24 Environmental Indicators and Sustainable Agriculture

Joe Walker*

Abstract

This chapter looks at how indicators can be used to assess agricultural sustainability. Indicators are biophysical, economic and social attributes that can be measured and used to assess the condition and sustainability of the land from the farm to the regional level. Reliable indicators provide signals about the current status of natural resources and how they are likely to change. They can be used to confirm that current farming practices and land-use systems are effective in maintaining the resource base or economic status, identify problems and highlight potential risks. Indicators provide useful information for initiating change or deciding on future on-ground investments.

本文论述健康诊断指标如何应用于农业持续能力的评价。诊断指标是可以量测的生物物理和社会经济特征，用来评价从单个农场到整个地区不同尺度的土地状况和持续发展能力。可靠的诊断指标能体现自然资源的当前状态，及其可能产生的变化。可用于辨别现行的农业生产活动和土地利用系统能否有效维持资源或经济发展水平，确认存在的问题，突出潜在的危机。它能为土地利用方式的修正和未来的土地投资决策提供有用信息。

FARMING practices are changing the environmental resource base. Some changes are for the better (e.g. organic farming), but many are deleterious and could endanger future agricultural activities. Rural and urban environmental changes caused by various human activities, not just farming, are increasingly felt, raising perceptions of the environmental costs of these activities. For example, in the cities, people experience poor air quality; some rivers and beaches are no longer fit for recreational use; and valued natural areas have been lost to suburban and industrial development. Farmers and rural inhabitants have seen soil loss through wind and water erosion; they are aware of areas that can no longer be farmed because of crop and pasture decline, and gully development in saline areas.

Observation of environmental deterioration in farmed areas is not a recent phenomenon.

* CSIRO Land and Water, PO Box 1666, Canberra, ACT 2601, Australia. Email: joe.walker@csiro.au

Walker, J. 2002. Environmental indicators and sustainable agriculture. In: McVicar, T.R., Li Rui, Walker, J., Fitzpatrick, R.W. and Liu Changming (eds), *Regional Water and Soil Assessment for Managing Sustainable Agriculture in China and Australia*, ACIAR Monograph No. 84, 323–332.

Australian farmers in the early 20th century noticed changes that were detrimental to productive agriculture such as an increase in unpalatable grasses and weeds, the advent of saline flows in previously fresh creeks and streams, the need for increased ploughing to retain a tilth in fallowed paddocks and a decline in crop yields and animal production. The signs were there, both visually and in quantifiably reduced yields.

Visible undesirable changes in the condition of the atmosphere, land and water are 'indicators' of degradation brought about through changes in environmental processes resulting from human activity. The changes may be due to the introduction of new processes (e.g. the addition of pesticides to the soil) or to increases or decreases in existing processes (e.g. more recharge leading to rising watertables in Australia and reduced recharge leading to falling watertables in parts of China). Visual indicators such as soil surface crusting, sheet and gully erosion, and stream and river turbidity have alerted us to problems. Thus, we have been using environmental indicators in agriculture for a long time and the concept is nothing new. However, there has recently been greater recognition of the role that indicators of environmental change could have in assessing and monitoring the effect of land use on natural resources. Indicators can be a powerful means for those managing the land to identify potential problems and assess the effect of their management practices on ecosystems (Walker and Reuter 1996; SCARM 1993; US National Research Foundation 2000; Pykh et al. 1999). Provided that indicators are meaningful to a range of users, from farmers to policy makers, they can help to achieve sustainable agriculture. However, indicators must be selected and used carefully if they are to be effective.

Farmers have long used indicators to decide on changes to farm practice. An obvious next step is to develop a more standard, yet simple, way of recording and assessing environmental change that can have immediate application at the farm and catchment levels. Farmers are already 'production literate' but they also need to be 'environmentally literate'. The two literacies working together can help ensure a sustainable future for agriculture.

How Can We Define Indicators?

Indicators are a subset of the many possible attributes that could be used to quantify the condition of a particular landscape, catchment or ecosystem (Walker 1998). They can be derived from biophysical, economic, social, management and institutional attributes, and from a range of measurement types. Indicators have been defined as 'measurable attributes of the environment that can be monitored via field observation, field sampling, remote sensing or compilation of existing data' (Meyer et al. 1992). Ideally, each indicator is precise and accurate in describing a particular process within the environment and will serve to signal undesirable changes that have occurred or that may occur (Landres 1992).

Researchers distinguish several types of indicators. For example, 'compliance indicators' identify deviation from previously defined conditions, 'diagnostic indicators' identify the specific cause of a problem and 'early warning indicators' signal an impending decline of conditions (Cairns and McCormick 1992). It is important to define the purpose of indicators and to select them on the basis of how well they can fulfil the required role.

Indicators are perhaps best viewed as communication tools that can turn scientific knowledge into a form better understood by a range of community groups, policy makers and others (Walker et al. 1996). Questions have been raised about the credibility of indicators for resource assessments, but this applies only if indicators are poorly selected. In selecting indicators it is necessary to look at certain criteria such as reliability, interpretability, data availability, established threshold values (needed to set class boundaries) and known links to processes (Walker and Reuter 1996;

Jackson et al. 2000). There are better grounds to question the aggregation of indicators into an index (e.g. catchment health rating) or subindex (water quality), since this involves the addition of disparate measures, usually in a simplistic way. Fuzzy approaches (Roberts et al. 1997) offer a possible means to be mathematically correct, but the interpretation of any given index is still an issue.

Steps in Using Environmental Indicators

Indicator development starts with defining a problem — identifying the issues and their value to society. We then ask questions to specify the issues more clearly. This involves making balanced and integrated judgments on the economic, social and environmental condition of a region's rural enterprises (SCARM 1998). The next step is to choose attributes to use as indicators; for example, current condition (or status) and the direction and magnitude of any change in condition. Certain indicators will be influenced by changes in other indicators, and these interactions must be taken into account.

Questions that could be used to determine the specific issues, for example for the grains industry, are:

- Where is farm productivity falling and the natural resource base declining?
- Where is farm productivity increasing or stable and the resource base stable?
- Where is farm productivity improving and the natural resource base declining?

These questions can be asked at individual paddock, catchment and region scales. By using different sets of indicators to answer these questions and by analysing the responses, an assessment report can be produced. If the report shows that current farming practices are having detrimental impacts on the resource base, it can be used as the basis for remedial action. Indicators can then be used to monitor the outcomes of whatever action is taken. These steps are depicted in Figure 1.

Many of the chapters in this book illustrate the use of indicators in summarising research knowledge. This section examines various issues involved in selecting suitable indicators of catchment and farm health, and in developing appropriate monitoring programs.

Interpreting Indicators at Different Scales

Different spatial scales often require different questions to be asked, requiring different indicator sets and thresholds (Walker et al. 2001). Table 1 illustrates the different kinds of questions asked at different scales. Table 2 lists some of the indicators that are relevant at particular scales. They include single indicators (e.g. soil nitrogen), composite indicators (e.g. cropping on steep slopes as an estimate of erosion risk) and aggregated indexes (e.g. soil moisture index or soil fertility indexes).

Data collected in farm surveys can be aggregated and reported at regional and even national level, provided that sampling intensity and measurement quality are adequate and the indicators reflect regional or farm diversity.

At the national and State scale (Table 1) the interest is mainly on policy development and identifying 'hot spots' that require immediate attention. 'State of environment' reporting at the national and State levels are examples. The approach is 'top-down': the initiative is taken by people from State and national bodies and the results handed over for implementation. The data used are generally readily available data with little attempt to collect detail. These issues are discussed more fully in Chapter 26.

Indicators for regional or local government/ provincial scales could also refer to a particular sector, reflecting concerns about the production and

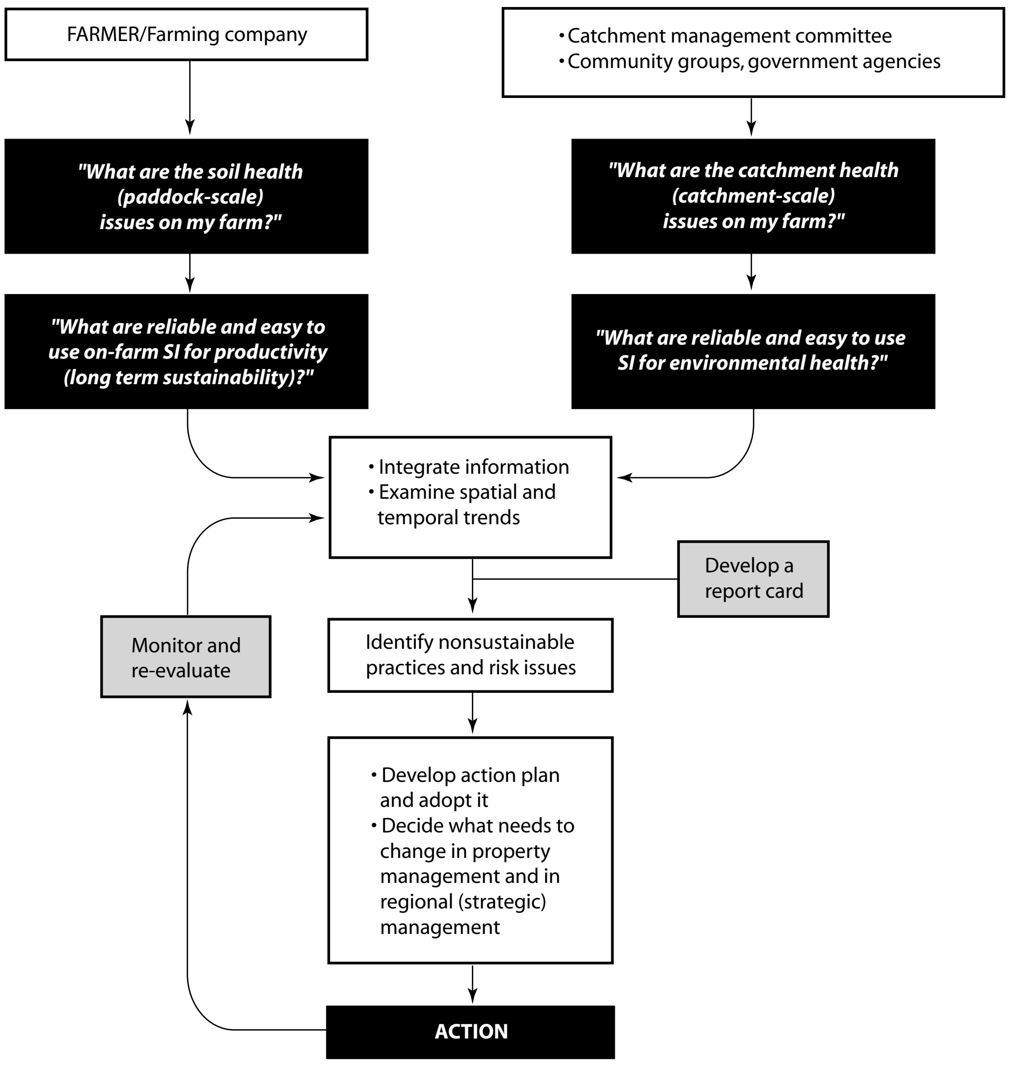

Figure 1. A logical decision tree for using sustainability indicators (SI).

economic future of a region. Examples of the kind of information available for indicator development at this scale are given in Section 3 of this Volume.

At the farm level, questions refer to specific management problems — how to identify undesirable changes and what action to take. The approach is 'bottom-up', with emphasis on self-help. The focus is on changing practices at the paddock scale in a way likely to improve farm and catchment health. Examples in this book are found in Chapters 21 and 28.

A Structured Approach to Using Sustainability Indicators

Indicators must be relevant, robust and scientifically defensible. There is little point in using indicators that have known weaknesses or that cannot be interpreted reliably. For example, mean soil worm density is difficult to interpret because of regional and seasonal variability; mean soil pH has little meaning at a catchment scale but is useful at a farm scale or for a particular soil landscape. We need to set criteria against which the merits of an indicator can be judged — for example, by rating

Table 1. The categories of questions asked at different scales.

National scale	Regional/catchment scale	Farm/site scale
Top-down approach	Top-down approach	Bottom-up approach
Purpose of indicators		
National/State assessment		Site assessment
Socioeconomics (resource economics)		Socially acceptable economic choices
Policy development	← Two-way linking process →	On-ground action
Agricultural sustainability	Social–economic–natural resources	Condition of the land (paddock)
State of environment (SoE) reporting		Assessing trends for a farm
Agricultural production		Whole environment/conservation urban/rural links
Indicator programs or groups interested in using them		
• DEST (SoE reporting) • State SoE reporting • SCARM (sustainability program) • ABARE (Outlook conference) • ABS (national statistics) • Research and development corporations such as LWRRDC, GRDC and RIRDC • State EPAs	• CALP boards • Regional land management boards • MDBC • State water/land/agriculture departments • NLP • Indicators of catchment health developed by CSIRO • ALGA • ABARE	• Farmer groups • Farm planning groups • Land care groups • Providers of extension services • ACF/SAWCAA • Streamwatch • Waterwatch • Farm 500
Questions		
1. How degraded are Australia's natural resources? 2. Where are the urgent problems? 3. How sustainable are our agricultural practices? 4. What are the broad trends in costs versus profits for agricultural enterprises? 5. What policies can be developed to encourage sustainable agriculture?	1. How can production, quality of life and profits be increased? 2. What methods need to be developed to better manage natural, social and economic resources? 3. What effects are agricultural practices having on natural, social and economic resources? 4. What impacts are social and economic events having on resource management?	1. How can I best manage my farm? 2. How can I make a living on my farm? 3. What sort of life can I have? 4. How can I assess land and water health on my farm? 5. How much will it cost to fix a biophysical/resource depletion problem?

ABARE = Australian Bureau of Agriculture and Resource Economics; ABS = Australian Bureau of Statistics; ACF = Australian Conservation Foundation; ALGA = Australian Local Government Association; CALP boards = catchment and land protection boards; DEST = Department of the Environment, Sport and Territories; EPA = environmental protection agency; GRDC = Grains Research and Development Corporation; LWRRDC = Land and Water Resources Research and Development Corporation; NLP = National Landcare Program; MDBC = Murray–Darling Basin Commission; RIRDC = Rural Industries Research and Development Corporation; SAWCAA = Soil and Water Conservation Association of Australia; SCARM = Standing Committee on Agriculture and Resource Management; SoE = State of environment

Table 2. Examples of linkages between issues, sustainability indicators and scales.

Scale	Issue	Sustainability indicator
National	Average real net farm income Access to key services	Farmer's terms of trade Distance to regional centres
State	Health of river basins	Trends in water quality
Agricultural industry	Meeting commodity market specifications Farmer's skills	Trends in silo protein levels for wheat % farmers using property management plans
Region	Health of rural environments	% land affected by salinity Condition and extent of native vegetation
Catchment	Meeting water quality targets	Trends in water quality % area with protected riparian vegetation
Farm	Optimising farm returns Planning the annual farm business	Disposable income per family Forecast trends in commodity prices
Paddock	Yield performance Soil health assessment	% potential yield or $ water use efficiency Reliable soil tests

each indicator in terms of relevance, ease of capture and reliability. Table 3, which broadly follows Jackson et al. (2000) and Walker et al. (2000), summarises the criteria for selecting reliable sustainability indicators.

Threshold guidelines for resource condition

Figure 2 shows how a hypothetical resource indicator in an agroecosystem might change with time. Initially, sample values vary within accepted thresholds. For example, even if a system has been changed from a natural to a managed agroecosystem, it may be performing within acceptable limits. Such a system is considered stable (e.g. not leaking nutrients or water to streams or groundwater systems) within the set thresholds. This is the concept of 'conditional stability' developed by Walker (1999). In later years, values may move outside threshold limits. For example, increased electrical conductivity could signal increasing salinity in soil or streams, or decreased soil nitrogen levels could indicate nutrient depletion under intensive cropping regimes. The main problem is in setting threshold values that apply nationally. Some thresholds are well defined (e.g. some water quality measures are related to human health), but values are more difficult to set in landscapes and catchments. Values are known to vary regionally and thresholds vary with spatial scale. This variability makes the idea of setting environmental targets difficult to define absolutely.

A suite of indicators is needed to examine changes in resource condition. For example, commercial soil sampling services offer clients multiple tests on each sample submitted. The results can then be

Table 3. Challenges for selecting reliable sustainability indicators (SIs).

Criteria	Challenges
Reliability	Is a standard method available to measure the SI?
	Are low errors associated with measurement?
	Is the SI measurement stable?
	Can the SI be interpreted and ranked reliably?
	Does the SI respond to change or disturbance?
	Is the SI accepted by farming communities?
Data capture and cost	Can SI data be easily captured?
	Is the data capture at low cost?
	Does the SI need to be monitored regularly?
Ranking and assessment	Can the SI data be mapped or graphed?
	Can SI assessments be integrated soundly in space and time?
	Do previous SI data exist?

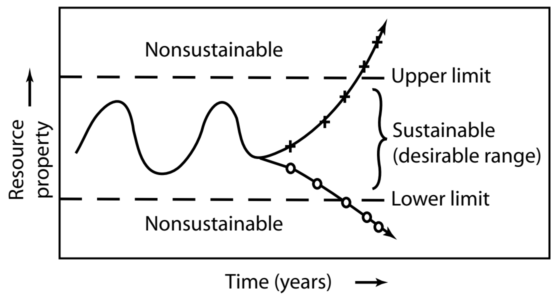

Figure 2. Conceptual diagram showing the requirement for validated upper and lower limits to assess temporal trends (A, B) in a resource property (indicator values) (Reuter 1998).

compared to relevant guidelines[1] and used to summarise trends. Farmers and their advisers can carry out these tests themselves at relatively low cost using practical 'do-it-yourself' test kits. Kits are available through the Western Australian Farm Management Society and Charles Sturt University. Rengasamy and Bourne (1997) have also developed a kit for assessing soil salinity, acidity and sodicity.

[1] For example, there are Australian guidelines for interpreting soil (Peverill et al. 1999), plant (Reuter and Robinson 1997) and water quality tests for assessment of stream condition (Ladson and White 1999).

Benchmarking farm business health

The Australian Bureau of Agricultural and Resource Economics (ABARE) has defined economic indicators of farm performance (ABARE 1999). These are derived as complex national or industry indexes, or estimated from aggregated data from various sources such as annual ABARE farm surveys, the Australian agricultural census and agricultural financial surveys from the Australian Bureau of Statistics (ABS). ABARE and ABS publish regular updates showing trends for economic indicators.

Dealing with large annual variations

When there are large annual variations in indicator values, it is important to know the trends over time. Many economic indicators, such as disposable income per family or profit at full equity, vary greatly from year to year through the combined effects of seasonal weather conditions, shifts in commodity prices and other market forces (e.g. interest rates). For these indicators, trends in data, acquired annually, should be assessed at constant dollar value over several years or decades to understand the magnitude and direction of longer term changes. The impact of rainfall on economic indicators can be partly circumvented by expressing data in units of rainfall received in any given season — the so-called dollar water use efficiency ($WUE) indicator.

National assessments of sustainable agriculture

The Standing Committee on Agricultural Resource Management (SCARM) published a series of reports during the 1990s. These culminated in a pioneering but incomplete report on the assessment of sustainable agriculture in Australia's 11 agroecological zones. Initially, 'sustainable agriculture' was defined and guiding principles were developed for assessing the level of sustainability achieved by the agricultural sector (SCA 1991). Subsequently, an indicator framework was devised for making these assessments (SCARM 1993). A pilot feasibility study was undertaken to evaluate the validity and availability of data for these indicators (SLWRMC 1996). A final report (SCARM 1998) documented the data and trends. Table 4 lists the indicators used by SCARM to assess sustainability in Australian agriculture. It also lists possible indicators that were not identified in the report but are now acknowledged to be important for a complete assessment of sustainable agriculture in Australia. Some of these indicators are now used in the National Land and Water Resources Audit.

Comparing Different Condition or Sustainability Assessments

It is often useful to compare agricultural performance with catchment condition or with other indexes (e.g. economic or social indexes). Figure 3 shows a cross-comparison matrix of ranked assessments of farm production and ranked assessments of catchment condition. The focus in the figure is on combinations that do not conform to expected (i.e. the diagonal). For example, if a

Table 4. Composite indicators and attributes used by SCARM (1998) to assess sustainability in Australian agriculture, together with some additional attributes required for a more complete assessment.

