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SOIL HEALTH STRATEGY - A COMPONENT OF CATCHMENT MANAGEMENT

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EXECUTIVE SUMMARY

Water quality in streams and lakes has received much interest from the community and the Government in the last two decades with the setting up of the Victorian Water Quality Monitoring Network (WQMN) and water quality is being monitored at some 280 stations around the State. Water quality in streams and lakes is a function of what happens on the land in the catchments feeding them. The Catchment Management Authorities (CMA) in Victoria were set up to promote sound land management in order to promote healthy rivers and streams. Promoting the health of the soil therefore is an essential task. What needs to be developed is an understanding of the hydrological, geochemical and biological functions of soils in catchments, and what constitutes a healthy soil from this perspective. We also need to develop better models to predict the flow regimes and water quality of streams as an (often secondary) function of soil and land management: at present there are constant changes of land use in many catchments with unknown impacts. These tasks are as yet not within the scope of WQMN and do not appear to receive sufficient attention within the Departments of Primary Industry and the Department of Sustainability and Environment.

This paper aims to highlight some of the links between land use and land use changes, and water flow regime and water quality. It is of necessity limited to a cursory investigation of those links in the Glenelg-Hopkins CMA region. A plea is made to consider those links more fully when land use changes are investigated by research bodies, proposed by planning bodies, or planned by landholders and managers.

INTRODUCTION

The Glenelg-Hopkins CMA region contains three drainage basins: Hopkins River (Basin 236, incorporating 5 monitoring stations including 1 lake), Portland Coast (Basin 237, incorporating 2 stations) and Glenelg River (Basin 238, incorporating 11 stations and 2 lakes) as shown in Figure 1. All monitoring stations measure pH, turbidity (Tb) and electrical conductivity (EC), but only 9 stations measure Total Nitrogen (TN) and Total Phosphorus (TP). A report commissioned by the then Department of Natural Resources and Environment (DNRE) and produced by Sinclair Knight Merz (undated, apparently 1999), using data from 33 stations in these catchments, concluded that in the majority of stations the water quality changes as a result of present land use in the last 10 to 20 years were negligible, except for EC. With respect to EC, it was possible to detect a *"loose regional trend with predominantly increasing trends in the southern and eastern areas of the region and predominantly decreasing trends in the north-western region"*. The data were analysed by a parametric method called General Additive Model (GAM) to estimate time trends in hydrologic time series data. GAM was considered to be particularly suited for investigating water quality trends, according to the authors. Streamflow, measured at the time of sampling of the pollutant was included in the GAM model. Their report also shows that, as well as quality data, monthly discharge data were available for 33 monitoring stations going back to 1977 in most cases.

It is difficult to point to a specific land use or land use change that would explain this loose regional trend of increasing EC in the southern and eastern parts of the catchment.

A later report commissioned by the Department of Sustainability and Environment (DSE) and produced by Water Ecoscience Pty Ltd (2002), rated water quality in terms of attainment results using State Environment Protection Policies (SEPP) objectives and ANZECC guidelines. Attainment was defined in how close the actual water quality approached the desired levels. It noted that:

- all bar 3 stations showed low attainment for EC in terms of ANZECC guidelines,
- all bar 1 station showed low attainment for TN,
- all bar 6 stations showed low attainment for TP,
- all bar 3 stations showed low attainment for oxidised forms of nitrogen (NOx), and
- all stations showed high attainment for suspended solids (SS) and turbidity by both SEPP and ANZECC criteria

Again, this diagnosis stops at mere water quality data. Why is the water quality what it is? And can we do anything about it? What happens if we change land use? What is the relationship with the lands and soils and their use in the catchment? These are urgent questions that deserve attention.

