8 SOIL CONSERVATION

Soil conservation is achieved when land is managed in a manner that maintains or improves the soil's stability and productivity without detriment to other lands, to water supplies or to other resources.

Erosion and loss of the soil's chemical or physical condition involve processes inherent in the land. However, the rate of such deterioration may increase when man uses the land, depending on the processes involved, the susceptibility of the land and the effects of management. The interrelations between these factors are discussed below in the light of the land features and processes discussed in previous chapters.

Susceptibility of lands to soil deterioration

Many parts of the catchment are particularly susceptible to disturbance due to a combination of adverse climatic, soil or topographic conditions. The sub-humid to semi-arid climate in the centre and north place seasonal stresses on protective soil cover. The dry conditions in recent millennia have also resulted in adverse soil features, such as weakly structured topsoils prone to compaction and erosion, accumulations of salts and dispersible subsoils that become unstable when exposed. Steep slopes are another hazardous feature in many areas.

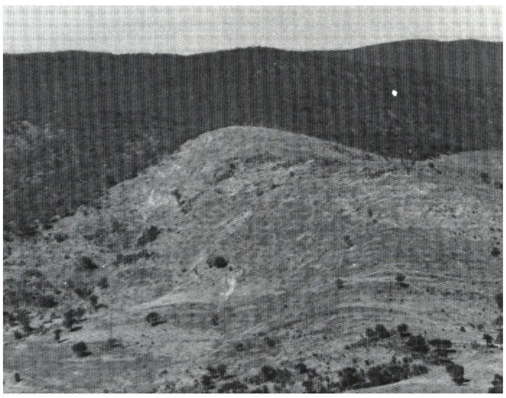
Many forms of soil deterioration have been recognised in the catchment, notably sheet erosion, gully erosion, salting, structure decline and nutrient decline. Wind erosion, landslips and streambank erosion are relatively minor problems. The quality and regulation of underground waters have also been affected.

The susceptibility of components to broad categories of disturbance within each land system has been assessed in detail in the previous chapter, based on field observation and current knowledge of relevant processes. Susceptibility is listed under the heading of primary resultant deterioration. The word 'primary' must be stressed because of the complex series of processes that a particular disturbance may activate. Chain reactions are particularly liable to occur when hydrological processes are altered, and under these circumstances off-site deterioration can be expected, with ramifications further down the catchment.

A typical sequence of processes related to trafficking or trampling is surface compaction, reduced infiltration of rainfall, decreased soil water content, weakened plant growth, decreased protective cover, increased sheet erosion and increased run-off. Off-site processes may follow. For example, on the valley floor the sequence may be increased run-on and gully erosion resulting in increased flooding and streambank erosion further down the catchment.

If the disturbance were reduction in the perenniality of vegetation and/ or depth of rooting without significant surface compaction, the sequence of processes may be reduced transpiration, increased soil water content and increased movement of waters and salts to groundwaters, leading to processes further downslope such as raised water table, increased evaporation, salting, reduced protective cover, sheet erosion, rill erosion and gully erosion.

The susceptibility of lands to various forms of deterioration recognised within the catchment is summarised below, together with remarks on the incidence.



Removal of trees from steep slopes has caused deterioration throughout the catchment. Its forms include sheet and gully erosion, land slips, excessive run-off, flash flooding, saline seepage areas, siltation and turbidity in water storages.

Sheet erosion

In the process of sheet erosion, soil is transported by unchannelled water or by water in shallow impermanent channels known as rills. The most critical factor affecting susceptibility is protective cover, usually afforded by vegetation or vegetative litter but also by inorganic materials such as stones. Other factors relate to climate, soil erodibility and slope gradient.

Seasonal stress on plant cover increases from the humid south to the semi-arid north, and also seasonally, with the greatest stress in late summer to early autumn. The hazard of soil detachment is further increased by the tendency for intense rainstorms to occur during summer and autumn (as shown in Table 5), when plant cover tends to be relatively sparse.

Most of the soils in the drier northern and central areas are highly erodible, having weakly structured surfaces, low in organic matter, prone to detachment by raindrop impact. In addition, most soils on gentler slopes have slowly permeable subsoils that promote overland flow.

