

DEVELOPMENT OF LAND INFORMATION SYSTEM OF THE COTTON-GROWING AREAS OF UPPER NAMOI VALLEY

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Introduction

The natural resources (including land and water) of this planet are not inexhaustible, and therefore require continual management for them to remain sustainable. However, the demand imposed upon these resources is huge and increasing on a scale more than natural cycles can replenish. Thus the sustainability and the management of these resources are vital for the survival of all living things, including the human race. Management of these resources require knowledge and information about them. In Australia and worldwide the importance of updating regional land resource maps has come to the forefront of many government and non-government organizations (Bui and Moran, 2001). This is due to increased awareness of environmental impact of land use and the fact that land is an important component of the agro-ecosystems, which needs to be conserved for the future generations. Knowledge of land feature distribution over large areas has become increasingly more important for numerous scientific and policy purposes (Cihlar et al., 2000). Digital land feature mapping can thus greatly increase the ease of which needed soil and land information can be assessed and applied to land use planning and resource management.

Digital land feature maps can be created from a variety of sources such as Digital Elevation Models (DEMs), remotely sensed data, laboratory analysis of collected soil samples and existing natural resource maps. In order to create a comprehensive land feature database it is essential that the data included is of the same spatial resolution and format. Integration of land cover information on some old topographic maps with land cover maps derived from satellite sensors is difficult because the geometric and thematic characteristics of historical maps are not always well known (Petit and Lambin, 2001). One of the processes involved in digital mapping is the transformation of analogue maps into a digital form. But, because of their nature digital maps are usually inevitably linked to Geographical Information Systems (GIS). GIS are essential for collecting and analysing data on environmental processes in space and time (Oldak et al., 2002). GIS, as a tool for collating all kinds of spatial information (Burrough and McDonnell, 1998) is in itself incapable of soil mapping, as the latter requires an intellectual framework (McBratney et al., 2003). However, GIS are especially useful in working with dynamic phenomena over large areas when the volume of information is large and environmental variables are interrelated (Burrough, 1986). Indeed, GIS are becoming more sophisticated as they continue to incorporate more complex modelling capabilities.

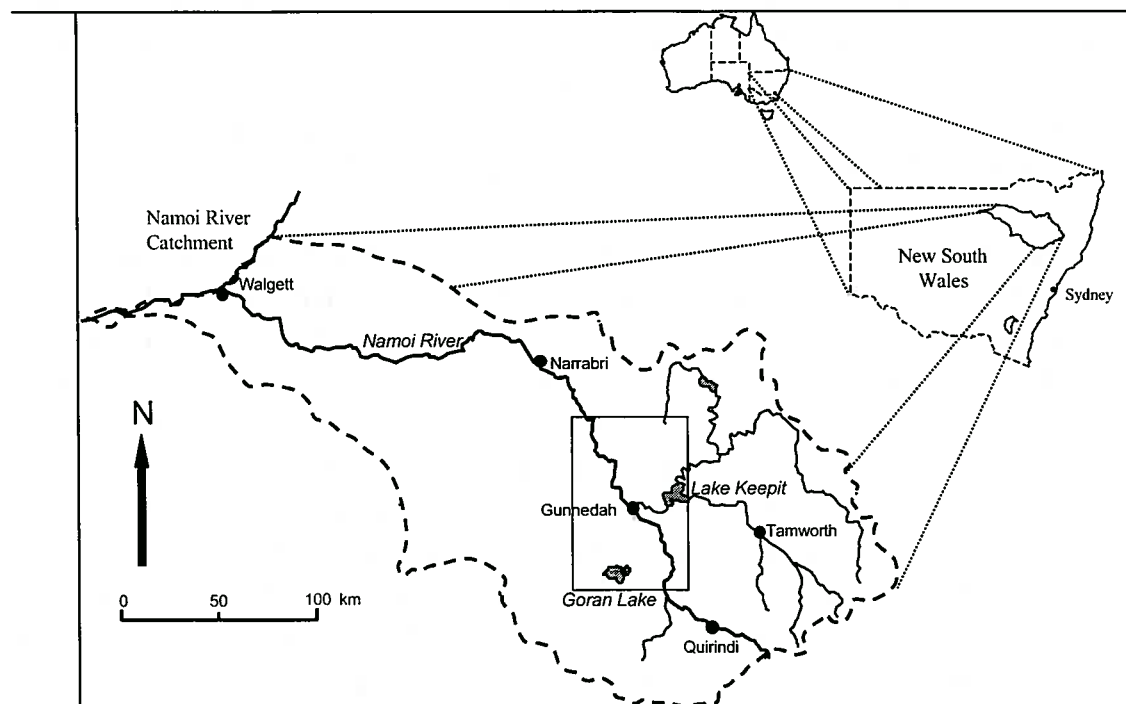
The main objectives of this paper were to collate and integrate various land feature digital layers to the same resolution and coordinate system, and to develop spatial prediction models, based on *scorpan*, for predicting selected soil attributes. The models will be based on correlation with

existing maps obtained from the New South Wales (NSW) Department of Infrastructure, Planning and Natural Resources (DIPNR). Additional land feature databases such as Gamma radiometrics, DEMs, aspect, slope, plan curvature and Topography Wetness Index (TWI) are also derived and utilised to increase the accuracy and therefore reduce the level of uncertainty of the digital soil attribute maps.

The Study Area

The location of the study area is in the north-western part of New South Wales (NSW), Australia, within the Namoi River catchment (Figure 1). The Namoi catchment comprises of more than 43 000 km², which is about 6% of NSW (EPA, 1997a). The study area is part of a larger survey project under the auspices of the Australian Cotton Cooperative Research Centre. The primary industry for the region is agriculture, which is predominantly irrigated cropping. The main crops grown are cotton, oil seeds and cereals (Banks, 1995). The proportion of land use for crop production, particularly irrigated cotton, has increased since the 1950's, when it became possible to cultivate the heavy textured soil on the plains.

