LAND USE CHANGE: UNDERSTANDING AND MANAGING SOIL DYNAMICS

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Lessons of the past show that care for the soil is fundamental to the rise and sustainability of agrarian civilisations. The responsibility for this care devolves to individual farmers, land managers and investors in agricultural production, all of whom are, by default, soil custodians. Soil condition is affected by land use practices; understanding the dynamics of soil and land use interaction is therefore critical in achieving sustainable soil management and the maintenance of soil health. Understanding and managing this dynamic requires good data and sound knowledge of farming systems and their interaction with soil properties and processes. The North Central Catchment Management Authority (NCCMA) region has soil and land use data at a range of scales that can assist in understanding the region's soil assets with respect to current and future farming systems. Programs that fully engage farmers in planning for soil health, and provide appropriate tools and information, will be a cornerstone for managing soil dynamics under pressure from climate and land use change. This paper explains the contexts in which soil spatial information and land use data are collected, provides examples for the NCCMA region, and briefly describes the challenge of providing soil information at the farm scale.

Keywords: land use, soil, agro-ecosystem, landscape, pedology, climate

ECOSYSTEMS are subject to different degrees of alteration by the human exploitation of natural resources. At the simplest level of intervention, hunting and gathering cultures make use of the innate productivity of ecosystems in provision of food, the ecosystems also providing habitat for human occupation in caves and simple structures built from readily available materials. In such systems, impacts on soil are minor and there is no necessity for such cultures to understand soil processes, nor is there any need to manage inputs into the soil in order to sustain production. In simple agrarian systems, such as 'slash and burn', there is a recognition that productivity declines with successive harvests and that the soil and land need time to recover fertility. In more developed and settled agrarian systems, such as those that evolved in the Nile delta, the need to manage soil fertility has been pivotal in determining the success of such societies. Understanding and managing soil has consequently been an integral component of the evolution of human society, in particular through various agrarian revolutions and the changes that these have brought about to natural ecosystems in exploitation of the soil and land (Sandor et al. 2006).

Intensification in the use of natural resources is exemplified in agro-ecosystems or agro-industrial ecosystems in which natural systems, excluding conservation reserves, have been altered to maximise the extraction of resources for human use. In some instances, the objective to increase the wealth and size of societies via such intensification, has led to severe soil and land degradation and contributed to the collapse of civilisations (Hillel 1992; Montgomery 2008).

Human activities have an enormous impact on soil condition. Land use practices can have negative or positive impacts on soil condition. The relationships between land use practices and soil condition are largely speculative, with little published quantitative research apart from results generated by standard approaches to plot scale water erosion studies (Mutchler et al. 1994). However, attempts have been made to model likelihood and risk of soil change due to land management practices, for a range of soil degradation hazards, using experts' best judgments of these relationships (McNeill & MacEwan 2007) and these have been helpful in establishing priorities for regional catchment management authorities (Dortmanns et al. 2006).

In this paper we present an account of soil and land use data collection, in Victoria, and issues of scale both with respect to data and end user needs. Examples are given for some of the data sources available within the North Central region of Victoria (Fig. 1).

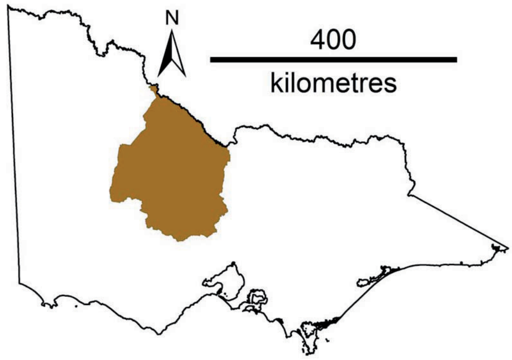


Fig. 1. Location of North Central Catchment Management Authority Region in Victoria.

SOIL PROPERTIES, SOIL MAPPING AND SOIL CHANGE

Soils are integral to many ecosystem processes: they support plant growth and primary production; they regulate the terrestrial component of the hydrologic cycle by intercepting rainfall and runoff, storing water and transmitting it to ground and surface waters; they cycle nutrients, store wastes, and play a role in atmospheric regulation. Soils are variable and they differ in their capacity to support these processes. In particular, differences between soils are recognised by their fertility and the vegetation or crops they support, and by their vulnerability to degradation, such as erosion, especially once cleared or disturbed. Understanding and describing these fundamental differences is the knowledge domain of pedology.

Soil mapping

Pedology serves to explain the nature, origin and distribution of soil types across landscapes and is the basis for soil survey and mapping. Such mapping is concerned with distinguishing one area of land from another on the basis of soil quality. The degree to which this mapping discriminates one soil from another depends on the spatial density of observations and the soil parameters that are measured. Resultant map scales range from highly intensive, or large scale, surveys such as those carried out in irrigation areas (1:5000 to 1:25 000 scale) to broad reconnaissance, or small scale, surveys usually for general resource appraisal in previously unmapped territory (1:250 000 to 1:1 000 000) (McKenzie et al. 2008). Soil mapping is based on relatively fixed attributes of the soil, i.e. properties of the soil profile such as texture and colour of principal soil horizons, soil depth, and stoniness. Standard methods are used to record these properties (McDonald et al. 1990) and to classify the soils in map units (Northcote 1979; Isbell 2002). Map boundaries are based on observable surface features such as changes in slope and landform. More recently, airborne gamma radiometric survey (GRS) data, collected for mineral exploration in Victoria, has been used to enhance the location of boundaries for soil mapping as it reveals differences in material in the upper 0.3–0.4 m that may not relate to obvious terrain differences. Fixed attributes of soil and landform can be interpreted for land capability (broad classification of land into 5–7 capability classes for particular land uses such as arable cropping, extensive grazing, or forestry) and the susceptibility of soil to hazards, such as erosion and waterlogging. Mapping of the factors affecting choice of land use and any soil hazards provide representation models of the landscape that are useful for land use planning.

