# SALT MASS BALANCE CURVES: WHERE ARE WE?

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## INTRODUCTION

If we begin with the premise that "All models are wrong, but some are useful" (Box 1979), we can investigate our interpretations of reality with an open and inquisitive mind. Further, we must remember that models are merely the construct of someone trying to understand reality by simplifying what is generally a complex system, into something that both they (and generally a computer) can handle. Thus, we realise that "their value tends to be when we discover inadequacies in our conceptualisation or mathematics, rather than any success in mimicking observations" (Hatton *et al.* 2002).

Such is the salt mass balance curve. An artificial construct trying to make sense out of reality, while we try to understand the reality we observe. This opens a number of potential dilemmas, which we will explore in this paper.

## THE SALT MASS BALANCE CURVE

Simply put, the salt mass balance curve for any catchment relates the output of salt from that catchment to the input. Thus, this is commonly measured as the input from salts in rainwater and the outputs measured in the stream as it exits the catchment. This immediately ignores a number of potential sources and sinks for the salt: wind-blown salt; re-mobilisation of salts in the regolith; weathering of salts in the catchment rocks; and, import in groundwater as inputs, and: salt absorption; deposition; and, export in groundwater as outputs. These components are important if we are to construct a complete picture of salt transport through the systems and a number of models are now attempting to do this (e.g., 2Csalt; Stenson *et al.* 2005).

There is also a common misconception that a catchment's salt inputs and outputs should be in equilibrium, i.e., output/input = 1. This can only be the case over an extremely long time frame and may be true as an average of all climatic and vegetative regimes, but should be thought of as a dynamic equilibrium at best, adapting to prevailing land use and environmental conditions. Understanding the response of systems with respect to their salt balance is the key to evaluating management response and need.

Interest in the salt balance curve stems from the desire to predict the response a catchment exhibits to any given change in land use, specifically those induce by anthropogenic activities. The classic case evolves around the extensive land clearing for agriculture as Australia's growing population of the last 2 centuries introduced more European-style crops and livestock to an environment that was largely incapable of supporting it. In particular, the requirement for consistency in the timing and intensity of rains led to substantial modification to the nation's largely ephemeral river and stream networks and the removal of perennial and opportunistic vegetation and their replacement with annual crops and pastures. This resulted in the re-mobilisation of salts stored in the near-surface into the moderated streams and hence caused a large imbalance in the salt output:input ratio. Realisation of this phenomenon has spurred much research but little system response as the realisation that our extreme land-use changes cannot be readily reversed, and that re-equilibration of the system will be a long time coming, if at all.

We may represent this process as a simple curve depicting the salt output:input ratio with time (Figure 1). The ideal (recovery) scenario would ultimately return the ratio to 1 (assuming appropriate intervention), or complete recovery of the system to baseline conditions. Two problems immediately arise:

1. Can we realistically assume the baseline condition to be in equilibrium; and,
2. Can we define the response of the system to the activity that caused the imbalance?

Further, we may not be able to return to the original balance, so have to define a new baseline to which we aim.

## COMPARISON TO OBSERVED DATA

Jolly *et al.* (1997) assessed the stream output:input ratios for catchments in the Murray-Darling Basin. A variety of trends were observed, but the timeframe of the assessment was short (10 years) and the influence of climate was not considered. Thus, for example, Muttama Creek in NSW appears to exhibit a peak in the ratio in the late 1980s and may now be returning to pre-clearing levels of salt output. This is corroborated with the data from Harvey & Jones (2003) on stream electrical conductivity (EC) that shows a similar trend. However, superimposing the climatic (rainfall) trend, we may also see that the ratio tracks rainfall, with approximately a 1-year lag (Figure 2). Both the salt output from the stream and the stream's EC may merely be reflecting a volume response to rainfall.

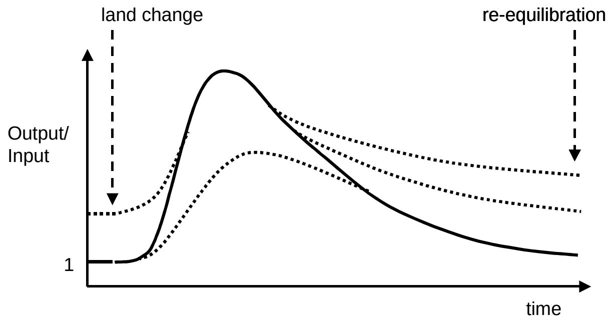


**Figure 1:** Idealised salt balance curve(s). Continuous line indicates idealised steady state curve. Dotted curves represent various scenarios for disequilibrium/dynamic equilibrium scenarios.