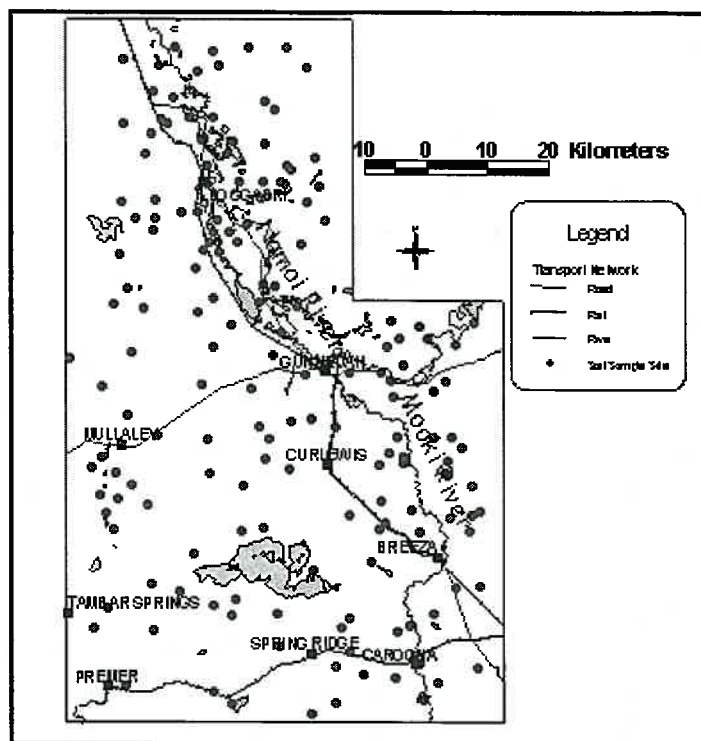
Figure 1 The Namoi River catchment showing the study area (in grey) within Australia and New South Wales (Modified from EPA, 1997a and b).



Previous surveys in the study area have been carried out by the NSW Department of Land and Water Conservation (Banks, 1995), now DIPNR. The extent of this survey was the Curlewis 1:100,000 map sheet. Soils in the area are defined in terms of soil materials (Banks, 1995) and also based on the standard classification systems of the Great Soil Groups (Stace et. al., 1968) and the Northcote Key (Northcote, 1979). The survey area consists of mainly clay plains interspersed with sharply elevated parts, which consist of older sediments capped with younger basalts (Duggin and

Allison, 1984). Within the study area the dominant geologic formation, comprising approximately 85%, is the Liverpool Plains. This area has a mainly flat land surface, with shallow slopes dipping towards the north (Duggin and Allison, 1984) and has a slope of less than 3° (Crawford, 1976) (Table 1). Other areas with slopes of less than 3° include the watercourses of the Namoi River, Mooki River and Cox's Creek. Flooding occurs mainly in the flat plains during January to March and occasionally in the month of July (Wiles, 1996). There are some local areas where the slope can be up to 80°, and this is usually associated with the Hunter-Mooki Thrust Fault system (Wiles, 1996).

Figure 2. Location of sample points used



Climatically the Gunnedah region is defined as having a dry sub-humid climate with annual average rainfall of 642 mm (Bureau of Meteorology, 2003). It has a dominant summer rainfall climate due to summer thunderstorms (Banks, 1995) but there is somewhat even spread across the year. Rainfall tends to decrease from east to west, from the hills to the plains (Hird, 1976). In terms of vegetation cover, the hill slopes in the upper Namoi have been cleared, except for the particularly steep ridges and the State Forests (Banks, 1995). The uncleared areas are dominated by white cypress pine (*Callitris glaucophylla*) and a number of eucalypts as subdominant species (Banks, 1995).

Methods

Field Sampling

In order to make digital soil maps for the study area, field soil sampling had to be undertaken. Because the study area is not a perfect rectangle we divided it into a northern and southern section, and samples were chosen within these sections. The soil samples locations (Figure

4) were obtained using a stratified random sampling system. Each section was divided into equal blocks to ensure that samples were taken across the entire region. The northern section being smaller was divided into 4 blocks and 15 locations were randomly selected within each block. The southern area was divided into 9 blocks, and, again, about 15 locations were selected within each area. Soil sampling involved taking of a soil core at each site and the core was subdivided into six depths: 0-10, 10-20, 30-40, 70-80, 120-130 and 190-120 cm. Morphological description of the horizon were done and recorded. At each site, slope, land use, vegetation, erosivity/erodibility, etc were observed and recorded. Samples were taken back to laboratory for chemical and physical analysis.

Laboratory analysis

All soil samples were first air-dried and ground to less than 2 mm, with the gravel fraction removed and its proportion determined. All subsequent analyses were based on the so-called earth portion (< 2mm diameter) unless otherwise stated. Particle-size fractions were determined using the micro-pipette method (Odeh et al, 2003). Cation Exchange Capacity (CEC) was determined using the method described in Rayment and Higginson (1992). Exchangeable bases (Ca^{2+} , Mg^{2+} , Na^+ and K^+) were the only cations extracted, as the soils in the surveyed area contain negligible amounts of other cations (Fe and Al). pH and EC were both determined using a 1:5 soil: water suspension, using deionised water, following the method of Rayment and Higginson (1992). The total carbon content was determined for the top two layers (0-10cm and 10-20cm) using the Dumas total combustion method in a CHN-100 elemental analyser (Leco Inc., St Joseph, MI, USA).