It is important to recognise that soil is described at points in the landscape based on augering (area <0.01 m^2), excavation of a pit (area ~ 1 m^2) or describing road cuttings (linear extent of a few metres). These point data then become extrapolated to larger land areas and attributed to polygonal map units (several km^2). There is therefore innate uncertainty built into soil map units and this is very rarely quantified. Coarse scale maps have greater uncertainty than fine scale maps for soil properties at locations other than the original point data site. Because of the high cost of soil survey there will be increasing reliance on modelled likelihood of soil properties at a range of scales using ‘soil inference systems’ (McBratney et al. 2002).

Soil mapping in Victoria

Soil mapping has a long history in Victoria extending for nearly a century (Martin 1987, 1998). The scale of soil mapping in Victoria ranges from very detailed surveys for irrigation areas, 1:9000–1:32 000), to broad scale surveys with landforms mapped at scales of 1:250 000, but having low density soil information only justifying 1:1 000 000 as soil-landscape maps. Victorian landforms are delineated at 1:250 000 in the Victorian Geomorphological Framework (VGF) (Department of Primary Industries 2007; Rees et al. 2010) and are essentially a revision of the landforms in Land Systems of Victoria (Rowan 1990; Rees 2000) with augmentation from 1:100 000 soil-landscape surveys in regions where these exist (e.g. Corangamite mapping of Robinson et al. 2003). The line-work for these landforms is available as the GMU250 and LSYS250 spatial data layers, respectively (Government of Victoria 2010, 2000), in the Victorian Government’s Corporate GeoSpatial Data Library (CGDL). (Data in the CGDL is currently freely available to government agencies including Catchment Management Authorities, and to external agencies by arrangement with data custodians in DSE and DPI). Geomorphology has a strong association with soil types due to the influence of geology and relief on soil development and soil types, so the GMU250 map units are a good guide to the regional inventory and distribution of different soils and soil properties, but each map unit usually includes at least three very different soil types. Soil attributes attached to these spatial layers in the CGDL are generalised and indicate dominant and sub-dominant soil types for the map units.

Raster data layer for soils. A raster data layer, NDG_SOIL20, has also been created with a 20 m grid cell reconciled to the VICMAP_ELEVATION_DTM_20M digital elevation model for the state. The cells are attributed with soil hydrological properties for the dominant soil type in each map unit in the LSYS250 layer, predicted from the pedotransfer functions of McKenzie et al. (2000) and data held in Victorian soils databases. The SOIL20 data layer has been deployed in the DPI’s Catchment Assessment Tool (CAT) to model regional scale catchment impacts of land management on groundwater, streamflow, nutrient movement, erosion and salinity (Beverly et al. 2005, 2009; Department of Sustainability and Environment 2007). The SOIL20 data layer provides catchment models with values for soil hydrological parameters, but, because of the source data, should only be regarded as representing soil properties at a regional scale of 1:250 000 or smaller. Larger scale soil data, particularly hydrological data for soils, are required to provide more realistic modelling of soil hydrology and crop water use at paddock to sub-catchment scales.

Digital soil mapping for Victoria. Legacy data (from past soil surveys and field experiments) are contained in hardcopy reports, field notebooks and laboratory records. These data are progressively being entered into a database for soil information, the Victorian Soil Information System (VSIS). Soil inference systems are being developed from the VSIS data, with enhanced mapping techniques that deploy satellite or airborne imagery and terrain modelling, to create grid-based digital soil maps for soil properties across Victoria (Robinson et al. 2010). This will be an improvement on the NDG_SOIL20 layer as, for any grid cell, there will be an estimate of uncertainty for the predicted soil properties (e.g. for pH, surface texture, % clay, etc.) and this should qualify interpretations of spatial model outputs for which soil data have been input parameters. Another level of uncertainty derived from the legacy data is due to the time span of the point data collection. Recorded values for some parameters may not be equivalent or comparable across the whole dataset for two reasons: the earliest data are more than 80 years old and were reported according to different standards from those used today; the soil has been used for agricultural production and some properties may have changed (e.g. pH, organic matter, nitrogen and phosphorus levels).

Soil change

Many soil properties are dynamic and are changeable. For example, soil moisture status is in constant flux and this, in turn, influences soil strength; soil strength — weak when wet, strong when dry — and affects the ability of the soil to withstand damage from foot and wheeled traffic and to resist erosion. Changes in soil properties occur over a range of time scales and may or may not be reversible (MacEwan 1997) e.g. soil acidification is a relatively slow but reversible process remedied through lime application, whereas soil erosion can be extremely rapid and is irreversible.

