternative rather than modified water structures and drainage canals (World Bank 1992). Water pricing strategies, water markets, effluent charges, and appropriate water allocation mechanisms are among the most popular water management alternatives being discussed (Wichelns, Houston et al. 1996) and (Rosegrant and Ringler 1997).

In this paper, we introduce a dynamic simulation model, which represents the major feedback mechanisms in salinization of irrigated lands (Saysel and Barlas 2001). The purpose of this model is to provide a comprehensive picture of the problem. The three sub-processes, drainage, groundwater intrusion and groundwater discharge are integrated with the irrigation. The unit of analysis is not the farm-level, but the whole basin where irrigated lands may expand annually. Model analyses provide an assessment of relative efficiencies of water management and drainage alternatives under changing loop dominance. It reveals that, the benefit from drainage diminishes as the drainage efficiency is increased. This calls for improved water management strategies rather than the drainage alternative. The model illustrates the condition when reinforcing feedback loops dominate and salinization reach alarming levels. Under this condition, increased drainage yields increased salinization, which is an unprecedented result.

II. Model Description

The salinization model represents the processes releasing and flushing salts in soil rootzone. Irrigation water is applied on annual basis depending on the water requirement of the crop selection and the water availability. Portion of this water adds to the water stored in soil rootzone. Remaining portion is drained into freshwater supplies and percolated into groundwater. Percolation adds to groundwater table. Increasing groundwater discharges into freshwater supplies and intrudes rootzone. Then, intrusion adds to the water in soil rootzone. Evapotranspiration and infiltration releases and flushes salts respectively. Finally, the stock of water in rootzone and the salinity stock affect the yield potential. These processes are represented in Figure 1.

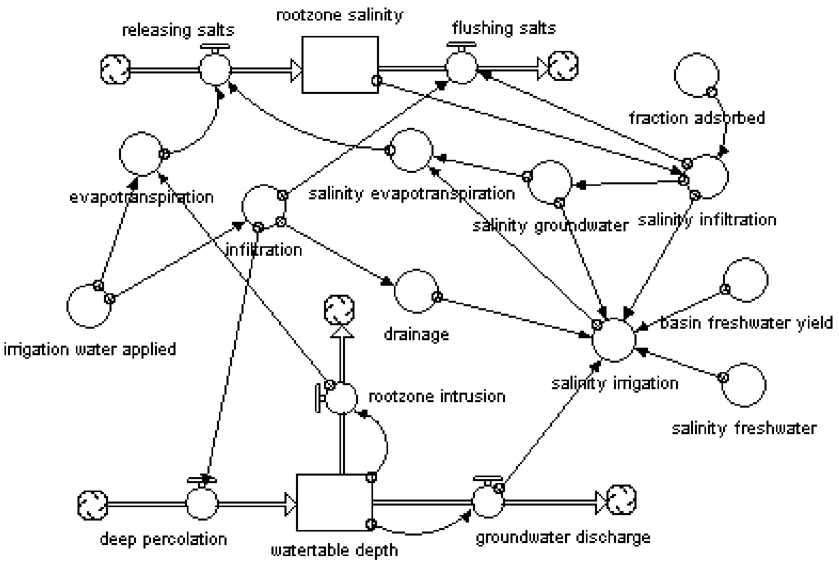

Figure 1. Simplified stock-flow diagram of the salinization model

The causal loop diagram in Figure 2 illustrates the feedbacks. The first two negative feedback loops represent the self-regulation of watertable level. As watertable is increased by percolation, it decreases by discharge and intrusion. First positive feedback loop represents the effect of drainage on rootzone salinity. As rootzone salinity increases, the salinity of the drained water increases and as it mixes into freshwater supplies, irrigation water salinity increases. This reinforces the overall salinization process. The second and third positive feedbacks represent the effect of groundwater discharge and intrusion on rootzone salinity respectively. As the saline groundwater discharges into freshwater supplies, irrigation water salinity increases. And as the saline groundwater intrudes into the rootzone, it increases the salinity of evapotranspirating water. By both of these processes, rootzone salinity, percolation salinity and then the groundwater salinity increases. However, since watertable level is regulated by the negative feedbacks 1 and 2, the positive feedback loops 2 and 3 are in effect self-stabilizing. But, the drainage, 1st positive feedback may play the critical role leading to excessive salinization under certain parameter settings. This is illustrated in the next section.

