# Improved hydropedological identification of soil salinity types in upland South Australia using seasonal trends in soil electrical conductivity

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## Abstract

Our hydropedological methods explain variations in seasonal changes during late winter (September) and late summer (April) to electrical conductivity (i.e. solute concentrations) in 19 near-surface (< 0.7 m) soil profile layers from a range of topographic settings within a 120 ha study area in the Mount Lofty Ranges, South Australia. By combining down profile trends of clay per cent, 1:5 water extractable cations and ions, and soil-landscape and terrain analysis patterns, we establish existence of four salinity types consistent with a new process-based salinity classification; two were associated with upper slope positions featuring perched watertables while the other two were associated with deep saline watertables, though in upper and lower landscape positions. Conceptual toposequence models for each salinity type explain the interactions between groundwater, soil morphology and landscape position. The methodology provides a convenient, cost-effective adjunct to conventional groundwater approaches (e.g. nested piezometers) to determine patterns of water flow and solute transport in saline landscapes

## Key Words

Salinity, electrical conductivity trends, 1:5 water extractable cations and anions, terrain analysis, hydropedology.

## Introduction

Salt-affected soils fall into two categories: (i) saline soils, and (ii) sodic soils. In Australia, the latter have an exchangeable sodium percent (ESP) ≥ 6 (Isbell 1996). Saline soils are typically dominated by halite (NaCl), although carbonate ($CO_3^-$), sulfate ($SO_4^{2+}$) and salts of other anions may dominate locally. In sodic soils with low soluble salts, excessive $Na^+$ causes physical degradation of soil structure, creating problems such as hard setting, reduced hydraulic conductivity and dispersion (Sumner 1995). Soluble salts are dissolvable under field water conditions (Soil Survey Staff 1993). As such, prevailing landscape hydraulic conditions may be detected by measuring changes in saline groundwater wetting fronts, and formation and persistence of salt concentration zones within the soil profile (Shaw 1988). The integrated study of these soil-regolith conditions fall within the research discipline of hydropedology, which bridges the inter-related disciplines of pedology, geomorphology and hydrology (Lin *et al.* 2008).

Fitzpatrick (2008) presents a salinity classification based on soil-regolith-hydrology types, with indicative salinity ranges (electrical conductivity of saturated paste extract, $EC_e$) . In this scheme, groundwater associated salinity (GAS) corresponds to commonly referred "dryland salinity" in Australia, and is formed where saline watertables intersect at or near the soil surface. Solum-affected non-groundwater associated salinity (NAS) (Fitzpatrick 2008) occurs mostly in sodic soils, and is restricted to the soil solum (i.e. the A and B horizons, typically < 1.5 m). It is present in upper landscape positions with no hydraulic connection to deep saline watertables, and is restricted to semi-arid or arid winter rainfall zones where the annual evaporation rates exceed rainfall. The subsoil form of NAS ($EC_e$ 2 - 8 dS/m) occurs typically in the depth range 0.3 - 1.0 m. Generally soils with solum-affected NAS feature loamy A horizons overlying clayey B horizons that are often sodic, and hence with low hydraulic conductivity. The poorly permeable B horizons contribute to formation of seasonally perched saline watertables in topographic sump-like landforms in the hillslopes, e.g. localised depressions. Salinity depth and concentration in these solum-affected NAS profiles therefore vary in response to seasonal conditions (i.e. rainfall, evaporation and transpiration rates).

The purpose of this paper is to apply the salinity classification that Fitzpatrick (2008) presents using multitemporal hydropedological approaches in a small (120 ha), rain fed catchment in the Mount Lofty Ranges (MLR) in South Australia to (i) diagnose salinity types, and (ii) develop conceptual models for the salinity types identified. The analytical methods apply repeat analysis of winter (2004) and summer (2005) salinity concentrations (i.e. $EC_e$ and ionic) that are measured in fixed incremental-depth layers from 19 shallow (< 0.7 m) soil profiles. We augment salinity classifications and conceptual model development by applying soil-landscape context (i.e. landform and hillslope position) supplied through field observation and digital terrain analysis.