Protocols for monitoring soil change in Australia have been documented by McKenzie et al. (2002) and have also been the subject of recent working parties commissioned by the Commonwealth Government (for example, Baldock et al. 2009). Understanding soil change, particularly in relation to land management, requires data, information and knowledge additional to that provided in a soil map (Tugel et al. 2005). The landscape decision framework proposed by Steinitz (1990) can be applied to the question of understanding land use change and managing soil dynamics. His framework, applied to our problem area, comprises six levels of 'models' that (1) represent the landscape (e.g. a soil map), (2) model soil processes (e.g. erosion), (3) evaluate soil health (e.g. value ranges for critical soil properties such as pH), (4) determine what may change (e.g. land use, climate, tillage practices), (5) model the impacts of change (i.e. impact on soil processes and soil condition), and (6) provide options for decision making (e.g. lime soil, change traffic and tillage, rezone land capability). The relationship of this framework to soil health decision making is explained by MacEwan (2007).

In attempting to populate these levels for the land use change-soil dynamics question we are often operating with imperfect or incomplete data, information and knowledge, as is the case with many other conceptual systems for decision making or discovery.

SOIL AND LAND DATA IN NORTH CENTRAL VICTORIA

The first soil survey in the region, carried out by the former Department of Agriculture (DA), began at Woorinen (near Swan Hill) in 1928, in collaboration with the former Council for Scientific and Industrial Research (CSIR) (Martin 1998). This was published at a detailed map scale of 1:16 000 to identify soil differences that would affect their use for irrigation farming (Taylor and Penman 1930). During the following 14 years, seven detailed surveys (not all in North Central Victoria) were carried out in irrigation districts along the Murray River as cooperative projects with CSIR. These early surveys were carried out in the northern (riverine) plains of Victoria, from Shepparton to Swan Hill and Robinvale, and were to be used for planning, investigation of district problems and water allocation. From 1928 to 2000 there have been many soil and land surveys, including land capability studies, in the region. These vary widely in scale and, consequently, the density and precision of soil information. The range of soil survey coverage for the region is shown in Figure 2 and Table 1. All of the reports listed in Table 1 are accessible through the Government of Victoria's library system and many are available for downloading as electronic documents from the Victorian Resources Online website (http://www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil-land-directory).

Geographical Information Systems (GIS) are now standard tools used to store and manipulate soil and land data, as these systems have great utility for spatial modelling. Line-work from the surveys listed in Table 1 is available in GIS format, but, in many instances, the soil data have to be sourced from the original reports as they are not yet attached as attributes in these digital datasets. Figure 3 shows the locations of the 714 points in the NCCMA region that have data in the VSIS. There are an estimated 14 000 additional soil survey points in the region that could be added but the highest density of these is in the areas covered by the detailed scale soil surveys carried out for irrigation developments. Because soil survey in Victoria has been led by successive Government Departments concerned with the agricultural management of land, there are generally very few soil data sites on public land in Victoria.

Soil orders (Isbell 2002) in the NCCMA region are dominantly Sodosols, with Red Sodosols (also formerly referred to as Red-Brown Earths) on the Riverine Plain, and Yellow to Brown Sodosols on the hillslopes and older alluvial plains in the upper catchment. Problems caused by soil sodicity, particularly gully and tunnel erosion, have been common during wet years. Vertosols, Chromosols, Calcarosols, Dermosols, Ferrosols and Tenosols (Soil Orders of the Australian Soil Classification – Isbell 2002) are all represented in the region. Each of these orders has different properties and different requirements for management. Their general distribution is understood but the precise location of differences is restricted by the limitations already described. The most complete landform data for the region is the geomorphology mapping in the GMU250, as shown in Figure 4.

The GMU250 map units have been used as a basis to divide Victoria into six primary regions and 22 sub-regions referred to as Victorian 'Agro-Ecological Landscapes' (AELs) or, 'Primary Production Land-

Table 1. Soil and land surveys in the North Central Catchment Management Authority region.

Fig. 2 legend	Survey area	nominal map scale	Published surveys
1	AVOCA	1:250 000	Lorimer and Rowan (1982)
2	E. WIMMERA	1:100 000	Badawy (1984)
3	CAMPASPE	1:100 000	Mikhail (1982); Lorimer and Schoknecht (1987)
4	LODDON	1:100 000	Schoknecht (1988)
5	KYNETON	1:100 000	Baxter, Jones and Boyle (1995)
6	MARONG	1:50 000	Bryant and Lorimer (1993)
7	WOODEND	1:50 000	Singleton and Lorimer (1992)
8	SWAN HILL	1:32 000	Taylor and Penman (1930); Churchwood (1960); Skene and Sargeant (1966)
9	ROCHESTER	1:32 000	Skene and Harford (1964)
10	MID LODDON	1:25 000	Skene (1971)
11	KERANG	1:32 000	Baldwin, Burvill and Freedman (1939); Sargeant, Newell and Walbran (1979)
12	HUNTLY	1:25 000	Bluml, Jones and Boyle (1995a)
12	STRATHFIELDSAYE	1:25 000	Bluml, Jones and Boyle (1995b)
13	LODDON MURRAY 2000	1:25 000	Agricuture Victoria (2000)