A further adverse factor is the common occurrence of steep slopes on hills composed of Ordovician sediments and granitic rocks, and on ridges of metamorphosed sediments.

Sheet erosion reduces on-site productivity -through reduced soil water content resulting from runoff, reduced available soil water capacity, which is particularly significant in inherently shallow soils, impairment of surface soil structure by scaling or by exposure of raw subsurfaces and subsoils and loss of nutrients, which tend to be concentrated in topsoils. Off-site effects are related to the generation of flash flows and sedimentation.

The incidence of sheet erosion varies with land management standards but, in general, varies from severe on the cleared steeper hills and ridges in the north to slight on the near-level alluvial plains.

Gully erosion

Gullies are relatively permanent, deep channels usually initiated by disturbances such as tracks, rabbit burrows or uprooted trees (Dowries 1949, 1958). Tunnels are also initiated in this way, eventually collapsing to form gullies. Once established, a gully tends to increase in length, width and depth until rock is reached. L. E. Milton (personal communication) has shown that several processes are involved in the detachment and transport of soil, including scouring by surface run-off, tunnelling, earth flows, sapping, block fall and spalling.

Severe gully erosion removes land from production, reduces accessibility and causes off-site problems such as siltation and turbidity of streams and water supplies.

A variety of mechanisms may occur in the one gully, and many factors affect susceptibility, including topography, vegetation, climate and soil.

Gullies occur where run-off and seepage waters accumulate, most commonly in valley alluvium. The areas at the greatest risk are the lower slopes and valleys on and adjacent to the steeper hills and ridges. Larger gullies tend to occur in the valley-floor alluvium of large catchments.

Headward erosion is intermittent, being influenced by the intensity and duration of rainfall. Climate also influences the hazard indirectly through effects on vegetation and soils.

Gullies have not been observed in areas with undisturbed native vegetation, where the deep-rooted, perennial species provide mechanical resistance to soil detachment and keep the soils relatively dry. Reduction in leaf area, rooting depth and perenniality following clearing has changed these conditions and further increased the hazard of soil detachment by promoting run-on from upslope. The hazard is greatest towards the drier northern areas, where growth on agricultural lands is relatively weak.

In the central and northern areas, the subsoils tend to have high dispersion and slaking tendencies, encouraging soil detachment. Increasing salinity in many low sites also promotes gullying through weakening of plant cover. In valley alluvium, layers of differing permeabilities frequently provide pathways for seepage, enhancing mechanisms such as sapping and undercutting.

The incidence of gullies is most severe on and beside cleared, sheet-eroded hills and ridges in the central and northern parts of the catchment where gully densities may be as high as 3 km per sq. km.

Although the amount of land directly lost to production is small, gullies reduce plant growth on adjacent land by promoting excessive drainage. This leads to logistic problems, such as restriction of movement of vehicles, machinery and livestock. It may also damage structures, including roads, bridges and culverts. The rapid drainage has off-site effects such as increased flooding, sedimentation and streambank erosion.

Salting

A considerable amount of research has been done on secondary (man-induced) salinisation of soils and waters in catchments to the north of the Great Dividing Range, including part of the Avoca catchment (Jenkin 1981).

Except for the leached landscapes in the humid southern parts of the catchment, soluble salts have accumulated in soils, rocks and unconsolidated sediments. The main origin of the salts appears to be by rock weathering and accumulation of cyclic salt in the past under different climatic conditions, as evidenced by the concentrations at depth in deeply weathered Ordovician rocks beneath gentle landscapes.

Saline seepage can cause complete destruction of all vegetation in the affected area.

Clearing of the perennial, deep-rooted native vegetation and its replacement by crops, pastures and bare fallows has altered the hydrological regime, resulting in, among other processes, increased seepage of salt-bearing waters. In the steeper areas, water seeping through rock strata may emerge from the upper slopes to produce hillside salt seeps. In alluviated valleys, raised water table levels result in valley-floor salt seeps.

The occurrence of salt seeps in the cleared central and northern parts of the catchment is affected by the permeability of soils and sediments. The prime areas of water intake are those with permeable soils, notably the shallow uniform or deeper gradational profiles of the steeper hills and ridges. These profiles lack clay subsoils of low permeability, which promote surface run-off rather than deep percolation. Seepage waters tend to follow preferred pathways such as fractures in rocks or permeable beds in rocks or unconsolidated sediments.

