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Towards understanding the spatial and temporal distribution and dynamics of soil organic carbon within a large temperate agricultural catchment

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Soil carbon has considerable temporal and spatial impacts on the ecohydrological state of all catchments. Total organic carbon, land use, climate, and soil physical and chemical properties are being monitored at 26 sites within a 7000 km^2 temperate agricultural catchment in south eastern Australia, to investigate total organic carbon dynamics. Preliminary results from multi-variable statistical analyses of data obtained during the first 6 months of an 18 month study are presented. The primary research goal is to understand and quantify point and catchment carbon stocks using relationships between remote sensing and other readily available data. This paper includes discussion of preliminary attempts to upscale point and hill slope data to the catchment scale.

Introduction Soil organic carbon (SOC; the entire organic fraction including undecomposed and decomposed plant and animal organic debris) is a major component of the global carbon store, containing nearly three times the carbon stored in the atmosphere and four times the carbon contained in terrestrial vegetation. Human activity has resulted in atmospheric CO_2 concentrations increasing at approximately 0.5 to 3 ppm annually (*Keeling and Whorf*, 2001), with increased levels being a known cause of global warming. Therefore management of soil carbon has significant potential to slow the build up of atmospheric CO_2. The global response to increasing atmospheric CO_2 concentrations is highlighted by the development of the Kyoto Protocol (*UNFCCC (United Nations Framework Convention on Climate Change)*, 1997), and the focus on CO_2 sequestration opportunities in an effort to mitigate emissions, particularly within the agricultural sector.

SOC has significant impacts and benefits on the physical, chemical and biological properties of soils. First, soil organic matter (SOM) retains up to 20 times its weight in water, and improves drainage and permeability (*Delgado and Follett*, 2002). A catchment's SOM status therefore has significant hydrological impacts by affecting the soil moisture status, surface runoff, and subsurface flows; factors rarely (if ever) included in hydrology models. Second, SOM affects soil aggregation and the stability of aggregates (*Coffin and Herrick*, 1999). It thus plays a critical role with regard to the susceptibility of soils to erosion (*Phillips et al.*, 1993), serves as a store for nitrogen, phosphorus and sulfur (*Delgado and Follett*, 2002), and plays a role in the cycling of essential nutrients (*Delgado and Follett*, 2002).

Despite current knowledge of the impacts and benefits of SOC, significant gaps remain in our knowledge of carbon cycle dynamics. The knowledge gaps most relevant to this study include: (1) The lack of a fundamental understanding of SOC dynamics at the molecular, landscape, regional, and global scales (*Metting et al.*, 1999; *Quideau et al.*, 2001); (2) Uncertainty in the magnitude and timing of the response of the soil carbon reservoir to changes in climate, land-use and land cover (*Wang and Hsieh*, 2002); (3) The paucity of data documenting erosional SOC losses and the fate of eroded SOC (*Jacinthe and Lal*, 2001); (4) Limited information about organic carbon export from agricultural catchments (*Jacinthe and Lal*, 2001); and (5) The lack of data for specific runoff events of SOC losses to enable calibration of empirical models, including a need for more detailed analyses of particle size distributions and densities of SOC within nested catchments (*Starr et al.*, 2000).

This paper reports on research concerning total organic carbon (TOC; that fraction of SOC which passes through a 2 mm sieve excluding all fine roots) from hydrological and scaling perspectives, and addresses the above knowledge gaps to various degrees. The research investigates spatial and temporal dynamics of TOC based on an analysis of field based, remotely sensed, and GIS data. The aim is to identify relationships that allow quantification of TOC at any point within a catchment, from routinely measured parameters such as soil type (specifically the proportion of clay); long term climate (with soil moisture and temperature being driving forces of biomass decomposition); the position in the landscape (for erosional and depositional effects); vegetation and/or land use (biomass for the input of carbon); and anthropogenic site history (including cultivation). Any longer-term change in TOC, the dynamical perspective, is expected to be a function of antecedent TOC; land use change; and climatic change. Shorter-term changes will be influenced by environmental factors including recent rainfall and perhaps recent tillage operations. Specific research objectives include: (1) assessing temporal patterns in measured and predicted TOC at monitoring sites; (2) upscaling and integration of these TOC distributions to assess spatial patterns and to determine total catchment carbon stocks; and (3) analysis of soil carbon storage for various land use and climate change scenarios. Data from an intensive network of monitoring sites are used to develop and evaluate predictive relationships for hillslope and subcatchment TOC dynamics in the top 300 mm of the soil profile.

Field Data The 7000 km^2 Goulburn River Catchment is a mixed grazing and cropping region located 200 km west of Newcastle in south eastern Australia. Figure 3.5 shows the catchment, its 10 major subcatchments and the 26 permanent monitoring sites used in the present study.

The mean annual rainfall over the past 100 years was 660 mm $\pm$ 200 mm (Bureau of Meteorology data). The maximum and minimum annual rainfalls over the same period were 1318 and 334 mm respectively. As a result, most rivers and streams in the Goulburn River Catchment are ephemeral. The region has encountered severe drought conditions in recent years; a factor that will be considered in the evaluation of current TOC distributions.

From an agricultural perspective, land use in the Goulburn River Catchment becomes marginal if years with significantly lower than average rainfall become a regular occurrence, resulting in semi-arid conditions across the region. Recent trends towards lower rainfall may be associated with natural and/or human induced climate change and variability.

The catchment is dominated by sandy soils in the south and heavy basalt clay soils in the north. The southern half retains large tracts of native eucalypt forest, whereas the majority of the north of the Goulburn River Catchment has been extensively cleared of natural vegetation with the lower slopes and areas adjacent to riparian zones comprising native or improved pastures interspersed with eucalypts. These different soil, vegetation and climate conditions result in a wide range of ecophysiological diversity.

