SALINITY ASSESSMENT WITH HARSD: LITTLE RIVER CATCHMENT, NSW

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Abstract

The HARSD method (Hydrogeomorphic Analysis of Regional Spatial Data) was applied for salinity assessment of the 1,075 km^2 Little River Catchment, Macquarie Valley, NSW. Automated terrain classification was performed using a 25 m resolution Digital Elevation Model (DEM) and potential groundwater discharge sites were identified from a regional-scale hydraulic head surface (HHS) constructed from sparsely-distributed borehole data using GIS and hydrologic techniques. These sites compared favourably with mapped salinity in the southern area, but less so elsewhere. Transmissivity, spatially distributed recharge and the HHS formed input to Flownet Analysis Software (FAS), a steady-state groundwater model associated with HARSD, to provide preliminary groundwater and, by inference, salt flux estimates for the 735 km^2 Buckinbah Creek subcatchment. Phase-II work will investigate salinity in a high-risk subcatchment of Buckinbah Creek, using hydrological, hydro-ecological and remote sensing techniques.

Introduction

Salinity is now recognised as one of the most pervasive and potentially damaging problems threatening riverine and terrestrial environments throughout the Murray Darling Basin (MDB). The severity and scale of the problem is documented in recent findings from both the Murray Darling Basin Ministerial Council's Salinity Audit (MDBMC, 1999) and a report to the Prime Minister's Science Engineering and Innovation Council (PMSEIC, 1999). The Audit identifies the Macquarie, Bogan and Castlereagh regions of Central West NSW as high-risk areas and focuses, in part, on the Little River and Talbragar catchments of the upper Macquarie Valley where salinity is particularly severe. The Central West Catchment Management Committee (CWCMC) recognises the importance of salinity in the region and in 1998 a joint commitment to develop a planning framework for the future management of salinity was established with the Department of Land and Water Conservation (DLWC).

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The current study was initiated through DLWC Project *Hydrological Actions for Central West Community Salinity Planning*[1]. Partners in the project include the DLWC - Central West Region, the Little River Landcare Steering Committee and the National Centre for Groundwater Management, University of Technology, Sydney. The study extends the scope of previous work in the area by applying HARSD, a GIS-based method for Hydrogeomorphic Analysis of Regional Spatial Data. The principal aim of the study was to develop a regional-scale groundwater model with reliable predictive capability. The model will assist land and resource managers in the selection and siting of appropriate management options designed to lower groundwater levels and optimise the benefits of expenditure during remediation and prevention of dryland salinity in the region.

Background to HARSD

The HARSD procedures were developed by Salama and colleagues (Salama *et al.*, 1999), CSIRO, Land and Water, Perth, WA following recent advancements in Geographical Information Systems (GIS). HARSD is a suite of methods and models designed to provide hydrogeological inferences for small and large catchments. In general, it uses parameters developed from spatial and temporal GIS datasets to model landuse scenarios aimed at controlling salinity (Salama *et al.*, 1997). HARSD comprises a suite of three main procedures (Salama *et al.*, 1996) incorporating:

- *Automated Terrain Classification* (Hydrogeomorphic Classification) of Catchments. This step involves the derivation of primary topographic attributes from a high resolution DEM, statistical and graphical analysis of these variables and classification of Hydrogeomorphic Units (**HGU's**), or domains which are expected to operate uniquely and have similar aquifer properties and recharge/discharge behaviour.
- *Generation of a Hydraulic Head Surface* (**HHS**) that uses two alternative hydrogeological techniques. In the first technique a least-squares regression is derived between the reduced water levels and surface elevation. The developed regressions are then used in a GIS environment to prepare water level maps. In the second technique a land unit classification based on the hydrogeomorphic characteristics of the catchment is used to define the depth to water in each zone using regression. The HHS can also be used to identify potential groundwater discharge sites.
- *Flownet Analysis Software* (**FAS**), a steady-state groundwater model that requires input from transmissivity estimates, spatially distributed recharge and the HHS to derive groundwater flux and, by association, salt flux. The flownet can also model groundwater level response to various climatic or landuse change.