DEM and Terrain Analysis

The utilisation of satellite data and digital elevation models (DEM) vastly increases the accuracy of predicting soil attributes for a particular area. However, this process requires the transformation of the satellite images into a digital grid form. DEM, with a spatial resolution of 250m, was acquired from CSIRO Land and Water, which provided a base of a 250 m grid for the study area. Specific geomorphometry (Evans, 1980) was utilised in this study to determine the point attributes of landform for the survey area. Odeh et al. (1991) defined specific geomorphometry as the measurement and analysis of specific land-surface features that are defined according to clearly defined criteria. For this study a number of primary terrain attributes were determined, including slope, aspect, plan curvature and profile curvature. These attributes, defined as primary terrain attributes, have considerable influence on the hydrological patterns of the surrounding area. For example, slope influences the rate of water and sediment flows (Odeh et al., 1994). Aspect defines the direction of flow and thus determines the upslope area of the catchment in which it originated. Plan curvature and profile curvature is the rate of change aspect and gradient respectively. The affect of changing aspect on the surrounding area influences the flow convergences or divergences, whereas the changes in the gradient affect the rate of flow acceleration and deceleration, which influences soil aggradation or degradation (Odeh et al., 1991).

The only secondary terrain attribute utilised in this study is the Compound Topographic Index (CTI). CTI or topographic wetness index (TWI) quantifies the position of a point in the landscape

in terms of water and sediment movement, and is a hydrological based index that is related to zones of surface saturation (Moore et al., 1993). The equation used for this calculation is shown below.

$$CTI = \ln\left(\frac{A_s}{\tan \beta}\right) \quad (1)$$

where A_s is the Upslope area and β is the slope radian. Combined with the FLOW ACCUMULATION and FLOW DIRECTION as derived using the modules of ARC/INFO (ESRI, 1992) and primary terrain attributes such as slope and aspect, the attributes provide not only good GIS layers for environmental modelling, but also provide useful input data for spatially predicting the difficult-to-measure soil properties.

Spatial prediction of soil attributes

In order to spatially interpolate some of the soil variables methods such as ordinary kriging, regression models, also known as *scorpan* (McBratney et al., 2003) and *scorpan*-kriging were used. Ordinary kriging can be best described as a moving weighted averaging that estimates property values at unsampled points based on the relative distance of the neighbouring sampled point (Webster and Oliver, 1990).

Multiple linear regression (MLR) models have been previously used for the purpose of deriving relationships between soil attributes and ancillary variables. MLR models are based on the linear equation (Eq. 1), which has been widely used because of its ease and availability (McBratney et al., 2003).

$$y = \beta_0 + \beta_1 x_1 + \dots + \beta_n x_n \quad (2)$$

where y is the predicted attribute; β_0 the intercept; x_1, \dots, x_n ; and β_1, \dots, β_n are the regression coefficients. With the use of the JMP program, MLR prediction formulas were derived using a stepwise regression technique that determined the soil variable predictors of the sampled sites and thus used in the prediction of the unknown areas of the survey site. For the soil attributes that produced a small R^2 value using MLR models a combination of MLR followed by ordinary kriging of the regression residuals and summing them (known as *scorpan*-kriging) was applied.

Scorpan-kriging as used here can be described as the combination of a multiple linear regression model with ordinary kriging of the regression residuals. The *scorpan*-kriging method was used in the prediction of soil attributes that had a low but significant MLR R^2 ; these include Electrical Conductivity (EC) for two sampled depths. The *scorpan*-kriging values are derived by

$$S(\mathbf{x}) = m(\mathbf{x}) + e'(\mathbf{x}) + e \quad (3)$$

where $S(\mathbf{x})$ is the predicted soil value, $m(\mathbf{x})$ is the regression value, $e'(\mathbf{x})$ is the locally varying component or regression residual values, interpolated by kriging.

GIS Analysis

Geographical Information Systems (GIS) have previously been used for integration of spatial and thematic data. Development of digital land feature maps included the conversion of existing soil information. Lithology, Land Management Units (LMU's) and soil descriptions from a variety of sources needed to be integrated onto a uniform geographic projection. Programs utilised in this process included ArcView[®], ArcGIS[®] and ERDAS IMAGINE[®] 8.4.

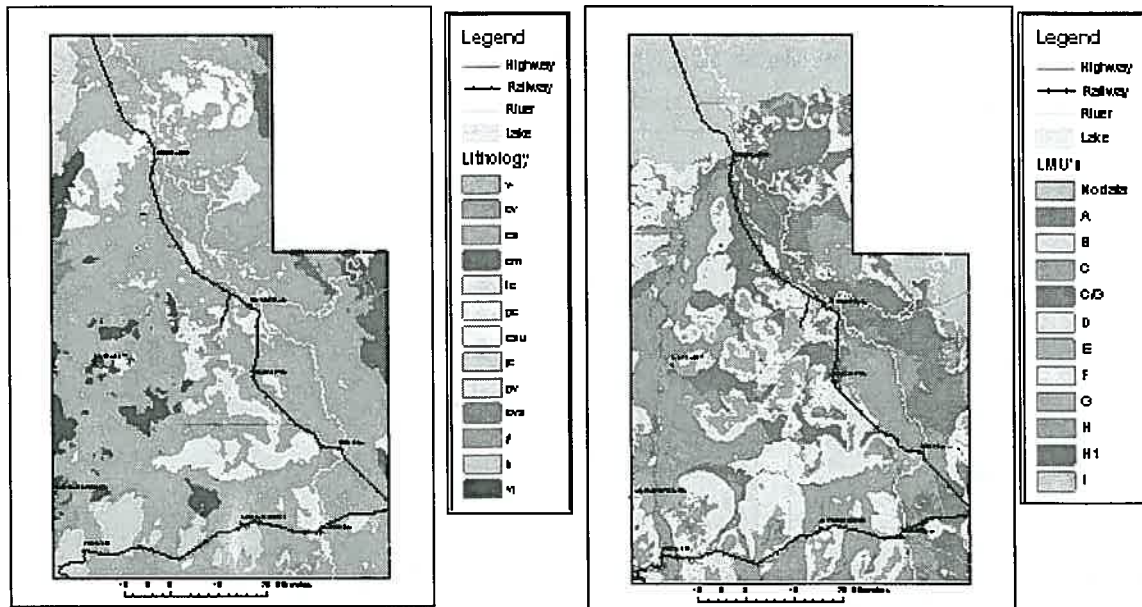
Soil informational data provided by DIPNR was of a different coordinate system and thus had to be converted into the geographical projection used in this study. Coordinate Calculator in IMAGINE[®] 8.4 converted the 1 800 000 grid cells of the lithology, LMU and Murray Darling soil groups layers into the uniform projection system, Universal Transverse Mercator (UTM) Zone 55 South, using Map Grid of Australia (MGA) 1994. Once this was achieved ArcView[®] and ArcGIS[®] were used to produce the predicted maps of the designated soil attributes. Included in these projections were roads, rivers and town areas that had previously been digitised.