LAND USE, LAND DEGRADATION AND SOIL HEALTH

Human activities on the land generally result in changing the rate at which natural processes take place; they may slow them down or accelerate them. How the soil reacts depends on its starting state, which includes unalterable properties such as its texture. The use made of the land by humans can activate or accelerate any degradation. For example, by clearing the vegetation on a sand dune it becomes more likely to suffer wind erosion than it was with its vegetation intact. Clearing of a wooded area will increase the deep recharge to the groundwater table and hence in many places increase the risk of dry land salinity. If the groundwater is very deep and no salt is stored above the groundwater table, dryland salinity will not occur.

All agriculturally used lands are in fact like managed ecosystems, or agro-ecosystems. To conserve these on a sustainable basis so that they will continue to provide food and environmental benefits for successive generations, we need to understand how they operate. Brouwer (2001) summarised the development of such understanding in a paper dealing with conserving biological diversity, with discusses a checklist called SYSTANAL that is also applicable to this Soil Health Management Strategy.

In Brouwer's view, and that of most agricultural and environmental scientists, ecosystems are complex with many interacting processes, biological, physical and chemical. But Brouwer specifically states that human use of the land, along with its economic and cultural elements, only increases the complexity of these processes. Any strategy therefore is unworkable unless it takes account of the human factors, but neither can it ignore the natural feed back loops resulting from a change of land management. Any strategy to preserve such (agro-)ecosystems, or to utilise them in a sustainable manner, must be based on a detailed and systematic analysis of how these systems function.

Figure 1 The Glenelg-Hopkins Catchment Area

The human factors can be engaged by communication and by participatory involvement of the land users and other stakeholders, including their very valuable local knowledge. The natural feed back loops arise from changing a current type of land management to another. As a side effect such a land management change may result, for example, in less water running off and streams being depleted and becoming more saline. The total outcome of the change may therefore be more harmful than not changing the land use, even if initially agricultural production goes up. It is often difficult or impossible to predict such side effects quantitatively, but they must definitely be taken into account if one wants to change the management of areas of land in a sustainable manner. The five key aspects of sustainability of agro-ecosystems are (a) productivity, (b) protection of the environment, (c) acceptability, (d) production security and dependability, and (e) economic viability. The aims and interests of the landholders and producers in relation to these five aspecte will be considered separately in the chapter by the Rural Economist.

Soil health defined

Soil health is defined as the state in which the soil currently exists compared to a condition in which it can support the highest potential biological productivity combined with the lowest environmental impact. This potential is limited by the soil's properties like structure, texture, natural fertility and biological qualities, which are different for different soils. Therefore two soils having the same state of health do not necessarily have the same productivity from an agricultural or biological point of view.

It is not correct to view the virgin condition of the soil as its greatest state of health, even though often the cultivation of a soil causes a decline of its biological productivity and its hydrological and environmental functioning. if sufficient care is taken it is possible to manage a soil in a manner that increases it biological productivity and diversity, or its other environmental functions, relative to its natural state. It is stressed, however, that there are often trade-offs to be considered between the various environmental functions.

The Glenelg Hopkins catchment occupies a large portion of Victoria with considerable variety in geology, topography and climate. As a result it contains quite a variety of agricultural industries and natural areas. In the GHCMA area there is no detailed inventory of the extent and severity of actual land degradation or soil health problems. Information on actual land degradation and soil health problems is only available in a general fashion from the land system mapping done by Gibbons and Downes (1964) and Sibley (1967). A survey of the community opinion found the following concerns with regard to soil health:

a) Soil acidification and nutrient decline;
b) Soil compaction, soil structure decline and water logging;
c) Sodicity is a low regional problem but potentially a high problem in certain locations, i.e. areas consistently treated with dairy effluent;
d) Organic solutions to soil health problems.