## Methods

### *Study area and soil sampling*

The Herrmanns catchment is located in the Mount Lofty Ranges (MLR) 40 km east of Adelaide, South Australia. The climate is Mediterranean-like with rainfall occurring predominantly during winter (May to October). A typical toposequence (Fritsch and Fitzpatrick 1994) consists of the following: Typic Palexeralfs → Aquic Palexeralfs → Albic Glossic Natraqualfs → Typic Natraqualfs (Soil Survey Staff 1993). A digital elevation model (DEM) with two metre ground resolution was generated from a stereo pair of 1:40,000 aerial photographs. Using ArcMap GIS, terrain analysis was performed to create various GIS coverages of terrain attributes, including two metre elevation contours and topographic wetness index (TWI) showing near-surface soil water through-flow and accumulation patterns (Figure 1). Georeferenced year 2001 summer and winter aerial photographs were integrated in the GIS as interpretative backdrops.

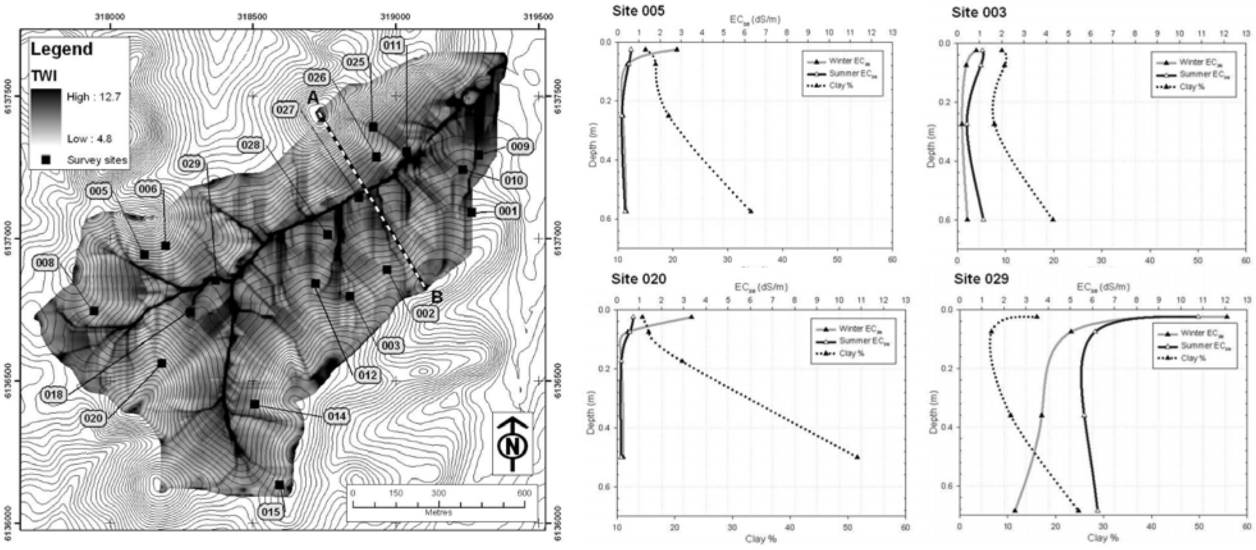

**Figure 1. Left, Herrmanns catchment study area TWI coverage showing patterns of high (dark shades) and low (light shades) rates of near surface water through-flows. Also shown are soil survey site locations and 2 m elevation contours. Right, typic down profile salinity ($EC_e$) and texture (clay %) trends for Model 1(a) NAS (Site 005), Model 1(b) NAS (Site 003), Model 2(a) GAS, and Model 2(b) GAS**

Nineteen soil profile locations were selected (Figure 1) based on prior field knowledge. Combinations of survey points were selected to form toposequences or paired sites from similar hillslope zones, but occupying positions in different local topographic features. Soil sampling was conducted during late winter (September) 2004 and then late summer (April) 2005. Each sampling site location was recorded using a differential GPS during the winter survey to assist site location during the subsequent survey. Sampling during the second survey was conducted one metre upslope of the first survey to negate altered soil profile hydrology. Four layers were sampled in each profile, comprising: L1 (0 – 0.05 m) and L2 (0.05 – 0.1 m), both dominating the A horizon; L3 (0.1 – upper B horizon), typically dominated by the E horizon and; L4 the upper B horizon to a maximum depth of 0.75 m.