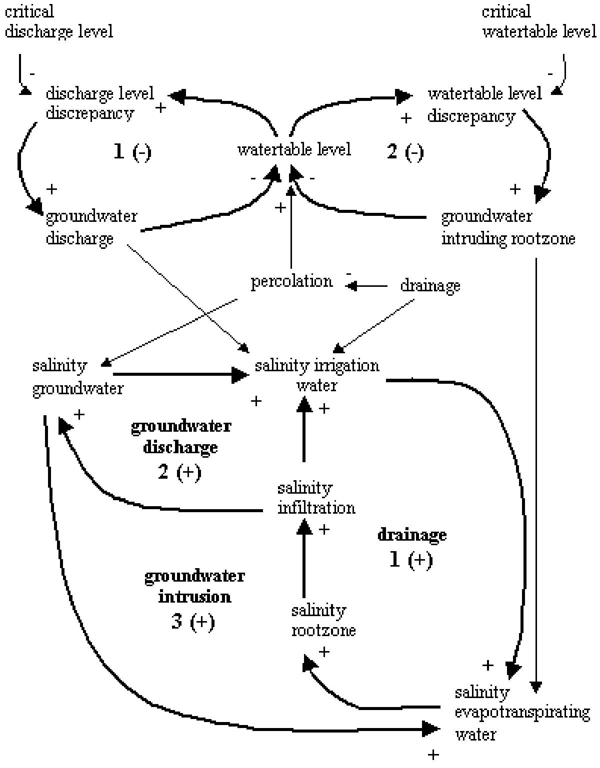

Figure 2. The causal loop diagram of the salinization model

III. Analysis and Results

The model is validated by structure oriented behavior tests (Barlas 1996). Due to the lack of long time series the behavior is not calibrated. Figure 3 shows the sensitivity of rootzone salinity to drainage. In this run the irrigated lands increase from 2000 to 160.000 ha and basin yield of freshwater is 3.5 billion m3/year. The linear increase in drainage efficiency creates diminishing decrease in rootzone salinity. This illustrates the limitations of the drainage alternative.

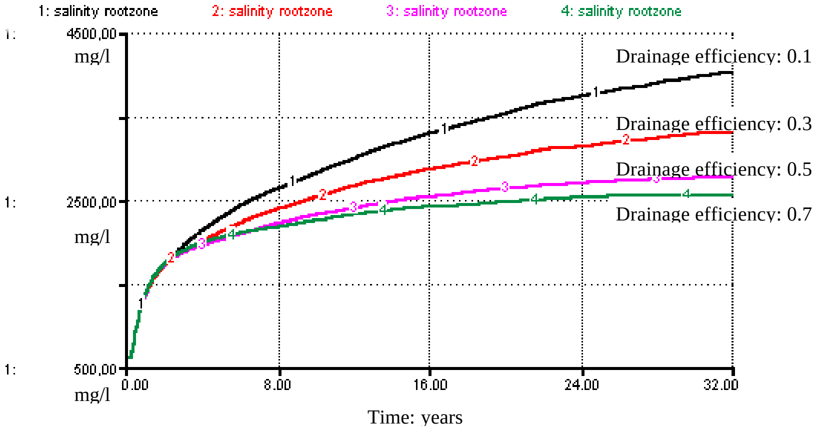

Figure 3. The limitations of the drainage alternative

Figure 4 shows the observed salinization pattern and its sensitivity to drainage efficiency when the basin freshwater supply is low, i.e. the drainage mixing ratio is high (positive feedback loop 1 active). In this run, basin freshwater yield is set as 1.5 billion m3/year. This illustrates how exponentially growing salinization patterns can emerge and under these settings, how increased drainage may yield unprecedented results.

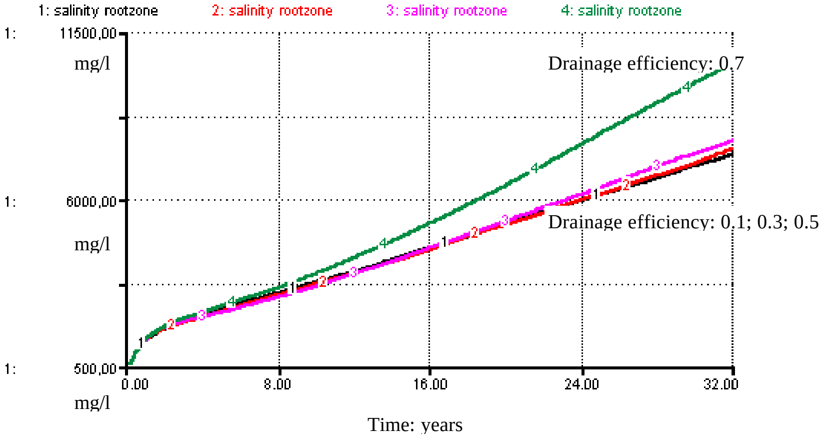

Figure 4. Sensitivity to drainage when basin freshwater supply is low

IV. Conclusion

The simulation model represents the major feedback mechanisms in salinization of irrigated lands. It integrates three sub-processes, drainage, groundwater intrusion and groundwater discharge with the irrigation. The benefit from drainage diminishes as the drainage efficiency is increased. When reinforcing feedback loops dominate the model behavior, salinization may reach alarming levels and drainage option yields unprecedented, increased salinity. This calls for improved water management strategies rather than the drainage alternative. In future research, this model can be improved to analyze the affect of different water management strategies and farmers' decision rules on salinization.

References

Barlas, Y. (1996). "Formal aspects of model validity and validation in system dynamics." System Dynamics Review **12**(3): 183-210.

Barrow, C. J. (1991). Land Degradation: Development and Breakdown of Terrestrial Environments. Cambridge, Cambridge University Press.

Johnson, D. L. and L. A. Lewis (1995). Land Degradation: Creation and Destruction. Cambridge, Blackwell.

Rosegrant, M. W. and C. Ringler (1997). "World food markets into the 21st century: environmental and resource constraints and policies." Australian Journal of Agriculture and Resource Economics **41**(3): 401-428.

Saysel, A. K. and Y. Barlas (2001). "A dynamic model of salinization on irrigated lands." Ecological Modelling **139**: 177-199.

Umali, D. L. (1993). Irrigation-Induced Salinity: A growing problem for development and the environment. Washington D.C., World Bank.

United Nations Environmental Programme. (1997). World Atlas of Desertification. New York, Wiley.

World Bank. (1992). Development and the Environment. World Development Report 1992. Washington D.C., World Bank.

Wichelns, D., L. Houston, et al. (1996). "Economic incentives reduce irrigation deliveries and drain water volume." Irrigation and Drainage Systems **10**: 131-141.

Back to the Top