HYDROLOGICAL AND WATER QUALITY IMPACTS OF LAND USE CHANGES

Improved pastures: deep ripping and subsurface drainage

The Dundas Tablelands lie within the Glenelg-Hopkins Catchment Area. Of the problems just listed a major limitation for agricultural production on the Tablelands is prolonged waterlogging in winter and spring. This waterlogging prevents cropping for cereals, causes lucerne pastures to drown and die, and increases groundwater recharge and hence the extension of dryland salting. Prior to clearing, the native parkland vegetation of red gums, shrubs and perennial herbs used up most of the rain fall. Removal of most of the trees and replacement with shallow-rooted annual pastures completely changed the water balance of the land. In part, severe waterlogging was believed to be due to a restrictive, very dense subsoil layer between 0.3 to 0.6 m (bulk density 1.7-1.9 t/m^3). Later it was found that the main throttle to flow occurred between 0.85 and 1.1 m with bulk density 2.5 t/m^3. (Brouwer and van de Graaff, 1988)

Deep ripping and planting perennial pastures (Phalaris and lucerne) at Gatum, in order to increase the depth of the rooting zone and evapotranspiration simultaneously to combat dryland salting caused two effects (Brouwer & van de Graaff, 1988). It did increase the water use and the yield of the crop with Phalaris yield going up from 4.5 t/ha to 7.0 t/ha, and lucerne from 2.7 t/ha to 3.5 t/ha. At the same time deep ripping changed the mean horizontal hydraulic conductivity in the ripped zone – 0 to 0.55 m – and further down as follows:

Soil horizon	Depth (m)	Ksat in natural soil (m/day)	Ksat in deep ripped soil (m/day)
A	0.12 – 0.27	5.27 (1 test)	3.2 (3 tests)
B2	0.47 – 0.61	0.15 (3 tests)	1.5 (4 tests)
BC	0.65 – 1.02	0.14 (4 tests)	0.23 (4 tests)

Where the unripped soil normally was fully saturated in the top 30 to 40 cm for extended periods in winter, so that additional rains just sheeted off, the deep ripped land was no longer saturated and therefore produced no runoff. The experiment thus resulted in increased transpiration and grass production as well as full survival of the lucerne over the winter period, but also in increased deep infiltration and reduced runoff. Widespread adoption could result in lower (fresh) peak flows and higher (saline) base flow to streams.

During the same years, a Department of Agriculture scientist introduced a combination of mole drainage and subsurface tile drainage. This work succeeded in eliminating waterlogging also, enabling the land to be cropped. We are not aware of any water balance being quantified but would imagine that the horizontal mole and tile drainage prevent a significant increase in deep infiltration, and may even act to reduce it.

In recent years, this idea has been adopted by a landholder on a large scale. Here, the water discharging from the tile system flows into dams and is retained there. The result on pasture productivity has been great, and, presumably due to the fact that the soil no longer suffers from prolonged waterlogging, the root systems survive over winter and are able to be active at depth in summer, providing water to the pasture where pastures on surrounding farms brown off and are unproductive. As the waterlogging was made much more severe by the land use (grazing) established by European settlers, drying up the soil may qualify as improving its health. In addition, large scale adoption could see much winter and spring water being released into the natural drainage system rapidly via the drain flow rather than slowly via the deep groundwater. This could lower the proportion of inflowing saline groundwater compared to fresh surface water, and flush out the saline stream water.

Blue gum plantations

A highly emotive issue in the GHCMA region is the rapid expansion of blue gum plantations on former grazing land. Land preparation frequently involves deep ripping and creating low raised bunds along the contour to retain surface water. Within the plantation, such soil management may be seen as improving soil health, yet the impact on stream flows has never been analysed.

Dairying

Economic imperatives drive the dairying industry to increasingly intensive operations. This means very high fertiliser application rates and very high stocking rates. In winter, the soils in the dairying areas often are also waterlogged, so that cattle create muddy pastures and highly sediment and nutrient-laden runoff. The recommended solution being adopted by some is to move the cattle to concreted surfaces during winter. Furthermore, research work being carried out by the DPI Ellinbank Research Station for Dairying (Barlow et al., 2004; Nash et al. 2005), suggests that, as soluble P is difficult to remove from drainage water, a farm runoff re-use pond will be the most effective way to keep P out of streams. Soil health improvement in terms of improving structure, increasing infiltration rate, improved grass cover, etc., apparently do not offer much scope. Thus, to protect stream water quality, large scale adoption will reduce stream flow.