SCARM indicators	Attributes assessed by SCARM (1998)	Attributes not assessed by SCARM (1998)
Long-term real net farm income	• Real net farm income • Total factor productivity • Farmer's terms of trade • Average real net farm income • Debt servicing ratio	• Costs of land degradation • Costs and benefits from remediating degraded resources • $ water use efficiency (for rainfed and irrigated farms)
Natural resource condition	• Phosphate and potassium balance • Soil condition: acidity and sodicity • Rangeland condition and trend • Diversity of agricultural plant species • Water use by vegetation	• Nitrogen and sulfur balances • Extent of soil structural decline • Level of groundwater reserve exploitation • Extent of land salinisation • Assessment of catchment condition
Off-site environmental impacts	• Chemical residues in products • Salinity in streams • Dust storm index • Impact of agriculture on native vegetation	• Impacts of soil erosion on river water quality • Extent of nonreserve native vegetation on farms
Managerial skills	• Level of farmer education • Extent of participation in training and Landcare • Implementation of sustainable practices	• Adoption by industry of best management practices • Extent of farmer access to the internet
Socioeconomic impacts	• Age structure of the agricultural workforce • Access to key services	• Capacity of rural communities to change • Extent of diversification within rural regions • Extent to which current infrastructure, policies and laws support sustainable agriculture

catchment is biophysically in poor condition and production is high, the system is probably maintained by high inputs of fertiliser and may not be environmentally sustainable. The matrix, which was developed by Walker et al. (2000), is not meant to show causal relationships, but suggests where more investigation is needed. It is particularly useful in broadly comparing biophysical indexes with production, economic and social indexes and in interpreting sustainability at catchment and regional scales. The matrix is based on a list of core indicators for benchmarking economic and resource health within catchments (Walker and Reuter 1996). The initial list was drawn up in 1996; other indicators were added following a national workshop (see Table 3 in Reuter 1998).

Conclusion

Most programs involved in monitoring and assessing environmental condition are ultimately associated with issues of sustainability. The word 'sustainability' has many connotations, including longevity, continuity, function and stability. There are thus different questions to ask and different approaches available. Process-based models have a place and also have limitations; so do indicators. Process-based models, as illustrated in other chapters in this book, can be useful to develop a range of scenarios, but in the context of indicators they can be particularly useful in setting workable threshold values. Unfortunately, many process modellers and reductionist scientists have relegated environmental indicators to the soft sciences, little

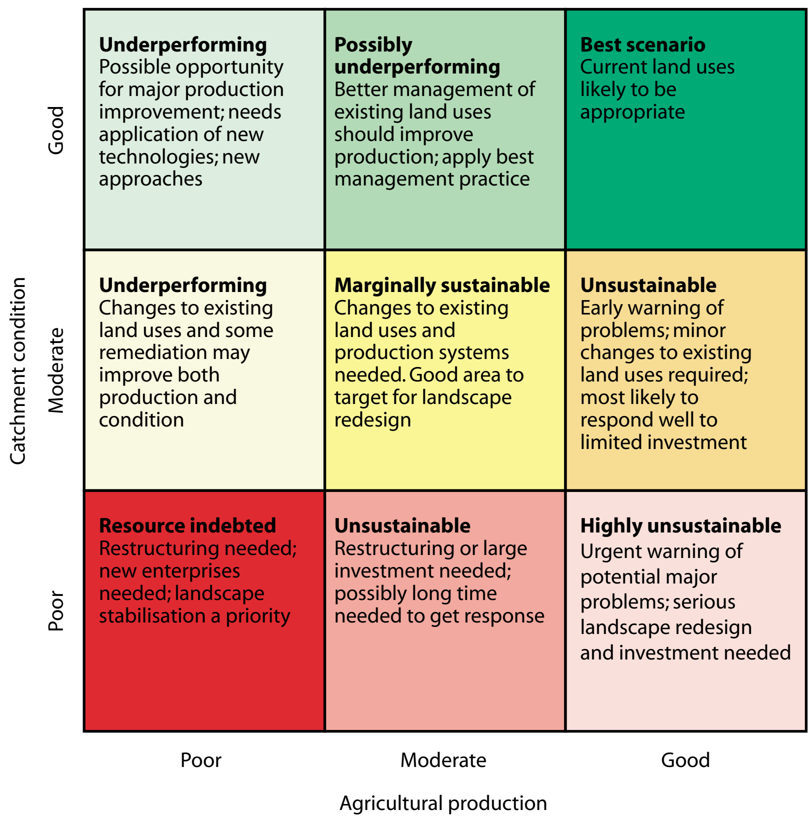

Figure 3. Possible interpretation of the catchment condition–agricultural production cross-comparison matrix.

realising that indicators have a process base. This attitude is usually based on ignorance about the derivation and use of indicators. The establishment of the new journal *Environmental Indicators*[2] will help to establish indicators as a credible systems approach to sustainability issues.

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25 Testing Readily Available Catchment-Scale Indicators as Measures of Catchment Salinity Status

Joe Walker,* Trevor I. Dowling,* Bruce K. Jones,† D. Peter Richardson,* Kurt H. Riitters‡ and James D. Wickham§

Abstract

This study compares a biophysical index of catchment salinity status based on readily available indicators with field measures of stream salinity. It also looks at the time required to compile a data set from readily available data, and whether meaningful results can be obtained from averaged data for third-order catchments. The catchments studied form the entire Upper Murrumbidgee catchment (approximately 12,000 km^2).

The study outlines a systematic approach to selecting relevant, appropriate and readily available indicators. The indicators selected were per cent forest cover, forested areas greater than 50 ha, road density per unit area, per cent agriculture on slopes greater than 5%, number of roads crossing streams/rivers per unit area and the hypsometric integral per catchment. The indicators were compiled and collated in 10 days. The field data comprised stream salt concentration, salt load and two measures of macroinvertebrate group richness—the number of families of macroinvertebrates and the number of families observed compared to the number expected (O/E). The field work required nine months to complete. The biophysical and field indexes were calculated using a simple additive model. The data were placed in three classes using threshold values equivalent to best, intermediate and worst, weighted as 3, 2 and 1 respectively.

Significant relationships were detected between stream salinity and the biophysical index, and between the biophysical and field indexes. A lesser but significant relationship was detected between O/E biota and the biophysical index. These relationships suggest that the readily available data ranked the salinity status of the catchment in a credible way. We suggest that coarse-scale data are grossly undervalued in developing comparative scenarios; indicators carefully selected from readily available data can be used to quickly derive big picture scenarios.

* CSIRO Land and Water, PO Box 1666, Canberra, ACT 2601, Australia. Email: joe.walker@csiro.au

† Environmental Sciences Division, US Environmental Protection Agency, EMSL, Las Vegas, Nevada, United States.

‡ Biological Resources Division, US Geological Survey, Knoxville, Tennessee, United States.

§ Environmental Research Center, Tennessee Valley Authority, Historic Forestry Building, Norris, Tennessee, United States.

Walker, J., Dowling, T.I., Jones, B.K., Richardson, D.P., Riitters, K.H. and Wickham, J.D. 2002. Testing readily available catchment-scale indicators as measures of catchment salinity status. In: McVicar, T.R., Li Rui, Walker, J., Fitzpatrick, R.W. and Liu Changming (eds), *Regional Water and Soil Assessment for Managing Sustainable Agriculture in China and Australia*, ACIAR Monograph No. 84, 333–341.

本文对比了反映流域盐化状况的生物物理指标和反映河流盐分状况的野外量测指标，前者基于从现有资料中选择出来的环境指标，后者由野外测量得到。也讨论了从现有资料中收集整理出一套指标数据所用的时间，以及平均数据能否得到对第三级流域有用的结果。此项研究覆盖了整个默如比基流域的上游地区（约一万两千平方公里）。

作者概述了从现有资料中选择相关、适当的诊断指标的一个系统化的方法。选择的指标有森林覆盖率，面积大于 50 公顷的林地，单位面积的道路密度，坡度大于 5%的农地比例，单位面积内跨越河流的道路数量，以及每个流域的高程积分。健康诊断指标数据在十天内完成编辑汇总。野外数据包括河流盐分浓度，排盐量和反映大型无脊椎动物群丰度的两个值－－大型无脊椎动物门数及其调察值与预期值的（O/E）的比值。野外作业需九个月完成。生物物理指标和野外量测指标由简单的加法模型计算得出。数据被分为三个等级，其阈值分别相当于好、中、差，权重分别是 3、2、1。

研究发现河流盐分和生物物理指标之间以及生物物理指标与野外量测指标之间有着明显关联。O/E 和生物物理指标间的关联比它们稍弱但仍很明显。这些联系表明简单易得的诊断指标对流域盐分状况的反映可信度很高。我们认为写意式粗线条数据的价值总的来说被低估，在作对比项目中，采用认真挑选的诊断指标，能够快速反映总体轮廓特征。

THE PRIMARY purpose of this study was to investigate the credibility of a stream salinity index based on a small set of easily obtained landscape indicators, by comparing the index with independent measures of stream salinity. The study was also designed to look at the time needed to compile a data set from readily available data, and whether meaningful results could be obtained from averaged data for third-order catchments.

Why use a set of landscape metrics to rate relative salinity risk across a group of catchments when the measurement of salt concentrations in streams is relatively simple? The answer is that there is a major dilemma with salt measurements from streams. The problem is illustrated by Figure 1, in which stream salinity — electrical conductivity (EC) in microSiemens per cm — is plotted against sample time. Figure 1 shows that EC is extremely variable and is related to stream flows: high flows tend to have low salt concentrations and vice versa. The range in salt concentrations can be important; for example, for stream biota and for livestock drinking the water. Given that most streams lack sample points, establishing catchment stream salinity status would require regular sampling over years or even decades.

An alternative measure of salinity risk is salt loads in streams (concentration × volume). In Australian streams, water volumes can vary quickly following rainfall, often in a timespan of hours; stream volume is therefore much more difficult to measure than EC. Sampling across a region can take several days, so it is difficult to sample similar parts of the stream hydrograph (plot of volume against time).

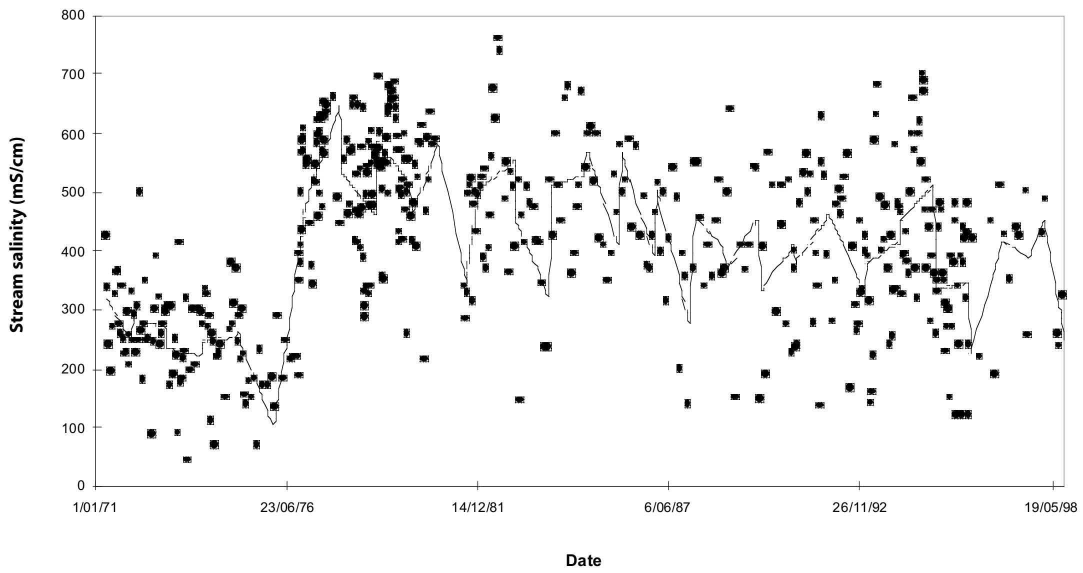

Figure 1. Stream salinity (electrical conductivity, EC) plotted with time for a stream in the Gininderra catchment, Australian Capital Territory (data from Environment ACT).

Accurate measuring of stream EC and volume requires permanent sampling stations and frequent (at least every hour) sampling. Such stations occur primarily on research sites or at the outlets of very large catchments, providing sparse but high-quality data. Dividing a large catchment into contributions from subcatchments can be a problem in the absence of sampling sites in the subcatchments.

We believe that stream salinity status can be assessed with appropriate landscape indicators. In this way, sparse, high-quality data can be complemented by poorer-quality, dense sampling. If the measures selected are the main drivers of the systems, the values obtained can act as benchmarks for further monitoring.

Study Area, Data Collection and Indicators

Figure 2 of the Overview shows the location of the Upper Murrumbidgee catchment. The catchment has a total area of approximately 12,000 km^2 and includes the national capital, Canberra (population 300,000), and the rural centres of Yass and Cooma, each with a population of less than 10,000. Land uses include cropping, extensive livestock grazing, forestry, viticulture, water catchments for the supply of town drinking water, national parks and many small hobby farms. Many areas have been cleared of native forest and woodland vegetation, and this contrasts with other areas that are in pristine condition. Issues identified by local Landcare groups and the Upper Murrumbidgee Catchment Committee include weeds, feral animals, waterlogging, salinity, stream turbidity, soil erosion and water quality.

Walker et al. (2001) and Jones et al. (1997) have suggested a series of steps in developing an indicator approach to resource assessment. These are:

- first identify *societal values*;
- then identify the *specific issue* to examine;
- frame an *assessment question* to address the issue; and
- select *indicators* that address the assessment question.

In this study of the Upper Murrumbidgee catchment, the societal value was good-quality water; the issue was the risk of increasing stream salinity; and the assessment question was 'What is the relative salinity status of catchments in the Upper Murrumbidgee?'

In order to gain an indication of how long it would take to complete a national assessment, a time limit for the study was set at 10 days. Another aim of the study was to determine whether a catchment size of about 500 km^2 could be used to assess catchment condition. The size is typical of catchments used by Landcare groups and as management units for regional planning and management. At an Australia-wide scale, catchments approximately 500–1000 km^2 in area are often third-order catchments and can be explicitly defined from appropriate digital elevation models (DEMs).

The strategy adopted to address the assessment question was as follows:

- identify and collate readily available spatial environmental attributes for the region;
- select indicators from the available attributes according to the criteria (reliability, interpretability, data availability, known thresholds and links to biophysical processes);
- use a simple additive model to calculate an index of salinity status for each catchment (a relative ranking from best to worst (good to bad)); and
- collect independent data on stream salinity and examine the relationship with the catchment condition values (the expectation is that a relationship should exist).

Figure 2 shows the subcatchments used in the study. The Upper Murrumbidgee region was divided into 13 third-order stream catchments defined by the New South Wales Department of Land and Water Conservation from previous and current gauging stations. Catchment No. 8 was larger than the others and subdivision would be desirable. However, only 13 catchments were gauged.

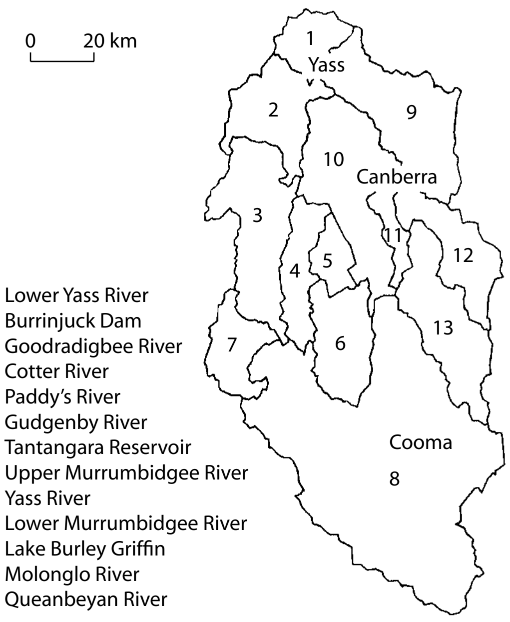

Figure 2. Subcatchments in the Upper Murrumbidgee Region of New South Wales.

Indicators of Catchment Condition

The processes driving salinisation in this region are well understood; they include urban development, tree removal for agriculture, destruction of the riparian buffer and shallow, salty groundwaters. We selected indicators that were linked with these processes and were readily available. The data sources were Thematic mapper satellite imagery,[1] a DEM at 250 m resolution (AUSLIG 1994), and cadastral and land-use information (AUSLIG 1996). The imagery enabled us to identify the major vegetation/land-use types — treed areas (woodland and forest with a projected cover of more than 20%), improved pastures, cropping areas and urban areas. The DEM allowed slope classes and catchment areas to be derived. From the DEM data we calculated two landscape indexes — catchment area and a hypsometric integral. Strahler (1952) defined a hypsometric integral as an area–altitude curve that relates horizontal cross-sectional area of

[1] Provided by Dr Tim McVicar and Lingtao Li, CSIRO Land and Water. See Chapter 16 for specifications of Landsat Thematic mapper.

a drainage basin to relative elevation about the basin mouth. The measure was considered to be related to several catchment processes, including hydrological regime, soil erosion, landscape age and sedimentation. It has seldom been applied or used to interpret catchment processes.

Six indicators collected were used in the analysis. Indicators used were per cent forest cover, per cent forested areas of more than 50 ha, road density per unit area, per cent agriculture on steep slopes (slopes of more than 5%), number of roads crossing streams per unit area and the hypsometric integral. Table 1 shows values for the biophysical indicators.

Classification

The individual indicator values were placed into three classes (thresholds), representing poor, medium and good (red, yellow and green), as illustrated in the example shown in Table 2. For four of the six indicators, the range in values was simply divided into three equal parts. For per cent forest cover, evidence from other studies suggested that classes at < 20%, 20–60% and > 60% were correlated with stream salinity (high to low). The three classes for the hypsometric integral were determined as equal areas under the frequency/value curve obtained from a more extensive study in the region. This classification gave approximately equal numbers of catchments in each class for each indicator (more by chance than design). Maps of classes for individual indicators were drawn using individual indicator values but are not presented here.

Class weightings

Weightings can be carried out in several different ways; similarly, the means to recognise class boundaries and to develop an index can have several variants. Weightings were applied to each of the classes as 1, 2 or 3 (poor, medium or good) and summed for each catchment to give an aggregated

Table 1. Biophysical attributes (indicators) for the catchments.

Catchment number	Road density per unit area	% Forest cover	% Forested > 50 ha	Roads crossing streams	% Agriculture on steep slopes	Hypsometric integral	Biophysical index
1	0.0165	2.99	0.00	0.3181	38.07	0.3787	7
2	0.0136	21.51	1.53	0.1443	46.64	0.2393	9
3	0.0137	72.41	32.20	0.1890	23.46	0.3995	14
4	0.0174	81.75	46.16	0.2695	16.05	0.4312	14
5	0.0169	54.79	17.68	0.1793	37.18	0.3836	12
6	0.0100	61.55	20.58	0.1780	33.41	0.4495	16
7	0.0108	60.99	8.12	0.2059	21.57	0.2916	12
8	0.0156	46.15	14.26	0.1449	28.81	0.3200	12
9	0.0152	13.63	0.17	0.0442	37.13	0.3578	8
10	0.0210	14.91	0.39	0.0598	46.02	0.3028	8
11	0.0282	17.89	0.26	0.0514	34.87	0.2195	9
12	0.0157	35.35	7.45	0.1130	27.96	0.3342	11
13	0.0144	48.57	15.04	0.1618	34.47	0.3853	13

value for its condition, as illustrated in Table 2. Thus, values for catchment biophysical condition ranged from 6 (all indicators poor) to 18 (all indicators good). These catchment ratings were then compared with independent field measures of stream salinity.

Table 1 shows the biophysical index values for the catchments using these threshold values and weightings.

Field Sampling for Stream Salinity and the Biotic Response

We selected four independent measures (termed field indicators) to reflect changes in stream salinity:

- salt concentration (measured as EC at base flow/discharge);
- salt load (salt concentration × stream base flow); and
- two measures of macroinvertebrate group richness (number of families of macroinvertebrates, and observed over expected number of families).

The measures were for an autumn sample and were taken at the exits of the 13 catchments during a period of base flow some 10 days after a rainfall event. The assessment team collected the data for EC. The Co-operative Research Centre for Freshwater Ecology (University of Canberra) and Environment ACT supplied the data for macroinvertebrates. These data are part of a national study that defined expected values and determined methods for sampling and analysis. One field site was omitted from the analyses (site 2 was sampled at the outlet rather than the inlet of Lake Burley Griffin), because the lake acted as a salt buffer.

The field sampling had to be deferred several times because of variable stream base flows across the catchments, and the need to coincide with the macroinvertebrate sampling. Sampling for EC required two field days, so we had to wait for the right conditions. Table 3 gives the values for the field measures and the field index.

Table 2. Classification of indicators using threshold values. Green indicates good; yellow indicates medium; and red indicates poor. Classes are weighted 1, 2 and 3, respectively (good to poor) and the weightings added to give an index score. The minimum score is 6 (all poor); the maximum is 18 (all good). Three examples are shown to introduce the working.