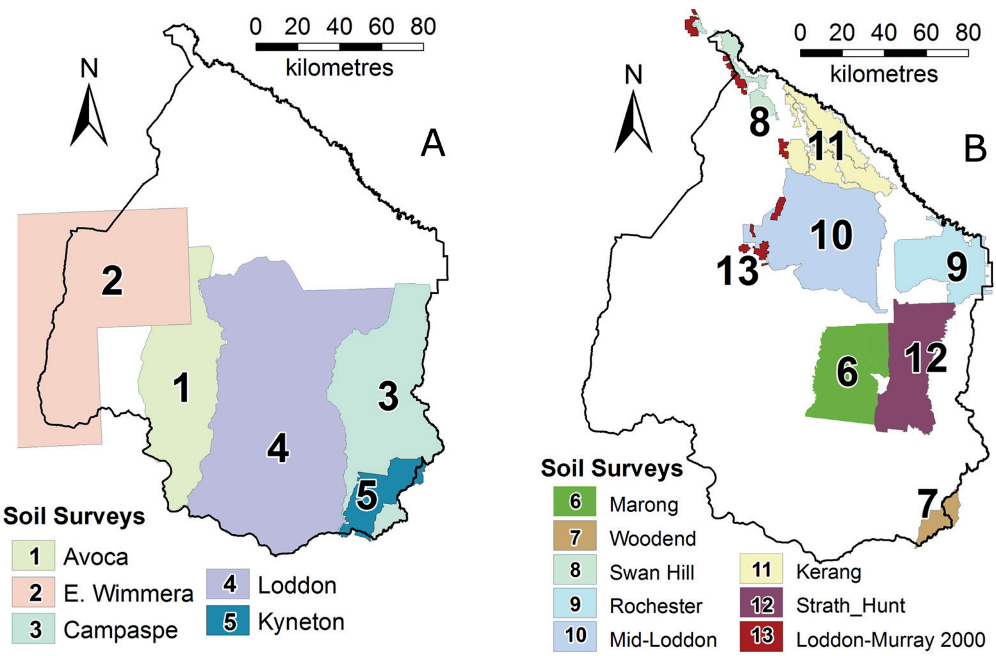


Fig. 2. Soil and land surveys in the North Central CMA region: A. coarse <1:100 000 scale surveys, and B. moderate and detailed >1:50 000 scale surveys. See Table 1 for references.

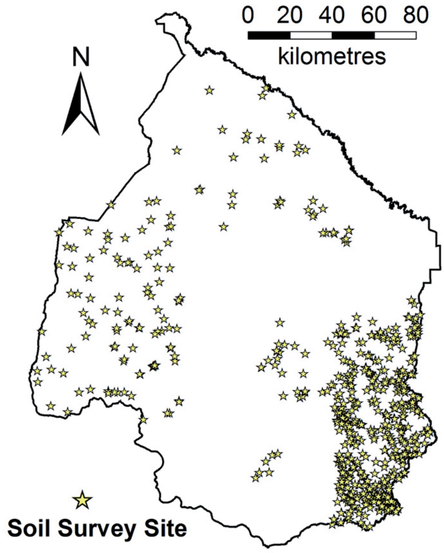


Fig. 3. Soil survey sites within the NCCMA that have data entered into the Victorian Soil Information System (VSIS).

scapes' (PPLs) (MacEwan et al. 2008). This spatial hierarchy provides a regional platform from which to explore climate change and climate variability impacts on agricultural industries, management practices and soils. The NCCMA region is overlapped by six PPL sub-regions, but dominated by two of these; unit 2a the Riverine Plain (Northern Plains), and 3a the Northern Slopes (Central Victoria) (Fig. 5). The principal soil types for these two PPLs and some associated constraints to management are shown in Figure 6.

LAND USE DATA

The Australian Collaborative Land Use Mapping Program (ACLUMP) (Bureau of Rural Sciences 2006a) has been coordinating efforts to classify and map land use nationally for the past 10 years. This program supports the production and delivery of two land use data sets — a national dataset used to map land use at a nominal scale of 1:2 500 000, and a catchment dataset at scales of 1:25 000 to 1:100 000 created by the state agencies (Commonwealth of Australia 2007). Catchment scale mapping in Victoria is linked to the state cadastre at a scale of 1:100 000 but has high reliability for land use at paddock scale. The Australian Land Use Mapping (ALUM) classification is the Australian Spatial Data Infrastructure (ASDI) standard for land use datasets (Bureau of Rural Sciences 2006a, 2006b) and consists of a three-tier numerical and nominal system used to denote the use or purpose to which land is committed e.g. agriculture, forestry, urban. Differences in areal estimates of primary land use are considerable and reflect the differences in methods used for the two datasets (Fig. 7). The national mapping method is a modelled output based on Australian Bureau of Statistics (ABS) agricultural commodity data, whereas the catchment scale mapping method uses extensive ground truth to support classification of Landsat imagery. The catchment scale dataset has

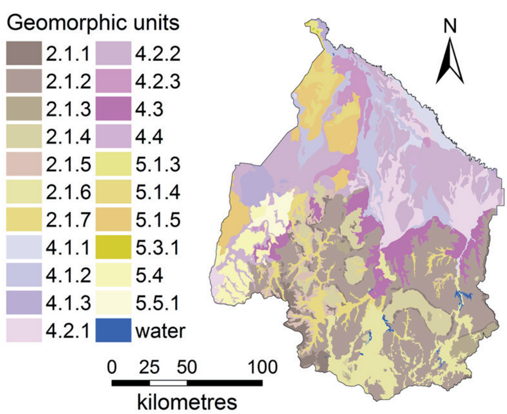


Fig. 4. Third tier geomorphic units within the NCCMA boundary.