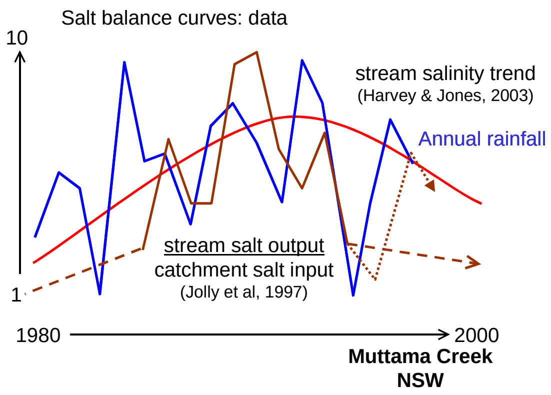


**Figure 2:** Example salt balance curve from western slopes, NSW. Note the concordance with the rainfall data.

## MODELLING CATCHMENT RESPONSE

Modelling of this data has traditionally been carried out assuming a sympathetic relationship of salt and water, and hence water transport models are used. Further, the response is commonly modelled as a unit response, i.e., to a single event that triggers the system response. It has been usual to apply an advection-dispersion model, which generates the response illustrated in Figure 3. Here a single flow path is assumed (i.e., the stream) and the system ultimately returns to equilibrium, requiring only the time constant to be evaluated.

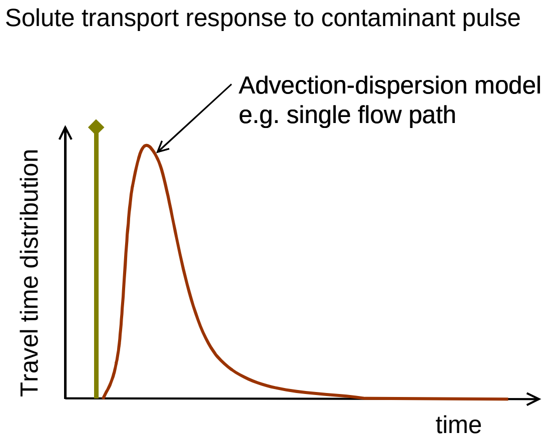


**Figure 3:** Simple water transport model applied to catchment disruption.

Peck & Williamson (1987) concluded that, for catchments in WA, where a well-constrained catastrophic event (land-clearing) allowed detailed analysis of catchment responses, the large temporal and spatial variability in groundwater salinity could not be interpreted within the context of a soluble transport equation. Instead, a transient, linear reservoir model was developed (Hatton *et al.* 2002, Peck & Hatton 2003) whereby non-steady state, 2-dimensional groundwater flow in an unconfined, non-homogeneous, but isotropic aquifer was parameterised for a partially cleared catchment and a simple exponential decay model invoked based on the ratio of groundwater discharge to a regolith salt storage term.

The resulting curve (Figure 4) shows a distinct difference to the advection-dispersion model and reflects the fact that the system is essentially already full. Hence it is not transporting a single pulse, rather, the pulse is re-mobilising an existing store. Response of the catchment to a change in conditions may be prolonged relative to that expected from the solute transport model.

Most Australian catchments, however, suffer from a lack of observational data, restricting our ability to reliably compare our models to reality. Kirchner *et al.* (2000) examined the data for a number of catchments in the Welsh borderlands and found that, while the stream runoff showed a sympathetic relationship with rainfall, the chloride content of the stream did not, but was best related through a fractal power spectrum, resulting in a gamma function describing the salt output (Figure 4).

If the distribution observed in Wales is applicable to Australian catchments the implication is that there will be a faster initial response to land-use change, but we may not return to original conditions in a reasonable timeframe.

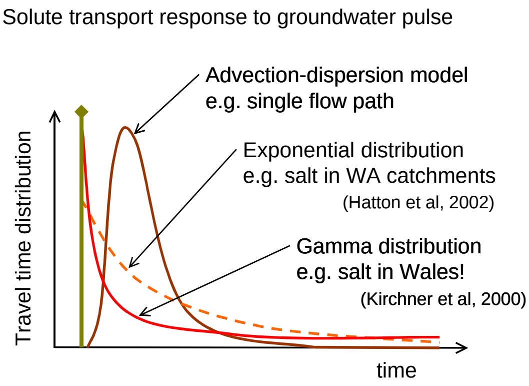

**Figure 4:** Application of an exponential distribution to model salt flux through a catchment with time (after Hatton *et al.* 2002) and a gamma function as determined from observations from Welsh catchments (Kirchner *et al.* 2000).

**MODELLING CONSTRAINTS**

The lack of adequate field data for most Australian catchments can lead to significant errors in modelled projections. Thus, for example, new data from outside previous experience will change the form of projection curves, such as has been realised following water allocation estimates based on incomplete data sets. In this instance, a change in projections can have significant monetary as well as environmental ramifications.

Further, uncertainty in data can have 2 serious implications:

1. The variability in observed data to which models are calibrated means that over-emphasis may be placed on spurious events; and,
2. A decision needs to be made determining the validity of mean, median and mode values as the appropriate baseline, and the effects of events that occur within the error bounds of the data, but extant to the mean value.

In addition, models generally include a number of parameters. If each of these parameters has an associated error or uncertainty, a significant difference in the final confidence limits will occur depending on whether the individual parameters are additive (i.e., similar in response—soil density measurements or water buckets) or multiplicative (i.e., dissimilar—flux determinations or salt distributions). In the former, uncertainty will decrease as we increase the number of determinations (proportional to $1/\sqrt{n}$), while in the latter, uncertainty will increase (proportional to $\sqrt{n}$) up to limits imposed by mass and energy constraints (Cook 2005).