Hillside seeps occur mainly on the steeper hills composed of Ordovician slates and sandstones, and on the metamorphic ridges. The incidence is particularly severe in the Moonambel district. Valley-floor seeps are less numerous, but the aggregate area affected is larger because of the relatively large groundwater bodies involved - for example, near Burkes Flat, where individual affected areas are as large as 10 hectares.

Where salt-bearing perched waters or groundwaters approach the surface, increased salinity of subsoils may cause declining yields, depending on the depth of rooting of trees, crops or pastures. Where the water levels lie within approximately 2 m of the surface, evaporation of waters rising by capillarity concentrates salts at the surface, resulting in eventual death of conventional crops and pastures and of native trees. Increased salinity of water supplies in farm dams and in the Avoca River is also a problem.

Changed hydrological conditions in the catchment also affect the salinity hazard on the Riverine Plain to the north, largely because of increased intake of water to the Tertiary gravel beds (deep leads) beneath the plains of the Avoca and adjacent catchments (Macumber 1969, 1978). Intake of water to the deep leads would be highest in the southern humid areas (themselves free of salinity problems). Pressures exerted by the deep lead waters result in discharge of saline waters in dryland farming areas. The pressures also hamper drainage in the irrigated areas further to the north (State Rivers and Water Supply Commission 1975).

Structure decline

Compaction of soils may occur directly by trafficking of vehicles and implements, or by trampling, usually of livestock. Indirect causes include raindrop impact after soil has been bared by cultivation or erosion, loss of organic matter following weakened plant growth, or settling of soil particles and fine aggregates following disruption of coarser aggregates by cultivation.

Susceptibility of the soils to structure decline has been deduced from the grade of topsoil structure observed at undisturbed sites, increasing in the order of weak, moderate and strong structure. The predominant soils in the central and northern areas have inherently weak topsoil structure, and their susceptibility has been rated as low. Soils with higher surface organic matter contents have a moderate susceptibility - for example, in the humid south on alluvial plains originally vegetated by grassy woodlands and in the north where the parent materials are calcareous aeolian dust.

Structure decline leads to loss of plant vigour through reduced infiltration of water, and it can hinder germination of seeds when topsoil structure has been rendered particularly weak. Secondary effects are increased run-off, erosion and off-site effects such as increased flash flows and sediment loads.

Nutrient decline

Little is known about the magnitude of processes that tend to reduce the nutrient status of soils in northern

Victoria following clearing of the native vegetation. Jenkin (1981) found that conversion of forests to dryland farms near Bendigo may be accompanied by loss of soluble ions such as calcium, potassium, magnesium and sulphate, in addition to sodium and chloride, which constitute the bulk of the ions in saline seeps. Some of these losses would be the result of erosion and removal of nutrients in produce, but the increased salinity of seepage waters indicates that leaching is the main process.

With present knowledge, estimation of susceptibility of soils to nutrient decline can be tentative only, and based on soluble ions in general rather than specific nutrients. In the previous chapter the estimate is based on leaching following reduction in leaf area, perenniality and rooting depth of vegetation. The severity is gauged by the nutrient status of soils in the undisturbed condition and their permeability.

On this basis the estimated hazard of nutrient decline varies greatly, ranging from high on the moderately permeable soils of high nutrient status formed from calcareous aeolian dust in the north to low on old slowly permeable soils of low nutrient status formed from gravelly Tertiary deposits.

Decline in nutrient levels may reduce production directly, depending on the original nutrient status of the soil, and any resultant weakening of growth can lead to other forms of deterioration such as sheet erosion, gully erosion and structure decline. Off-site effects on soils and water quality result from the increased movement of ions to perched waters and groundwaters.

Wind erosion

Bare or lightly vegetated surfaces that are weakly or finely structured and of loose consistence are prone to movement by the wind through the processes of saltation and suspension. Such processes characteristically occur on soils with sandy surfaces, but loamy and clayey topsoils will drift under adverse circumstances such as poor management and prolonged droughts. The hazard increases towards the north with increasing aridity. Exposed situations such as the crests of rises are also vulnerable.