	Threshold values for the 13 site analysis						
Weighting	Forest cover (%)	% Forested areas > 50 ha	Road density per unit area	% Agriculture on steep slopes	No. of roads crossing streams per unit area	Hypso-metric integral	
1 (poor) (red)	< 20	< 5	> 0.015	> 36.0	> 0.2	< 0.31	
2 (medium) (yellow)	20–60	5–10	0.015–0.010	22.0–36.0	0.1–0.2	0.31–0.4	
3 (good) (green)	> 60	> 10	< 0.010	< 22.0	< 0.1	> 0.4	
Catchment no.							Field index
1	2.9	0.00	0.0165	38.1	0.318	0.3787	7
2	21.5	1.5	0.0136	46.6	0.146	0.2393	9
3	72.4	32.2	0.0137	23.5	0.189	0.3995	14

Relationships Between Catchment Condition and Field Measures

The four field data sets and the field index were plotted against the catchment biophysical index. Figure 3 shows the plots that had a significant linear relationship (note that some points are plotted on top of each other, giving apparently different numbers of catchments). The relationship between stream salinity (measured as EC) and the biophysical index (Fig. 3a) was negative and the correlation strong ($r^2 = 0.75$, $P < 0.001$). This suggests that the index is predicting the salinity status of the streams very well.

The relationship between the biophysical index (based on indicators) and the field index (which includes biological and stream salt measures) (Fig. 3b) was likewise strong and positive ($r^2 = 0.74$, $P < 0.001$). The relationship between the macroinvertebrate data (observed number of macroinvertebrate families over expected number) and the biophysical index (Fig. 3c) was positive but weak ($r^2 = 0.34$ $P < 0.05$). This suggests that at the scale of catchments used in the study (500–1000 km^2), the influence of landscapes and changes in land use is reflected in the stream fauna. Although weak, this relationship is encouraging, given the limited nature of the field data and the potential for large variability. The relationship between salt load and the biophysical index (not shown) was very weak ($r^2 = 0.04$). An examination of the biophysical data set suggested that the measure dominating the results is per cent tree cover remaining in the catchment.

Discussion and Conclusion

This study set out to compare readily available landscape biophysical data, which can be collected quickly, with stream measurements, which take much longer to collect and also require specialist

Table 3. Field measurements of salinity and biota in the catchments.

Catchment Number	Conductivity (EC)	Salt load (concentration × flow)	Macro-invertebrates (observed mean)	Macro-invertebrates O/E	Field index
1	974	1.412	8.50	0.86	7
2	406	0.128	2.00	0.21	7
3	102	2.239	14.00	1.11	10
4	64	0.077	10.50	0.83	11
5	99	0.072	12.20	1.08	12
6	140	0.057	11.20	0.97	12
7	30	0.777	13.00	0.89	11
8	494	0.401	11.00	0.97	11
9	1081	0.954	8.00	0.79	6
10	970	0.085	5.15	0.57	6
11	456	0.133	5.33	0.55	7
12	505	0.504	8.20	0.88	9
13	314	0.412	7.80	0.78	9

O/E = number of families of macroinvertebrates observed compared to the number expected expertise. The strong correlation between the biophysical landscape data and the field data suggests that, at least for the area examined, the index performed very well.

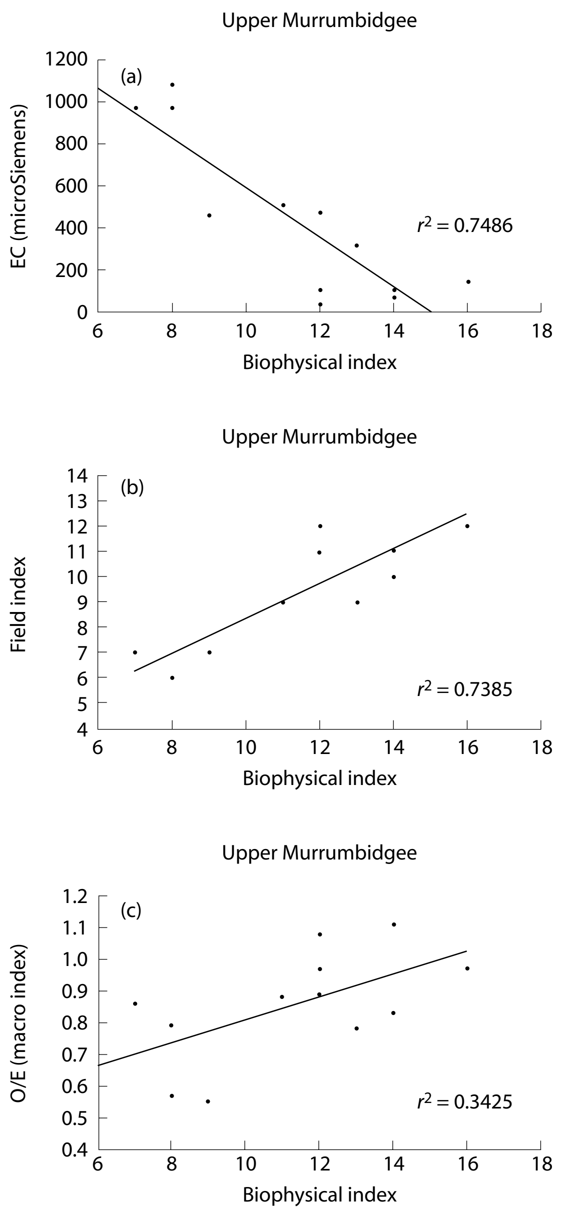

Figure 3. Relationships between catchment condition and stream measurements: (a) plot of stream salinity versus the catchment condition biophysical index; (b) plot of the biophysical versus field catchment condition indexes; and (c) plot of observed/expected macroinvertebrate groups versus the biophysical index of catchment condition.

The mechanisms controlling salinity in the study area were reasonably well known and the question arises as to whether the same indicators can be used in other areas to rate salinity status. Sufficient research has been carried out across Australia to suggest that different mechanisms are at work in different regions (e.g. seasonality of rainfall, magnitude and mobility of salt stores and different kinds of groundwater flow systems contributing to dryland salinity). Recent groundwater mapping as part of the National Land and Water Resources Audit (Coram et al. 2000) shows the areas with local, intermediate and regional groundwater flow systems. Inspection of the maps suggests that the indicator set could apply to the southeast temperate areas of Australia on the western side of the Great Dividing Range, mapped as local or intermediate groundwater flow systems.

The catchment size used approximated third-order catchments, with the majority ranging in size from 500 to 1000 km^2. Subsequent studies over smaller and larger areas suggest that size does influence the results, particularly threshold values, and the indicators that are appropriate (Walker et al. 2001). There could be many different reasons for this effect, but the most obvious with respect to stream salinity are that:

- as size increases, varying inputs of high-quality versus salty water along the length of the river will affect the relationships, and
- at smaller scales, the impacts of good management practices can reduce salt inputs from the land (e.g. repairs to the riparian zone can reduce overland flows).

Data for these parameters are generally not available at the broader scales. Therefore, it is advisable to use sizes of around 500 km^2. Nevertheless, the indicator approach described can be useful as context information at the more detailed scale, and detailed data can be added when available.

The collation of the data sets was carried out within a week, suggesting that application at a national level is possible within a realistic timeframe. Regional differences are important in such an exercise, and it would be advisable to identify the local mechanisms controlling salinity inputs.

Because the study was confined to 13 catchments it has statistical limitations. The next stage, before a national study, involved collecting data from 169 subcatchments in the Upper Murrumbidgee and more intensive field sampling. Some results of this work are reported in Chapter 26.

The results raise an interesting question about the use of coarse-scale data as opposed to detailed measurements to carry out 'big-picture' assessments. It may well be that detailed measurements will not perform any better, and past experience suggests that spatial density is a major consideration. Perhaps continental-scale data have been undervalued and a top-down approach will suffice for most applications relevant to planning or policy development.

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26 Using Indicators to Assess Environmental Condition and Agricultural Sustainability at Farm to Regional Scales

Doug J. Reuter,* Joe Walker,† Rob W. Fitzpatrick,* Graham D. Schwenke‡ and Philip G. O'Callaghan§

Abstract

In this chapter we review recent experiences in using soil, terrain, landscape and catchment indicators to assess the condition of the resource base underpinning agricultural activities. We describe the use of indicators in three case studies, and suggest potential indicators for assessing and monitoring system sustainability in the northern grains region of Australia.

本文回顾了近些年来使用诊断指标对土地和流域健康状况进行评价的经验，介绍了三个具体的研究实例，并提出了可评估和监测澳大利亚北部产粮区生态系统持续能力的一套指标。

IT IS IMPORTANT to choose indicators that match predetermined regional needs and priorities, be they for farm production or environmental issues. In choosing indicators, current knowledge about their strengths and weaknesses needs to be consolidated (see Chapter 24). For example, publications such as SOILpak (Daniells et al. 1994) or Soil Matters (Dalgliesh and Foale 1998) deal with

* CSIRO Land and Water, PMB 2, Glen Osmond, SA 5064, Australia. Email: dreuter@bigpond.com
† CSIRO Land and Water, PO Box 1666, Canberra, ACT 2601, Australia.
‡ NSW Agriculture, Tamworth Centre for Crop Improvement, Tamworth, NSW 2340, Australia.
§ Neil Clark and Associates, PO Box 540, Bendigo, Vic 3552, Australia.

Reuter, D.J., Walker, J., Fitzpatrick, R.W., Schwenke, G.D. and O'Callaghan, P.G. 2002. Using indicators to assess environmental condition and agricultural sustainability at farm to regional scales. In: McVicar, T.R., Li Rui, Walker, J., Fitzpatrick, R.W. and Liu Changming (eds), *Regional Water and Soil Assessment for Managing Sustainable Agriculture in China and Australia*, ACIAR Monograph No. 84, 342–357.

the management of soils in the northern grain belt. In southern Australia, PADDOCKCARE (McCord et al. 2000) consolidates information on 51 farm indicators. PADDOCKCARE, which is available as a CD-ROM, allows farmers to record and graph indicator data over time and to progressively rank and integrate the status of a range of issues assessed by indicators. Dalal et al. (1999) provide an example of selecting indicators for the central Queensland grain region.

Whilst industry and regional benchmarks for assessing economic indicators are available, our focus is on the sustainability of the resource base. The following case studies show how data sets can be integrated and visualised at catchment to regional scale, using biophysical indicators. In each study, we used geographic information systems (GIS) to produce interpolated surfaces of risk. In the Upper Murrumbidgee region, we used surrogate indicators (indirect measures) to assess catchment conditions. In the Mount Lofty Ranges of South Australia, we determined risks for soil salinity, sodicity and acidity by extrapolating from a subcatchment to a subregion using detailed point source data and knowledge of landscape processes. In the Young area of southern New South Wales, we assessed several catchments using report cards based on easily measured indicators. At a regional scale, we developed indicators to assess the sustainability of the northern grains industry. The Overview provides background information about these areas and shows their location (Figure 2 of the Overview).

Case Study 1: The Upper Murrumbidgee Catchment

To construct maps of catchment condition, we focused on readily available rather than high quality data, as the latter are often not available for the whole region. We identified key regional issues, then refined the assessment questions and sampling strategy for a small group of indicators, generally surrogates, relevant at the catchment scale. The study area was the Upper Murrumbidgee catchment (Canberra–Yass–Cooma), comprising 169 subcatchments in an area of approximately 12,000 km^2. The main environmental issues were salinity and sediment movement. The preliminary study of 13 large catchments in this area is described in Chapter 25.

We used seven readily available biophysical indicators (all surrogate indicators):

- percentage of forest cover (surrogate for estimating departures from the original condition and also related to stream salinity);
- percentage forest cover greater than 50 hectares (habitat);
- agriculture on steep slopes (potential erosion);
- road density (human impact);
- roads crossing streams (correlated with sediment input to streams); and
- intact forest along streams (a riparian zone/ habitat and sediment filter).

The data were obtained from satellite imagery, AUSLIG[1] road information and digital elevation model (DEM) information, all of which is readily available and can be assembled within one week. We estimated each indicator for a total of 169 catchments and placed the value in one of three classes: (1) good, (2) intermediate and (3) poor.[2] Catchment condition scores were obtained by summing the weightings for each indicator per catchment to get an aggregate catchment condition value. These values ranged from 8 to 16 and were divided into three catchment classes: 8–10 (good),

[1] Australian Surveying and Land Information Group.

[2] The use of good and poor raises semantic issues, and some prefer to use best to worst when the analysis gives a relative ranking. However, in this case we had a reasonable idea of the threshold values and used good to poor ranking. See Chapter 24 for details on weightings and aggregation.

11–13 (intermediate) and more than 13 (poor). Figure 1 shows the distribution of these classes in the Upper Murrumbidgee catchment.

This condition map is best considered a risk map. Catchments in poor condition are most likely to contain areas with evident or likely future environmental degradation, those in intermediate condition are likely to have some problems or to develop problems in the future, and those in good condition are likely to have few biophysical condition problems.

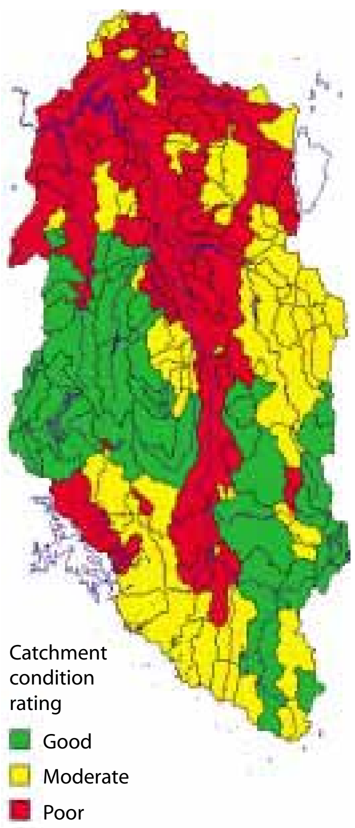


Figure 1. A preliminary catchment condition assessment for the Upper Murrumbidgee basin.

Case Study 2: Mount Lofty Ranges

We integrated soil, vegetation and terrain indicators using a GIS framework and assessed variability in drainage/waterlogging, salinity and acidity/alkalinity using remotely sensed data. Based on the results we developed an index of catchment health and a field manual. The purpose of the manual is to enable landholders and regional advisers to identify problems on properties and plan remedial action.

Study site

The regional study area in the Mount Lofty Ranges of South Australia covers approximately 80 km^2, including the town of Mount Torrens and an area to the east of the town (Fitzpatrick et al. 1999). The climate is Mediterranean and representative of the eastern part of the Mount Lofty Ranges, with a mean annual rainfall of 650–700 mm. A northeast to southwest topographic high east of Mount Torrens bisects the area: small catchments to the west drain into the Onkaparinga and Torrens catchment systems; catchments to the east form part of the Murray–Darling Basin system. Based on morphological, chemical and physical soil data (Fritsch and Fitzpatrick 1994), landscape DEM data (Davies et al. 1998), and water quality and remote sensing data (e.g. AIRSAR/TOPSAR; Bruce 1996), four focus areas were selected:

- a toposequence (~400 m in length) from the Herrmann area;
- the Herrmann area (~0.20 km^2);
- the Herrmann focus catchment (~2.0 km^2); and
- the Mount Torrens regional area (~80 km^2), comprising 55 smaller catchments.

Soil degradation index

We constructed a best-estimate map for each type of soil degradation data and used the maps to develop a soil degradation index (SDI), which itself is part of the broader catchment health indicator (see below).

In the Herrmann focus catchment, the processes by which drainage/waterlogging, salinisation and acidification/alkalisation occur are well understood (Fritsch and Fitzpatrick 1994; Fitzpatrick et al. 1996). We extrapolated spatial patterns of soil degradation processes at toposequence scale (400 m within a 0.2 km^2 key area) to catchment (2 km^2) and regional (80 km^2) scales (Fitzpatrick et al. 1999). By integrating data obtained on the ground with remotely sensed, DEM and vector GIS data, we created best-estimate maps for soil salinity (Fitzpatrick et al. 2000; see Figure 2), waterlogging/drainage (Davies et al. 2000) and acidity/alkalinity (Merry et al. 2000) for the 80 km^2 regional area. A prediction that 3% of the soils of the region would be extremely saline or very saline and that 10% would be slightly saline was validated by data from 50 randomly selected sites and other observations across the 80 km^2 region (see Chapter 21).

Index of catchment health

The United States Environmental Protection Authority (Jones et al. 1977) ranked catchments at large regional scales to obtain an index of relative condition. Our approach is similar in that we ranked attribute values from best to worst for soil salinity, waterlogging/drainage and acidity/alkalinity, and then summed rankings across all three categories to give an aggregated score. Thus, the method differs from the aggregation approach used in the Upper Murrumbidgee study. This method has also been applied to smaller catchments and fewer categories of indicators (Bruce et al. 2000; Fitzpatrick et al. 1999).

Most of the 55 small catchments or watersheds lie totally within the rectangular regional boundary. Catchment subdivisions were based on general surface water flows interpreted from topographic shapes and stream flow patterns (Bruce et al. 2000).

We constructed an SDI by ranking each of the 55 catchments according to the area of degradation due to soil salinity, waterlogging/drainage and acidity/alkalinity and then summed the rankings for each catchment to derive new SDIs (Bruce et al.

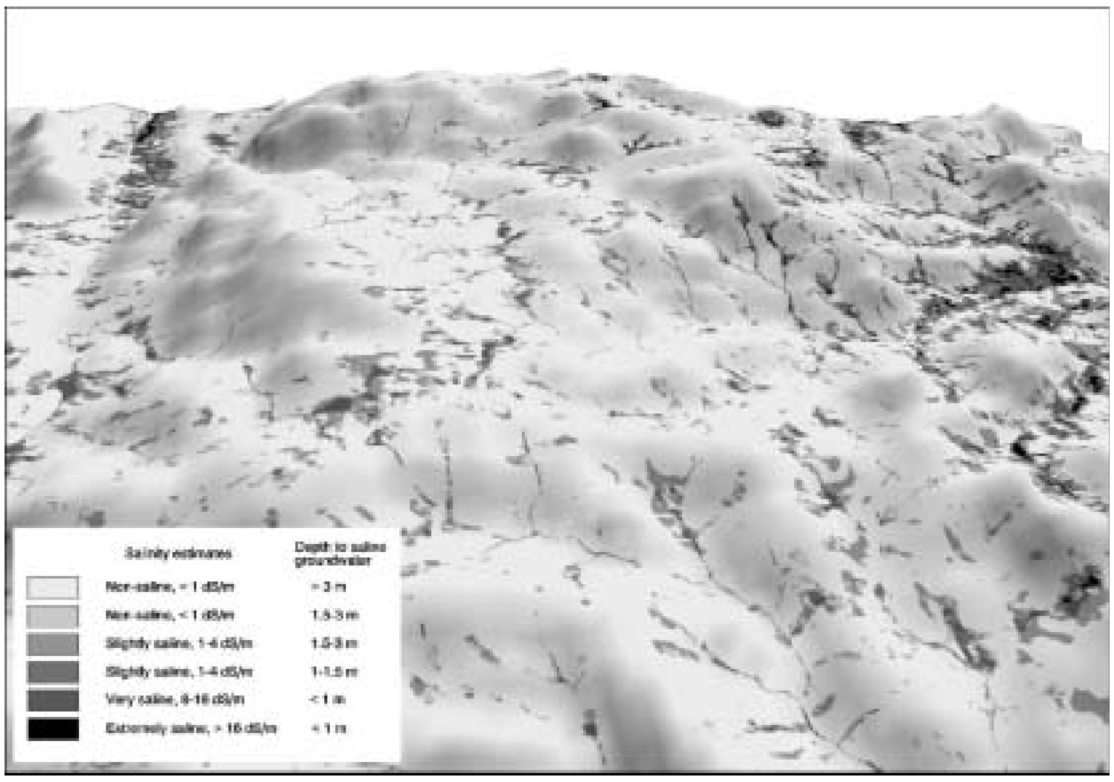


Figure 2. Three-dimensional representation showing six classes of salinity for part of the 80 km^2 study area (from Fitzpatrick et al. 2000).

2000). We used regional maps for best estimates of these three categories to produce a composite, regional-scale assessment of soil degradation.

As illustrated in Figure 3, we used the following indexes to rank the 55 catchments in terms of landscape processes and subsequent environmental effects such as stream water quality:

- SDI — developed from the best estimates of salinisation, drainage/waterlogging and acidity/alkalinity;
- land cover index (LI) — developed from land cover and DEMs;
- riparian land cover index (RLI) — developed from the intersection of buffered streams and land cover; and
- road index (RI) — developed from a summation of the weighted lengths of roads.