### *Laboratory physicochemical analyses*

Laboratory analyses were conducted on the ground (< 100 µm), dried < 2 mm soil fraction of samples. The analyses involved wet chemical analyses using 1:5 soil:water extractions (i.e. water extractable Ca, K Mg, Na, $PO_4$, Cl and $SO_4$) (Rayment and Higginson 1992). Mid-infrared (MIR) analysis was used to predict soil particle size analyses. The electrical conductivity of saturated paste extract ($EC_e$) was estimated using a conversion factor after Cass *et al.* (1996) from EC1:5 and soil texture. MIR was used to estimate the soil texture, which was incorporated to convert Shaw's (1988) soil texture classes used in the EC1:5/$EC_e$ conversion methodology.

## Results

### *Physiochemical trends*

Seasonal down profile solute trends are graphically displayed with clay per cent to assist interpretations of near-surface hydrological processes and salinity types. Interpretations were assisted by knowledge of soil type and soil landscape patterns (e.g. TWI and elevation). Down-profile salinity trends for winter and summer plotted against clay per cent indicate the prevailing landscape hydraulic conditions according to: (i) changes in saline groundwater wetting fronts, and (ii) formation and persistence of salt concentration zones within the soil profile. Four salinity types were identified using the hydropedological methods (Figure 2). The salinity types identified are as follows:

i. Solum-affected NAS, topographically perched in upper hillslopes - Model 1(a);
ii. Solum-affected NAS, low lying areas of mid-upper hillslopes - Model 1(b);
iii. GAS, upper hillslopes - Model 2(a); and
iv. GAS, lower hillslopes - Model 2(b).