The valuable topsoil on a cultivated alluvial terrace is shown being removed by wind action.

Within the catchment, significant wind erosion is limited to duplex soils with sandy surfaces, particularly where fallows have been prepared on aeolian rises in the north and, to a lesser extent, on heavily cropped alluvial plains. Minor drifting occurs on other sandy topsoils, particularly where the parent materials are Tertiary gravelly deposits and granitic rocks. Clay plains at the edge of the Wimmera will also drift during prolonged droughts.

The main effects of wind erosion on productivity arise through the removal of nutrients concentrated at the surface, and by the exposure of hard-setting subsurfaces or subsoils.

Landslips

Mass movement of soils on steep slopes is initiated mainly by loss of strength in subsoil layers upon saturation with water. Clearing of the perennial native vegetation increases the hazard by extending the periods when subsoils are wet, and by loss of the anchoring effect of deep, thick tree roots.

The hazard of landslips is greatest on the steep slopes of the Pyrenee Range, the scattered metamorphic aureoles and the granitic hills. However, the incidence is minor because such areas tend to remain forested.

Landslips reduce productivity through effects such as the exposure of raw subsoils. They may also bring about management difficulties by hindering access, and cause damage to structures such as fences, buildings or roads.

Waterlogging and flooding

Significant loss of production through waterlogging is confined to minor areas such as the heavy clay soils on basalt in the south, the high terraces formed on lacustrine material in the Natte Yallock area, the heavy clay soils on Tertiary deposits in the central-west and the isolated depressions on the alluvial plains in the north.

Minor occasional flooding occurs on the drainage-floor components in many land systems. The main effect is subsequent improved vegetative growth resulting from the additional soil moisture.

Streambank erosion

The Avoca River and its tributaries suffer only minor streambank erosion during flood periods. Each of the four land systems on alluvium contains sections where the streams are deeply incised. Undercutting and the presence of layers of varying stability lead to slumping of steep banks into the river. Red gum trees, which characteristically line the banks, frequently fall into the water, creating turbulence and subsequent increased streambank erosion.

Land management

While the susceptibility of land to disturbance and the forms of deterioration are fixed by land type, the extent of deterioration depends mainly on the forms of use and the management practices. To improve and then sustain the land's stability and productive capacity, we need to understand the effects of management practices on complex on-site and off-site processes. This understanding, and thus our ability to achieve soil conservation, varies considerably within the catchment depending on land type and form of use.

Grazing

The establishment of long-term pastures with contour cultivation and subsequent maintenance of vigorous swards contributes greatly to the achievement of stability and improved productivity. Considerable information is available from the Department of Agriculture on grasses, clovers and fertilisers appropriate to various land types. Well-managed pastures can improve the inherently low nutrient status and weak structure in many soils of the catchment. Such pastures have reduced deep percolation and overland flow of water, but further improvement of hydrological conditions is required, through the greater inclusion in the pasture mixture of species capable of rooting vigorously at depth in poorly structured subsoils. Phalaris *(Phalaris tuberosa)* and lucerne *(Medicago sativa)* are used, but they do not appear suited to many of the land types, particularly poorly drained sites. A range of species capable of deep vigorous rooting is required to meet soil conservation goals. The introduction of a limited number of trees to pastured areas could well be the most appropriate management to improve and diversify production as well as to improve the hydrological condition in many land types.

In the northern parts of the catchment, the low rainfall limits the successful establishment of introduced pasture species on the steeper lands. Overgrazed native pastures predominate. Run-off results in severe sheet erosion and downslope gully and streambank erosion. Excessive deep percolation leads to reduced productivity and severe off-site effects such as increased salinity of soils and waters.

The re-establishment and maintenance of native grasses on steep lands in northern Victoria are being examined by the Soil Conservation Authority (S. Zallar, personal communication). Certain species such as kangaroo grass *(Themeda australis)* have the capacity to root vigorously at depth, but the maintenance of vigorous swards is difficult. The steep lands have a limited grazing potential, and re-establishment of trees may frequently afford the only practicable means of protecting more productive adjacent lands.