Using these indexes, catchments were ranked based on the zonal summation of raster GIS attributes per vector subcatchment polygon. To normalise for different catchment areas, the index value was divided by the area of the catchment.

We combined the rankings by summing each ranking for all catchment characteristics. The final

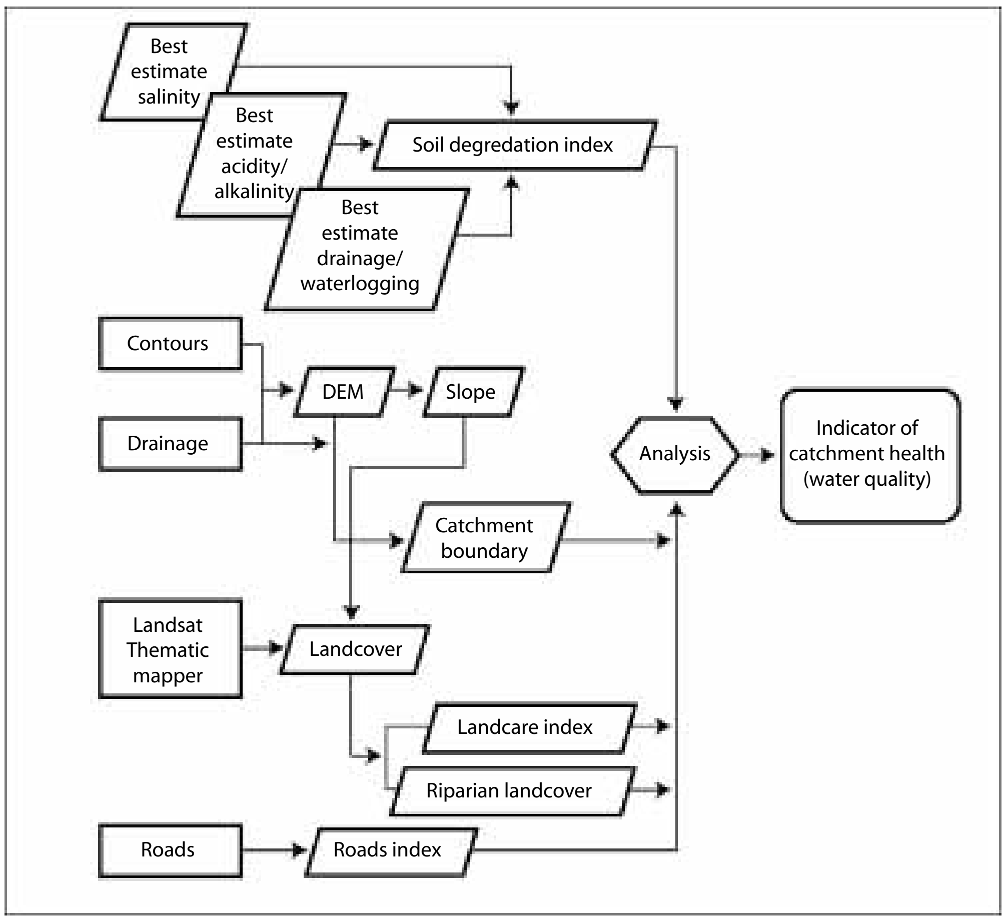


Figure 3. Data model used for the generation of catchment indices (from Fitzpatrick et al. 1999). DEM is digital elevation model.

catchment indicator (CI) of health was calculated using the following model:

$$CI = SDI + RI + LI + RLI$$

We then grouped catchments into quintiles, and rated soil and surface water quality.

To give land managers graphic tools on which to base management decisions, we produced maps such as the final CI map, which used different colours to indicate differences in quality (e.g. catchments with red tones were considered to have poor quality soil and water). The Herrmann focus catchment in the Mount Torrens region fell in the poorest category. Our knowledge of the area suggested that other catchment rankings were valid, but they require validation on the ground.

In the 'Catchment Condition' project of the National Land and Water Audit, Walker et al. (2001) developed a decision system called CatCon that enables indicator aggregations and spatial scenarios to be produced easily.[3]

Availability of data

Most data sets that are needed to aggregate from point measurements in focus catchments to regions are readily available throughout Australia; for example, there are regional data sets for most Australian agricultural regions. Although radar data (used here to refine the drainage/waterlogging and salinity maps) are not readily available for the whole country, the data sets that are readily available still allow for very robust analysis. The key data sets used in this case study need to be combined with knowledge from a representative key study area ('training area'). A hydrologically correct DEM (obtained by editing contour and stream data for the terrain analysis of the region) is needed, as is expert knowledge of the soil hydrological processes for a small key area.

[3] http://www.brs.gov.au/mapserv/catchment/

Application of the approach to other areas

Information gained through use of indicators has been used to help landholders better assess problem sites and develop property management plans. The approach can help Landcare groups, government agencies and others to make resource management decisions and assess the social and economic viability of a region.

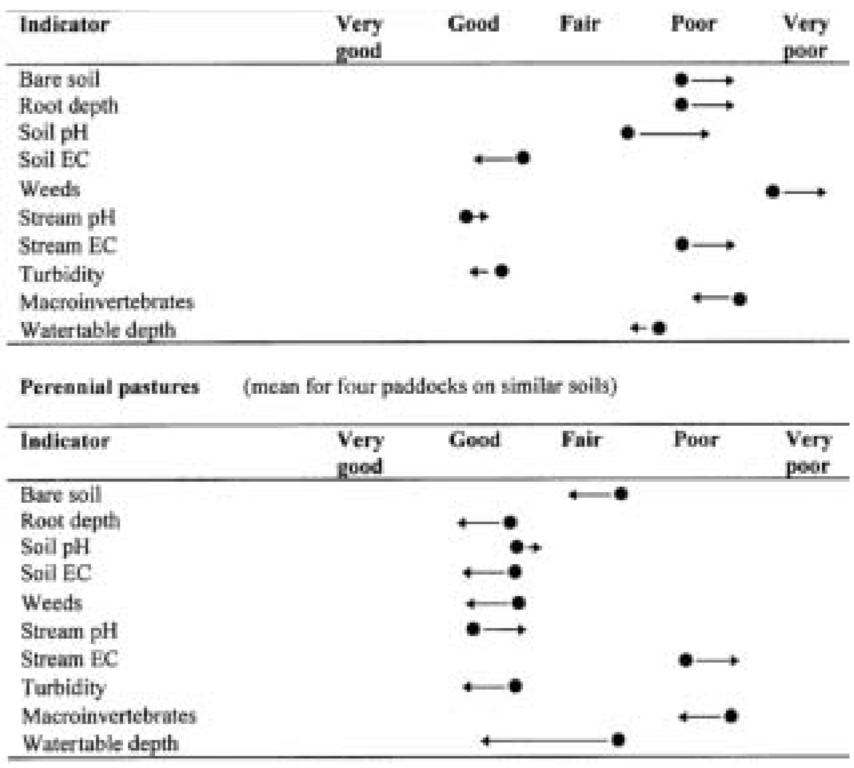
Case Study 3: Catchment Condition Report Card for the Young Area

A great strength of an indicator approach is that it can identify individual activities that are causing specific problems, which is useful in planning and implementing remedial actions. Walker et al. (1996) applied landscape indicators to a mixed farming area around Young in the Upper Murrumbidgee catchment. The outputs were presented in a report card that summarised the indicator values, classes and trends (see Table 1 for an example of a report card).

Table 1 shows a report card for two groups of paddocks — one with annual pastures (low capital input), the other with improved perennial pastures (lucerne established after lime and phosphate fertiliser application) — with each indicator giving a measure of some aspect of system health. Standards to rank each indicator from very good to very poor were established using locally collected data. The table shows that the condition of annual pastures was generally poor and deteriorating: weeds and bare soil were high, plant rooting depth was shallow and the saline watertable had stayed at a constant level.

For perennial pastures, the trends were generally good and improving. Depth to the watertable had increased (the watertable was saline and needed to be well below rooting depth). The rooting depth was greater than in the annual pastures and was expected to improve water use efficiency (WUE); the higher percentage yield implied that the pastures were making better use of the available

Table 1. A trend report card for paddocks with annual pastures and perennial pastures.



EC = electrical conductivity

rainfall; and stream water quality, especially turbidity, was satisfactory for most indicators.

There were some negative signs for the perennial pasture system. The trend in pH indicated that liming was necessary to maintain production, and the low macroinvertebrate biodiversity counts in nearby streams implied a higher than acceptable level of salinity in water moving from paddocks. An increase in stream electrical conductivity (EC) could indicate that more areas might be affected by salinisation in the future; therefore, a more detailed examination, such as mapping EC with appropriate equipment, could be warranted.

Overall, the health of the landscape had slowly degenerated. The following actions were suggested to reverse the downward trend:

- changes in crop rotations (generally wheat in this area) towards longer periods of permanent pasture to improve soil and water health (these improvements at the farm scale would have flow-on effects in improving the general health of the landscape);
- possibly tree planting across the contours and above evident discharge areas (salinity levels have been partially stabilised under the perennial pasture system but are still of some concern); and
- closer monitoring of streams, because their poor biological condition implies that pollution other than salinity is a problem.

The report card approach gives landholders sufficient information to decide on positive actions. Decisions about what to do in any specific example will depend on commodity prices versus continuing slow declines in the health of the landscape.

Application to the Northern Grains Region

The northern grains region lies on the subtropical slopes and plains of eastern Australia (SCARM 1998) between latitudes of 21°30' (north of Clermont, Queensland) and 33° (south of Dubbo, New South Wales). It comprises three agroecological zones: western, eastern and central Queensland (Fig. 4). The region is bounded on the east by the Great Dividing Range (152°E at its eastern extremity) and on the west by rainfall isohyets suitable for dryland cropping (146°E at its western extremity). Agriculture is the dominant land use. In 1997–98, 25% of the region was cropped and 25% was sown to pastures (ABARE 1999). The remaining land was used for extensive grazing or nonagricultural uses such as state forests, national parks and mining. Between 1995 and 1999, 17.5% of the Australian grain crop was harvested from this region, of which 65% was produced in the eastern zone (Knopke et al. 2000).

Land use

The region incorporates a variety of farm enterprises; the ratio of cropped land to pasture land ranges from 0 to 1. The cropping–pasture mix tends to ebb and flow according to commodity prices and farmers' aspirations, but the following general types of farms can be identified in the region:

- *Mixed farming*. Livestock and cropping enterprises are integrated and use the same land. This form of land use is usually practised more in the older, eastern areas of the region.
- *Cropping only*. Intensive, continuous cropping is mostly undertaken on the more fertile lands of the region and where there are small areas of irrigation. Few, if any, livestock graze these areas.
- *Separate cropping and livestock industries on the same farm*. Cropping and livestock enterprises are undertaken on the same farm, but each is located in a separate area, often determined by factors such as soil type and slope. On the fertile Darling Downs of Queensland and the Liverpool Plains of New South Wales, cropping is practised on flat to undulating alluvial plains, while livestock graze the steep nonarable slopes. In the western part of the region, traditional livestock farms are gradually changing into mixed, but nonintegrated, farming enterprises.
- *Livestock only*. Much of the region is used only for cattle and sheep grazing, as the land is unsuitable for cropping or the landowner does not wish to produce crops.

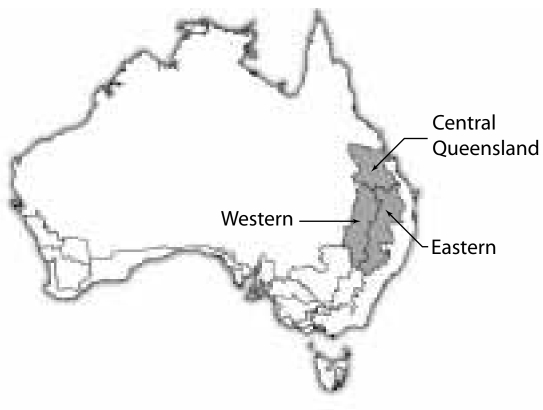


Figure 4. The northern grains region of Australia consists of three subregions: western, eastern and central Queensland.

Areas of dryland and irrigated cotton growing fall into the first three categories. Dryland grain cropping in the region is dominated by winter and summer production of cereals (chiefly wheat, sorghum, barley and corn). The dominant soil types for cropping are Vertosols (black, grey and brown cracking clays), Sodosols (solodised solonetz and solodic), Chromosols (red-brown earths) and Ferrosols (Krasnozems and Euchrozems) (Webb et al. 1997). The moderate to high water-holding capacity of the Vertosols is important for the production of winter crops because most rain falls in the summer, particularly in the north. Webb et al. (1997) provide more information about the region, its soils and the characteristics of its climate.

Sustainability issues for the northern grains region at various scales

The first step in using indicators is to identify the key sustainability issues facing the region. These vary at paddock, farm, catchment and regional level, as shown in Tables 2–4.

At the paddock and farm scale, soil health is a key issue. Soil erosion causes loss of surface structure, decreased storage of plant available water, and loss of soil nutrients in eroded sediments. Other issues include increased risk of salinisation, sodicity, soil acidification and structural damage, crop pests and weeds and diseases; and reduced diversity and abundance of soil fauna. These issues are related to site-specific factors such as soil type, climate, agronomic management and farm history. In some cases, the problems may not be recognised by land managers because they are relatively insidious or not well understood (e.g. subsoil compaction, deep drainage, vertical and lateral leakage of solutes, and the conservation of beneficial soil organisms).

Most catchment-scale issues relate to water quality. Catchment-scale issues tend to have downstream and offsite impacts on whole communities, affecting towns, cities, forests, national parks, beaches, estuaries and coral reefs as well as agriculture. For example, widespread soil erosion in the Fitzroy River catchment, which drains much of the central Queensland agricultural area, has led to high levels of suspended sediments, nutrients and pesticides in streams and groundwater (Noble et al. 1997). For many local towns, this in turn impacts upon their sole water supply. In the Liverpool Plains in northern New South Wales, six key natural resource management issues pertinent to the sustainability of the catchment have been identified: dryland salinity (and groundwater recharge),

Table 2. Performance indicator levels in Queensland showing the number of businesses in each category.

	Performance targets				Queensland sample (% of farms in each category)			
Farm indicators	Weak	Medium	Strong	Dynamic	Weak	Medium	Strong	Dynamic
Disposable income Per family ($'000)	< 30	30–60	60–100	> 100	33	29	24	14
Farm input costs Operating costs/farm income (%)	> 60	60–50	50–45	< 45	65	21	10	4
Land productivity Operating surplus/land value (%)	< 8	8–15	15–20	> 20	31	43	16	10
Farm size Land value per family ($'000)	< 400	400–800	800–1200	> 1200	6	55	18	21
Debt servicing Financing costs/total income (%)	> 15	15–7	7–3	< 3	29	37	16	18
Machinery Machinery market value/farm income (ratio)	> 1.2	1.2–0.8	0.8–0.6	< 0.6	53	21	18	8
Nonfarm income Net nonfarm income per family ($'000)	< 5	5–15	15–30	> 30	63	16	17	4

flooding, soil erosion, water quality and quantity, biodiversity and riparian zone degradation (Dames and Moore 2000).

At the regional level, most sustainability issues relate to soil nutrient depletion, soil structural degradation, soil erosion, diseases, pests, weeds and chemical contamination of food and the environment (Clarke and Bridge 1997). Until recently, cropping in the region was often characterised by nutrient 'mining', as nutrients (particularly nitrogen) removed through harvested grain, stubble removal (either hay-baling or burning) and soil erosion were not replaced (Dalal and Probert 1997). Although many farmers now replace 'harvested' nutrients with fertiliser inputs, the regional balance is still negative (Knopke et al. 2000). SCARM (1998) found phosphorus and potassium balances for broadacre industries in the subtropical slopes and plains to be consistently negative during the period 1986–95, with no indication of improvement. Another regional issue is stream eutrophication and turbidity (Knopke et al. 2000).

Table 3. Business health indicators.

Indicators	Performance targets				Qld median
	Weak	Medium	Strong	Dynamic	
Business health					
Disposable income/family ($'000)	< 30	30–60	60–100	> 100	46
Net worth—Net assets/family ($'000)	< 500	500–1000	1000–1500	> 1,500	971
Income drivers					
Production system Farm income per hectare per 100 mm annual rainfall ($/ha/100 mm rain)					
• Intensive cropping	< 60	60–70	70–80	> 80	51
• Mixed farms	< 40	40–50	50–60	> 60	51
Farm input cost—Operating costs/farm income (%)	> 60	60–50	50–45	< 45	62
Farm size—Land value/family ($'000)	< 400	400–800	800–1200	> 1200	656
Debt servicing—Financing costs/total income (%)	> 15	15–7	7–3	< 3	11
Machinery—Machinery market value/farm income (ratio)	> 1.2	1.2–0.8	0.8–0.6	< 0.6	1.2
Nonfarm income					
Net nonfarm income/family($'000)	< 5	5–15	15–30	> 30	2
Resource use					
Land productivity —Operating surplus/land value (%)	< 8	8–15	15–20	> 20	10
Labour—Income per labour unit ($'000)	< 100	100–150	150–200	> 200	115
Return on capital—Return on farm capital (%)	< 2	2–7	7–12	> 12	3

Table 4. Associating farm productivity issues in the northern grains region with commonly advocated indicators.

Sustainability issue / component	Scale	Suggested sustainability indicators	Possible action to take	Investor (who pays?)	Likely time to achieve benefit
Declining productivity					
Poor WUE by crops (declining crop yields)	P, F	• % of potential yield • WUE	• Adopt improved agronomy • Identify yield limiting constraints including subsoil factors • Use water balance / push probe to better target yields	• Farmer • Farmer / advisory companies / research funds • Farmer / adviser	• Within season • Few years • Within season
Declining profitability	P, F	• $WUE • Disposable income per family • Net profit per hectare	• Optimise inputs and rotation sequence (opportunity cropping) • Be aware of commodity price shifts	• Farmer / adviser / researchers • Farmer / cooperatives / commodity markets	• Few years • Within season
Declining product quality					
Declining protein in cereals	P, F	• % protein of crop	• Attend N budgeting workshop • Increase N applications • Rotate annual cereal crops with legumes	• Farmer / agriculture departments / cooperatives / grain boards / grain companies	• Within season
	R	• % protein at local silo	• As above	• As above	• Few years
	P, F, R	• Nonlegume:legume ratio in rotations	• Grow pulses or legume-based pastures	• Farmer	• Season after pulse crop
	P, F, R	• % legume in pasture	• Increase pasture legume composition	• Farmer	• Season after pasture removal (effect may last several seasons)

F = farm; N = nitrogen; P = paddock; R = region; WUE = water use efficiency

Suggested indicators for the northern grains region

Tables 4 and 5 list potential sustainability indicators at paddock to farm scale; Table 4 shows those more relevant at the catchment to regional scales. Some indicators are common to different scales. The tables also describe actions that could be taken in order to solve problems, suggest who is likely to invest in solving either farm or environmental problems, and provide estimates of how long after remedial treatment benefits are likely to accrue. Clearly, not all indicators will be used simultaneously. Individual farmers or rural communities need to determine the most pressing issues.

A popular and effective means for creating a greater knowledge base for targeting local issues are programs such as 'Farming for the Future', where farmers learn together in facilitated action-learning groups. A recent survey by Lobry de Bruyn (1999) found that farmers across northwestern New South Wales monitored soil health through soil tests, crop performance (yield and protein), visual observation of plants and soil, and the structure and workability of soil (by a soil 'feel' test).

Where more than one problem is identified, combined corrective measures often produce a synergistic response. For example, some 16% (195,000 ha) of the Liverpool Plains catchment is considered to be at risk from salinisation, with 50,000 ha currently exhibiting symptoms of dryland salinity (LPLMC 2000). This is a significant local issue and one worth monitoring and addressing, because farm profit and environmental outcomes are linked. Soil tests (EC), piezometer monitoring (watertable height and EC), observations of salt scalds, dominance of pastures by salt-tolerant plant species and permanently waterlogged areas within paddocks are all useful indicators for identifying salinity. Where salinisation is identified or where the risk of salinisation is high, farmers may fence off salt-affected land, plant deep-rooted perennials, use salt-tolerant species, or use reverse interceptor banks (especially on sloping duplex soils) to divert lateral subsoil water. Landowners usually pay for these actions, but Landcare funding is sometimes available. It is important to realise that where changes to groundwater hydrology are sought, the results of these actions may not be manifest for several years or even decades.

