Root Zone WSB Model: towards a framework for the sustainable application of saline effluent on land.

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Abstract
The sustainability of a system for land disposal of saline effluent is fundamentally dependent on whether salt concentrations in the soil can be maintained at levels that allow adequate plant growth to remove water, salt or other undesirable solutes. Hence a suitably high leaching fraction is required to limit salt accumulation. If other undesirable solutes are present, the excessive amount of water application may give rise to other environmental problems of excessive solute accumulation or discharge. A framework is required to balance these opposing requirements for a sustainable land disposal system. A simple and robust Root Zone WSB (Water and salt balance) model has been developed on an excel spreadsheet that can accurately predict the deep drainage and salt concentrations in the root zone. This model has been successfully applied to land disposal sites for non-saline and saline industrial effluents in Queensland and results show reasonably accurate prediction of deep drainage and salt concentration in the root zone over a 4 year period.

Key words
Saline land disposal, effluent irrigation, water balance, salt balance, deep drainage.

Introduction
Industrial cities produce large volumes of effluent waste, and often this waste is discharged into waterways creating a health hazard. Land application of the effluent can be a viable alternative which keeps waterways clear from toxic chemicals. The effectiveness of land application of effluent depends on both plant and soil properties. The presence of vegetation is essential to assist the removal of water through transpiration. Where the effluent is saline, it is also essential that the soil maintains sufficiently high hydraulic conductivities to allow adequate leaching and limits salt accumulation in the root zone.
The application of saline effluent on land is governed by two material balances in the following order of priority (So *et al.* 2004):

1) The water balance of the root zone where the input of water equals the output of water, or

$$P + I = ET + \Delta W + RO + DD \quad [1]$$

where: P = precipitation (mm), I = irrigation (mm),
ET = evapo-transpiration (mm), RO = run-off (mm),
ΔW = change in soil water storage (mm), DD = deep drainage (mm).

1) The salt balance of the root zone where salt input equals salt output, or

$$D_iC_i + S_m = D_dC_d + S_p + S_{pl} \quad [2]$$

where D_i and D_d are the depth of irrigation and drainage water,
C_i and C_d are concentrations of irrigation and drainage water,

S_m, S_p and S_{pl} are the amount of salt dissolved from soil minerals, precipitated in the soil and removed during plant harvest respectively. The parameters S_m, S_p and S_{pl} are generally small and negligible, thus reducing the salt balance to:

$$D_iC_i = D_dC_d \quad [3]$$

These steady state equations are approximately correct for sufficiently long periods of observations where climatic extremes are absent. It assumes uniform conditions throughout the root zone, and the term DD in equation 1 is equivalent to the term D_i in equation 2 and 3. Clearly, the real situation is that salt concentration will be lowest at the surface (C_i) and increases towards the bottom of the root zone (C_d), except for the immediate surface soil.

Where the groundwater is sufficiently shallow, some salt will accumulate at the immediate surface due to evaporation. The pattern of increase in salt concentration with depth depends on the removal rate of water, which is determined by the rate of evapo-transpiration of the vegetation. The salt balance may not apply to conditions where the combination of distribution of rainfall and soil are such that it leads to short periods of high leaching, e.g. sandy soils with short periods of intense rainstorms.

The interactions between these processes are dominated by the water balance where the DD component becomes the determining factor for the degree of salt accumulation in the root zone or any other compound. As the sustainability of a saline land disposal system is fundamentally dependent on whether salt concentrations in the soil can be maintained at levels that allow adequate plant growth to remove water (ET), salt (S_{pl}) or other solutes, a suitable leaching fraction will be required to limit salt accumulation to desired levels.

If the fate of other nutrients are of interest within this system, it can readily be added as a third material balance such as a nitrogen balance. However this will not be disc used in this paper.

Computer models which can predict water and salinity levels can be useful in the management of these processes. This paper describes a root zone water and solute balance (Root Zone WSB) model which can be used to accurately estimate the amount of deep drainage and salt concentration of the root zone under a saline land disposal system. This model can be used as a framework to develop sustainable land disposal systems or evaluate the sustainability of such systems.

The Root Zone WSB Model.

The Root Zone WSB model is based on the water balance equation [1] with the salt balance equation superimposed within each layer. It is developed as an Excel spreadsheet model with the input and outputs managed using macros written in visual basic.

The model assumes vertical heterogeneity in the soil by considering soil horizons or layers with uniform soil properties. The current model allows up to 5 horizons, but can readily be modified to any desired number of layers. These layers are treated in a cascade pattern where the DD from the layer above is taken as the input into the layer below. Evapotranspiration is divided into Evaporation from the bare soil (layer 1 only) and the Transpiration from the plants. Water extraction from the lower soil layers is considered as occurring only as transpiration. The contribution from each of the soil layers to the total transpiration is considered as proportional to the distribution of effective water absorbing roots in that layer, not total roots present. Calculations were conducted with a daily time step.