Increased lime application

A serious sleeping threat to soil health is the slow, but inexorable increase in acidity due to improved fertility, especially the use of superphosphate. This stimulates the growth of legumes (clovers), and in turn increases the fixing of atmospheric nitrogen that, initially via proteins, ultimately becomes re-mineralised to nitrate. As the NO_3^- ions are leached out of the soil profile by rainwater, they take cations such as Ca^{+2}, Mg^{+2}, etc., with them. These are not replaced by calcium and magnesium at equivalent rate from fertilisers and hence they are replaced by H^+ ions, the supply of which in rain water is inexhaustible. Slowly the cation exchange complex of the soil becomes enriched in exchangeable H^+ and the soil acidifies. Once the soil pH passes a low 4.5-5.0 the original clovers fail to grow and Al^{+3} ions are being released from dissolving clay mineral crystal edges. Aluminium toxicity can develop. Pastures and crops grow less vigorously and transpire less water. The cost of liming to correct the problem may become too high on land that has always been of only low productivity. The hydrologic impact is very difficult to predict.

A CATCHMENT-WIDE INVENTORY FOR SETTING PRIORITIES IN IMPROVED SOIL MANAGEMENT

The available data base for the Soil Health Strategy for the GHCMA consists of the only detailed land studies of two areas with the region: Land Systems of South Western Victoria (Gibbons and Downes, 1964) and Land Systems of the Grampians Area (Sibley, 1965). There is also a rapid reconnaissance soil inventory (1:250,000) of south western Victoria (Maher and Martin, 1987), and Baxter and Robinson’s Land Resource Assessment in the Glenelg Hopkins Region (2001).

The Land System studies mentioned provide detailed descriptions of the land forms, soils and native vegetation, as well the agricultural uses of the land, but they are out of date with regard to the latter. They have much soil chemical information. Maher & Martin covered an area extending from Queenscliff and Ballarat to the border with South Australia. They dealt exclusively with the chief soil types in their mapping units, but present no laboratory data or information on soil problems They also used the boundaries of the geological maps at the same scale to delineate their soil mapping units. Baxter & Robinson collated the work of Gibbons & Downes and of Sibley, and others, but used up-to-date geological maps in combination with radiometrics and a digital elevation model in preference to the original mapping. However, they did not have the opportunity to do more ground-truthing and as such their mapping is incomplete.

In view of these facts, we used geological maps as a base for transposing the Gibbons & Downes and Sibley mapping, and their wealth of descriptive material to describe the mapping units to the maximum extent, including their assessments of soil-related environmental problems. All the soil classificatory terminology has been updated to what is in use in Australia today. All the appendices with soil profile descriptions and soil laboratory data were scanned, more effectively arranged and re-published, as, without this, the information will be lost because the original publications are out-of-print.

We then attempted to obtain as much categorical information on agricultural land uses, including yield data and information on profitability. From the economic data and by assessing the environmental consequences of significant soil health problems, we developed a system for prioritising these soil health issues.

The Soil Health Strategy Report (van de Graaff et al. 2006) recommends a number of soil health management strategies by which the overall state of soil health can be improved, suggests priorities for these strategies, and evaluates the costs and benefits of improved health to land holders. Priority areas are identified at the scale of sub-catchments and explicit recommendations on soil management activities are made. The costs and likely financial benefit that will follow of each proposed soil management practice are estimated.

Practices that are likely to be profitable are therefore able to be identified. Areas that are identified as high priority, but are uneconomic for landholders to treat are also identified and an estimate made of the inputs required to implement the practices that would restore soil health. All information is provided as hard copy, in electronic form, and has been given a GIS format that can be interrogated.