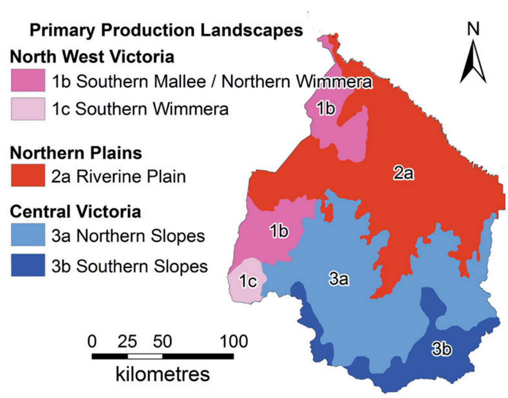


Fig. 5. Primary Production Landscape sub-regions within the NCCMA boundary.

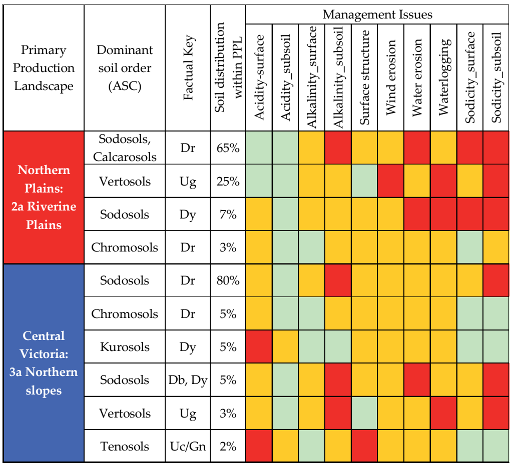


Fig. 6. Principal soil types and their management constraints (red for major hazard; amber for potential hazard; green for no hazard) in PPL sub-regions 2a and 3a in the NCCMA region. Soil classifications are the Australian Soil Classification (ASC) of Isbell (2002) and the Factual Key of Northcote (1979).

been widely used in spatial and economic modelling and remains the most current and accurate source of land use data.

Land use can be regarded as a level in a hierarchy comprising tenure, use, cover and management practices (Fig. 8.) and the following definitions, adapted from Bureau of Rural Sciences (2006b), apply:

Land Tenure – the legal regime in which land is held (e.g. freehold, public, leasehold). Some forms of tenure, such as pastoral leases or nature conservation reserves, relate directly to land use and land management practice.

Land Use – the purpose to which the land cover is committed. Some land uses, such as agriculture, have a characteristic land cover pattern.

Land Cover – the physical state of the earth's surface. It includes various combinations of vegetation types, soils, exposed rocks and water bodies as well as anthropogenic elements, such as agriculture and built environments. Land cover classes can usually be discriminated by characteristic patterns using remote sensing.

Land Management – the way in which a land use is carried out in order to manage the land cover.