A dense stubble layer protects a sandy, erodible topsoil from possible intense summer thunderstorms.

In the cropped northern and central parts of the catchment, short-term introduced pastures are used in rotation, to improve crop yields through improvement of factors such as nitrogen status and surface tilth.

Cropping

Cropping greatly increases the hazards of soil deterioration, particularly structure decline, nutrient decline and erosion, plus off-site gully erosion, sedimentation, salting and flooding,

Cultivation impairs soil structure, and this is particularly significant on the widespread red duplex soils with inherently weak structure in topsoils. Under intensive cultivation these topsoils become hard when dry and they lose strength upon wetting. When this condition is reached, two or more consecutive years under pasture are required to restore surface structure. The use of ameliorants such as gypsum is being tested by the Department of Agriculture (R. S. B. Greene, personal communication).

Removal of soil nutrients is increased under cropping through removal of grain, stubble burning and processes such as erosion and leaching on bare fallows prepared to maximise soil moisture contents. Phosphorus, sulphur and calcium are applied in superphosphate, and nitrogen is restored by legumes in pastures (Ellington *et al* 1979). Other nutrients such as potassium and magnesium are not being replaced. The lower horizons of the more-fertile cropping soils tend to be well endowed with such nutrients.

The hazards of erosion are severe on much of the cropping land. Wind erosion occurs widely, while sheet erosion by water tends to be confined to the undulating areas. These problems are accentuated by the use of long, bare fallows, with which the highest yields in the area are recorded (Sims 1977). Alternatives to finely worked bare fallows - involving stubble mulching with the use of implements such as rod weeders and sweep blades, or chemical control of growth on fallows - usually result in lower immediate yields, but are likely to be economically justified in the long term (Marston 1978). Other means of reducing sheet erosion by water are contour cultivation and contour or graded banks surveyed by officers of the Soil Conservation Authority.

Pressures exerted by intensive cropping have also increased the incidence of gully erosion in drainage floors, particularly on undulating lands. Arrest of the movement of gully heads up the drainage floors is achieved by improved management in the sub-catchments. This frequently requires costly measures - for example, gully head structures installed to Soil Conservation Authority specifications.

Forestry

Hazards of land deterioration are relatively low under forestry because alteration to the hydrological regime and soil disturbance tend to be confined to the infrequent establishment and harvesting phases. Selective loggings causes minimal disturbance - for example, in the box-ironbark forests of the north and the messmate-blue gum forests of the Mount Avoca-Mount Lonarch areas. Relative to the early days, these forests are now well managed, with retention of slash and litter, fire-protection, control of grazing and well-maintained access tracks.

Only near Lonarch in the extreme south of the catchment is the climate regarded as sufficiently humid for the production of pines. Stringent practices are required to minimise land deterioration on the steeper slopes, such as contour windrowing of burnable native vegetation, contour cultivation, leaving undisturbed native forests in drainage lines, and locating roads on or close to ridge tops. These and other practices are contained in prescriptions prepared by the Forests Commission of Victoria.

Eucalyptus-oil production

Land deterioration has been particularly severe in undulating areas on Ordovician sediments near Wedderburn and St Arnaud where mallee scrub is harvested for the distillation of eucalyptus oil without significant use of fertilisers. Branches are cut close to ground level at about 2-year intervals, leaving the soil

bare, and resulting in sheet erosion of the originally shallow soils, compaction and nutrient decline. Increased flash flows and sediment loads affect adjacent, better-quality land.

Many aspects of management require attention if soil conservation is to be achieved under this form of use, such as harvesting only the gentler slopes, leaving a proportion of stems and leaves to protect the soil, deep ripping on the contour to improve water penetration, maintaining well-sited access tracks and using fertilisers.

Construction uses

In many parts of the catchment, specific land features impose limitations on constructional uses. The swelling clays that occur on lacustrine alluvium, basalt and calcareous aeolian deposits cause many problems in foundations. The uneven pressure or heaving effect of the swelling-shrinking clays after seasonal wetting cause warping, buckling and cracking of floor slabs, roads, runways and foundations and the tilting of fence posts and telephone and power poles.

