An overview of catchment-scale salt mobilisation models

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Introduction

Modelling is often used to develop strategies for management of salinity issues at a catchment-scale. This is particularly important when dealing with large spatial scales and limited data availability, such as in the Murray-Darling Basin, Australia. There are many modelling approaches that describe processes relating to the movement of water and salt from subsurface landscape stores to the landsurface and to surface water systems. These different approaches have a range of complexities, data requirements, suit different scales of application, and tend to focus on particular salt mobilization processes at the expense of others.

Salt mobilisation occurs when water pathways intercept and mobilise salt stores. These pathways vary both within and between catchments and can operate across a range of spatial and temporal scales, complicating the prediction of salt mobilisation at a catchment scale. Confidence in the outcomes of suitable modelling approaches will only result from conceptual understanding of the underlying physical processes.

There are several approaches used for the modelling of salt mobilisation at a catchment scale. These range from relatively simple prioritisation tools, through to fully-distributed physically-based models. While there is no single accepted and adopted approach for salt mobilisation at a catchment scale, it is clear that the development of frameworks (such as the Groundwater Flow Systems framework) which allow linkages, and promote greater levels of consistency and data sharing between models is a useful step towards managing salinity issues at a catchment and regional scale.

This paper focuses on salt mobilisation models which predict the impacts of land-use change on surface and groundwater contributions of water and salt to catchment streamflow In particular it focuses on models developed for application to: dryland (non-irrigated, and non-urban) areas; upland areas (hence typically gaining streams); and feeding unregulated rivers. The aims of this paper are to:

- Classify several catchment salt-mobilisation models in terms of the complexity of their catchment representation and water/salt pathways.
- Provide guidance on the use of these models to address questions across different scales.
- Highlight data limitations and technical gaps in existing salt mobilisation models

Catchment representation

A fundamental difference between salt mobilisation models is the way in which they spatially represent the catchment. The choice of representation typically depends on two things: 1) scale at which the output is required, and 2) scale of the management options which are used as input. For example, different spatial representations would be used to predict the end-of-catchment impact of broad land-use change, compared with farm-scale impacts of targeted site-specific management actions. In broad terms, we can place catchment models into three main classes: lumped, generalised, and distributed.

Lumped

This is the simplest representation, where all water and salt pathways are spatially averaged to provide a single output. The catchment is modelled as being spatially homogenous, and populated with a single parameter set of average catchment properties.

SMAR and Sacramento (O'Connell et al. 1970, Burnash and Ferral 1972, Kachroo 1992) are examples of this type of model, where catchment water balance is described using a series of buckets to represent surface and subsurface water stores. Typically, stream salinity is estimated using a simple flow-salinity relationship, applied to the modelled stream flow time series.

In order to predict the impact of land-use change, it is necessary to manipulate the ET input parameters to mimic the desired change in water. In doing this, the modeller is forcing the model to achieve the required outcome. Models such as CATSALT (Tuteja et al., 2003) overcome this limitation by using the results from complex unsaturated zone modelling (Hydrus-2D; Šimùnek et al. 1999) to derive regionally specific scaling factors for the influence of land-use change on surface runoff and recharge.

Another lumped approach is to predict impacts by using simple relationships (such as the simple two parameter model of catchment evapotranspiration described by Zhang et al. (2001)) to predict the impacts of land-use change on stream flow.

Generalised

Spatially generalised models sub-divide a catchment into a number of spatially explicit units. This allows for some spatial variation in hydrological properties and salt store to be modelled within a catchment. However, each modelled unit is treated independently, with catchment outcomes typically obtained by summing them or using very simple routing techniques. By treating the units independently, the catchment model is kept relatively simple, and connectivity and feedbacks between units is not considered.

The BC2C (Gilfedder et al. 2005) and 2CSalt (Stenson et al., 2005) models divide a catchment into multiple units based on topography. These form the fundamental modelling units, which can be aggregated to provide totals at the catchment outlet. By separating the catchment into many separate units, this allows the impacts of management options (such as land-use change) to be variable across the catchment, depending on the hydrological and salt store properties of each of the units.

Distributed

In this case, the catchment area is separated into many interconnected units. Complex equations that represent water flow through porous media are used to estimate water movement through landscapes to stream. This allows for a physically-based prediction of water pathways and salt mobilisation. Unfortunately, these models have high requirements for input data, and parameters to describe water movement. These models are not frequently used for catchment scale salt mobilisation modelling, and their use is often targeted at investigating detailed hydrological behaviour in smaller areas.

Salt stores

Salts are stored in areas of the landscape where high concentrations of salt have accumulated. The sources of these salts are varied and may include: cyclic salts from rainfall, salts from aeolian deposition, as well as salts formed from geological weathering or marine sediments. Important salt stores for catchment modelling are found in the soil, regolith, and groundwater. These stores may be intercepted by pathways of water across and through the landscape and mobilised to streams. Often salt stores are assumed infinite because estimating a continuous mass balance of these salt stores is difficult without detailed three-dimensional mapping. Added to this difficulty is the spatial and temporal complexity and variability in mobile and immobile salt stores.