Results & Discussion

Land feature maps

As stated previously both primary (slope, aspect, plan curvature, profile curvature) and secondary terrain attributes (TWI) can provide vital information on the hydrological patterns of the survey area. Fig. 3 shows some of these layers. Flow direction, flow convergence and sediment accumulation, just to mention a few, are all derived from DEM and play a vital role in the development of digital land feature maps. TWI provides valuable information on the flow patterns and accumulation areas of water. This is demonstrated in Fig. 3(b) where the high TWI values depict the likelihood of water accumulation. Fig. 3(a) and Fig. 3(c) respectively show the spatial patterns of plan curvature and DEM that illustrate hydrological patterns of the survey area; plan curvature is highly influential on the rate of flow acceleration or de-acceleration. Therefore, understanding the hydrological properties and physical parameters as depicted by these digital layers useful for catchment modelling and planning can greatly benefit the management of natural resources. For further information, more of the terrain attribute layers are shown in Appendices (B4).

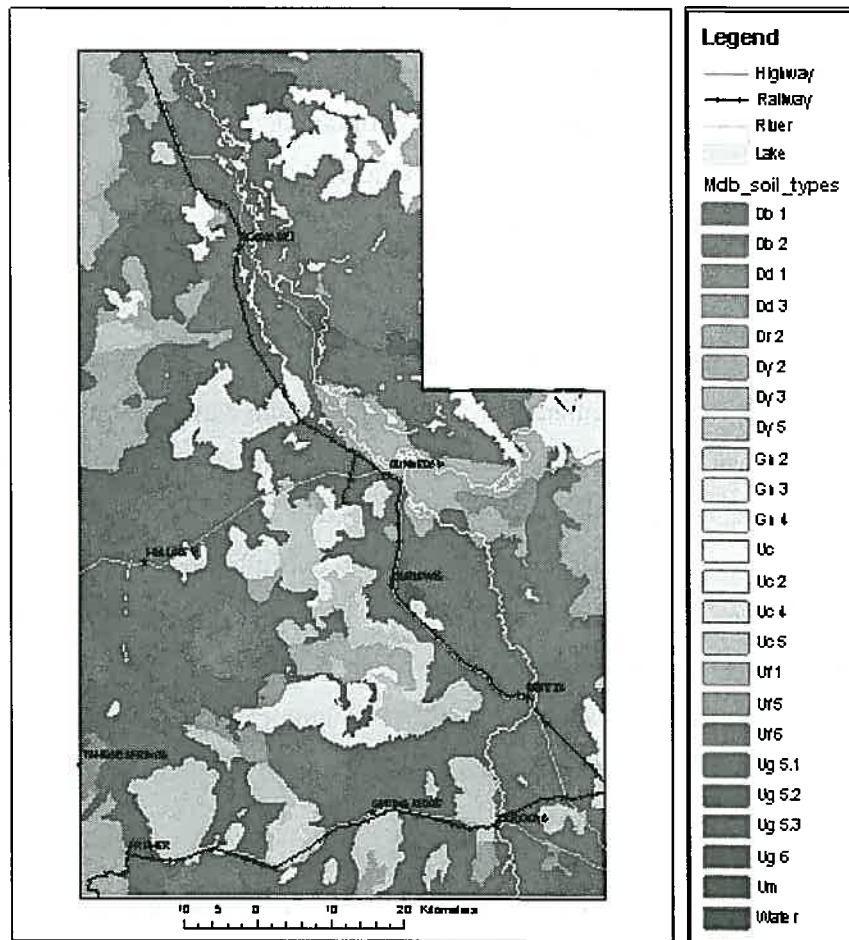
Based on fundamental understanding of the relations between the soil attributes on the one hand, and terrain and landscape features on the other, soil attributes especially the more-difficult-to-measure ones, could be predicted more accurately. In pursuing this endeavour both data sets require a common coordinate systems and projection, which could allow for the spatial interpolation of sampled sites parameters onto the unknown locations. Secondly the number of predictor variables used in the *scorpan* model more often determines the degree of accuracy; thus the more ancillary variables are used in the prediction model the greater the chance of reducing the uncertainty of the prediction. Applying attributes derived from DEM, Landsat images and previously soil and landscape layers for the study area will evidently increase the accuracy of the resulting digital soil attribute maps.



As mentioned above one of the additional information sources was Land Management Units (LMUs) (Fig. 4b), which was sourced from DIPNR (Robert Banks, per comm.). LMUs were derived based on dividing the landscape into areas based on slopes and soil types, as a reflection of how they can be managed. The LMUs therefore constitute useful GIS layers that can be used for predicting soil attributes, as they are very versatile. However, the LMU data does not cover the entire study area, because the LMUs were developed for the Liverpool Plains only. The lithology (or geology) GIS layer (Fig. 4a) was derived from the geologic map (1:250k) sheets. It covers the entire study area unlike the LMU map. The lithology data provides one of the most valuable layers for the prediction of the soil attributes.