The above example of salinity deals with farm and paddock-scale remedial actions. Broader-scale solutions are typically required to prevent salinity in the first place. At a catchment scale, indicators of salinity include soil, groundwater and streamwater EC, electromagnetic surveys (mapping of EC within the landscape), and DEM (inferring and mapping likely areas of salinity hazard based on landscape position). Catchment management strategies are typically funded by federal or State governments. An example at a State level is the New South Wales Salinity Strategy (August 2000), which set interim end-of-valley salinity targets for salt load and EC to be achieved by 2010. An example of a catchment-scale response is the Liverpool Plains Catchment Investment Strategy, which proposes an environmental management system to be used as a tool for sharing the cost of implementing solutions to problems such as dryland salinity (LPLMC 2000). One recommended action is to cease cropping in designated land management units where deep drainage is most likely, and instead establish and maintain tree cover (farm forestry).

Future directions

Farming and rural communities will adopt sustainability indicators only if they believe they will improve the short-term benefits and long-term viability of their enterprises. It is worth remembering that the farming community has always used broad indicators in farming practice and management. This is often thought of as 'experience' and it extends to reading the likely weather, knowing when to fertilise, examining trends in commodity prices and exchange rates and

Table 5. Associating soil health issues in the northern grains region with commonly advocated indicators).

Sustainability issue / component	Scale	Suggested sustainability indicators	Possible action to take	Investor (who pays?)	Likely time to achieve benefit
Soil health					
Poor surface structure / reduced water infiltration	P, T	• Dispersion / slaking tests • Exchangeable sodium percentage • Soil organic carbon • Soil consistency • Water intake rate • Surface crusting / sealing / pugging	• Grow pastures • Apply gypsum • Reduce tillage • Increase organic matter	• Farmer	Few years up to a decade
Subsurface compaction	P, T	• Effective rooting depth • Soil consistency • Visual assessment • Push probe measurement	• Avoid trafficking (machinery or grazing animals) on wet soils • Practise controlled traffic	• Farmer	Few years up to a decade
Soil erosion	P, T, C	• % bare soil • Slope class • Exchangeable sodium percentage • Presence of rill/gully erosion • Soil movement under fences	• Maintain groundcover • Reduce tillage • Stubble retention • Grassed waterways • Contour banks	• Farmer • Landcare groups • Catchment management committees	Straight after introduction of most actions
Sodicity	P, F, C?	• Dispersion tests • Exchangeable sodium percentage • Sodicity meter	• Apply gypsum • Use low sodium irrigation water • Plant pastures instead of crops	• Farmer	Within first season after application

Table 5. (cont'd) Associating soil health issues in the northern grains region with commonly advocated indicators).

Sustainability issue / component	Scale	Suggested sustainability indicators	Possible action to take	Investor (who pays?)	Likely time to achieve benefit
Soil health					
Salinisation	P, F, C, R	• Electrical conductivity • Electromagnetic surveys • Digital elevation modelling • Salt scalds observed • Areas dominated by salt-tolerant species • Permanently waterlogged areas within paddocks	• Fence off salt-affected land • Plant deep-rooted perennials • Use salt-tolerant species • Use reverse interceptor banks (especially on sloping duplex soils) to divert lateral subsoil water	• Farmer • Landcare	Years to decades
Nutrient deficiencies	P, F	• Soil and plant tests • Nutrient balance sheet (inputs x efficiency / outputs)	• Match projected and actual nutrient exports with fertiliser application • Use regular soil/plant testing	• Farmer • Fertiliser industry	Within first season after action (effects may last for several years)
Acidification	P, F, C	• Trends in soil pH	• Adopt liming practices • Use less acidifying practices	• Farmer • Agribusiness	Several years
Crop diseases	P, F, C	• Crop rotation index • Plant diagnosis • Soil DNA probes • Climate prediction model	• Identify disease problem • Alter tillage practices • Adopt better crop rotations • Use disease-resistant varieties	• Farmer • Plant breeders • Plant pathologists	Within season or within new rotation

C = catchment; DNA = deoxyribonucleic acid; F = farm; P = paddock; R = region; T = toposequence so on. Making the effort to collect relevant environmental data beyond soil tests should not be a major shift in attitude, provided the tests can be interpreted in a way that is meaningful to the productivity of the farm or region. The adoption of environmental measures in Farm 500 (a group of 500 Australian farmers collecting environmental and production indicators) and the collection of information in 'precision farming' demonstrate that many farmers believe that benefits can be obtained.

If farmers are to adopt the indicators, they must first be shown how to collect, store and interpret the data. After that, the greatest success is likely to come from self-help groups.

Conclusions

Several packages to help land managers to address sustainability issues at the paddock, farm and catchment scale have now been developed and implemented in some of Australia's southern farming regions. A common feature of the cases discussed in this chapter is the incorporation of knowledge about the soil and landscape characteristics with various direct and indirect (surrogate) indicators, and the conversion of this information to a regional scale using technologies such as DEM, GIS and remote sensing. This level of complexity is not always necessary; the message here is to encourage farmers to clearly identify the issues to be assessed, to ask assessment questions likely to provide the information they need, to identify the best indicators, and then to record the indicators consistently and accurately.

Australia's northern grains region, where soil and catchment degradation are recognised as significant issues, would benefit from the kind of knowledge and decision-support packages that we have described for southern Australia. We have assembled a suite of sustainability indicators to help identify paddock, farm and catchment health issues and to monitor the situation after remedial action. We hope these may form the beginning of wider recognition of soil and catchment sustainability issues in the north.

Acknowledgments

Case study research was funded in part by ACIAR, the Land and Water Resources Research and Development Corporation (LWRRDC), the National Soil Conservation Program , the Natural Heritage Trust (NHT) and the National Land and Water Resources Audit. We are grateful to members of the Tungkillo Landcare Group for their encouragement and assistance. We thank the many colleagues in CSIRO Land and Water, the Bureau of Rural Sciences and NSW Agriculture who contributed to these studies. Thanks are also due to Greg Rinder and Trevor Dowling from CSIRO Land and Water for graphics.

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27 Ecosystem Rehabilitation on the Loess Plateau

Li Rui,* Guobin Liu,* Yongsheng Xie,* Yang Qinke* and Yinli Liang*

Abstract

The Loess Plateau is well known for its deep loess deposits and serious soil erosion. The region covers five provinces and 0.62 million km^2; 45% of the area is eroded and there is an average soil loss of 3720 tonnes/km^2/year. Since 1985, the comprehensive reclamation of the Loess Plateau has been listed as a key science and technology project in China. Eleven small catchments have been selected as experimental and demonstration areas for ecosystem rehabilitation in different regions of the plateau. After 15 years, each of the 11 catchments has formed a good model for local areas. A set of technologies to control land degradation has been developed. The average yield of farmland has increased by 100–300%, the area under crops has decreased by 30–70%, perennial vegetation cover has increased by 70–150% and soil erosion has decreased by 60–80%. The economic structure of the region has undergone major changes, with income from grain down from 80% to 30%. Other sources indicate that farmers' incomes are 5–10 times greater than previous levels.

The key task in the region is to improve land use. In the loess hill region, cultivated land occupies more than 40% of the total area, most of which is on steep slopes (more than 15°) and about 20–30% of which is on slopes of more than 25°. Only 12% of the region is forested, and only half of that forested area effectively controls soil erosion. Only 30.5% is grassland, of which almost 69% has deteriorated from overgrazing. Land use should consist of flat area cropping for subsistence; forestry in gullies to protect the local ecology; and fruit growing and animal husbandry on sloping land for income.

Results from the 11 trial areas indicate that small catchments can be ecologically rehabilitated, but that they must pass through three stages—restoration, stabilisation and sustainable development—taking 15–20 years. The prospects for the Loess Plateau are bright, but there is a long way to go.

黄土高原以其深厚的黄土沉积和严重的水土流失著称于世。黄土高原地区涉及 5 个省（区），62 万平方公里。其中水土流失面积占 45%，每平方公里平均每年有 3720 吨的土壤流失掉。从 1985 年开始，国家把黄土高原的水土保持综合治理列为重点科技攻关项目，在不同类型区选择了 11 个小流域作为国家生态恢复重建试验示范区。经过 15 年连续治理，这 11 个小流域均成为当地的先进样板。研究开发了一套防治土地退化的技术。农田的单位面积

* Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, NWSUAF, Yangling, Shaanxi 712100, PRC. Email: lirui@ms.iswc.ac.cn

Li Rui, Guobin Liu, Yongsheng Xie, Yang Qinke and Yinli Liang. 2002. Ecosystem rehabilitation on the Loess Plateau. In: McVicar, T.R., Li Rui, Walker, J., Fitzpatrick, R.W. and Liu Changming (eds), *Regional Water and Soil Assessment for Managing Sustainable Agriculture in China and Australia*, ACIAR Monograph No. 84, 358–365.

产量提高了 1-3 倍，林草植被覆盖度增加了 70-150%。土壤侵蚀减少了 60-80%，农民收入提高了 5-10 倍。土地利用和经济结构发生了根本变化，农耕地面积减少了 30-70%，种植业的收入在总收入的比例由过去的 80%以上变为 30%左右。

15 年的研究结果表明：调整土地利用结构是首要而关键的任务。黄土丘陵区农耕地面积占总面积的 40%，大部分是 15 度以上的坡耕地，20-30%的耕地的坡度大于 25 度。有林地面积只占总面积的 12%，其中能起到控制水土流失作用的林地只有 6.5%。草地面积只占总面积的 30.5%，其中 68.8%的草地由于超载放牧严重退化。根据 11 个试验示范区的研究结果，黄土高原的土地利用和产业调整的基本原则为平地为农耕地，实现粮食基本自给；沟壑坡地宜发展生态保护型林业；在坡地上发展草业和果，这将是该区商品经济潜力所在。

11 个试验示范区的实践表明，一个退化的小流域生态系统是可以通过有序治理达到恢复重建的，但要经过 3 个阶段，即恢复阶段、稳定发展阶段和良性循环阶段。一般需要 15-20 年时间。所以，黄土高原的治理前景是美好的，但需要付出时间和投入。

THE Loess Plateau, located in the middle reaches of the Yellow River, is the cradle of Chinese civilisation. Cultivation in this region started 6000 years ago. The national economy relies on the energy base of the Loess Plateau for its heavy and chemical industries. The plateau is rich in sunlight and heat energy, the soil layer is thick, and there are vast areas of land suitable for forestry, fruit trees and grass. However, predatory exploitation, wanton deforestation, overgrazing and other forms of malpractice caused by a population explosion have caused degeneration of the ecosystems on the plateau. As a result, local economies are underdeveloped. The Overview provides background information about the region; Figure 1 of the Overview shows its location.

People in the Loess Plateau region have struggled long and hard against soil and water loss. The government has increasingly paid attention to the region, especially in the past 50 years, and has made great efforts to improve conditions. Since 1985, state authorities have listed the control of water and soil losses on the Loess Plateau as key research topics.

The Study Areas

Eleven experimental and demonstration areas (EDAs) were set up on the Loess Plateau on the basis of natural and social differences. Figure 1 shows the location of the experimental and demonstration areas; Table 1 shows the main environmental characteristics of the sites.

All EDAs represent seriously depleted ecosystems on the Loess Plateau. We have developed a set of technologies to control land degradation, as a result of which each EDA is expected to develop as a

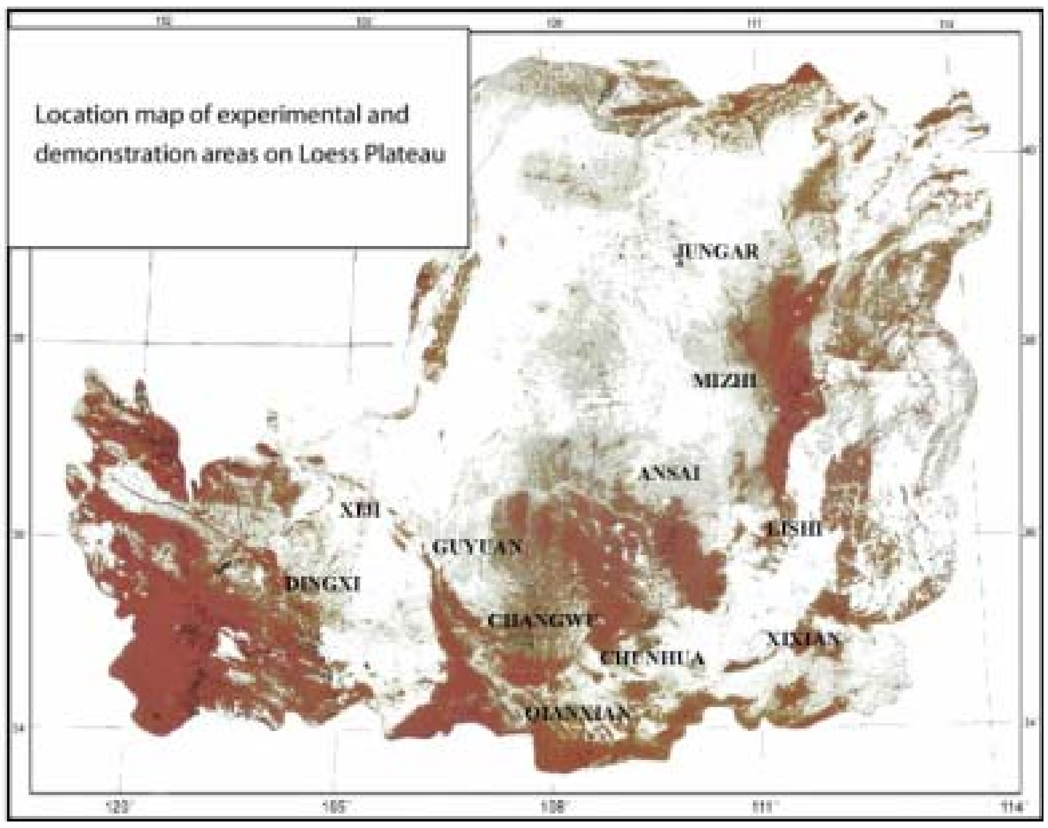

Figure 1. Location of experimental and demonstration areas on the Loess Plateau.

Table 1. Main environmental characteristics of experimental and demonstration areas (EDAs) on the Loess Plateau.

Type of region	Name of EDA	Area (km^2)	Annual rainfall (mm)	Annual average temperature (°C)	Population (persons)	Density of gully (km/km^2)
Windy and sandy	Jungar	7.7	344.2	5.3	330	2.37
Loess hill	Mizhi	5.6	422.0	8.4	586	3.00
	Ansai	8.3	497.6	8.8	407	3.06
	Lishi	9.1	484.7	9.0	1235	3.81
	Guyuan	15.1	472.0	7.0	785	2.16
	Xiji	5.7	402.0	5.3	491	3.32
	Dingxi	9.2	415.0	6.3	1564	1.57
Loess tableland	Changwu	8.3	584.0	9.7	1815	2.76
	Chunhua	9.2	600.0	9.8	2708	2.13
	Qianxian	8.5	590.0	10.8	1806	1.89
	Xixian	10.9	510.6	8.8	1211	1.46

Source: Database of the office of EDA project, Bureau of Resources and Environment, Chinese Academy of Sciences sustainable farming zone on a large scale. Each EDA has formed a good model for the local region.

Main Achievements of the Program

During the past 15 years, the 11 EDAs have undergone great change. The average yield of farmland has increased by 100–300%. Grain yield has increased from 5737.5 kilograms per hectare (kg/ha) to 8196 kg/ha; average personal income has risen from 218 yuan/year to more than 2000 yuan/year (US$1 = 8.0 yuan). The amount of reclaimed land has increased from 46.1% to 80.2%. Research achievements have been applied to up to 10 million hectares of farmland, with some 5.55 billion yuan in increased crop value.

The project has not only improved the regional economy and farming practice on the Loess Plateau, but also promoted rehabilitation of the regional ecosystem. Some 150,000 km^2 of eroded land has been controlled by various conservation measures. The flow of sediments into the Yellow River has been reduced by about 300 million tonnes/year. By the end of 1995, reclamation had already led to an increase of 53.9 million tonnes in the aggregate grain yield over the previous 10 years. Increases in crop yield through the prevention of soil erosion and flood containment have resulted in economic returns of 180 billion yuan according to 1995 prices. Statistics from more than 2000 small watersheds showed that in each of the past 20 years, more than 4% of the eroded area has been controlled by soil and water conservation engineering on the Loess Plateau (before the 1980s, the figure was less than 1%) (Li Yushan 1996; Yang Wenzhi et al. 1992).

Land Use

Improving the land-use structure

The Loess Plateau has a long history of cultivation but natural and social factors have resulted in severe land-use problems, in particular a low proportion of vegetation cover and severe soil erosion and desertification.

Proportion of cultivation and vegetation cover

In loess hill areas, cultivated land occupies more than 40%, most of which is on steep slopes, with about 20–30% on slopes of more than 25°. There is little vegetation cover and the grassland is severely degraded, with less than 50% grass cover in most areas. For example, in south Nixia, grass yield is less than 500 kg/ha. Recent investigations have suggested that forested areas account for 12% of the whole region, of which only 6.5% can effectively control soil erosion. Most regions have only 30.5% grassland, of which 68.8% has deteriorated to some extent from overgrazing (Yang Wenzhi et al. 1992; Li Rui et al. 1992).

Soil erosion and desertification

The Loess Plateau suffers severe soil erosion and desertification. The long-term average sediment load of the Yellow River is about 1.6 billion tonnes per year, most of which comes from the plateau. Table 2 shows the main types of soil erosion on the Loess Plateau; Table 3 shows the intensity of the erosion.

Principles of rational land use

Experience, environmental characteristics and the nature of the land-use problems on the Loess Plateau suggest that the following principles should be considered for land-use planning in this region.

Table 2. Types of soil erosion on the Loess Plateau.

Soil erosion type	Area (km^2)	Proportion of total area (%)
Water erosion	289,300	46.36
Wind erosion	156,500	25.08
Water and wind erosion	178,200	28.56

Source: Tang Keli (unpublished lecture notes on soil erosion and conservation in China for the 2nd International Training Course on Soil and Water Conservation, September 1993).

Consider the economic benefits and ecological effects together

Human impact on the environment is continually increasing as the population increases and more demands are placed on land resources. If ecological effects are neglected during cultivation, land degradation and environmental deterioration will be more severe. Considering the economic benefits and ecological effects together will bring land reclamation and cultivation into ecological balance. On the other hand, soil conservation measures are unlikely to be followed by farmers if economic benefits are neglected.

Look at the integrated structure of land use

We must look at the overall regional economic arrangements as well as comprehensive land use. As mentioned above, semiarid regions have a variety of land-use types, which tend to be distributed in regular patterns. For example, in the hilly area, land types are in the following order: hilltop; land with a gentle slope (< 8°); steeply sloping land (15–35°); gully slope land (< 30°); gully terrace land (< 5°); and gully bed. Land-use arrangements must match the structure of the land type.

Remember that the overall function is bigger than the sum of the parts

This is one of the principles of systems engineering. Land use must match local conditions and there are mutual benefits between different land uses. For example, imagine that there are three hills to be used for planting crops, grass and trees. There are at least two ways to proceed. One is to plant crops on one hill, grasses on another and trees on another; the other is to plant grasses on the top, crops on the middle part (with gently sloping terraces), and trees on the lower part (the gully slope) of each hill. The first method means that one hill will produce grain, another forage and another wood. The results are the sum of the parts: 1 + 1 + 1 = 3. In the second method, the three kinds of uses can provide mutual benefits: the grassland on the top can protect cropland from water and soil erosion; trees on the lower part can control gully erosion. The results are more than the sum of the parts: 1 + 1 + 1 > 3. The second method is known as the integrated (or 'inlaid') method (Ju Ren et al. 1992; Song Guiqing and Quan Zhijie 1996). The key to realising this principle is to correctly handle the relationships between the subsystems and to establish a coordinated environment.

Table 3. Intensity of soil erosion on the Loess Plateau.

Grade of erosion	Amount of soil lost through erosion (t/km^2/year)	Area (km^2)	Proportion of total (%)
Very slight	< 1,000 (500)[a]	99,434	15.94
Slight	1,000 (500)–2,500	192,348	30.83
Moderate	2,500–5,000	40,622	6.51
Severe	5,000–10,000	111,384	17.85
Very severe	10,000–15,000	94,162	15.00
Extreme	> 15,000	86,049	13.79

[a] The figure in brackets refers to rocky mountain regions, not the loess region
Source: Tang Keli (unpublished lecture notes on soil erosion and conservation in China for the 2nd International Training Course on Soil and Water Conservation, September 1993).

Combine land use with land construction

Land degradation — soil erosion, desertification, salinity, soil deterioration and so on — occurs easily on the Loess Plateau. The situation is exacerbated because the poor economic situation means that there is little input to the land. We recommend the following techniques to reduce soil degradation.