The research utilises the unique data set of the “Scaling and Assimilation of Soil Moisture and Streamflow” (SASMAS) project currently being conducted in the Goulburn River Catchment. Precipitation, soil and air temperatures, soil moisture, and stream flow are monitored continu-

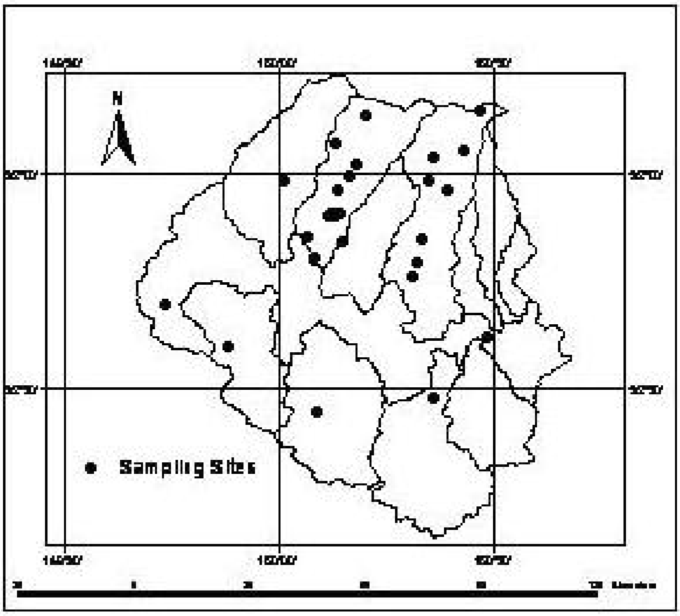

Figure 3.5: Major subcatchments and permanent monitoring sites within the Goulburn River Catchment.

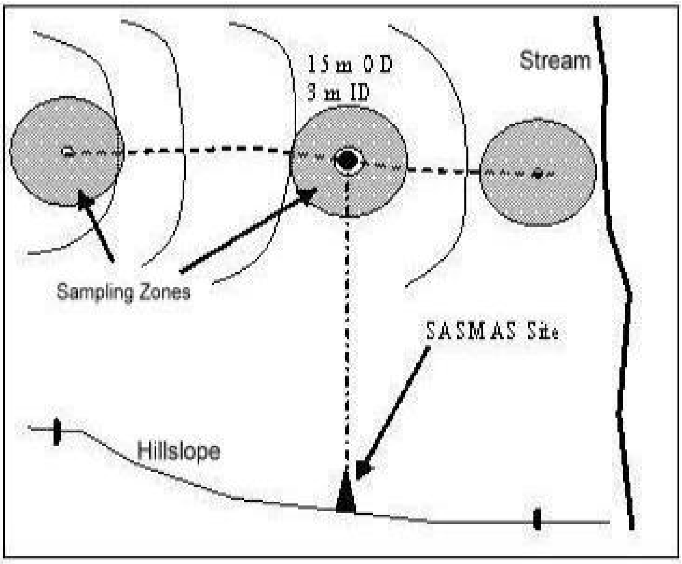

Figure 3.6: Schematic of hill slope transect studies.

ally across the network of monitoring sites*. Land form, land use, soil physical and chemical properties, and vegetation data (living and litter) have been obtained from GIS data sets, and are supplemented with data from a number of intensive field campaigns. Soil samples 50 mm in diameter and to a depth of 300 mm are collected at 6-weekly intervals over an 18 month period from each of the 26 monitoring sites. The sites have unique combinations of soil type, soil depth, biomass, soil moisture, soil temperature, and terrain characteristics. Samples are being collected each trip from 3 randomly generated vectors within a 15 m radius of each monitoring site. This

*see `http://www.civenv.unimelb.edu.au/~jwalker/data/sasmas` allows investigations into local scale variability as well as assisting in bias removal. Additional samples are being collected quarterly from 3-point hill slope transects for 10 of the 26 sites. The data are being used for lateral transport studies. The transects are shown generically in figure 3.6.

All samples are being analysed for TOC, nitrogen, pH, conductivity, and soil physical parameters (bulk density, field capacity, porosity, hydraulic conductivity). The combined data sets are analysed using multi-variable statistical techniques to determine and calibrate relationships for TOC prediction.

Results This paper presents preliminary results of the spatial and temporal variability of TOC within the Goulburn River Catchment from six temporal samples of TOC for all 26 monitoring sites, and two temporal samples of hill slope transect data. Preliminary multivariate statistical and graphical analyses of the data sets for each site will be presented including the dominant impacts of each of the parameters on TOC levels and distributions. Preliminary results will also be presented of biomass assessments based on remote sensing as well as initial erosion risk analyses for the selected hill slopes. We will report on the development of relationships between TOC and a range of static and dynamic site characteristics, and explore strategies for how these relationships may be used with remote sensing and GIS data to predict TOC levels at any point in space and time in the Goulburn River Catchment, without needing expensive field and laboratory data.

One complete set of TOC data for the 26 monitoring sites has been determined. These showed that minimum and maximum TOC levels within the Goulburn River Catchment were 0.39% and 5.7% respectively. The mean for all sites was 2.45% $\pm$ 1.42%. These values were within the range commonly reported in literature for similar climate and land use systems. Although one data set is insufficient for the identification of temporal patterns and trends there was an apparent correlation between soil texture and TOC. The sandy sites had lower TOC values and heavy clay sites had higher values. This is potentially due to the sandy soils having a lower sequestration capability due to a much smaller clay component, and the free draining nature of those soils. This was an expected result.

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