Figure 1 shows the flow diagram of the processes employed in the model. The available water in layer 1 is calculated from the initial water content in that layer with inputs/outputs of evapotranspiration, rainfall, irrigation and runoff. Following rainfall or irrigation, evapotranspiration is split into evaporation from soil and transpiration based on the vegetation cover. Evaporation is assumed to be a linear function of the available water level in the soil. The water content of the soil, calculated in the above step, is then used to modify evaporation from layer 1. Transpiration is allocated to each soil layer based on the proportion of active roots in each layer. These modified evaporation and transpiration are then combined to give the actual ET for layer 1. This value is then used in step 1 to recalculate the available water and the associated deep drainage when it occurs. This deep drainage becomes the input to the next soil layer. The water removal from these deeper layers are treated as occurring only through deep drainage and transpiration, with each layer contributing an amount of transpiration proportional to its effective rooting density.

The salinity in each of the layers is calculated from the salinity of irrigation water, modified by appropriate dilutions or concentration due to the recharge in each of the soil layers. The salinity of the water moving from one layer to the next is considered to be the salinity of the saturated soil extract of the layer above.

The model was validated against measured deep drainage and root zone salinity on land disposal systems with effluent irrigation under two different scenarios. Locations of both of these projects were close to the city of Brisbane. In project 1, Mahogany trees were grown under different Nitrogen levels with a grass plot as the control, with domestic effluent of low salinity levels (Edraki 2002). Components of the water balance of these plots were monitored over a period of 22 months. The deep drainage values in each of these plots were measured. In project 2, saline effluent irrigation was applied to grassland of about 50 ha continuously for over 5 years and the levels of salinity in each of the soil layers were monitored over most of this period. (So *et al.* 2003)

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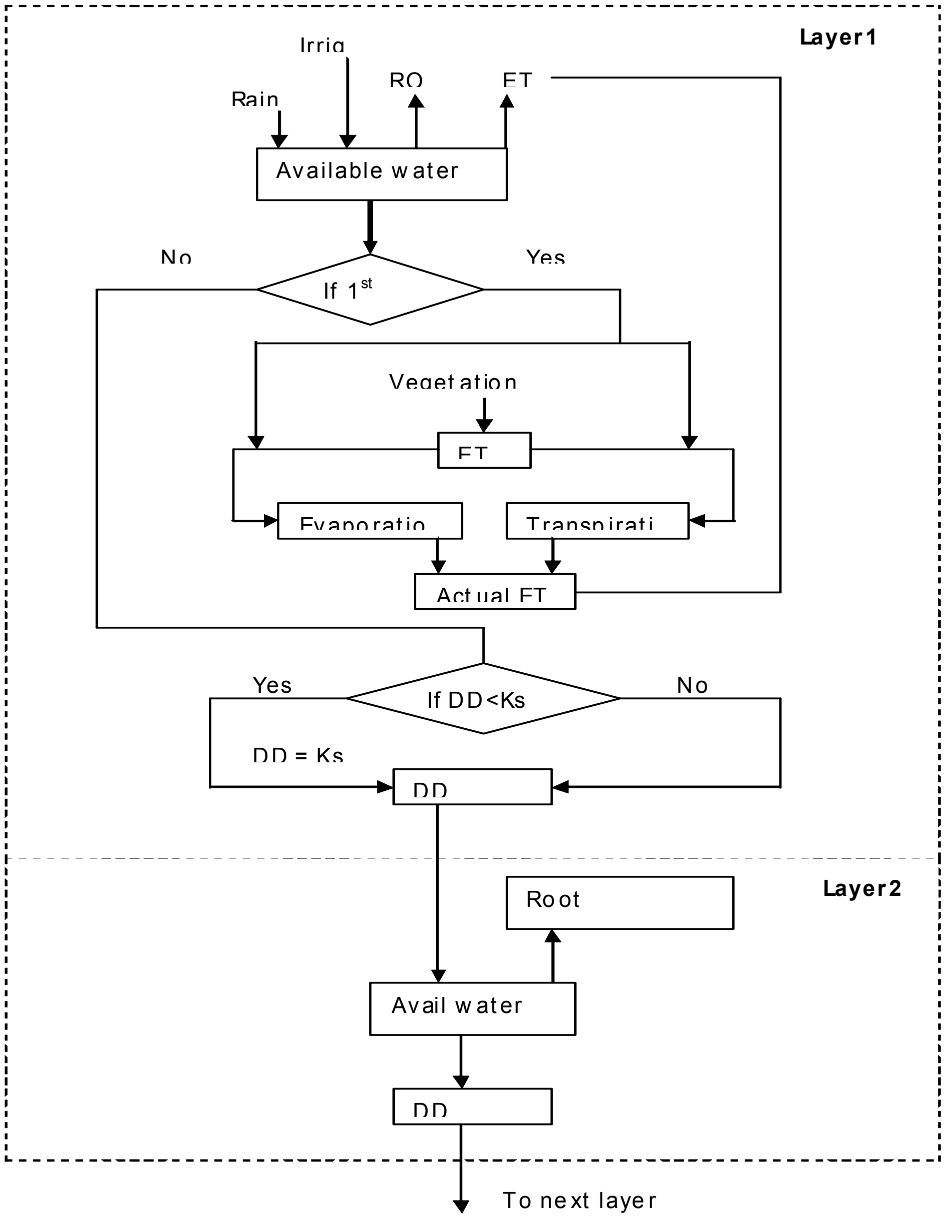