The Murray Darling Soil Information layer (mdb for short) (Fig. 5) illustrates one of the many problems faced when undertaking this type of research. As is demonstrated from the elongated legend the data obtained from DIPNR had detailed soil classifications, in the Northcote format. Originally the data source had over 50 soil classifications that hindered the modelling process. To overcome this problem an abridgement of minor soil types had to be carried out. The end product is as shown in Fig. 5 that contained 28 abridged soil classes, consisting mainly of Duplex, Uniform and Gradational soil types classed to the dominant colour. As soil class is a very important factor in the prediction of soil attributes the abridgement process had to be justified with the range of soil types at the sampled locations.

Figure 5 Murray Darling Basin (MDB) Soil Information dominant soil groups of the study area



Digital maps of soil attributes

The results of our spatially predicting soil attributes are several digital maps of several soil properties. These maps are displayed in an integrated geographic information system which can be viewed, combined or queried for useful information for land management. For lack of space in this paper we present the maps of two groups of soil properties: the clay content and salinity maps created for several sampled depths— 0-10, 10-20, 30-40 and 70-80 cm.

Maps of particle-size fractions— the clay content

With the development of a soil attribute database comes increased efficiency in hydrological and catchment modelling. Knowledge of hydrological properties and catchment characteristics is an essential part in the sustainability and management of natural resources. Soil digital maps produced for catchment managerial bodies or any other environmental resource managers need to be accompanied with the uncertainty associated with the soil maps. As important input to catchment and hydrological models digital information such as clay, sand and silt need to be highly accurate and easily accessible. Having such sources of readily available digital GIS layers would greatly enhance the modelling process and lead to an informed decision on resource management.

Particle-size proportion is regarded as one of the important factors in the development of hydrological models. Clay, sand and silt percentages give a basis in which to assess the physical properties of the soil landscape, especially water infiltration, overland flows, flux of material through the soil and into the groundwater. Fig. 6 (a,b,c,d) show the resulting maps from the Multiple Linear Regressions (MLR) of % Clay and demonstrate a heightened accuracy and definition.

On a closer look at Fig. 6(a,b,c,d), it seems that there is slight increase in % clay especially in the river plains. It also confirms the predominant of high to medium clay zones in the flood plains of the Namoi and Mooki rivers. These zones are traditionally used for agricultural production, thus for management and further agricultural practices this particular land feature map would be highly beneficial. Fig. 6(a) demonstrates the topsoil clay content exemplifying the natural topography of the study area. It illustrates the coincidence of low clay content with the sedimentary slopes depicted in the LMU map (Fig. 4b). Also as shown in the Murray Darling soil landscape map (Fig. 5) there is a direct correlation between the locations of uniform soil types (Uf) and areas with medium to heavy clay in all layers (Fig. 6 a,b,c,d); this is consistent with uniform clay content throughout the profile.

The natural drainage lines and accumulation points for both sediments and water are illustrated in Fig. 6(c) and 6(d) with clearly defined lines apparent in both maps. Slope, elevation and profile curvature were all used in the multiple linear regression models and were clearly the dominant predictors.