Hardpans in the subsoil restrict the water-holding capacity of the soil and therefore have severe limitations for absorbing waste effluent from septic tanks or industry. They also increase the cost of excavation and place a physical limitation on the depth and effectiveness of water storages. In obtaining gravel for constructional uses, deep pits are preferable to surface stripping of large areas, even if drilling and blasting through hardpans is necessary. The area of disturbance and off-site effects are thereby minimised.

The widespread weakly structured topsoils are prone to severe compaction when subjected to only light pressure on construction sites. Once they are compacted, a vegetative cover becomes difficult to maintain. Compacted areas not only present a dust problem during the dry periods of the year, but after intensive rainfall quickly become areas of flash flooding or rapid run-off.

Contour banks and grassed waterways allow the safe collection and disposal of overland water flow.

Constructional uses involve disturbance to vegetation and soil, resulting in soil erosion and sedimentation to a degree dependent on the susceptibility of the area and the preventive measures taken. Usually the practice on a new construction site is to completely remove the vegetation and push the topsoil aside. Infiltration of rain is reduced on the compacted surfaces and surface run-off from the site increases. The short time interval to peak flow and the increased volume of water cause soil detachment.

Deterioration on-site includes sheet and rill erosion, gully erosion and a decline in soil structure. The off-site effects can cause considerable costs to the community - for example, increased flooding with related damage and inconvenience, increased water turbidity and related costs of water treatment, death of fish and other aquatic life and streambank erosion. Detailed guidelines for minimising erosion and sedimentation from construction sites have been published by the Soil Conservation Authority (Garvin *et al* 1979). These include planning work activities to minimise the time in which the site is most susceptible to deterioration. Topsoil can be stockpiled, for spreading and seeding once operations have been completed. Fencing out the newly seeded areas allows most rapid recovery. Silt traps and sediment basins minimise the movement of soil off-site.

Soil conservation research

Many techniques have been developed to combat deterioration on the sensitive lands widespread in the catchment, with emphasis on erosion problems. However, further investigations are required into the nature and magnitude of processes involved in the several forms of deterioration outlined above, and the implications for management. The complexity of such investigations will vary according to processes and uses.

Considerable progress has been made in estimating the susceptibility of soils to sheet erosion and the management techniques required using formulae such as the universal soil-loss equation (Wischmeier and Smith 1961). This equation has factors for the erosive power of rainfall, erodibility as determined by soil characteristics, slope length and gradient, vegetative cover and conservation practices such as contour banking. Further improvements to the local use of such formulae are being studied by the Soil Conservation Authority - in particular, estimation of the erodibility of local soils (D. Cummings, personal communication). Such studies of erodibility are also required for wind erosion.

Similar methods need to be developed for other forms of deterioration, particularly structure decline, nutrient decline, gully erosion and salting. Studies of gully erosion are relatively complex because of the effects of off-site factors on the hydrological conditions and the several possible mechanisms involved in gully initiation and expansion (L.E. Milton, personal communication).

Even more complex is the problem of secondary salinity, in which alteration to the hydrological regime may occur at a local or regional scale (Jenkin 1981). Control is required both in recharge and discharge areas. Recharge may be greatest in the higher-rainfall areas, themselves free of saline soils or waters. Treatment of discharge areas will vary with locality, but investigations are needed into treatments such as drainage and leaching or the use of halophytic crops and pastures.

Considerable research is required before soil conservation can be achieved in its fullest sense on the many sensitive lands of the catchments.

REFERENCES

Beadle, N.C.W., and Costin, A.B. (1952).
Ecological classification and nomenclature. *Proceedings of the Linnaean Society of New South Wales,* 77,61-82.

Butler, B.E. (1956).
Parna -an aeolian clay. *The Australian Journal of Science, 18,* 145-51.

Charman, P.E.V. (1978).
Soils of New South Wales. Soil *Conservation Service, New South Wales, Technical Handbook* No. 1.

Christian, C.S., and Stewart, G.A. (1953).
General report on survey of the Katherine-Darwin region, 1946. C. S. *1. R. 0. Australia, Land Research Series* No. 1.

Colwell, J. D. (1963).
The estimation of phosphorus fertiliser requirements of wheat in southern New South Wales by soil analysis. *Australian Journal of Experimental Agriculture and Animal Husbandry, 3,* 190-7.