Figure 1. A flow diagram of the processes employed in the Root Zone WSB model.
DD= deep drainage; ET= Evapotranspiration; RO= Run-off; K_S= Saturated Hydraulic Conductivity.

Results

The deep drainage values predicted with the model and the measured values are shown in Figure 2. The model predictions agree well with the measured deep drainage values.

Overall the predicted values of total deep drainage over the period of monitoring (22 months) agrees well with the total measured values of deep drainage. There were a few outliers and in particular plot 4 (triangle in Figure 2 which was not included in the regression) where the predicted value was significantly below the measured values. The reasons for these are not clear as the experimental data were collected several years prior to this work.

In project 2, monitoring of soil water and soil salinity was conducted from 2000 to 2003. Inputs were daily rainfall and irrigation over this period, and the initial soil water content and soil salinity in January 2000. Soil water content profiles were regularly monitored with a neutron probe, and soil salinity levels were monitored annually. Simulation was conducted using 3 soil horizons (0-30 cm; 30-80 cm and 80-180 cm depths) with a daily time step. Effective root distributions were derived from two soil water content profiles in January 2000. The results of predicted salt concentrations in the 3 soil horizons at 1, 2 and 3 years of irrigation and rainfall are presented in Figure 3.

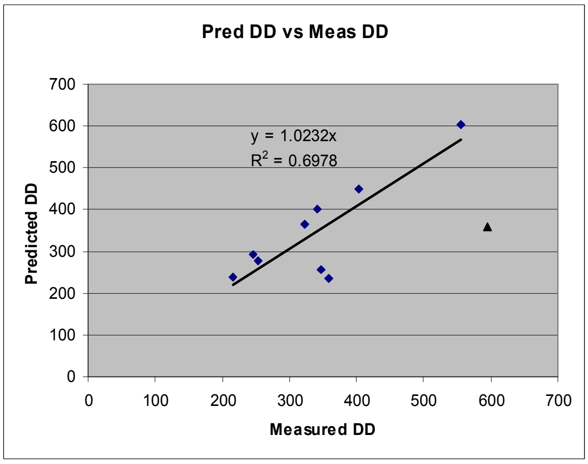

Figure 2. Plot of predicted DD and measured DD from project 1. Plot 3 (Δ) is an outlier and was not included in the regression.

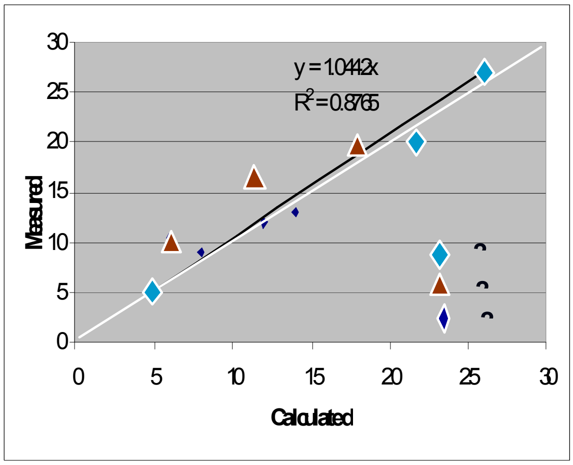

Figure 3. Predicted salt concentrations in 3 soil horizons plotted against measured salt concentration in project 2. Initial soil water contents, salt concentrations and root distribution were determined in January 2000. Data were for 2001 (◆), 2002 (▲) and 2003 (◆).

At this stage, only total amounts of DD and EC within the root zone has been predicted with reasonable accuracy (slope approximately equal to one, with an R^2 of 0.7 for DD and 0.88 for EC). At no stage of the simulation were parameters adjusted to fit the data, all parameters used were measured parameters. The simplicity and the minimal amount of data required make this approach useful for the end-user. The model can readily be enhanced by the inclusion of a third material balance e.g. NO_3.

In **conclusion**, we have shown that a simplistic water balance model of the root zone with minimal inputs and soil layers can potentially be developed as a useful tool for the development and management of sustainable land disposal systems for saline effluent.

Acknowledgement

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