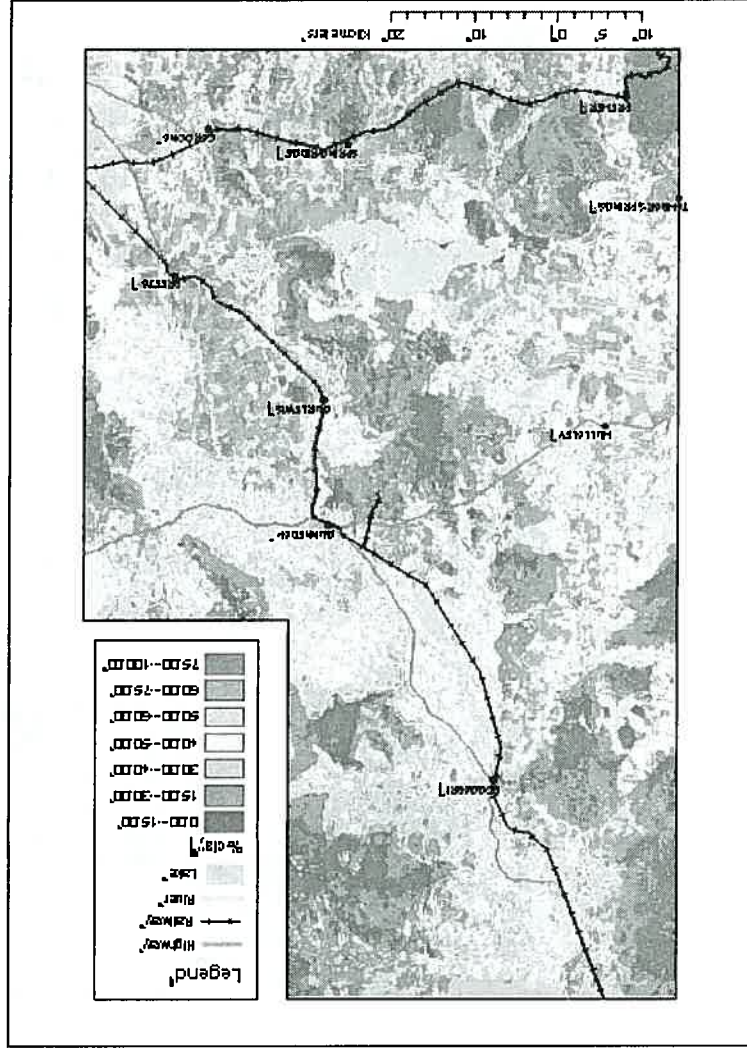
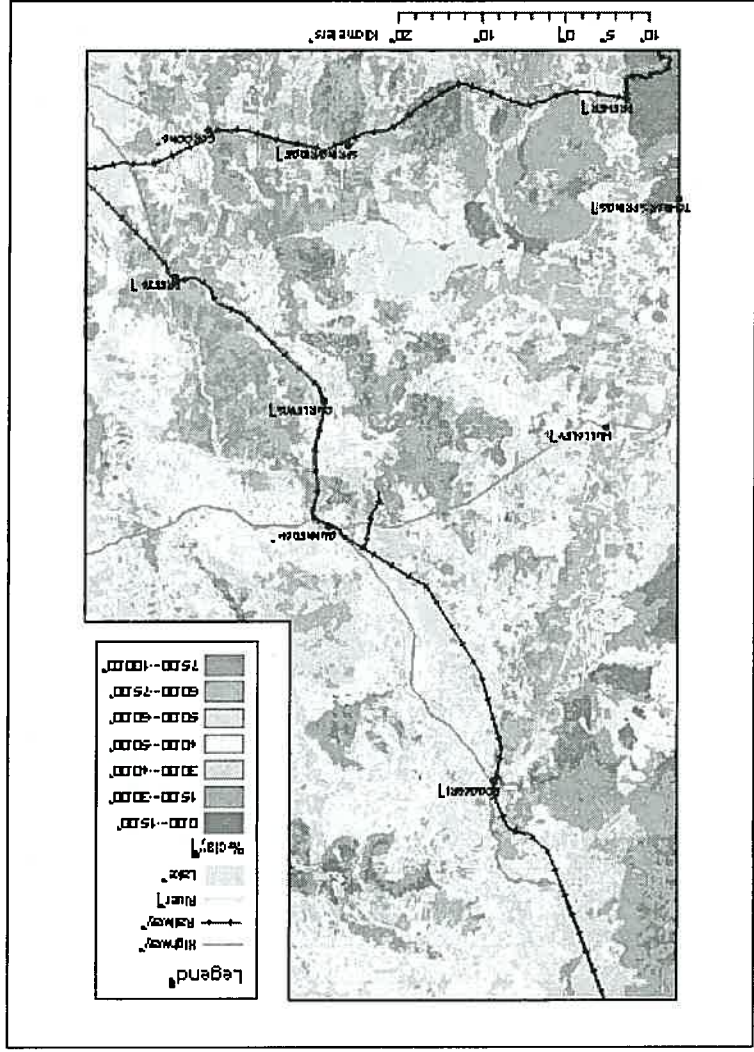
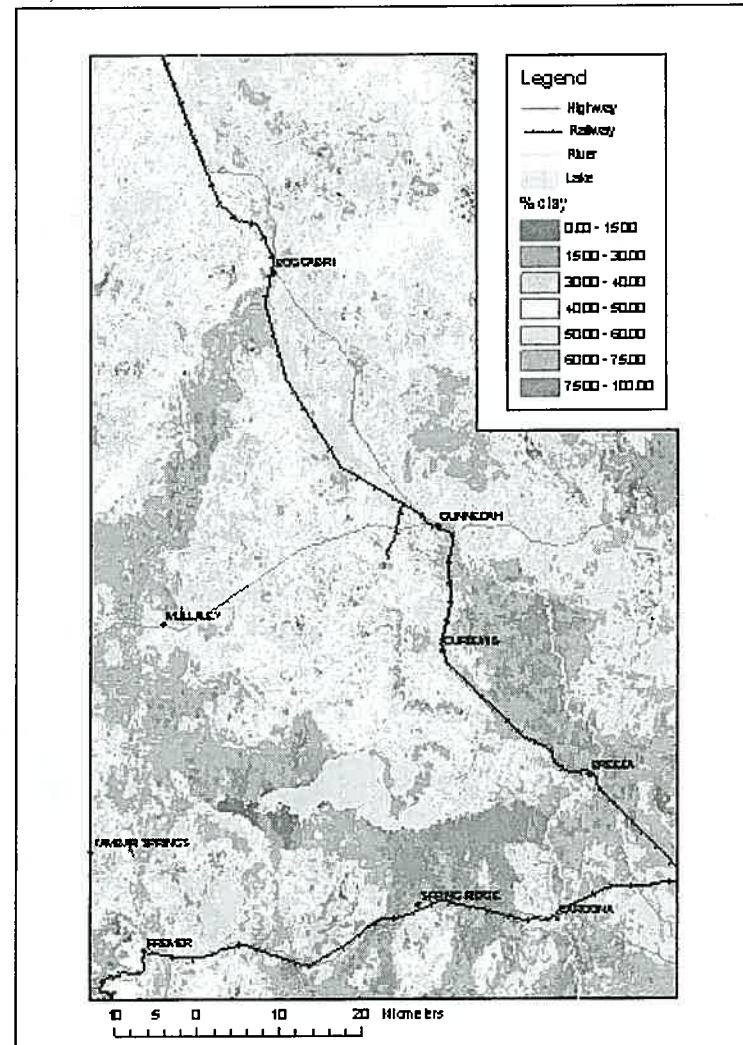
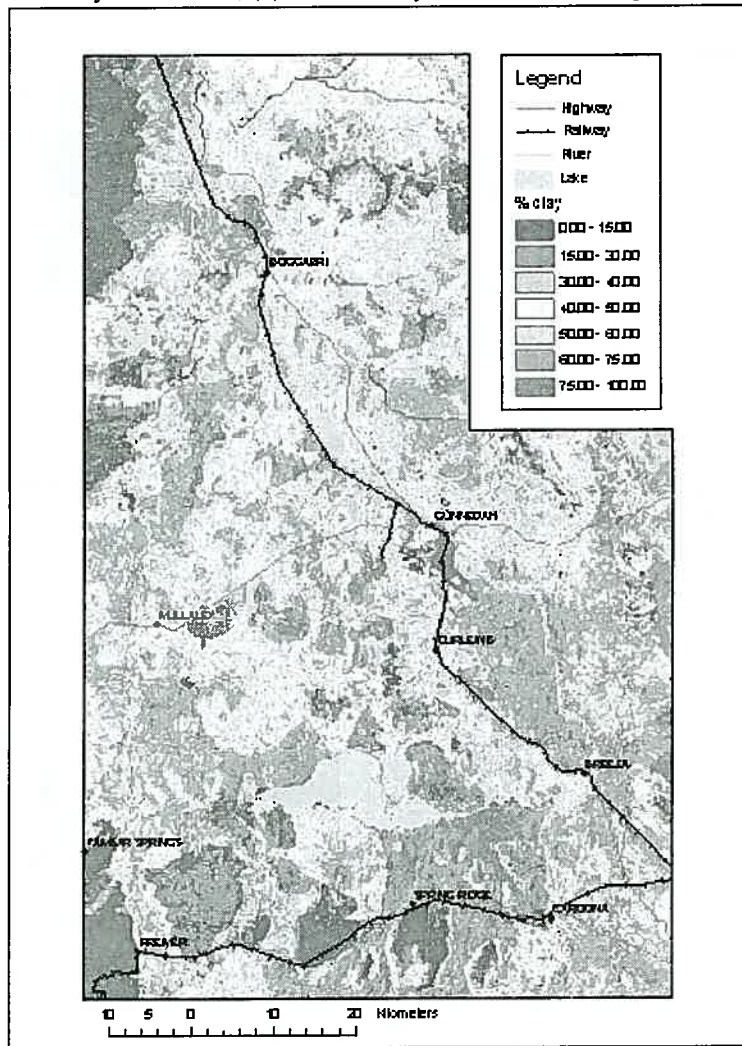