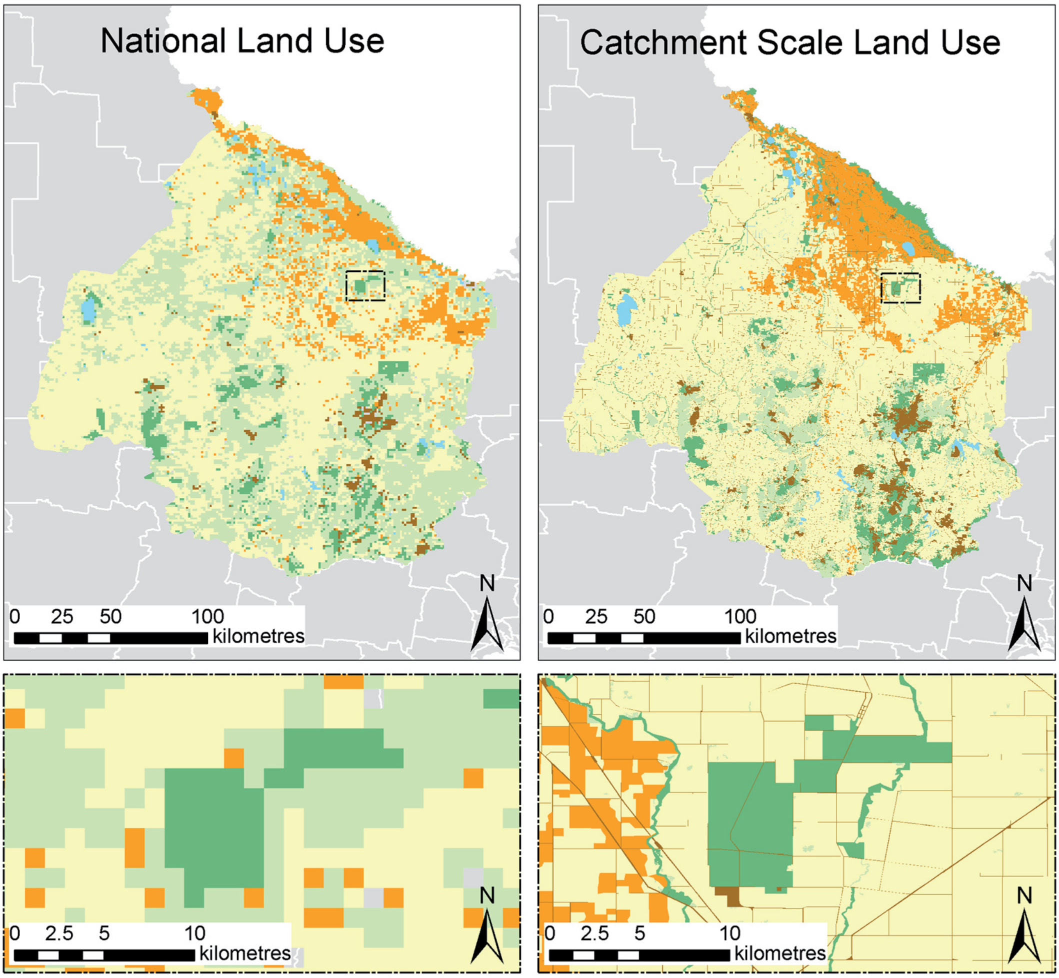
It is possible to have many land cover types within one land use; for example, wheat, canola, barley and pasture can all be part of a cropping land use enterprise. However, it is not possible to have many land uses within one land cover. Similarly, there can be many land management practices per land cover and many more per land use but the relationship does not hold the other way. A new land use information database, the Victorian Land Use Information System (VLUIS) is being created for Victoria, integrating various spatial data sets to classify parcels into land use and land cover (Department of Primary Industries 2009a). Land cover information is interpreted using satellite remote sensing supported by ground truth, and land use is derived from the data collected for the Valuer-General Victoria.

CLIMATE IMPACTS ON LAND USE CHANGE AND SOIL IN NORTH CENTRAL VICTORIA

Climate observations and modelling have confirmed or predicted changing conditions affecting seasonal soil moisture availability for dryland agriculture in south east Australia (Hennessy et al., 2008; Timbal & Jones, 2008). For example, Figure 9A illustrates cumulative rainfall minus evaporation interpolated for Malmsbury in the south of the North Central Region, whilst Figure 9B shows the equivalent rainfall minus evaporation data for Kyabram in the Riverine Plain. An approximation to the growing season using a start date of 1st May has been represented by subtracting the cumulative daily evaporation from the cumulative daily rainfall. Four scenarios are illustrated in Figure 9 using data for: the long term average from 1889-2008, a mid term recent average for 1975-1995, the recent drier period from 1996-2008, and the average taken from the 10 driest years in the weather station record.

The curves in Figure 9 clearly indicate the contrasting different surpluses of rainfall over evaporation during the growing season for these different time periods. The primary consequence of this for soil moisture in the most recent (1996-2008) period has been that soil profiles have not 'filled' to the theoretical water holding capacity. The positive impact is that waterlogging in the region has either not occurred or has been less severe. The negative impact is that, combined with early finish to the season, there has been insufficient soil moisture to maintain spring pasture growth or fill grains.

From 1970-1995 land use practices had to adapt to high oil prices, very wet growing seasons, waterlogging, water erosion and increasing problems with salinity. Since 1996 the drier conditions have resulted in falling groundwater levels, reduced water avail-



	National Land Use (Ha)	Catchment Scale Land Use (Ha)
Class 1 – Conservation and Natural Environment	159 254	235 330
Class 2 – Production from Relatively Natural Environments	1 025 507	180 226
Class 3 – Production from Dryland Agriculture and Plantations	1 456 218	1 999 754
Class 4 – Production from Irrigated Agriculture and Plantations	244 767	320 140
Class 5 – Intensive uses	49 420	180 479
Class 6 - Water	29 221	45 339

Fig. 7. Land use mapping in the North Central CMA region showing comparison between outputs from the national and catchment scale mapping methods for first tier land use classification. Lower image pairs show expanded views of identical inset areas from the national and catchment land use maps and illustrates the spatial resolution achieved at land parcel level in the catchment land use mapping.