Coupling salt to water transport models thus requires knowledge of the response time and intensity of the salt store and of the parameters in the water transport model that might change as a function of salinity, or with time. These include: immobile phases; non-conservative behaviour; varying water retention capacity; and, varying hydraulic conductivity with salinity.

Water (and salt) retention in the regolith is largely a function of the clay content of the materials. Increasing clay content increases available porosity (whilst commonly also decreasing permeability) and hence the water retention capability. The magnitude of this effect is dependent on the clay type, with smectitic clays capable of substantial expansion and incorporation of water into the clay structure, relative to non-swelling clays such as illite and kaolinite (Tan *et al.* 2005).

The effect of clay content on the size and strength of the capillary fringe, between saturated and unsaturated materials, is strongly influenced by clay content. Clay-rich materials exhibit both a thicker zone of influence, as well as an increased water holding capacity towards saturation. Thus, drainable porosity (that porosity available to transmit water) is reduced when the water table is further from the ground surface (> 3 m) than for sand-rich materials (< 1 m).

There has been a recent realisation that bromide does not behave conservatively in many materials (e.g., Figure 5; Lischeid *et al.* 2005), raising the concern that other salts may similarly be retarded relative to the water in which they are (presumably) dissolved. This may impose limits on the amount of salt that can be liberated from a given regolith material.

Highly saline waters are also known to affect an increase in hydraulic conductivity in clay-rich materials. This has recently been graphically demonstrated using X-ray tomography of materials from central NSW (Figure 6; Turner 2001). Thus, models in saline environments need to facilitate varying hydraulic conductivities as the system freshens, or salinises.

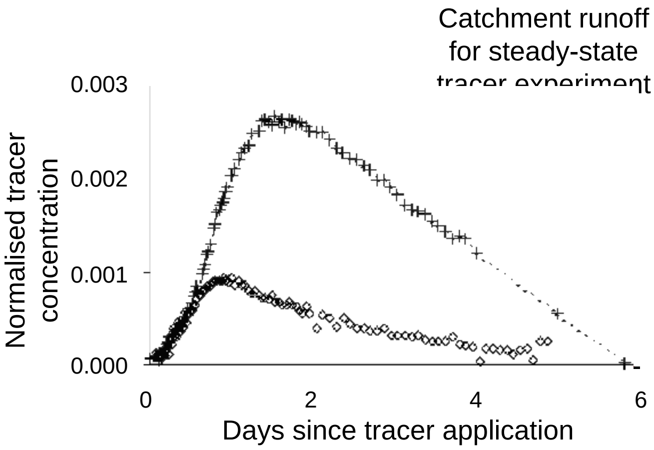


**Figure 5:** Breakthrough curves for simultaneous addition of bromide and deuterium tracers to a catchment in Sweden. Note that only 20% of the applied bromide is seen, implying a non-conservative behaviour (Lisheid *et al.* 2005).

## CONCLUSIONS

In conclusion, models for water mass balance are reasonably well understood and calibrated against observations. Models for salt transport, however, still suffer from inadequate observational data for calibration and incomplete parameterisation for the variable environments in which they operate. There is a requirement to employ good modellers to generate appropriate models, rather than employ models that may be inappropriate for the purpose.

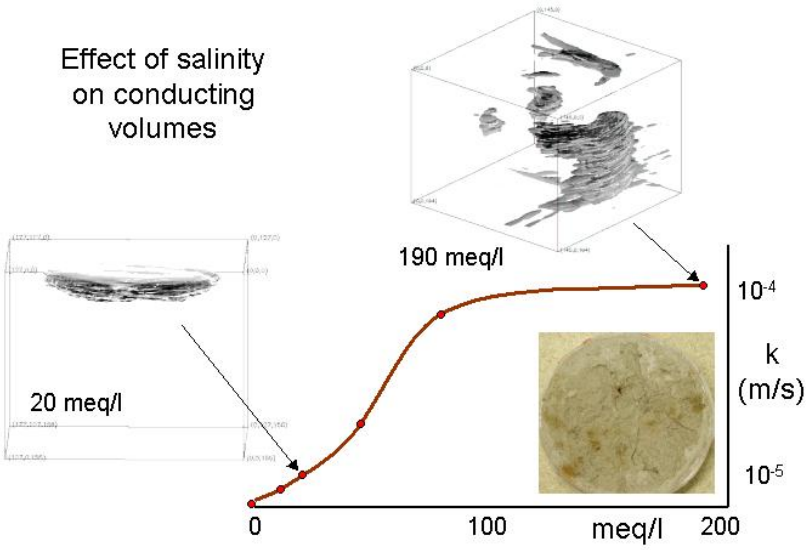


**Figure 6:** Example of the effects of the salinity of infiltrating waters on the hydraulic conductivity of the materials. The sample contains 4% smectite. From Turner (2001).

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