Fig. 8. (a) Topsoil Clay % 0-10cm, (b) Subsoil Clay % 10-20cm (Multiple linear regression)

Fig. 8. (c) Subsoil Clay % 30-40cm, (d) Subsoil Clay % 70-80cm (Multiple Linear Regression)



Salinity map layers

As is the case with physical properties, chemical properties can play significant roles in the development of hydrological and catchment models. Chemical properties that were analysed and predicted for the survey area were EC, ESP, CEC, OC, P and pH. We present the results of salinity as measured by EC. As previously stated MLR predictions EC resulted in low R^2 values the method was adopted for the chemical attributes as well. This method, however, was not good enough for EC with low R^2 ($R^2 = 0.11$ for 0-10 cm layer and 0.17 for 70-80 cm layer). However, in spite of relatively low R^2 for layers 10-20 and 30-40 cm, the MLR residuals do not show sufficient spatial correlation for *scorpan*-kriging to be used. The MLR results were accepted for these layers. For layers 0-10 and 70-80 cm, *scorpan*-kriging was used to produce good EC maps. All the results are shown in Fig. 7. Obviously, the top layers (Fig 7 a & b) exhibit less variation than the subsoil layers as shown in Fig. 7(c, & d). Careful observation of Fig. 7 clearly demonstrates increased EC with increase in depth, which is not surprising. These layer data can thus provide valuable information for the management of salinity in the study area. It is noteworthy to point out the high EC in the subsoil (70-80cm) in the plains north of Gunnedah and around Boggabri and further south in the Liverpool plains around Curlewis and Breeza (Fig. 7d). These areas are major agriculturally productive farmsteads of the upper Namoi region. It points to the importance of targeting resources to managing salinity in these areas.

Fig. 10. (a) Topsoil EC (dS/m) 0-10cm, (Multiple Linear Regression) (b) Subsoil EC (dS/m) 10-20cm (Scorpan-Kriging)