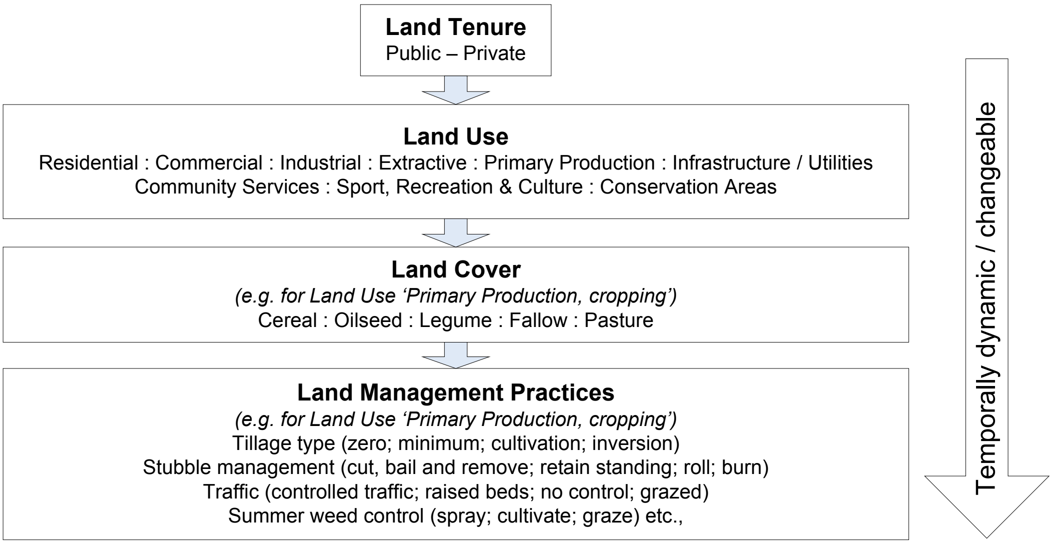


Fig. 8. Hierarchy of land tenure, use, cover and management.

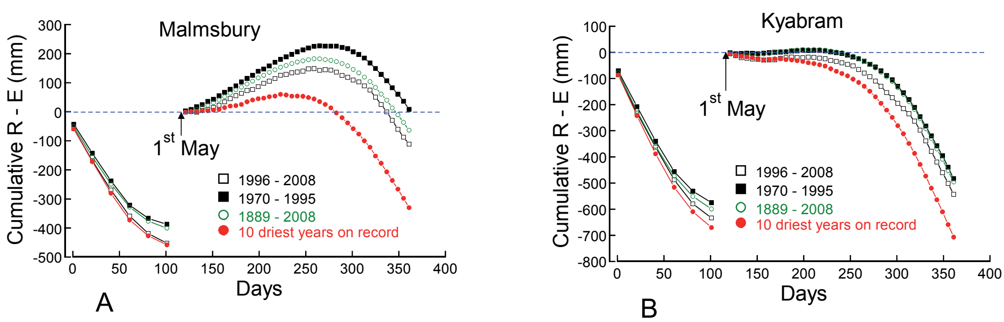


Fig. 9. Cumulative Rainfall minus Evaporation for: A. Kyabram in the Riverine Plain, and B. Malmsbury in the Southern Slopes of Central Victoria.

ability for irrigation, and insufficient soil moisture in many years to fill grain in dryland crops. These changing seasonal conditions are resulting in changes in land use practices in the irrigation districts and in dryland agriculture. Changes in the irrigation areas include reducing, or removing, irrigation. Consequently, the extent of perennial pasture has decreased by 70% from 1997 to 2008 due to limitation in irrigation water supply (Fig. 10) (Morse-McNabb et al. 2008). Changes in dryland farming include, harvesting of cereal and oilseed crops for hay, planned increases in sheep numbers, and a general quest for productive farming systems in a changed climate.

ENGAGEMENT WITH STAKEHOLDERS FOR MANAGEMENT OF SOIL DYNAMICS

Efforts over the last 80 years have contributed to an understanding of soil in the North Central Catchment Management Authority region. In the last 25 years, Commonwealth and State funding initiatives such as the 'National Soil Conservation Program', 'National Landcare Program', and 'Caring for our Country', have created partnerships between farmers, government agencies and research providers to address soil degradation issues, improve soil man-

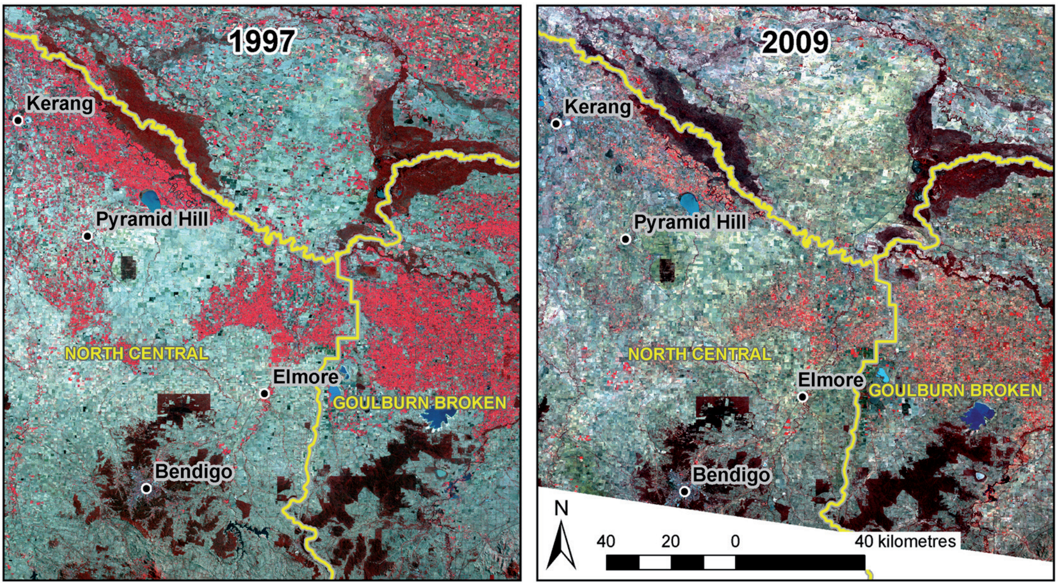


Fig. 10. Landsat images of Northern Victoria. Red areas show summer irrigation in 1997 (11 April) and 2009 (23 February).