Costin, A.B. (1954).
'A Study of the Ecosystems of the Monaro Region of New South Wales with Special Reference to Soil Erosion.' (Government Printer: Sydney.)

Costin, A.B., and Wimbush, D.J. (1961).
Studies in catchment hydrology in the Australian Alps. IV. Interception by trees, cloud and fog. *C. S. I. R. 0. Australia, Division of Plant Industry, Technical Report* No. 16.

Downes, R.G. (1949).
A soil, land-use and erosion survey of parts of the Counties of Moira and Delatite, Victoria. *C S. I. R. 0. Bulletin* No. 243.

Downes, R.G. (1958).
Land management problems following disturbance of the hydrological balance of environments in Victoria, Australia. *Proceedings of the Seventh Technical Meeting of the International Union for Conservation* of *Nature and Natural Resources, Athens, Greece.*

Ellington, A., Reeves, T.G., Boundy, K.A., and Brooke, H.D. (1979).
Increasing yields and soil fertility with pasture/ wheat/ grain-legume rotations and direct-drilling. *Proceedings of the 49th A.N.ZA.A.S. Congress, Auckland, New Zealand.*

Foley, J.C. (1945).
Frost in the Australian region. *Commonwealth Meteorological Bureau Bulletin* No. 32.

Garvin, R.J., Knight, M.R., and Richmond, T.J. (1979).
'Guidelines for Minimising Soil Erosion and Sedimentation from Construction Sites in Victoria.' *Soil Conservation Authority, Victoria, T C.* 13. (Government Printer: Melbourne.)

Gary, M., McAfee, R. Jr, and Wolf, C. L. (eds) (1974).
'Glossary of Geology.' (American Geological Institute: Washington, D.C.)

Gibbons, F.R., and Downes, R.G. (1964).
'A Study of the Land in South-Western Victoria.' *Soil Conservation Authority, Victoria. TC.* 3. (Government Printer: Melbourne.)

Gibbons, F.R., and Haans, J.C.F.M. (1976).
'Dutch and Victorian Approaches to Land Appraisal.' Soil *Survey Papers No. 11. (Soil* Survey Institute: Wageningen, The Netherlands.)

Haldane, A.D. (1956).
Determination of free iron oxide in soils. Soil *Science, 82,* 483.

Hutton, J.T. (1956).
A method of particle size analysis of soils. *C. S. L R. 0. Australia, Division of Soils, Divisional Report* No. 11 / 55.

Jenkin, J.J. (198 1).
Terrain, groundwater and secondary salinity in Victoria Australia. *Seminar Papers, Land and Stream Salinity Seminar, Perth, W.A., 1980.*

Land Conservation Council, Victoria (1978).
'Report on the North Central Study Area. (Government Printer: Melbourne.)

Lawrence, C. R., Macumber, P. G., Kenley, P. R., Gill, E.D., Jenkin, J.J., Neilson, J. L., and McLennan, R.M. (1976).
Quaternary. In 'Geology of Victoria', ed. J.G. Douglas and J. A. Ferguson. *Special Publication* of *Geological Society of Australia* No. 5.

Leeper, G.W. (1950).
Thornthwaite's climatic factor. *Journal of the Australian Institute of Agricultural Science, 16,* 2-6.

Loveday, J. (ed.) (1974).
Methods of analysis of irrigated soils. *Commonwealth Bureau of Soils Technical Communication* No. 54.

Macumber, P.G. (1969).
Interrelationship between physiography, hydrology, sedimentation and salinization of the Loddon River Plains, Australia, *Journal of Hydrology,* 7,39-57.

Macumber, P.G. (1978).
Hydrologic change in the Loddon Basin: the influence of groundwater dynamics on surface processes. *Proceedings of the Royal Society of Victoria, 90,* 125-38.

Manley, G. (1945).
The effective rate of altitudinal change in temperate Atlantic climates. *Geographical Review,* 35, 480-517.

Marston, D. (1978).
Conventional tillage systems as they affect soil erosion - in northern New South Wales. *Journal of the Soil Conservation Service of New South Wales,* 34(4), 194-8.