The HARSD method uses geomorphological theory and experience to infer spatial codependence among aquifer parameters and other controls on groundwater behaviour. The approach asserts that, at least in erosional landscapes, surface topography reflects the spatial coevolution of these properties. Combined with some hydrological understanding and even very sparse hydrological data, the technique offers a more efficient, objective and constrained parameterisation than continuum mechanics-based groundwater models. The HARSD procedure maintains that the shape of a landscape is a function of climate and geology, resulting in slopes which, together with geology, control the movement of groundwater through their mutual influence on transmissivity and hydraulic gradient. The resulting HHS is largely a subdued and smoothed reflection of topography (Salama *et al.*, 1996a).

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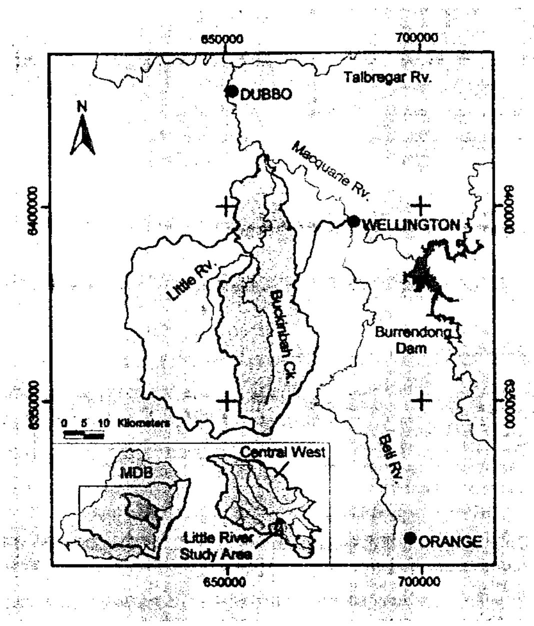

Figure 1. Location of Little River Study Catchment

HARSD technology was successfully applied to the Axe Creek Catchment, Victoria (Salama *et al.*, 1997). The geology of Axe Creek is similar to Little River and the study is regarded as an appropriate comparison. Water level maps generated by HARSD were used to map flow regimes, delineate areas of groundwater recharge, transmission and discharge and simulate the impact on groundwater discharge under different land management options. Other studies include those for the Upper Kent River Catchment, Western Australia (Salama *et al.*, 1997a) and the Loddon and Campaspe catchments, northern Victoria (Salama *et al.*, 1999a).

Catchment Description

Location: The 1,075 km^2 Little River study catchment is situated on the lower-western flanks of the Great Dividing Range in the central-eastern portion of the MDB. The area is located in the Upper Macquarie Valley, Central West Catchment, NSW (Fig. 1).

Climate: The area has a temperate climate with four well defined seasons. The annual mean minimum and maximum temperatures are 10.4 and 22.5° C respectively. The mean annual rainfall (604 mm) is evenly distributed throughout the year, however slightly more rain falls from October to January. Rainfall and evaporation data infer that recharge is maximised in June and July.

General Morphology: The catchment is elongated N-S with maximum orthogonal dimensions of 72 x 26 km. Local relief ranges from 265 m ASL in the north to 740 m ASL in the south. The mean elevation is 447 m. The terrain is characterised by undulating and hilly landform with break of slope features developed at all elevations. The mean and maximum slopes in the study area are 3° and 36° respectively.

Hydrology: The area is largely drained by the major, northward-flowing Buckinbah Creek. This system drains into Little River which enters the Macquarie River at the northern end of the study area at a point downstream from Wellington and upstream from Dubbo, Narromine and the environmentally significant Macquarie Marshes. Previous workers have identified local and intermediate (fracture-controlled) flow systems in the area and established that groundwater mixing between the two regimes is restricted (Callan, 1995 and Kazemi, 1999).

Landuse: Primary landuse types in the study area are dominated by mixed pasture (61%) and cropping (34%). Timber covers a total area of ~5% and contributes to a very high Landuse Hazard Rating (Humphries, 2000).