A BIG KNOWLEDGE GAP IDENTIFIED

What is lacking in this exercise is a better link with water quality and stream flow regime. As discussed above, there is a great need for more profound study of what land use changes, which are mandated by a changing economic environment, will mean for the Catchment in terms of its hydrology. Without that, we are likely to discover that we have allowed yet another environmental problem to creep up on us. With the GIS base that is now available, it may be possible to develop catchment-wide modelling of these hydrological impacts of various land use change options.

A beginning has been made in the Water and Land Use Change Study (WatLUC) carried out by SKM Pty Ltd (2005) with support from several organisations, including the Glenelg Hopkins CMA. The WatLUC study covered more than the Glenelg Hopkins Rivers catchments and considered the hydrological impacts on a sub-catchment basis. It based its modelling on the water use characteristics of each land use, running a soil water and salt balance model (*SoilFlux*) for each land use, soil type and depth to water table, and predicting deep aquifer discharge and surface drainage. However, it contains as yet no explicit connection to soil health in the Glenelg Hopkins CMA area.

CONCLUSION

This paper, based on a study of the condition of the soils in the Glenelg-Hopkins Catchment Region, argues that one cannot understand, and therefore manage, water quality in streams and lakes without reference to the land that produces the water, both as runoff and seepage, and hence the use of the land and the health of the soil. This is a task for joint work by soil scientists, hydrologists and geographic information experts. It should be continued with great vigour.

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REFERENCES

Barlow, K., David Nash, and Rodger Grayson (2004). *Phosphorus export between the paddock and the farm boundary. SuperSoil 2004 3rd Australian/New Zealand Soils Conference, Sydney, NSW.*

Nash, D., L. Clemow, M. Hannah, K. Barlow and P. Gangaiya. (2005). *Modelling phosphorus exports from rain-fed and irrigated pastures in southern Australia. Aust. J. Soil Res., Australian Journal of Soil Research, Vol. 43 No. 6 Pages 745 – 755.*

Baxter, N. M., and Robinson N. J., (2001). *Land Resource Assessment in the Glenelg Hopkins region*. *Agriculture Victoria, Department of Natural Resources, Bendigo, Victoria.*

Brouwer, J., (2001). *SYSTANAL: a checklist for analysing ecosystems for the conservation of biological diversity*. *Ostrich Supplement No.15:p.178-182. Wetlands International, P.O.B., 7002, 6700 CA, Wageningen, The Netherlands.*

Brouwer, J. and R.H.M. van de Graaff (1988). *Readjusting the water balance to combat dryland salting in southern Australia: Changing the hydrology of a texture contrast soil by deep ripping. Agricultural Water Management, 14, 287-298.*

Gibbons, F.R., and Downes, R.G., (1964). *A Study of the Land in South-Western Victoria. Tech. Comm. #3, Soil Conservation Authority, Victoria.*

Maher, J and Martin, J. (1987). *Soil and landforms of south-western Victoria – Part 1. Inventory of soils and their associated landscapes. Dept. of Agriculture & Rural Affairs Research Report series No.40.*

Sibley, G.T., (1967). *A Study of the Land in the Grampians Area. Tech. Comm. #4. Soil Conservation Authority, Victoria.*

Sinclair Knight Merz (1999). *Victorian Water Quality Monitoring Network Trend Analysis – Glenelg Catchment Management Authority Area.*

Sinclair Knight Merz (2005). *Water and Land Use Change Study – Stage 2 Community Report.*

Van de Graaff, R.H.M., S.L. Lang, I. Allan, and A. Patterson (in preparation). *Glenelg Hopkins Catchment Soil Health Strategy. Report prepared for the Glenelg Hopkins Catchment management Authority.*

WATER ECOscience Pty Ltd (2002). *Victorian Water Quality Monitoring Annual Report: 2002.*