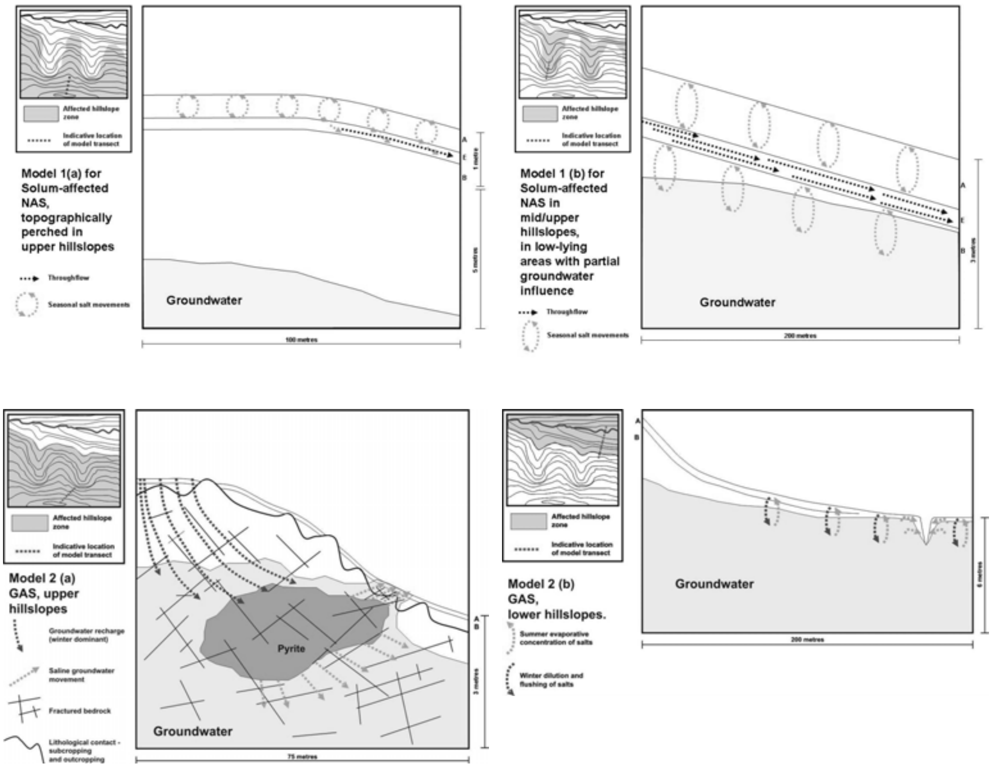

**Figure 2**. **Conceptual models for Model 1(a) Model 2(b), Model 2(a) and Model 2(b) The conceptualised contour map that is inset identifies possible affected areas in the landscape, and the indicative location of the transect described in the model.**

*Conceptual models*

Each salinity type showed distinct topographic setting and profile trends (Figure 2 and Table 1). Hydropedological conceptual models for each salinity type that summarise the key topographic, profile morphological and hydrological features of each are presented in Figure 2.

## Conclusions

The hydropedological interpretation of combined site knowledge, soil layer texture (according to clay %), and seasonal soluble salt chemistry (inferred from $EC_e$ and selected water extractable major cations and anions) at various near-surface profile depths (< 0.7 m) in a Mount Lofty Ranges catchment have given rise to four distinct hydropedological models for salinity types. These are presented as conceptual models in Figure 2. Two of the models are dominated by solum-affected non-groundwater-associated salinity (NAS) processes located at either topographically perched, upper hillslopes or from topographically non-perched, mid/upper hillslopes with groundwater influence. The remaining two models are dominated by groundwater-associated salinity (GAS) processes in either upper or lower hillslopes locations. The low-cost investigation methods described shows the importance of seasonal hydropedological changes in the near-surface (< 0.7) of soils in the study area. The multitemporal hydropedological method for identifying salinity types significantly augments the traditional approaches to interpret pedogenic and degradation processes in soil-landscapes, which include detailed layer morphological description and interpretation, and the installation of costly nested piezometers. The methodology will provide a convenient, cost-effective adjunct to conventional groundwater approaches (e.g. nested piezometers) to help determine patterns of water flow and solute transport in saline landscapes.

**Table 1. Summary of trends for salinity types presented in Figure 1.**

| Salinity type | Topographic position | Down profile morphology | Winter and summer down profile salinity trend (Figure 1) | | Sites represented (Figure 1) | Description |
|---|---|---|---|---|---|---|
| | | | A horizon | B horizon | | |
| Solum-affected NAS, Model 1(a) | topographically perched in upper hillslopes | Texture contrast | Seasonally variable, moderate to strong | Seasonally constant, low | 001, 002, 005, 006, 008, 010, 012, 014, 015, 025, 026 and 028 | Seasonal circulation of perched salts in A horizon. Saline groundwater beyond hydraulic influence of upper profile. |
| Solum-affected NAS, Model 1(b) | low lying areas of mid-upper hillslopes | Texture contrast, prominent E horizon | Seasonally variable, moderate | Seasonally changing, low | 003 and 009 | Seasonal circulation of perched salts in A horizon. Saline groundwater within seasonal hydraulic influence of upper profile. Prominent E horizon truncates hydraulic connectivity between upper A and B horizons. |
| GAS, Model 2(a) | upper hillslopes | Texture contrast | Seasonally variable, moderate | Seasonally constant, low | 020 | Upslope pyritic body flushed by groundwater supplies seasonal salts (featuring SO4-)to upper profile |
| GAS, Model 2(b) | lower hillslopes | Gradational | Seasonally constant, strong | Seasonally changing, strong | 011, 018, 027 and 0029 | Salts accumulate in A horizon while B horizon is influenced by seasonally changing watertable depth |

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