Slope Hazard: The study area has a high Slope Hazard Rating and is typified by major elevation and slope variation, medium to high energy drainage lines and significant break of slope formations. A slope category/land capability map produced for Little River shows higher angle slopes associated mainly with intrusive rocks.

Erosion and Salt Occurrences: The Little River area has a very high Salinity Hazard Rating (Humphries, 2000) reflecting a large salt store in the landscape, a high recharge potential from highly complex rocks and a landscape which promotes salinisation at surface. Humphries (2000) estimates that the total area affected by salinity in the catchment has increased 24% from 1,200 ha to 5,000 ha in the past ten years. Over 42% of the study area is affected by erosion. Sheet erosion is the most widespread type with a surface expression of 448 km^2.

Geology: The Little River study area occurs within the northeastern portion of the Lachlan Orogen, a composite Orogenic Belt that developed during the Palaeozoic Era on the eastern margin of the Australian Plate. This Orogen is one of the most complex geological systems associated with dryland salinity. Stratigraphic sequences in the Orogen have sustained several deformation events resulting in the formation of meridional structural packages typified by intense folding and multiple thrust sheets. The intense fracturing has promoted the development of salinity and resulted in the study area being assigned with a very high Geological Complexity rating (Humphries, 2000). The geology of the Little River area is detailed in the Dubbo 1:250,000 Explanatory Notes (AGSO, 1999) and summarised in Davies (2001).

Local lithologies range in age from Mid Ordovician to the Cainozoic. Mafic to felsic volcano-sedimentary Formations of Late Ordovician to Devonian age dominate the central and eastern parts of the study area and include the significant Canowindra Volcanics. These rocks typically occur as broad, prominent strike ridges that extend for over 60 km. This Formation is host to several saline sites, many of them preferentially localised along contact zones (Nicholson, 1996). The area to the west is intruded by composite calc-alkaline plutons of the Early Devonian Yeoval Batholith. Components of the Permo-Triassic Gunnedah Basin onlap Devonian Gregra Group rocks in the northwest.

The area has a very high Salt Source Potential of Lithology rating (Humphries, 2000) based on the conducive properties of the rocks to produce and concentrate salts. This rating also reflects the high proportion of sediments with a marine origin, rock geochemistry and the strong weathering tendency of volcanic rocks and coarse-grained, porphyritic and felspathic igneous rocks. The catchment has a high Soil Permeability rating due to the dominance of non-sodic duplex clay loam soils.

Results

Hydrogeomorphic Classification

A GIS-based approach was used to classify the landscape of the Little River study area into Hydrogeomorphic Units (HGU's). This was achieved using automated terrain classification involving the derivation of topographic attributes (e.g., slope, break of slope, minimum slope, aspect, profile curvature and plan curvature) from the DEM, statistical and graphical analysis of these variables and map overlay using lithology and soil outlines. Four HGU's were initially defined on the basis of elevation using conventional standard deviation breaks. Slope was also incorporated into the landscape disaggregation process as it showed a close spatial relationship with lithology, yet maintained its independence from elevation. The slope grid was reclassified by applying a < or > the mean slope (2.96°) condition and amalgamated with the reclassified elevation grid to produce eight HGU's

Prediction of the Hydraulic Head Surface (HHS)

The regional HHS for Little River was constructed using GIS and hydrological methods on sparse, irregularly-distributed, pipe-1 groundwater level data, observed in bores penetrating surficial aquifers, extracted from the current DLWC (Dubbo) borehole database. The primary dataset represents an 80 year observation period from 1920 to 2000. All derived topographic variables were attributed to bore points in GIS. Linear regression analysis was selected in preference to the HGU approach for HHS construction due to insufficient borehole data within several HGU's. The relationship between elevation, slope and water level was investigated using:

• **Pw = Z - (k*S)** Equation 6.4 (Salama *et al.*, 1996)

Where:

Pw = Local hydraulic head elevation

Z = Surface Elevation

S = Minimum Slope

k = A constant derived by calibration with the observed standing water level (SWL) in bores

The constant '**k**' was derived from elevation and observed bore water levels by rearranging the above formula to:

• **k = (Z - Pw) / S**

Where: Pw = Actual SWL elevation (in bores)

The k-values were sorted and their relationship to topographic attributes examined. It was found that k-values formed definite groups with natural breaks that correlated best with minimum slope. Eight, finely-divided minimum slope classes were established on the basis of these k-value breaks. The k-values were averaged for each minimum slope class and used in the original form of the equation to derive *Pw* (now representing the predicted HHS at boreholes).