- *To transform steeply sloping land into level land.* Steeply sloping lands are widespread in the Loess Plateau. They are known as 'three losses land' because they tend to lose water, soil and fertiliser . Terracing and dam lands[1] are effective in improving conditions. Some problems can be solved by conservation measures such as reduced ploughing.
- *To enrich the soil.* Loess soil is a young soil with low fertility, so it must be enriched in order to get higher yields. We recommend rotation cropping (for example, grass–crop–grass–crop or grain–beans–grain–beans, etc.) and increasing the amount of farm manure and chemical fertiliser.
- *To develop limited irrigation*. In arid and semiarid areas, water is an important limiting factor for agricultural development. Water conservation and optimal water use are key measures for increased agricultural production.

Techniques for Maximising Land Productivity

Grain is essential for people's survival. In the past, people have resorted to every possible means to provide farmland to obtain grain, including deforestation. Deforestation has led to the destruction of ecosystems, causing chronic and increasing impoverishment. To change this scenario, we must increase grain output per unit area, and transform the primitive practice of extensive cultivation — and its concomitant notorious low productivity — into intensive cultivation. Yields will increase and the environment will be rehabilitated if all land resources on the plateau are used rationally in the balanced development of various farming undertakings, including crop plantation, fruit production, forestry and animal husbandry. Increasing grain yield is the main objective of our work on the plateau, in order to eliminate poverty among the local inhabitants and boost the rural economy. The grain production target on the Loess Plateau is 400–500 kg per capita, at which level the local people will have a slight surplus of grain. Our experiences in the experimental zones prove that such a target may be reached within five years if input is increased sufficiently and if key agronomic instructions are available at the right time (Li Yushan 1996).

Any increase in grain yield depends on the planted crop strain, the amount of good basic farmland, agronomic measures taken for crop cultivation, etc. In order to cope with natural conditions and the current grain-planting situation on the Loess Plateau, the key to increasing grain yield lies in an improved water supply for farmland irrigation and in fertiliser application.

Increasing the amount of applied fertiliser and farmyard manure is especially important. The level of fertiliser application on the plateau is about 32% of the national average. Initially, chemical fertiliser was used to increase yields from medium (0.75 t/ha) to high (1.5–2.25 t/ha) levels. In the experimental areas, yields doubled or tripled when chemical fertiliser and farmyard manure were applied together. At a demonstration point in Dingxi Prefecture, for example, yield increased by 79.9% when the amount of chemical fertiliser was increased by 166%. Similarly, when the amount of chemical fertiliser at a demonstration point in Changwu County was increased by 144%, a yield of 5.25 t/ha was achieved, an increase of 99.5%. On average, the application of 1 kg of impurity-free

[1] Dam land is a kind of flat land at the bottom of a gully, formed by the deposited soils eroded from the slope.

fertiliser to Loess Plateau farmland will increase grain yield by 6–10 kg (Li Yushan 1996).

For nonirrigated farmland, yields are increased primarily by collecting water from seasonal rainfall. When there is sufficient water, fertiliser plays a key role in increasing yield up to a certain point, but above this point water is again the decisive factor for further increases in yield. Over many years, our work has shown that it would be impossible to break the ceiling of 3 t/ha for dryland wheat yield by simply increasing the amount of fertiliser applied. It is also necessary to increase the water supply; for example, by collecting runoff from seasonal rainfall, using plastic film to suppress evaporation from the ground surface and making more effective use of available water. Farmland tests in the demonstration zones in Luochuan, Guyuan and Changwu counties showed that these measures could be both feasible and effective. For example, in Guyuan County, when 40 m^3 of water (one-quarter to one-third of the amount of water required for the whole crop) was applied to spring wheat just before the tillering stage, the yield increased from 2.175 to 3.915 t/ha, three-quarters of the yield in fully irrigated crops. In this case, the water use efficiency is about 42 kg/ha using 1 m^3 irrigation water. On the other hand, there is considerable potential to make better use of local precipitation. In semiarid areas of the plateau, 25–30% of natural precipitation is absorbed by individual crops in transpiration, 10–20% becomes runoff on the ground surface and flows away, and the remaining 55–65% evaporates. Rainwater can be used more effectively by collecting runoff and reducing surface evaporation with plastic film.

Stages of Ecosystem Rehabilitation of Catchments

In Ansai County in northern Shaanxi Province, we restored a tiny watershed to its original state by mending and rebuilding the depleted ecosystem and ensuring that any further development would be sustainable. The watershed was a barren and depopulated gully in Zhi Fanggou in the hilly heartland of the plateau that had been plagued by serious water loss and soil erosion. From the 1940s to the 1990s Zhi Fanggou underwent 40 years of land degradation followed by 20 years of restoration. Before the drive, farming was a primitive kind of extensive cultivation; the grain yield was 0.6 t/ha and income as pitifully low as 222.1 yuan (about $27.80) per person per year. After the reclamation drive, the proportion of uncultivated land went down from 51.5% to 18%. The proportion of forest and meadow increased to 41.2%. By 1995, there was 0.18 ha/person of farmland, 0.47 ha/person of woodland, and 0.14 ha/person of artificially created pastureland; the average per capita income was 1658 yuan. Almost all peasant households now have their own television sets; 40% own colour television sets. Every village has its own ground-based equipment for receiving satellite-relayed television signals. Hence the countryside has undergone a radical change in appearance (Lu Zongfan et al. 1997). The experimental zones have become high-level models for comprehensive reclamation of the plateau; they also provide a base for theoretical exploration and an exemplary agrotechnological system for water and soil preservation.

The Loess Plateau is a backwater of the Chinese hinterland, plagued by poverty, underdevelopment, and serious water loss and soil erosion. Our work in Zhi Fanggou for the past 20 years suggests that in order to ensure that the Loess Plateau has a bright future it is best to focus efforts on sustainable ecological development rather than just on economic return. In line with this approach, in the context of stability and progress in the local farming system, we recommend the following three stages to develop ecoagriculture on the plateau while maximising water and soil preservation (Lu Zongfan et al. 1997).

Restoring the ecosystem

The main task of restoration is to increase vegetation cover by returning some cultivated land to forest. The ecological benefits are likely to be seen earlier than economic benefits, although the gap between the two is decreasing and the effectiveness of the investment increases as the original vegetation is gradually restored. At present, restoration is hampered by the difficulty of communicating the complex technological information that forms the basis of any restoration to the local people who carry it out.

Making sure the ecosystem is stable

The newly restored ecosystem is weak and relative unstable. It may revert to its previous state unless care is taken. It is therefore very important to maintain a balance between ecological benefits and economic return. A timeframe of 5–10 years is usually practical for both ecological and economical benefits.

Making sure the ecosystem is sustainable

As the ecosystem becomes sustainable, people's natural and social attributes reach harmony. Both family planning and the rational exploitation of natural resources become conscious actions, with well-defined goals among the local inhabitants. The ecoagricultural system will be more complicated but will function more efficiently. Farming practice and business management are based on scientific and technological data and information resources. Our studies at Zhi Fanggou suggest that the following parameters should be regarded as standardised targets for appraising the three stages in developing an ecosystem rehabilitation in a small catchment: the area of controlled land, the basic amount of farmland and cropland per capita, and the yield (see Table 4).

Table 4. Stages and targets of ecosystem rehabilitation of a small catchment.

Stages	Time (years)	Area controlled (%)	Basic farmland (ha/person)	Cropland (ha/person)	Yield (t/ha)
Restoration	10–15	40	0.07–0.1	0.5–0.8	0.6–0.975
Stabilisation	5–10	60	0.1–0.13	0.4–0.53	0.96–1.35
Sustainable development		80	> 0.17	0.27–0.4	1.875–2.25

Acknowledgments

This article reports a number of research results by Mrs Li Yushan, Lu Zongfan and other scientists.The authors are greatly indebted to them as well as to Wang Lizhi, Wu Pute, Zhao Hongxing and other scholars for their generous contributions to this paper.

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28 Reclaiming the Saline Soils of Nanpi County: Turning Knowledge into Practice

Xiaojing Liu,* Renzhao Mao,* Pujun Bai† and Chungda Luo†

Abstract

Through studies over five years the authors assessed the health of a catchment in a saline region of Nanpi County in Hebei Province, China using a set of key indicators. The indicators chosen included groundwater table level, electrical conductivity in groundwater, soil colour, pH and consistency. From this assessment they constructed a knowledge transfer network involving the Nanpi Eco-Agricultural Experimental Station, local government, a technical extension station, scientists, technicians and key users.

根据区域农业发展存在的环境问题，利用环境质量评价指标体系，建立了南皮县盐碱地环境质量评价体系。体系的构成包括地下水水位、水质、土壤颜色、土壤 pH 值、土壤紧持度等一系列指标。在指标建立的同时，建立了指标的推广体系。这一体系包括中国科学院南皮生态农业试验站、南皮县政府、南皮县技术推广站、直至农民用户。通过努力，一个持续健康发展的农业体系必将在盐碱地环境下建立。

NANPI County is located in the east of Hebei Province, which is near Beijing and Tianjin on the North China Plain (NCP). The county is 70 km west of the Bohai Sea, at an elevation of 6–13 m. It covers 690 km^2 and has a population of 320,000. Annual mean temperature is 11.3°C and mean precipitation is 500–600 mm. Over 70% of annual rainfall occurs in July, August and September. The shallow groundwater table is about 5–8 m below the

* Shijiazhuang Institute of Agricultural Modernization, Chinese Academy of Sciences, 286 HuaiZhong Road, Shijiazhuang, Hebei 050021, PRC. Email: xliu@ms.sjziam.ac.cn

† People's Government of Nanpi County, Hebei 050021, PRC.

Xiaojing Liu, Renzhao Mao, Pujun Bai and Chungda Luo. 2002. Reclaiming the saline soils of Nanpi County: turning knowledge into practice. In: McVicar, T.R., Li Rui, Walker, J., Fitzpatrick, R.W. and Liu Changming (eds), *Regional Water and Soil Assessment for Managing Sustainable Agriculture in China and Australia*, ACIAR Monograph No. 84, 366–370.

surface; about two-thirds of the shallow groundwater is saline. The deep groundwater table is 60 m below the surface and is declining. Wheat, corn, cotton and Chinese dates are the main cultivated crops of the region. The Overview provides further details about the NCP region; Figure 1 of the Overview shows its location.

The lower reaches of many rivers are located in Nanpi County, so it is a region of salt deposit and accumulation, with a history of problems due to saline soils. Chapter 13 describes the chemical properties of some of the soils in the region. It has been said that in wet seasons the region has only frogs, in dry seasons only locusts and in normal seasons only salt. Until the 1960s, about 30% of the land area was saline. With water shortages, better water engineering and better reclamation of saline soils, the area affected by salinity is rapidly decreasing and now accounts for less than 5% of the land area.

Problems for sustainable agriculture in saline areas of Nanpi County

Although the area of saline soil in Nanpi County has been reduced, the remaining saline area will be more difficult to reclaim because of water deficit and secondary salinity (because the salt in the reclaimed soils has not moved out of the region). In 1995, the Dalangdian reservoir was constructed to provide water from the Yellow River for domestic and industry use in Cangzhou city. This development will affect the groundwater table and may lead to further soil salinisation. Thus, drought, water deficiency and soil salinity are major problems for the development of sustainable agriculture in Nanpi County. Methods to assess catchment health are needed in order to achieve sustainable agriculture.

Long-term studies on the reclamation of saline soil have provided much knowledge, which should be shared not only with scientists but also with end users such as landholders and local officers. To do this, the knowledge must be converted into simple, transferable environmental indicators. This approach will benefit Nanpi County and adjoining regions such as Huanghua and Haixing, where there are about 100,000 ha of saline soil (Liu and Tian 2000).

Selection of Key Indicators and Saline Soil Reclamation

Table 1 shows the key indicators selected for assessing soil salinity in Nanpi County based on the criteria developed by Walker and Reuter (1996) and on the theory and experience of saline soil reclamation (Mao and Liu 2000).

In Nanpi County, soil salinity and soil formation are controlled mainly by groundwater and water quality. The groundwater table itself is affected by

Table 1. Threshold guideline for soil salinity indicators in Nanpi County.

Indicator	Very good	Good	Fair	Poor	Very poor
Groundwater table (m)	4.5–6	3.5–4.5	2.5–3.5	1.5–2.5	< 1.5
Electrical conductivity in groundwater (dS/m)	<0.5	0.5–1	1–1.5	1.5–3	> 3
Soil colour	–	–	Grey brown	White	Grey black brown
Soil pH	7–7.5	7.5–8	8–8.5	8.5–9	> 9
Soil consistency	Loose	Soft	Firm	Very firm	Rigid

dS/m (deciSiemens per metre) = mS/cm (milliSiemens per centimetre) climate, topography, irrigation and drainage, and is thus an important indicator of trends in water and salt balance. Based on a study at the Nanpi Eco-Agricultural Experimental Station (NPEES) of the Chinese Academy of Sciences, the groundwater table is declining by about 2–3 m each year (NPEES 1996,1997,1998,1999). The reduction in the depth of the groundwater table helps to remove salt from the soil, but if it is too extensive it will result in seawater entering the watertable, increasing salinity.

Groundwater electrical conductivity (EC) is an indicator for irrigation water quality and soil alkalinisation during soil desalination. Soil colour is an important attribute for assessing soil quality, and in Nanpi County, soil colour can easily be used as an indicator of soil salinity. For example, saline soil containing chloride is grey, black or brown; saline soil containing sulfate is white. The pH value of soil can easily be measured with pH paper; the consistency of the soil can be tested by hand.

We used the indicators and methods of saline soil reclamation to construct a diagram for guiding saline soil reclamation (Fig. 1). The model indicates that controlling the groundwater table is the most important aspect of saline soil reclamation. Rainwater, irrigation and the construction of drainage systems are important in the adjustment of the groundwater table. Fertilisers and biological methods can also be used in soil reclamation (e.g. to supply N to raise the bioproductivity and grow salt-tolerant plans such as lucerne for fodder production).

Knowledge Transfer

In order to turn this knowledge into practice, we developed a knowledge transfer network and built several testing plots (Fig. 2). The network included NPEES, local government, a technical extension station, scientists, technicians and key users.

- *NPEES.* The station is a centre for knowledge creation and transfer, where scientists study indicators of salinity, assess trends in soil

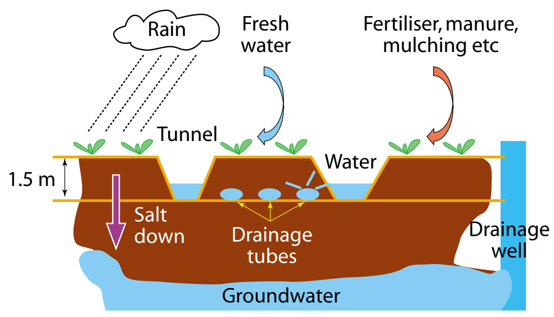

Figure 1. Diagram of saline soil reclamation in Nanpi County.

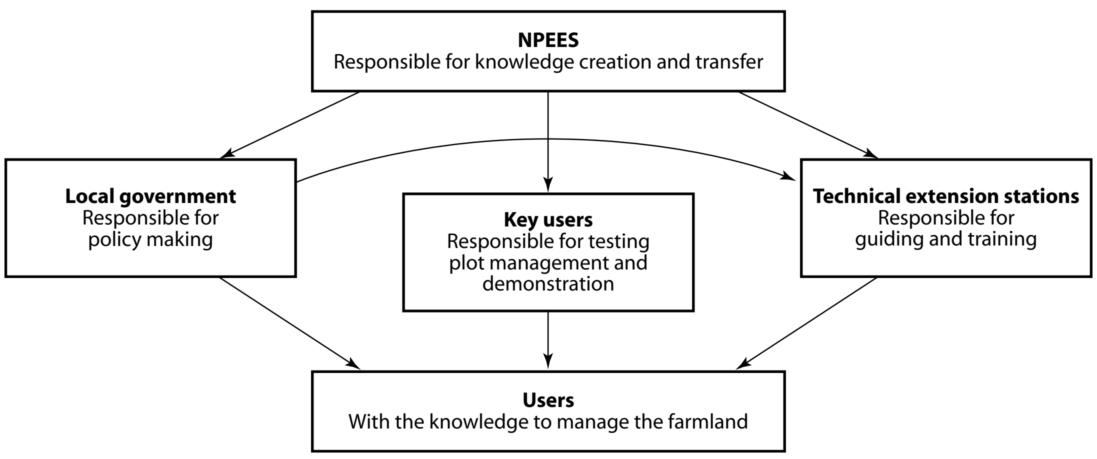

Figure 2. Knowledge transfer network in Nanpi County. NPEES is the Nanpi Eco-Agricultural Experimental Station.

salinity and monitor changes in the groundwater table. Twice a month, technicians from NPEES measure the groundwater table and electrical conductivity, and take water samples. In alternate months, starting in January, soil samples are also taken, to measure salt content and electrical conductivity. Scientists use the results to write proposals for local government and provide technical support for technical extension stations and users. NPEES has built five trial plots to demonstrate research results directly to end users. For example, in a trial plot close to the Dalangdian reservoir, vegetables are grown in greenhouses in winter. Groundwater is recharged mainly between November and January, when the introduction of fresh water improves the quality of the shallow groundwater and raises its level. Farmers can pump irrigation water and obtain a good income while improving groundwater use and controlling soil salinisation. Other trial plots demonstrate the irrigation of winter wheat and the use of cotton fields to grow pasture in winter.

- *Local government.* At least twice each year the local government in Nanpi County formulates policies based on technical reports and proposals from NPEES for managing regional agriculture. Local government asks extension stations and technical departments to use the research results, and it assists with knowledge transfer by providing some funding for publishing technical reports and holding meetings.
- *Technical extension stations.* Nanpi County has several technical extension stations, including an agricultural technical service and a soil and fertiliser technical station. Technicians at these stations are familiar with the needs and practices of the end users and are well placed to transfer knowledge to them. Therefore, NPEES asks the local government to send five technicians from different technical extension stations to NPEES, to act as a bridge between the institution and end users during the growing seasons. Funds are available from local or higher levels of government for technology transfer.
- *Key users.* Key users are the landholders who use the indicators first and then demonstrate the results to other users. In China, landholders are often poorly educated; in order to be successful in implementing new practices, they need a good understanding of the changes they are being asked to make. Key users play an important role in knowledge transfer. Several well-educated users are taught how to use indicators to assess plot health and make rational decisions about plot management. Once these key users have obtained acceptable results, several site meetings are held on their plots, with other landholders invited to attend. Generally, these meetings are jointly organised by NPEES, local government and technical extension stations. In a meeting, a key user tells other landholders about the results he has obtained and how he has achieved them. Through this process, knowledge is transferred easily and quickly.
- *Users.* In a family unit in China, each landholder has only a small area of land: in Nanpi County this is about 0.8 ha/family. To see an effect of the indicators on catchment health, all the landholders in a village must be involved, which is difficult to achieve. Administrative measures and site meetings can be useful in organising landholders.

Results and Discussion

Over the past five years, we have made progress in using indicators to assess health in a saline environment. The area of saline soil in Nanpi County has continually decreased and there is no secondary salinity around Dalangdian reservoir. The mean income of landholders increased from 1100 yuan/person in 1996 to 2400 yuan/person in 2000 (US$1 = 8.0 yuan). In certain areas where trial plots were located, such as Dalangdian, the net income per hectare increased from 6000 yuan to 30,000 yuan. The groundwater table has been maintained at around 5 m and water quality is improving. The local government has formulated three policies for catchment health:

- building greenhouses around the Dalangdian reservoir;
- irrigation of winter wheat in spring; and
- using cotton fields in winter to grow pasture.

More than 3500 indicator report cards have been sent out. Eight site meetings have been held and more than 1000 landholders attended.

Although much has been achieved in assessing catchment health using indicators of salinity, much remains to be done because this is a new technique for China. Indicator research on a regional scale with remote sense techniques and a computer-based transfer network is needed.

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29 Transferring Scientific Knowledge to Farmers

Rob W. Fitzpatrick,[*] Jim W. Cox,[*] Bruce Munday,[†] John Bourne[‡] and Chunsheng Hu[§]

Abstract

This study describes the development of a systematic approach to identifying important soil morphological and vegetation field indicators. The objective was to use the indicators to target land management in degraded landscapes in a specific region. The authors linked soil–landscape features to the main soil and water processes operating within the landscape. In Australia, they used this information to develop a set of field indicators (e.g. soil colour) within a user-friendly soil classification key that was linked to land-use options to form the basis of a manual. Information written in this format helped farmers and regional advisers to identify options for remediation of waterlogged and saline areas and to improve planning at property and catchment scales. The authors identified a series of steps to be taken in producing the manual. Steps 1 to 5 describe the soil layers and construct them in toposequences, which are then used to map soil types in key surrounding areas. Steps 6 to 9 involve the local community in developing the manual.