agement and enhance agricultural productivity. The body of this paper has been concerned with the collection and interpretation of spatial data, in particular, soil and land use. These data are most relevant to stakeholders concerned with planning and reporting at regional to national scales. They are also essential inputs for models used to predict impacts of land use change (for example, Beverly et al. 2009; McNeill & MacEwan 2007). The data and information needs of the various stakeholder groups are quite different but the objective to achieve sustainable soil management is generally shared. Ultimately, the landholders and managers are the most significant stakeholder group in determining a sustainable future for soil. This group needs translation of data, information and knowledge so that it has relevance at the local, parcel and enterprise scale where it can be applied in management practices. As discussed above, the spatial scale of soil data is at best only suited to large catchment or regional scenario modelling and does not provide information that is directly applicable at paddock scale without some level of interpretation supplemented by site investigations.

Soil Health Management Plan Pilot in North Central Region

Addressing the hiatus between farm scale and state or regional soil information can only be achieved by putting knowledge and skills directly in the hands of the land managers or consultants to land managers. If the latter path is chosen, there must be an ongoing relationship between the consultant and the manager so that there can be monitoring of soil changes or soil condition in consort with management changes. A trial for a soil health management planning process has been conducted with a farmer group in the Mid Loddon catchment (Department of Primary Industries 2009b). The farmers engaged in this trial already had considerable extension activity via training courses run as part of a national soil health project, field days associated with soil management trials on their farms, and talks by experts on different aspects of soil and agronomy. The process involved identification of the farm parcels and paddocks in a GIS and using the available coarse scale data to provide context for soils and geology (Fig. 11).

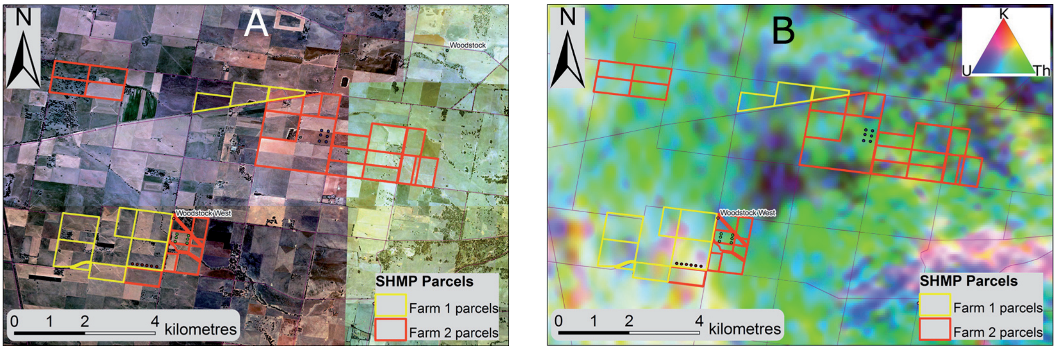


Fig. 11. Parcel boundaries for farms involved in soil health management trial overlain on: A. air photography, and B. airborne gamma radiometric spectral data.

Several soil pits had been characterised to represent soil types in the area bounded by the farmer group so there was a reasonable basis to build discussions with the farmers about their particular soils. The principles of the soil health management plan are based on the decision making framework of Steinitz (1990) with the levels presented as: inventory and interpretation (representation and processes); monitoring and evaluation (soil condition and trend); planning and management (what could be changed, what the result might be and decision for implementation). Engagement with the trial farms entailed small group discussion and one-to-one farm walks in which the farmers selected the paddocks to visit with the soil scientist. It was this latter activity that made the real difference as it became apparent to the farmer that there were issues that they directly observed as needing management. These were simple issues and had been presented on soil pit days, group field walks, training sessions and talks by experts, but it was only in this direct experiential situation that the information became knowledge for the farmer.

CONCLUSIONS

In the last 10 years the region has been subject to reduced rainfall and inadequate soil moisture for crop maturation. Soil data and a good understanding of the relationships between soil processes, climate and land management practices are needed to support agricultural production and maintain or improve soil condition. Knowledge of soil dynamics and soil change, in response to land use practices and climate influences, is best acquired from long term plot studies but there are few of these and they have limited spatial relevance. At the regional scale, soil survey, monitoring and modelling has the potential to provide an indication of trends in soil condition but there are three sources of uncertainty in these approaches: spatial uncertainty with regard to distribution of soil types; temporal uncertainty with regard to the use of legacy data and the associated limitations of changes in analytical and reporting methods; and historic uncertainty with respect to site history and management. It should be recognised that the real changes occur at the paddock and property scale as a result of land manager actions and that there are different levels of information needs of the diverse stakeholder groups. The challenge is to match coarse scale data with good information and to create appropriate direct experiences for managers on the ground so that they can recognise issues requiring management, but also know where to seek further knowledge and expert advice.

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