Elevation residuals were derived by subtracting the predicted HHS elevation from observed water level elevation. Major spikes (approximately 6% of the data) were identified at this stage and removed from the primary database. Linear regressions were developed for the eight minimum slope classes within the 1920 to 2000 dataset in addition to five temporal subsets using five regression types.

These variations were examined to determine the most appropriate time frame and best regression formulas to apply to the elevation grid during generation of the HHS. The parent, pipe-1, 1920 to 2000 (major spikes removed) dataset was selected for HHS construction as linear regression results for minimum slope classes within smaller temporal subsets were in many cases affected by insufficient data. Best regression results were obtained from this dataset using Bore SWL v's Surface Elevation. Regression formulas for individual minimum slope classes were then applied to the elevation grid to generate the HHS (Table 1). In a more ideal situation, groundwater levels taken over a very short time frame from a sufficient number of strategically distributed bores would optimise results.

Satisfactory results were obtained from linear regressions testing the predicted HHS (at bore points) v's observed SWL's (r^2 = 0.9) (Fig. 2). Results however, were less satisfactory for Depth to HHS v's Depth to Bore SWL. Residuals were small for data from bores in areas of low slope, but showed increasing variation with increasing slope. While variability was minimised within smaller, more recent data subsets (e.g., 1990 to 2000), the trend remained in the data and regression formulas and r^2 values changed only slightly.

Table 1. Regression results used to generate the regional groundwater surface at Little River from SWL Elevation v's Surface Elevation for Minimum Slope Classes (DLWC data, Pipe-1 data, 1920 to 2000, Major Spikes Removed).

Minimum Slope Category	General Morphology	R-Squared	Linear Regression Formula
0.00 - 0.09*	Morass	0.9975	y = 1.1027 (x) - 13.151
0.09 - 0.19	Flats - 1	0.7525	y = 0.9440 (x) + 5.0181
0.19 - 0.35	Flats - 2	0.9909	y = 1.0357 (x) 21.186
0.35 - 0.50	Flats - 3	0.9970	y = 1.0497 (x) - 24.571
0.50 - 0.80	V.Gently Inclined - 1	0.9978	y = 1.0016 (x) - 9.1459
0.80 - 1.11	V.Gently Inclined - 2	0.9939	y = 1.0108 (x) - 12.941
1.11 - 2.00	Gently Inclined	0.9974	y = 0.9872 (x) - 2.7807
> 2.00	All steeper slopes	0.9966	y = 0.9888 (x) - 3.6822
(degrees)			(Where: y = HHS; x = elev. grid)

*This category has insufficient data for reliable regression. The R-squared value and formula used here is taken from the global regression performed on the combined minimum slope classes.

Potential Discharge

Mapped saline site polygons were used to *cookie-cut* topographic attribute datasets to examine signatures associated with areas of known groundwater discharge. This was based on the assumption that saline sites represent areas where groundwater is effectively in contact with the surface. Result histograms show that saline sites generally occur within areas where *minimum* break of slope is less than 1.0° and profile curvature is > -0.05° (dominantly concave morphology).