This chapter describes how manuals were produced for two badly degraded areas in southern Australia (the Mount Lofty Ranges in South Australia and an area in western Victoria) and suggests how they can be applied elsewhere. Descriptive soil information and pictures taken along toposequences are used to identify key soil features. The use of coloured cross-sectional diagrams and photographs of soil and vegetation helps local groups to understand complex scientific processes and terminology, and see how best management practices can be used to advantage. A similar approach using indicators such as soil colour and morphology was developed in Luancheng County on the North China Plain. Scientists in this region linked their data to farmers' observations to provide a set of indicators to help farmers manage their land more effectively.

本章介绍了确定重要的野外土地形态和植被诊断指标的系统方法，目的在于应用这些指标对特定区域退化的土地进行治理。作者将土地景观与其上面的主要土壤与水文过程结合为一体，形成一套野外诊断指标（如土壤颜色），置于一个简单易懂的、与土地利用方式相联系的土壤类别比照图内，制作成应用指南。此种形式的信息可帮助农民与有关人员选择渍涝与盐碱地

* CSIRO Land and Water, PMB 2, Glen Osmond, SA 5064, Australia. Email: rob.fitzpatrick@csiro.au

† PO Box 375, Mount Torrens, SA 5244, Australia.

‡ Primary Industries and Resources, South Australia, PO Box 752, Murray Bridge, SA 5253, Australia.

§ Shijiazhuang Institute of Agricultural Modernization, Chinese Academy of Sciences, 286 Huaizhong Road, Shijiazhuang, Hebei 050021, PRC.

Fitzpatrick, R.W., Cox, J.W., Munday, B., Bourne, J. and Chunsheng Hu. 2002. Transferring scientific knowledge to farmers. In: McVicar, T.R., Li Rui, Walker, J., Fitzpatrick, R.W. and Liu Changming (eds), *Regional Water and Soil Assessment for Managing Sustainable Agriculture in China and Australia*, ACIAR Monograph No. 84, 371–384.

的改良措施，改进农场和区域的利用规划。作者总结了制作此应用指南的一系列步骤，包括土层及其在坡面的构成，土壤类型图的生成等，也涉及当地社区在此过程中所起的作用。

文章具体讲解了南澳两个土地严重退化地区应用指南的制作以及如何将该指南用于其它区域。描述性的土壤信息和沿坡面拍摄的照片用来辨明土壤的主要特点。彩色的截面土壤和植被照片及图表可以最大程度地帮助当地居民和团体了解复杂的科学知识和专业术语，了解可以采取的措施。太行脚下的栾城县也采用了一种相似的、以土壤颜色或地貌特征作为指标的方法。该地区的科学家将他们的数据跟农民的观察结合起来，提供了一套指标系统来帮助农民更有效的管理他们的土地。

MUCH has been published on the general application of soil indicators and tests, and on the causes and remediation of land degradation in Australia (e.g. Hunt and Gilkes 1992; Charman and Murphy 1991; Dalgliesh and Foale 1998; Moore 1998; NSW DLWC 2000). Most of these publications provide a good general overview of the major issues but are not designed to address land-use and degradation issues for a specific region, although there are exceptions like SoilPak (McKenzie 1998), which is specific for irrigated cotton in New South Wales. The objective of the studies described in this paper was to develop some tools to communicate scientific knowledge to farmers and regional advisers in order to help them to identify land degradation in specific regions. In Australia, the approach was to produce a manual to help landholders to identify and remedy degradation. The study focused initially on two regions in southern Australia where dryland salinity and waterlogging cause major land degradation — the Mount Lofty Ranges of South Australia and an area in southwestern Victoria. In Luancheng County on the North China Plain, the approach was to show farmers how they could better manage their lands using easily observable soil indicators.

Field indicators linked to landform elements help landholders and regional advisers to identify areas of soil degradation. Indicators used for characterising ‘soil quality’ can be descriptive or analytical (Fitzpatrick et al. 1999). Standard descriptive soil indicators such as visual indicators (e.g. colour) and consistency are often used by farmers, regional advisers and scientists in the field to identify and report attributes of soil quality (Fitzpatrick 1996). For example, soil colour can provide a simple means to recognise or predict salt-affected, waterlogged wetlands caused by poor drainage (Fitzpatrick et al. 1996), providing an alternative to the difficult and expensive process of documenting watertable depths to estimate water duration in soils (Cox et al. 1996). Visual indicators may be obvious (e.g. white salt accumulations on soil surfaces) or subtle (e.g. subsoil mottling patterns). Analytical indicators include electrical conductivity (salinity) and dispersion (sodicity). Combining descriptive and analytical indicators can provide vital information about soil–water processes to improve land management and remediation of degraded land (Fitzpatrick et al. 1994). The challenge is to communicate this information to landholders and agricultural advisers.

Fitzpatrick et al. (1994, 1998) have previously shown that complex scientific processes and terminology can be effectively communicated to local groups using coloured cross-sectional diagrams and photographs of soil and vegetation. By combining this approach with community advice, the authors developed easy-to-follow manuals that incorporated soil–landscape and vegetation keys. The manuals could be used as a simple decision-making tool for land management based on recommendations in the scientific literature.

Developing a Manual: a Systematic Approach Used in Australia

Topography strongly affects the physical and chemical characteristics of soils, because landform influences the flow of water both through and over the soil surface. For example, excessive runoff on sloping ground reduces plant growth by decreasing the availability of soil water, increasing erosion (leading to reduced soil depth) and causing loss of nutrients. On flat land at the bottom of slopes, severe waterlogging can have a pronounced effect on plant production. A specific type of landscape or catchment is generally characterised by a particular succession of soils down the slope of the topo-sequence, associated with changes in soil moisture (Milne 1934; Sommer and Schlichting 1997).

To understand the lateral linkages and relationships between soil profiles down landscape slopes, we developed a systematic approach for studying the morphological (e.g. colour and textural patterns), chemical and mineralogical characterisics of soils and their underlying weathered bedrock or saprolite (Fritsch and Fitzpatrick 1994; Fitzpatrick et al. 1996). We linked these soil–landscape features to the main soil and water processes operating within the landscape and developed a set of field indicators, described in easy-to-follow practical manuals. The manuals help farmers and regional advisers to identify options for remediation of waterlogged and saline catchments and to improve planning at the property and catchment level.

Box 1 shows the sequence of steps used to develop the manuals. Steps 1 to 5 describe the soil layers and construct them in toposequences, which are then used to map soil types in key surrounding areas. Steps 6 to 9 involve the local community in developing the manual. Figure 1 summarises the steps involved.

The steps were identified and evaluated during work at a study site in the Mount Lofty Ranges of South Australia (Fitzpatrick et al. 1997) and in western Victoria (Cox et al. 1999). Both regions have 500–600 mm annual rainfall; in both, the problem of land degradation is worsening and farmers are concerned about the rapid increase in saline scalds. Figure 2 shows the location and some characteristics of the Mount Lofty Ranges. Figures 3–5 show some of the tools used in developing and applying the manual: Figure 3 shows an example of a key; Figure 4 shows how major soil types are linked to on-farm management options; Figure 5

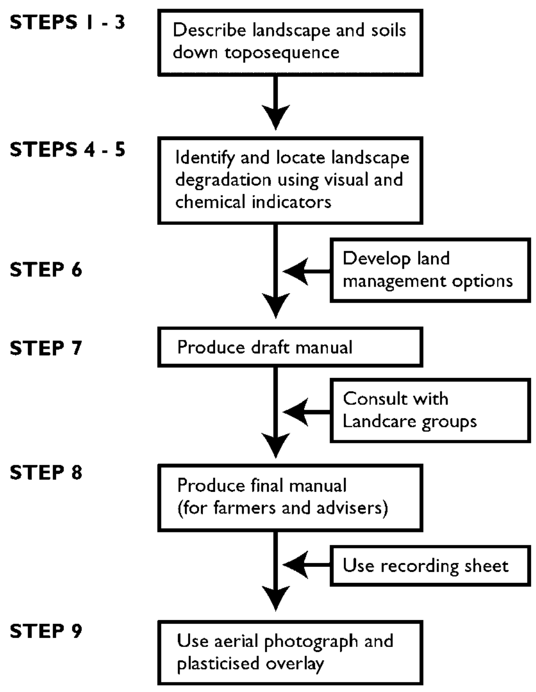


Figure 1. Flow diagram showing the main steps involved in developing a pictorial manual to aid property and catchment planning.

Box 1. Steps in developing an Australian manual

This box summarises the main steps involved in developing a pictorial manual to aid property and catchment planning. These steps are described in detail below and summarised in Figure 1.

Step 1. Select representative focus catchments and landscape sequences

Two tasks are required for this step:

- *Collate soil, geological and climatic information.* Using published broad-scale (e.g. regional) soil, geological and climatic maps such as the one shown in Figure 2a; the first task is to select a representative focus catchment such as the one shown in Figure 2b (Fitzpatrick et al. 1997).
- *Reconnaissance survey soil in the focus catchment.* Establish the most common succession of soil types within the representative catchment, using aerial photographs, road cuttings (if available), random soil augering and soil pits along toposequences. Then select a suite of the most commonly found soils along an idealised toposequence (X–Y shown in Figure 2b).

Step 2. Describe in detail soils along the selected toposequence

This step requires two tasks:

- *Describe soil layers in detail.* This step involves three stages:
  - identify and photograph the complete sequence of soil profiles down the toposequence (X–Y, Figures 2b and c);
  - identify and describe, by depth interval only, all similar soil features (i.e. soil components with similar consistency, colour, textural and structural patterns, and chemical and mineralogical properties) using conventional soil description handbooks (e.g. McDonald et al. 1990; Soil Survey Division Staff 1993); and
  - draw boundaries around the similar soil features within the soil profiles and record them (Boulet et al. 1982; Fritsch et al. 1992, Fritsch and Fitzpatrick 1994).
- *Describe soil horizons and classify soil profiles.* Identify standard soil horizons in order to classify the soils according to soil taxonomy (Soil Survey Division Staff 1998) or the Australian Soil Classification System (Isbell 1996).

Step 3. Group and map similar soil features in the toposequence

This step requires two tasks:

- *Group similar soil features into fewer soil layers using structural analysis.* Structural analysis of the soil involves three stages:
  - use nested or concordant relationships to group soil features, and discordant relationships to separate them;
  - draw boundaries around similar features between the soil profiles to link them down the toposequence, and map them at toposequence scale in cross-sections (Boulet et al. 1982) (Note: soil horizons are not used to demarcate these boundaries because the features used to define soil horizons are too strictly grouped to allow accurate lateral linking between profiles along toposequences); and
  - group similar soil features into a smaller number of soil layers based on concordant and discordant relationships.
- *Display the combined soil layers of the toposequence graphically in cross-section.* Using computer software, display the soil layers graphically in cross sections down toposequences (Rinder et al. 1994). The colour patterns down the X–Y toposequence in Figure 2c display the soil layers.

Step 4. Match soil layers to hydrological processes

- *Field monitoring and laboratory analyses.* Monitor rainfall, watertable fluctuations (in piezometers and dipwells), soil water content, soil redox (Eh electrodes) and chemical changes (e.g. electrical conductivity, cations and anions) (Cox et al. 1999; Fitzpatrick et al. 1996). To select representative sites and determine soil depths where field instrumentation should be placed, monitoring

Box 1. (cont'd)

must focus on identifying changes in soil layers along the entire length of the toposequence.

- *Link soil and hydrological processes to soil layers.* Link soil and hydrological processes (e.g. water flow paths and salinity) to each soil layer displayed in cross-sections. In Figure 2c hatching represents soil salinity and arrows indicate water flow.

Step 5. Develop vegetation and soil–landscape keys

- *Develop easy-to-follow vegetation keys.* Photograph and list groups of plants that identify high, moderate and low levels of salting (e.g. Matters and Bozon 1995). Also record features such as plant density, vigour, health and abundance for each category of plant.
- *Develop simple soil–landscape keys.* Identify up to 10 soil types that best represent the soils in the study region (which could contain 100 or more soil series), based on topography, simple morphological features and chemical tests. Construct a taxonomic key to enable the reader to easily identify these soil types. The key comprises a colour photograph of the typical soil type, an indication of where the soil is usually found (e.g. crest, mid-slope, lower slope, footslope) and drainage characteristics (well drained, poorly drained). Each soil layer (e.g. top, bottom layer 1, bottom layer 2) is clearly demarcated using a thick black dotted line. Alongside each layer, easily observable (e.g. colour, white salt crystals, vegetation) or measurable (e.g. soil consistency and dispersion) features can be recorded. The key is ordered so that the reader moves systematically through the identification of the soils in a stepwise progression, answering 'yes' or 'no' to the question of whether the features shown for each soil are present. Selected portions from a key are shown in Figure 3.

Step 6. Link major soil types to on-farm management options

For each soil type, identify appropriate management options based on input from a wide range of technical experts, including pasture agronomists, salt land agronomists, livestock advisers, specialists in woody perennial revegetation, soils and drainage specialists, and key community members. Summarise management options in a box above a colour photograph of the soil type located along the generalised toposequence. This process is illustrated in Figure 4.

Step 7. Draft the manual

- *Develop a framework*. Set up a framework for the spiral-bound manual, including:
  - soil keys based on colour photographs of soils and plants;
  - an idealised cross-section of a toposequence sketched in colour compiled from the features found in most of the major toposequences of the region (Figs. 2 and 4); and
  - recording sheets for use in the field.

Figure 5 illustrates a recording sheet.

- *Consult with community groups.* Work with potential users of the manual to obtain feedback.

Step 8. Produce the final manual

Revise the manual in the light of feedback from potential users. Recommendations following the field trials described above included expanding the number of photographs of indicator plants, using high-grade graphics for production of all photographs and constructing a water-resistant summary sheet or insert. The quality of the diagnostic photographs was improved so that that they could be more easily recognised by landholders, and the text was revised with input from both the Northern Hills Soil Conservation Board and local officers of Primary Industries and Resources South Australia.

Step 9. Obtain aerial photographs

Obtain aerial photographs for the paddocks (fields) and overlay with clear plastic, on which field observations and management options can be marked. Figure 6 illustrates aerial photographs for the selected catchment.

shows one of the recording sheets used in the field. At present, salinity affects only about 1500 ha in the Mount Lofty Ranges but it has a serious impact on Adelaide's water resource and the expanding wine grape industry. A similar approach was subsequently used in Luancheng County, on the North China Plain. The Overview provides some background information about the study areas in China and Australia; Figures 1 and 2 of the Overview show their location.

The Northern Hills Soil Conservation Board, in South Australia's Mount Lofty Ranges, expressed an interest in developing a manual based on recommendations in the scientific literature and incorporating a soil–landscape and vegetation key

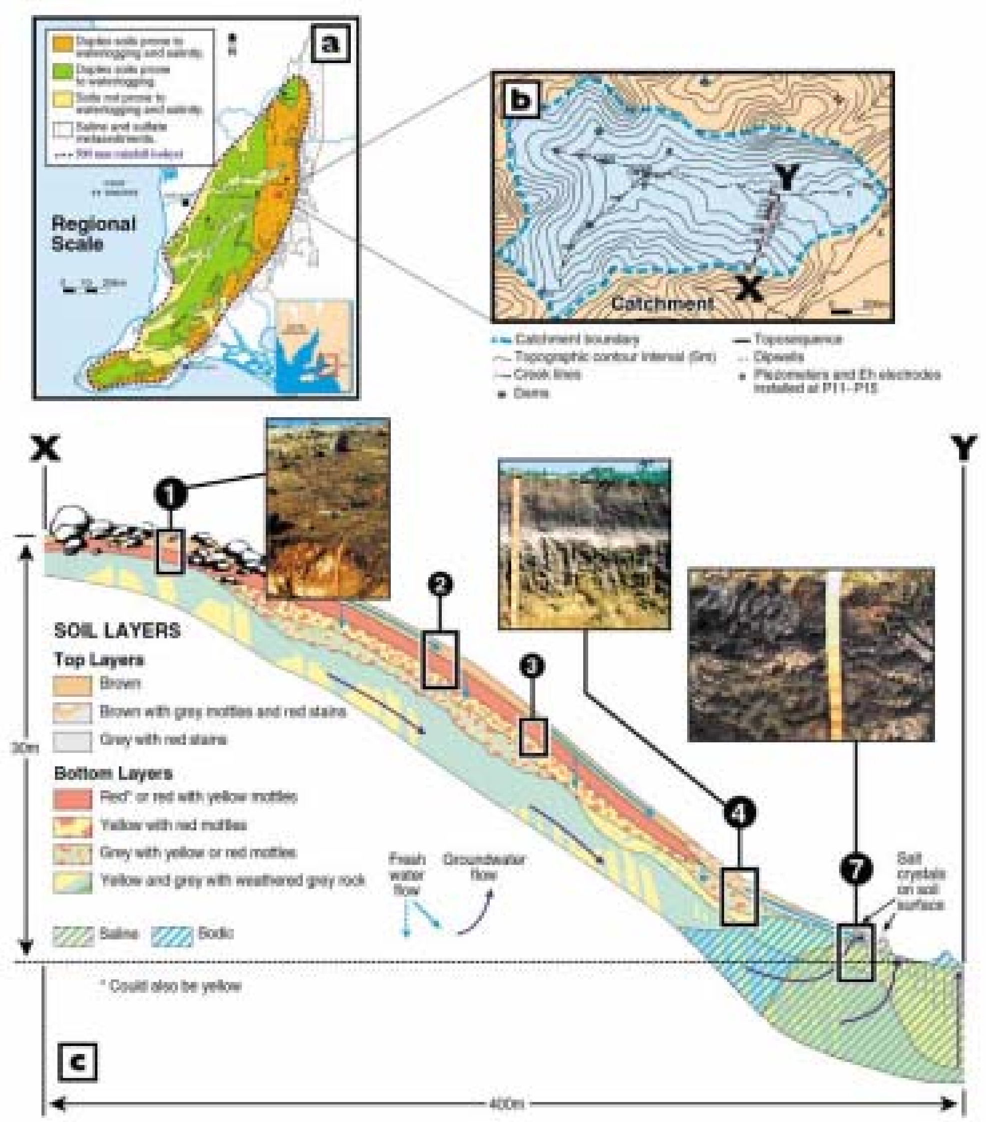


Figure 2. Diagram showing (a) a regional map of the Mount Lofty Ranges with generalised rainfall, geology, and soil pattern, (b) selected focus catchment, (c) toposequence with soil features and water flow paths and three selected soil profiles (modified from Fitzpatrick et al. 1997).

(Fitzpatrick et al. 1994). The board thought that the key described in this work used too much scientific terminology and could be improved if it were made more practical and written in a language and style that would engage landholders. Although the board accepted the need for a simple decision-making tool, it wanted to avoid the approach of 'glossy' booklets that are seldom used because they are written in obscure language, involve impractical tests or advocate unrealistic options. The board also required the manual to be 'road tested' to demonstrate that it would provide accurate interpretation and lead to realistic management options.

Applying the manual to a farm

To use the manual on a particular property, a landholder selects several transects across a paddock (usually down a slope) likely to have waterlogging or salinity problems, and marks them on a plastic overlay on an aerial photograph of the property. Starting at the top of the hillslope (observation point a1, Fig. 5), observations are made on the recording sheet at several points down the slope (observation points a2 – a7, Fig. 5). Where needed, soil samples are collected for measuring dispersion and pH in the field, using methods described in the manuals.