Metson, A.1 (1956).
Methods of chemical analysis of soil survey samples. *New Zealand D.S.I.R. Soil Bureau Bulletin* No. 12.

Murray, J.S., and Mitchell, A. (1962).
Red gum and the nutrient balance. *Proceedings of the Third Australian Conference on Soil Science, 1,* 96.1-96.6.

Northcote, K. H. (1960).
'Atlas of Australian Soils, Sheet U(C. S. 1. R. 0. and Melbourne University Press: Melbourne.)

Northcote, K. H. (1979).
'A Factual Key for the Recognition of Australian Soils.' 4th ed. (C.S.I.R.O. and Rellim Technical Publications: Adelaide.)

Northcote, K. H., and Skene, J. M. K. (1972).
Australian soils with saline and sodic properties. *C.S.L R. 0. Australia, Soil Publication* No. 27.

Piper, C. S. (1942).
'Soil and Plant Analysis.' (University of Adelaide: Adelaide.)

Rowe, RX. (1967).
'A Study of the Land in the Victorian Catchment of Lake Hume.' Soil *Conservation Authority, Victoria, T* C. 5. (Government Printer: Melbourne.)

Sims, H.J. (1977).
Cultivation and fallowing practices. In 'Soil Factors in Crop Production in the Semi-arid Environment', ed. J.S. Russell and E.L. Greacen. (University of Queensland Press: Brisbane.)

Skene, J.K.M. (1952).
Soils. In 'Resources Survey Loddon Region'. Central Planning Authority. (Government Printer: Melbourne.)

Specht, R.L. (1970).
Vegetation. In 'The Australian Environment', ed. G. W. Leeper. 4th ed. (C. S. 1. R. 0. Australia and Melbourne University Press: Melbourne.)

Stace, H.C.T., Hubble, G.D., Brewer, R., Northcote, K. H., Sleeman, J. R., Mulcahy, M. 1, and Hallsworth, E.G. (1968).
'A Handbook of Australian Soils.' (Rellim Technical Publications: Glenside, S.A.)

State Rivers and Water Supply Commission, Victoria (1975).
'Salinity Control and Drainage; a Strategy for Northern Victorian Irrigation and River Murray Quality.' (State Rivers and Water Supply Commission Report: Melbourne.)

Sutherland, A. (1888).
'Victoria and its Metropolis - Past and Present. (McCarron Bird and Co.: Melbourne.)

Thornbury, W.D. (1969).
'Principals of Geomorphology.' 2nd ed. (John Wiley and Sons Inc.: Sydney.)

Thornthwaite, C.W. (1948).
An approach toward a rational classification of climate. *Geographical Review, 38,* 55-94.

Trumble, M.C. (1939).
Climatic factors in relation to the region of southern Australia. *Transactions of the Royal Society of South Australia, 63(1),* 36-43.

Tucker, B. M. (1974).
Laboratory procedures for cation exchange measurements on soils. *C.S.LR.O. Australia, Division of Soils, Technical Paper* No. 23.

United States Department of Agriculture (195 1).
'Soil Survey Manual.' U.S.D.A. Handbook No. 18, with supplement (1962) replacing pages 173-88, (Government Printing Office: Washington.)

United States Department of Agriculture (1975).
'Soil Taxonomy - a Basic System of Soil Classification for Making and Interpreting Soil Surveys.' *U.S.D.A. Soil Conservation Service Agriculture Handbook No.* 436. (Government Printing Office: Washington.) Wentworth, C.K. (1922). A scale of grade and class terms for elastic sediments. *Journal qf Geology, 30,* 377-92. Willis, J.H. (1970). 'A Handbook to Plants in Victoria. Vol 1. Ferns, Conifers and Monocotyledons.'2nd ed. (Melbourne University Press: Melbourne.)

Willis, J.H. (1972).
'A Handbook to Plants in Victoria. Vol 2, Dicotyledons.' (Melbourne University Press: Melbourne.)

Wischincier, W. R, and Smith, D. D. (196 1).
A universal soil-loss equation to guide conservation farm planning. *Transactions of the 71h International Congress qf Soil Science, Madison, Wise., U. S. A. 1960.1.*