The predicted HHS grid was then subtracted from the elevation grid using map algebra to generate the Depth to HHS grid. Potential discharge areas were defined by combining negative results from the Depth to HHS grid with the salt signature conditions outlined above. The estimated potential discharge area within the study catchment totals ~16 km^2. This area expands 50% to 25

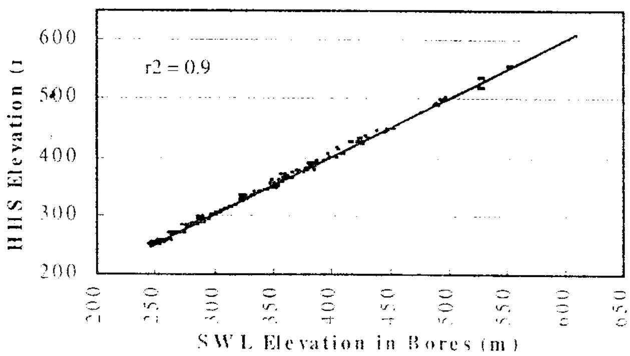

Figure 2. Linear Regression for HHS Elevation (m) v's SWL Elevation in Bores (m) DLWC data, 1920 to 2000, Pipe 1, Spikes Removed (1974 points).

km^2 when the critical groundwater depth is relaxed to within 2 m of surface. A comparison of the potential discharge map with known salt sites shows reasonably good correlation in the southern part of the catchment, but less so elsewhere. Although the potential discharge map is regarded as 'approximate', the results provide a relative basis for identifying areas at high risk of salinisation at regional scale.

Flownet Analysis

A Flownet was constructed for the 735 km^2 Buckinbah Creek Catchment to determine groundwater and salt flux. Key input included a smoothed and aggregated HHS grid, the catchment boundary and recharge and transmissivity files. Input values for recharge (20 mm/yr; 3.3% recharge rate using 604 mm./yr rainfall) and transmissivity (2 m^2/d) were selected using limited data from previous work. Flownet simulations were conducted using five different recharge estimates to examine the resulting changes in groundwater flux. The results demonstrate that any recharge above approximately 5 to 6 mm/yr will contribute to groundwater rise because the system only has the capacity (assuming a maximum transmissivity of 2 m^2/d) to conduct **17,872 m^3/d**. The system reaches its maximum capacity to carry water when the recharge rate is ~1% (assuming an average annual rainfall of about 604 mm).

Using a groundwater flux of 17,872 m^3/d and an average groundwater salinity of 1,772.4 mg/l (2,532 µS/cm) the salt flux for the catchment is estimated at about 31.7 tonnes/day. This equates to an annual total of 11,500 tonnes/yr (15.7 tonnes/km^2 per yr). Salt input to the Flownet catchment from an average rainfall of 604 mm/yr was calculated at 9 tonnes/day. This equates to an annual total of 3,278 tonnes/yr (4.46 tonnes/km^2 per year).

Conclusions

The HARSD method has proved a useful tool for salinity assessment at regional scale in the 1075 km^2 Little River study catchment. Hydrogeomorphic classification has applied automated techniques based on the DEM and its derived topographic attributes to disaggregate the landscape into HGU's in an objective, repeatable and efficient manner. Visual examination of identified landscape units reveal their close spatial relationship to both geology and topography.

A HHS was generated from sparse borehole data by developing linear regression relationships between surface elevation and observed groundwater levels taken over an 80 year period from 1920 to 2000. Regression formulas were derived for eight finely-divided slope categories and applied to the elevation grid to construct the regional scale groundwater surface. The predicted HHS compared satisfactorily against observed groundwater levels ($r^2 = 0.99$). Residuals were small for areas of low slope, but showed increasing variability with increasing slope. Potential discharge sites were identified using map algebra on surface elevation, the HHS and topographic attribute conditions derived for saline sites. These sites compared favourably with mapped salt sites in the southern part of the catchment, but less so elsewhere.

A flownet constructed for the Buckinbah Creek subcatchment using FAS has produced estimates for groundwater and salt flux. Simulations using different recharge estimates show that any recharge above approximately 5 to 6 mm/yr will contribute to groundwater rise because the system only has the capacity (assuming a maximum transmissivity of 2 m^2/d) to conduct 17,872 m^3/d. Using this groundwater flux and an average groundwater salinity of 1,772.4 mg/l (2,532 µS/cm) the salt flux for the catchment was estimated at about 31.7 tonnes/day.

Follow-up work planned for Phase-II of this project will focus on hydro-ecological and hydrological studies and remote sensing applications to investigate salinity in a high-risk subcatchment of Buckinbah Creek identified during the current study.

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