A further issue is that catchment models are usually run over relatively short time periods (decades), while salt accumulation processes are typically occur over much longer time periods (centuries – millennia). Catchment models generally treat salt stores as constant, by focusing on measured salinities from groundwater discharge, and assuming these salinities unchanging over time. In thesemodels, the changes in stream salinity are brought about by changing the partitioning of water into pathways, rather than changing the salinity of each pathway.

Water pathways

Salt stores can be mobilised by changes in the partitioning of rainfall into runoff, lateral flow, recharge and evaporated components. There is a range of methods for partitioning rainfall into these pathways, and for dealing with the interaction of these water pathways with salt stores.

Surface water partitioning

Catchment salt mobilisation models partition water using different spatial conceptualisations.

At the simplest level, a lumped bucket model assumes spatial homogeneity in hydrologic parameters using A single set of parameters to represent water stores and fluxes of water between stores. Evapotranspiration is estimated using spatially averaged parameters across all land-uses in the modelled area. These types of models require calibration of internal parameters using stream flow data from stream gauging stations. Examples of this type of model include SMAR, SACRAMENTO, CATSALT and the three-store Lucicat model (Bari and Smettem, 2003). The output from these approaches is typically calibrated to, and hence resolvable to, an entire area above a gauging station.

A whole-of-catchment top-down modelling approach can also be used, where a simple relationship (based on empirical analysis) can be used to predict impact of basic land-use change on catchment evaporation. The approach of Zhang et al. (2001) is a good example of this approach.

Catchment models which have multiple independent areas (i.e. "generalised approach" in previous section), use a range of sub-models to perform their water partitioning. Models such as CAT3D (Beverly et al., 2005) and 2CSalt (Stenson et al., 2005) can use physically based 1D water balance models such as PERFECT (Littleboy et al., 1992), while the BC2C model (Gilfedder et al., 2005) utilises the simple relationship of Zhang et al. (2001).

Groundwater

The handling of groundwater pathways is an important aspect of catchment salt mobilisation models, as groundwater discharge is often a mechanism for salt generation to streams. At a simple level, catchment groundwater can be treated as a single store, with an associated delay function, or as part of the overall water portioning (e.g. SMAR and SACRAMENTO).

Spatially generalised approaches may use multiple stores for each modelled unit – which will accept recharge and then discharge to stream using a storage-discharge relationship (e.g. 2CSalt), or with a groundwater response time delay (e.g. BC2C). Alternatively, catchment recharge may be used to feed underlying physically based models such as MODFLOW (McDonald and Harbaugh, 1988).

The consideration of groundwater processes is important to quantify the relationship between recharge and discharge, Typically, a recharge signal is highly episodic responding to seasonal fluctuations in rainfall. The groundwater system dampens this variability for different slope, flow length and hydraulic properties. Groundwater properties often vary considerably across a catchment and the Groundwater Flow Systems Framework is a widely used approach to capture this. In many areas there is a paucity of data describing groundwater systems which limits the use of complex models such as MODFLOW. Many of the salt mobilisation models developed in eastern Australia have been designed to be compatible with the data available in Groundwater Flow Systems mapping.

Discussion

Question vs data

Choice of model will depend on both the nature/scale of the question and on the availability of data to match. It is an obvious statement, but still needs to be said that the complexity of the model should match the complexity of the available input data.

A multitude of models

There are many models that have been used to investigate salt mobilisation at a catchment scale. There are several reasons for this, which include: 1) contributions from multiple scientific disciplines (e.g. soil, surface hydrology, agronomic, geological); 2) multiple policy drivers (e.g. ranging from Basin management to farm-scale management); and 3) specific local issues and needs.

Model = software + data

A model is generally seen as a piece of computer software and is promoted as a useful tool once software development has been completed. However, the software is useless for decision making until it is parameterised, calibrated and/or validated and populated with data for a catchment. Models should be seen as a combination of the scientific software and the underpinning data. This concept is already well entrenched in some areas (e.g. Murray-Darling Basin) where a range of river routing models have been developed using the same software but different geographical data (e.g. IQQMMurrumbidgee, IQQM-Namoi, IQQM-Condamine).

Recommendations

Improved modelling of salt mobilisation at a catchment scale can be achieved through:

- Advances in the mapping of regolith salt stores and geological structures. This will allow better identification of intersection of water pathways with salt stores, show accumulation of salt, and contribute to the ongoing improvement of the GFS framework.
- Matching model complexity to data complexity and question complexity
- Clever disaggregation/conceptualisation catchments (both surface and subsurface), allowing for improved spatial connectivity. Techniques which allow the nesting of scales (i.e. detailed components with broader models as required).

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