From the information on the recording sheet, the boundaries between soil types and the soil type number (1 – 7) are marked (Fig. 6a), making use of the landholder's personal knowledge of the paddock, contours and vegetation differences to improve the accuracy of the boundaries. Finally,

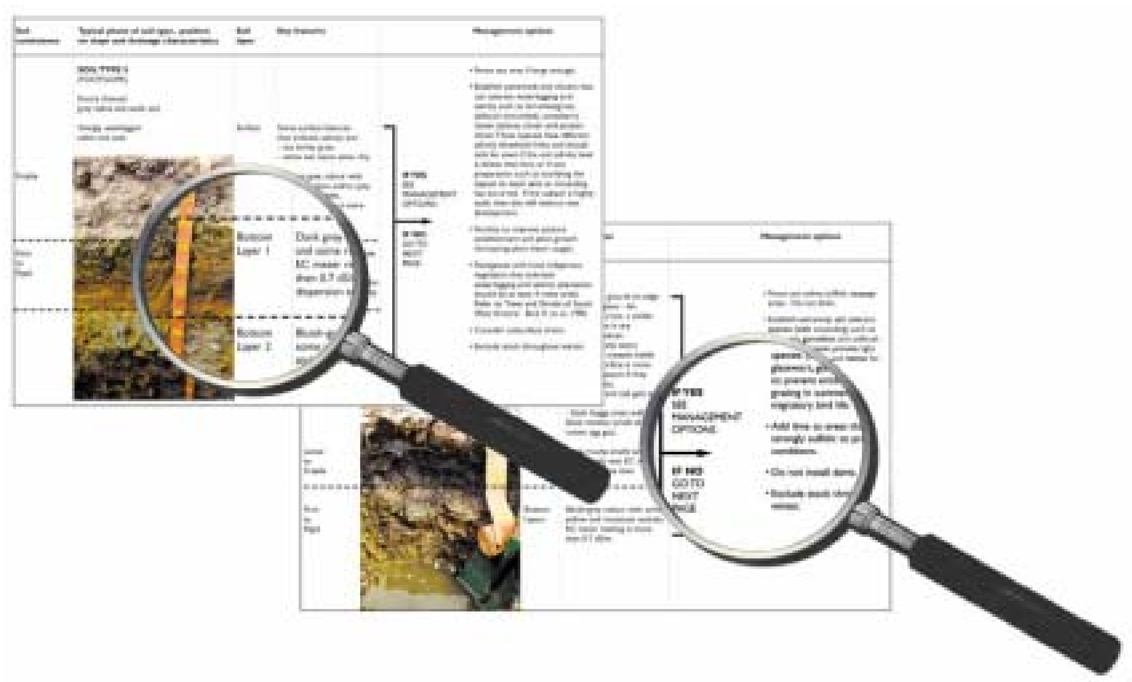


Figure 3. Examples of two pages from the taxonomic key for identifying soil features that indicate degrees of waterlogged and saline conditions, and management options (modified from Cox et al. 1999). Magnified areas appear in bold text to give an indication of the nature of the key.

management options associated with each of the soil types listed in the key are selected and recorded using a set of symbols (Fig. 6b).

Evaluating the manual in the field

Members of the Woorndoo Landcare Group in western Victoria tested the key developed for their area. Some profiles were found to lie between one standard profile in the key and the next, a situation that has implications for determining appropriate management options. The group had a pre-conception about the sequence of soils they would find in the landscape, based on surface features such as slope, but discovered that their estimate of the location of profiles was often inaccurate.

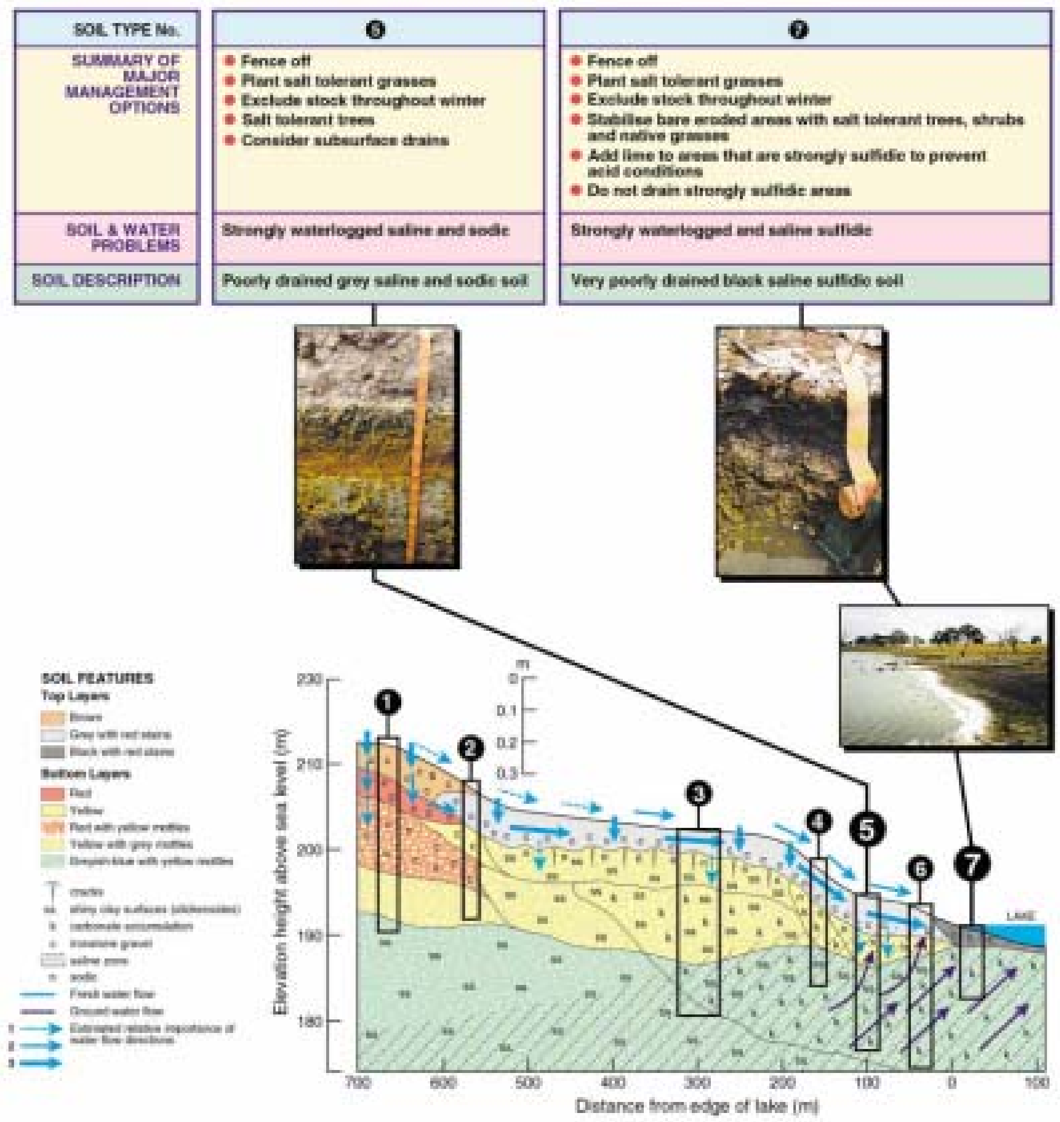
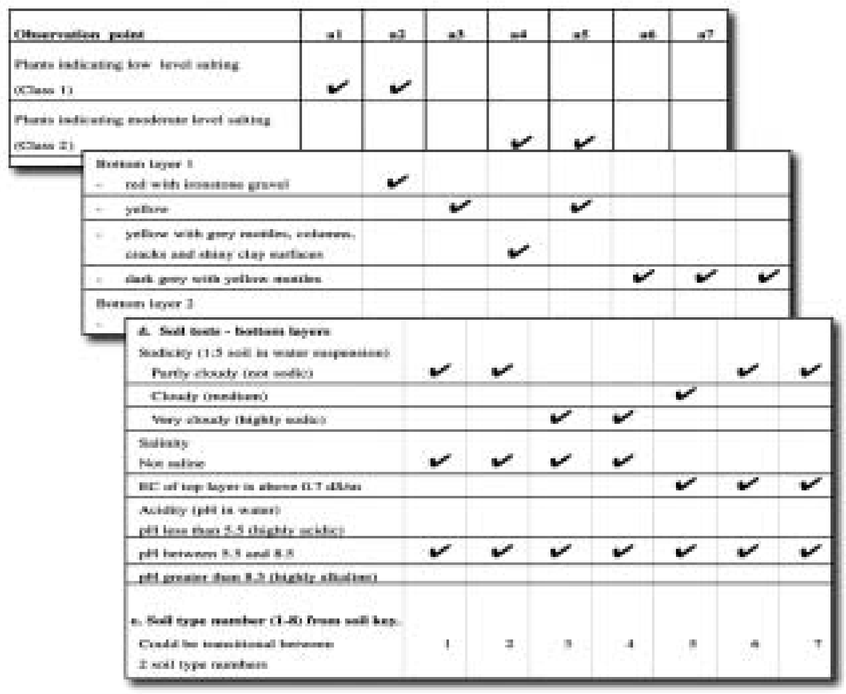


Figure 4. Sequence of soils down a slope to a lake (two of the seven soils are illustrated) with brief summaries of management options associated with each of the soil types (modified from Cox et al. 1999).



Observation point	a1	a2	a3	a4	a5	a6	a7
Plants indicating low level salting (Class 1)	✔	✔					
Plants indicating moderate level salting (Class 2)				✔	✔		

Bottom layer 1							
– red with ironstone gravel	✔						
– yellow		✔		✔			
– yellow with grey mottles, columns, cracks and shiny clay surfaces			✔				
– dark grey with yellow mottles					✔	✔	✔
Bottom layer 2							
–							

d. Soil tests - bottom layers							
Sodicity (1:5 soil in water suspension) Partly cloudy (not sodic)	✔	✔				✔	✔
Cloudy (medium)					✔		
Very cloudy (highly sodic)			✔	✔			
Salinity Not saline	✔	✔	✔	✔			
EC of top layer is above 0.7 dS/m					✔	✔	✔
Acidity (pH in water) pH less than 5.5 (highly acidic)							
pH between 5.5 and 8.5	✔	✔	✔	✔	✔	✔	✔
pH greater than 8.5 (highly alkaline)							
e. Soil type number (1-8) from soil key. Could be transitional between 2 soil type numbers	1	2	3	4	5	6	7

Figure 5. Three sections from the field recording sheet, which consists of three A4 pages (modified from Cox et al. 1999).

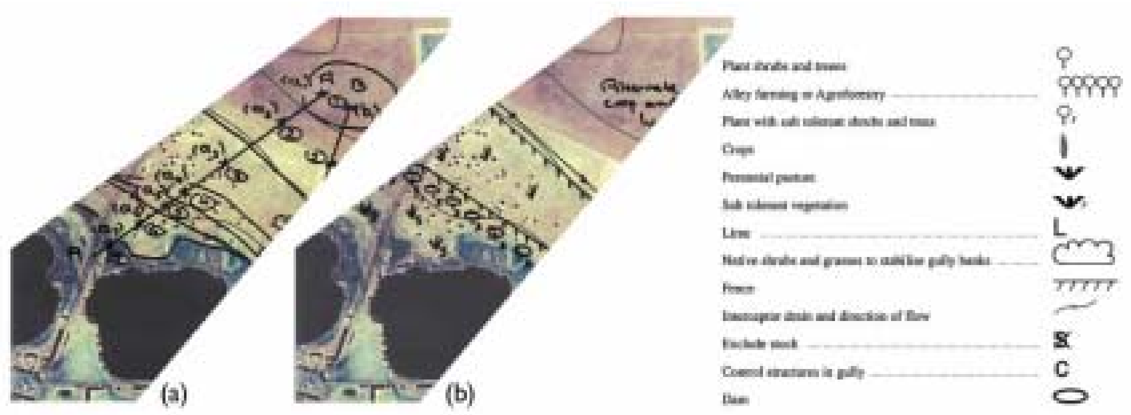


Figure 6. (a) Soil type number marked and boundaries demarcated along a single transect on a portion of an aerial photograph, (b) management decisions marked on the aerial photograph showing perennial pastures, fencelines and areas to plant with salt-tolerant shrubs and trees (modified from Cox et al. 1999).

Developing Indicators at an Appropriate Scale: the Chinese Approach

Indicators are measurable attributes of the environment that can be monitored via field observation, field sampling, remote sensing or the compilation of existing data. Each indicator describes a particular function of the environment and can signal desirable or undesirable changes that have occurred or that may occur in the future (Walker and Reuter 1996). Different users have different concerns and objectives, and different indicators may be required for different scales of land use (farmland, county, region). For example, soil colour, soil texture and leaf colour are suitable indicators for farmers but measured data may be more useful for people working on a county scale. Figure 7 shows how soil colour and texture are suitable soil health indicators for farmers. Chinese scientists have developed a set of indicators at farm scale based on measurements of soil properties (Hu Chunsheng and Wang Zhiping 1999; Hu Chunsheng 1999). Box 2 shows how indicators were selected and verified to assess soil health on the NCP.

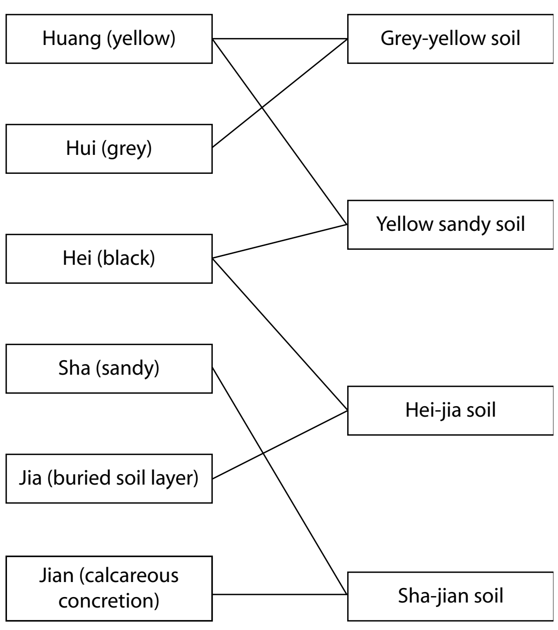


Figure 7. Example of soil classification used by Chinese soil scientists (right) and equivalent categories recognised by farmers (left).

Discussion

The key was a crucial component of the Australian manual. Local advisory officers from Primary Industries and Resources South Australia (PIRSA) and members of the community-based Northern Hills District Soil Conservation Board tested the key developed for the case study area in the Mount Lofty Ranges. A typical subcatchment on a local property was selected at random, and groups of advisory officers each completed separate transects down a toposequence. Surface observation down one transect suggested saline conditions because saline-tolerant plant species dominated much of the area. By exposing the soil profile at a number of points along the transect (Fig. 6a) and comparing it to the standard profiles outlined in the key, it became clear that waterlogging was the major problem, with salinity present only in the lowest part of the subcatchment. Along a second transect there were no plant indicators of saline conditions, and the area was not saline. The group was surprised to find that the profile at the top of the transect was waterlogged rather than well drained, meaning that the pasture species being grown at this location was not ideal.

Trialling the manual in the case study areas confirmed the value of the key. It also emphasised the need to look beyond surface soil and plant factors, and to consider additional soil observations and measurements to better understand and manage local situations. Combining the manual with observations of subsurface soil features can improve management decisions. For example, the pasture species most appropriate for well-drained areas on upper and mid-slopes would be different from those selected for areas that are periodically waterlogged, but it would be difficult to distinguish well-drained areas from waterlogged areas by surface observation alone. Similarly, surface

Box 2. Selecting key indicators to assess soil health on the North China Plain

At the farmland scale, the main soil indicators should include soil colour, texture, bulk density, field capacity, wilting point, total organic material, total nitrogen, available phosphorus and available potassium. Morphological properties such as soil colour, soil texture and the structure of soil profiles are very useful indicators for farmers to assess the health of the land.

In Luancheng County on the piedmont plain of Mount Taihang, farmers can identify six categories of soil that can be used to indicate the degree of soil fertility, the soil tilth index, the degree of porosity and the degree of conservation of soil water and nutrients. These categories are:

- Huang (yellow soil colour), which is associated with good water drainage and good tilth;
- Hei (black soil colour), associated with a high organic matter content;
- Hui (grey soil colour), associated with an even higher soil organic matter content than Hei;
- Sha (sand), associated with good drainage capacity but a low nutrient content and a poor ability to conserve soil water and nutrients;
- Jia, which is soil with a 'buried' soil layer, indicating clay, with poor-quality tilth restricting the growth of seedlings but suitable for older shoots; and
- Jian, which is soil with calcareous concretion or a calcium horizon, which restricts root growth.

These categories are the easiest and most practical way for farmers to assess soil health.

Soil in Luancheng County is typical cinnamon soil with a thin humus layer and middle or thick solum. The buried layer, clay course, calcareous concretion layer, sand soil layer and ploughed layer are the standard diagnostic horizons for soil species classification. Soils can be divided into 17 soil types. The boxes on the right side of Figure 7 show four examples of the soil classification used by soil scientists; those on the left indicate the equivalent categories recognised by farmers.

Case study: grey–yellow soil

From the name of the soil, farmers can judge that this kind of soil has good soil structure, tillage properties and moisture capacity, but that there is a plough pan with high bulk density where the soil becomes lighter in colour (Tables 1 and 2). Measurement of root density, consistency and texture confirms farmer perceptions based on soil colour.

Table 1. Morphology and root density of grey–yellow soil in Luancheng County.

Layer	Thickness (cm)	Consistency	Colour	Texture	Root density (cm/cm^3)	
					Corn	Wheat
A_1	0–17	Soft	Grey brown	Sandy loam	3.49	1.12
A_1B	17–30	Very hard	Light brown	Sandy loam	1.63	0.48
B_1	30–65	Firm	Dark brown	Loam	0.51	0.26
B_2	65–90	Firm	Dark brown	Loam	0.34	0.25
BK	90–145	Very hard	Light yellow	Light clay	0.16	0.12
B_3	145–170	Very hard	Gray yellow	Light clay	0.18	–
BC	170–190	Very hard	Light yellow	Medium clay	–	–

Box 2 (cont'd)

Table 2. Physical indicators of grey–yellow soil in Luancheng County.

Layer	Thickness (cm)	Field capacity (%)	Wilting point (%)	Plant available water (%)	Bulk density (g/cm^3)	Total porosity (%)	Air-filled porosity (%)
A_1	0–17	36.35	9.63	26.73	1.41	46.42	10.07
A_1B	17–30	34.86	11.37	23.49	1.51	42.62	7.76
B_1	30–65	33.25	13.92	19.33	1.47	44.14	10.89
B_2	65–90	34.28	13.91	20.37	1.51	42.62	8.34
BK	90–145	34.36	12.95	21.41	1.54	41.48	7.12
B_3	145–170	38.98	13.87	25.11	1.64	37.68	1.42
BC	170–190	38.05	16.44	21.61	1.59	39.58	1.53

(reverse interceptor) drains are sometimes installed to remove water to improve pasture establishment (e.g. Cox and McFarlane 1995); in sodic subsoils they are likely to fail due to dispersion of soil particles, but this condition is difficult to determine simply from surface soil observations.

The manual helps users to make good decisions, improves their understanding of the processes of dryland salinity and waterlogging, and offers solutions to improve the quality of their properties. Where the manual has been applied in the Mount Lofty Ranges area, degraded saline wet areas have been rehabilitated and erosion has been halted through measures such as realigning fencelines and revegetation.

The manual developed for the Mount Lofty Ranges has been used as a standard text in the small farms land management course that is run four times a year by the local soil board. Bruce Munday, a farmer near Mount Torrens, during an interview with Pyper and Davidson (2001), stated:

> The publication of the CRC–CSIRO manual on waterlogged, saline and acid sulfate soils in the Mount Lofty Ranges has also made land management that much easier for farmers … The manual is very much a do-it-yourself kit that has enabled us to manage these things properly, rather than by trial and error ... Trial and error has always been a great standby for farmers, but it sometimes has dire consequences.

Conclusions

We have summarised a set of procedures for identifying the best set of soil–landscape and vegetation field indicators for a region. Farmers, catchment groups and natural resource management agencies can use the approach to achieve the following outcomes.

- Knowledge of soil and hydrological processes and production systems can be brought together and used as the basis for recommendations for appropriate management options.

- Viable land-use options and management systems (including mosaic farming) that are more resource efficient than current 'trial and error' practices can be adopted.

- Significant impetus for land-use change based on sound scientific knowledge and community involvement and an understanding of community needs.

- Effective extension mechanisms that can be used to transcend institutional boundaries (e.g. the Commonwealth Scientific and Industrial Research Organisation (CSIRO); PIRSA; catchment boards; Landcare groups). The mechanisms provide a model for other multiagency interdisciplinary research.

The following procedures are used to identify the best set of soil–landscape and vegetation field indicators:

- identifying easily recognised landform elements and soil morphological features, such as soil colour and consistency, down an idealised slope sequence (toposequence);

- using an idealised toposequence to encompass a compilation of the main features present within most of the major toposequences of a specific region;

- linking the soil and vegetation indicators to a pictorial soil–landscape and vegetation key and thereby matching to locally practised on-farm management options;

- using, where needed, simple tests for soil electrical conductivity (salinity), dispersion (sodicity) and pH (acidity); and

- packaging information in an easy-to-follow pictorial manual with input from Landcare groups.

The approach has generic application.

Acknowledgments

The research was funded in part ACIAR, Land and Water Australia, the National Landcare Program and the Natural Heritage Trust. We are grateful to members of the Tungkillo Landcare Group for their assistance. Scientists who contributed substantially to the study include Dr E. Fritsch (ORSTOM), Dr P. Self, Mr G. Rinder, Dr D. Reuter, Ms Mary-Anne Fiebig (CSIRO) and Dr H. Cadman (Biotext).

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