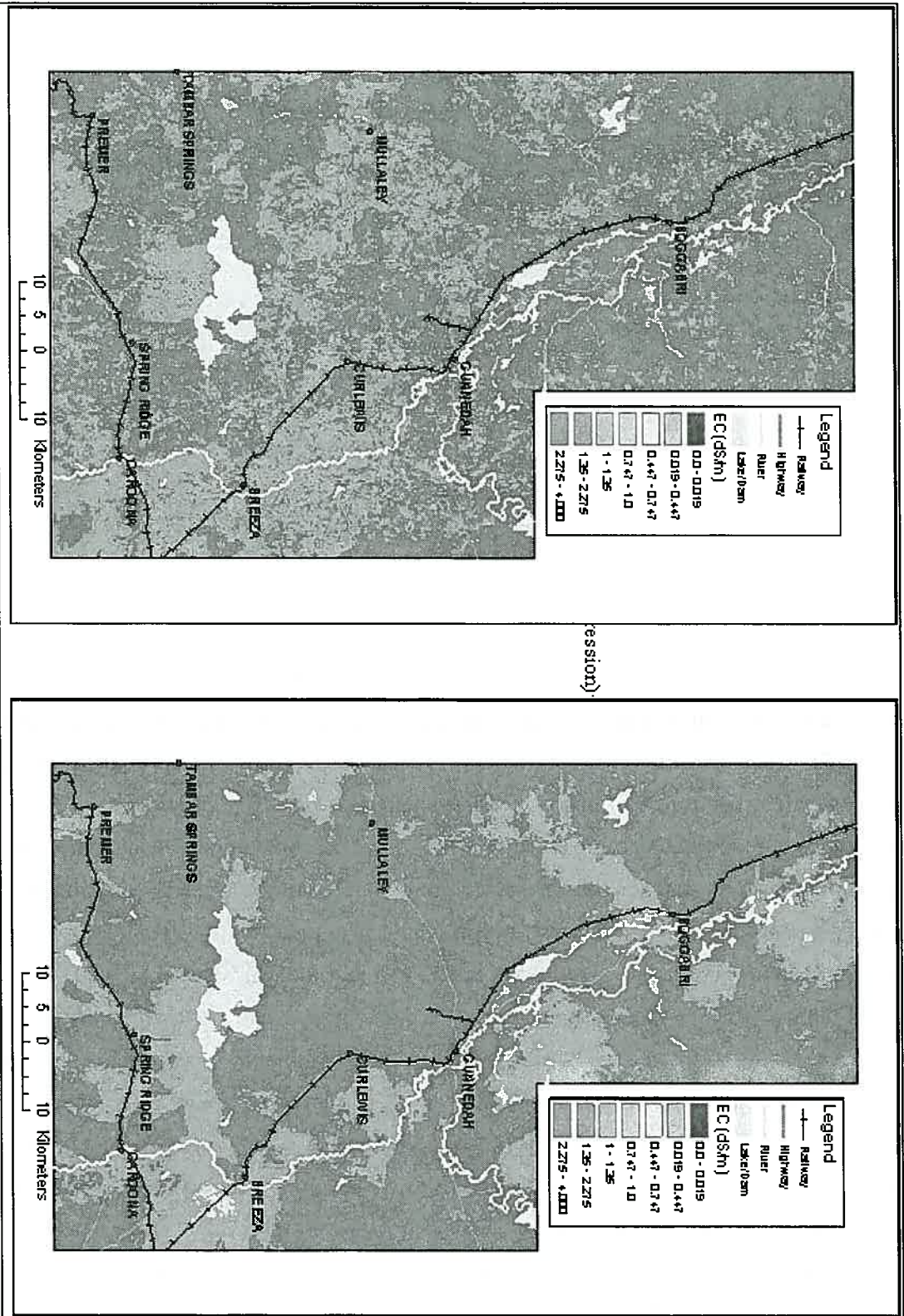
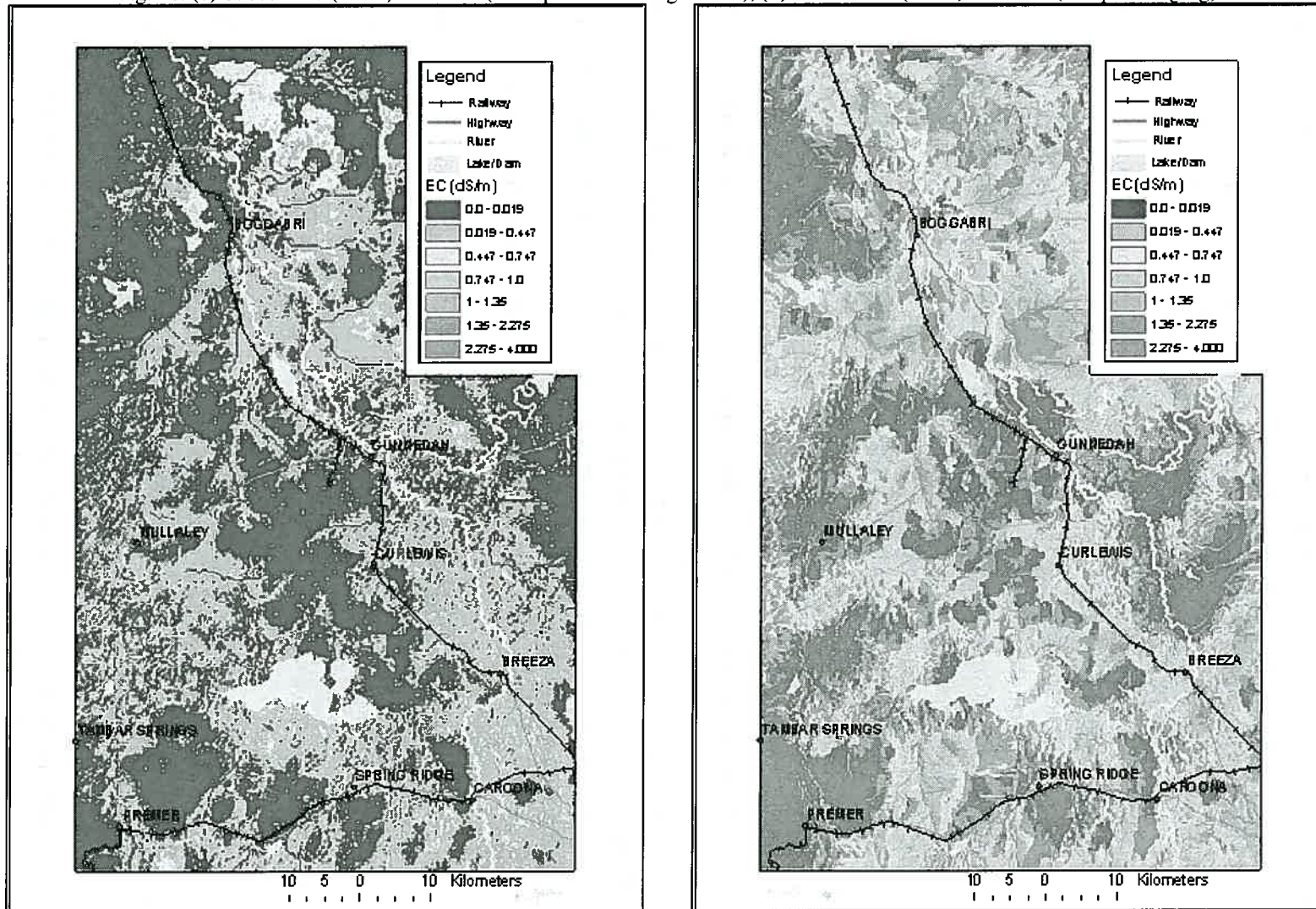


Fig. 10. (c) Subsoil EC (dS/m) 30-40cm (Multiple Linear Regression), (d) Subsoil EC (dS/m) 70-80cm (*scorpan*-kriging)



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